

ALL DTIC DOCUMENTS RELATED TO MQ-1C GRAY EAGLE

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Gray **Eagle).** We found in our prior work that in recent years, the

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s **Gray Eagle** and between the Air Force's Global Hawk and the Navy

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1C **Gray Eagle** has several technical differences from its Air Force counterpart, the MQ

1C **Gray Eagle** Unmanned Aircraft System," accessed September 10, 2014, http

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1C **Gray Eagle** (Group 4) support to the Division. Rotational forces are

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Army **Gray Eagle** Company Officer WO Enlisted Total MOS O50U Other Operations MOS 15P Operator

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1C **Gray Eagle** and Air Force's Group 5 MQ-9 Reaper.

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Army **Gray Eagle Company** .....

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Gray **Eagle Unmanned** Aircraft System." Accessed September 10, 2014, http:

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, **Gray Eagle** Unmanned Aircraft System (MQ-1C), and Little Bird

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1C **Gray Eagle** Unmanned Aircraft System (MQ-1C Gray Eagle) As of

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- 1C **Gray Eagle**) As of FY 2017 President's Budget Defense Acquisition Management

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** Unmanned Aircraft System (MQ-1C Gray Eagle) DoD Component
- 1C **Gray Eagle**) DoD Component Army Responsible Office References SAR Baseline (Production Estimate
- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** Unmanned Aircraft System (MQ-1C Gray Eagle) provides the
- 1C **Gray Eagle**) provides the Division Commander a dedicated, assured, multi-
- 1C **Gray Eagle** provides reconnaissance, surveillance, and target acquisition; command and control
- Fifteen **Gray Eagle** Warfighting companies are assigned as follows: ten companies assigned to Army
- 1C **Gray Eagle** defines an operational requirement for Improved Gray Eagle (IGE).
- Improved **Gray Eagle** (IGE). IGE provides for increased range, endurance,
- A **Gray Eagle** Company is configured into three equal platoons. The Gray Eagle System
- The **Gray Eagle** System consists of 12 MQ-1C aircraft, each with the
- full **Gray Eagle** System equipment strength. Each Gray Eagle company will consist of 125
- Each **Gray Eagle** company will consist of 125 soldiers within the Divisional CAB and the
- 1C **Gray Eagle** is fielded across tactical and operational elements: the CAB in support
- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** Follow-on Test & Evaluation (FOT&E) was
- the **Gray Eagle** hardware performed exceptionally well throughout the test, preliminary observations and feedback
- 1C **Gray Eagle** Configuration Steering Board (CSB) was held on July 14,
- 1C **Gray Eagle** program to procure one additional Echelon Above Division (EAD

co**mpany**

- Improved **Gray Eagle** and considered the revised Gray Eagle CPD requirement for validation. The
- revised **Gray Eagle** CPD requirement for validation. The CSB, Army Systems Acquisition Review
- 1C **Gray Eagle** and granted authority to pursue the extended range capable MQ-1C
- 1C **Gray Eagle** configuration for FY 2015 and FY 2016 procurement. The CSB approved
- Improved **Gray Eagle** aircraft. An ADM dated August 13, 2015, approved procurement
- 1C **Gray Eagle** Unmanned Aircraft and associated ground support equipment for a total of 167
- 1C **Gray Eagle** aircraft. Additionally, the ADM approved and authorized an acquisition and
- for **Gray Eagle** extended range modifications. An updated APB is in staffing and planned
- 1C **Gray Eagle** acquisition program costs are stable. There are no anticipated program requirements
- 1C **Gray Eagle** production continues with Firm Fixed Price FRP I, II and III
- 1C **Gray Eagle** aircraft have been delivered. To date, there are nine companies
- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- Gray **Eagle December** 2015 SAR March 21, 2016 17:33:19 UNCLASSIFIED

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- 1C **Gray Eagle December** 2015 SAR March 21, 2016 17:33:19 UNCLASSIFIED

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** program baseline includes the Common Sensor Payload (CSP) procurement,

- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** program Milestone C decision, like all life cycle cost estimates previously
- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- A **Gray Eagle** Company is configured into three equal platoons. The Gray Eagle System
- The **Gray Eagle** System consists of 12 MQ-1C aircraft, each with payloads
- full **Gray Eagle** System equipment strength. Each Gray Eagle company will consist of 125
- Each **Gray Eagle** company will consist of 125 soldiers within the divisional Combat Aviation Brigade
- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** capability entrance into theater as quickly as possible. Initial LRIP Decision

- 1C **Gray Eagle** systems which equates to six platoon sets (24 aircraft).
- 1C **Gray Eagle** systems which equates to 18 platoon sets and includes LRIP I (
- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle**. (Estimating) +6.8 +8.5 MILCON Subtotal +8.5
- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** program does not have an Acquisition Operations and Maintenance (O&
- 1C **Gray Eagle December** 2015 SAR March 21, 2016 17:33:19 UNCLASSIFIED

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- Improved **Gray Eagle.** Cost and Schedule Variance Explanations Cost and Schedule Variance reporting is not
- 1C **Gray Eagle December** 2015 SAR March 21, 2016 17:33:19 UNCLASSIFIED

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- 1C **Gray Eagle December** 2015 SAR March 21, 2016 17:33:19 UNCLASSIFIED

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- 1C **Gray Eagle December** 2015 SAR March 21, 2016 17:33:19 UNCLASSIFIED

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- 1C **Gray Eagle** aircraft of 167 planned (152 planned in Current APB) completed
- 1C **Gray Eagle** aircraft is the metric used for deliveries and is converted to

yst**ems**

- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** O&S cost estimate includes 152 MQ-1C Gray Eagle
- 1C **Gray Eagle** acquisition program aircraft, 31 platoons with associated ground equipment, and
- 1C **Gray Eagle** program in accordance with the program schedule. An updated APB is
- 1C **Gray Eagle** system includes balanced platoons, each with four aircraft and associated support
- per **Gray Eagle** Company, an Automated Take Off and Landing System which includes two
- 1C **Gray Eagle** Company is configured into three equal platoons and includes nine MQ-
- 1C **Gray Eagle** aircraft for conventional companies (non-deployed) and when deployed
- 1C **Gray Eagle** System strength (12 aircraft and associated ground support equipment).
- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** Average Annual Cost Per System No Antecedent (Antecedent) N/
- 1C **Gray Eagle** No Antecedent Current Production APB (Antecedent) Objective/Threshold Current
- 1C **Gray Eagle** system equipment strength (12 aircraft and associated ground support equipment)
- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle** December 2015 SAR March 21, 2016 17:33:19

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- 1C **Gray Eagle for** the Army. The large underrun from the F-35 aircraft
- 1C **Gray Eagle in** negating the overrun from the AH-64E Remanufacture. The change

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- 1C **Gray Eagle** 183.772 152.058 34 $ (1,078.28) -17% PIM 12.206

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- 1C **Gray Eagle** 185.427 155.340 34 $ (1,022.98) -16% PIM 12.316

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- 1C **Gray Eagle** FCS P-8A VH-71 MP-RTIP Patriot/

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- 1C **Gray Eagle** Gray Eagle Unmanned Aircraft System Army MQ-4C Triton Triton Unmanned
- Eagle **Gray Eagle** Unmanned Aircraft System Army MQ-4C Triton Triton Unmanned Aircraft System

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- 1C **Gray Eagle** Unmanned Aerial Systems (UAS); an Assault Helicopter Battalion with

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- 1C **Gray Eagle** cannot conduct shipboard operations, but its extended range allows for manned
- implement **Gray Eagle** UAS into maritime intelligence, surveillance, and reconnaissance roles will offset

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- 1C **Gray Eagle** The MQ-1C Gray Eagle is an unmanned aircraft system built
- 1C **Gray Eagle** is an unmanned aircraft system built by General Atomics Aeronautical System Inc

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- one **Gray Eagle** platoon (United States Army 2016). The Gray Eagle can
- The **Gray Eagle** can carry an electro-optical sensor and up to four AGM

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- 1C **Gray Eagle** Unmanned Aircraft System (UAS).” http://

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- : **Gray Eagle** Training Modules .....

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- the **Gray Eagle**, and the MQ-9 Reaper are totally different systems.

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- 1C **Gray Eagle** and MQ-9 Reaper, in an effort to compare training
- the **Gray Eagle**. Reaper and Predator training are nearly identical, and, therefore

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- until **Gray Eagle** was fielded. Initially, they flew MQ-1s owned by
- the **Gray Eagle** to carry 4 Hellfire missiles. Increases in autonomy allowed Gray Eagle
- allowed **Gray Eagle** operations to have an enlisted, universal operator capable of

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- and **Gray Eagle**. Simplicity of operations has strong value in the Army and has
- divisional **Gray Eagle** company is assigned to each of the Army’s active duty
- larger **Gray Eagle** companies are assigned to Intelligence and Security Command (INSCOM),

- . **Gray Eagle** followed this model. In a nearly opposite operational approach to the
- a **Gray Eagle** from an established runway away from the battlefield and then performing a

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- creating **Gray Eagle** companies at echelons above division (EAD) designed to conduct split
- these **Gray Eagle** companies have 165 soldiers and 12 air vehicles. Currently, the

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- Operational **Gray Eagle** companies have a dismal record maintaining required readiness. Installations that maintain
- collocate **Gray Eagle** companies regardless of whether the airspace environment is conducive to training.
- (**Gray Eagle** Project Manager), interview by the author, 5 January 2017

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- the **Gray Eagle**. The UAS overarching mission objective is 17 Interview with Gray Eagle
- with **Gray Eagle** instructor from 2-13th Aviation Regiment, 5 January 2017.

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- the **Gray Eagle** maintenance course. Viewed through Schein's methodology, the Army

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- classifies **Gray Eagle** and the MQ-9 Reaper as Group 4 Unmanned Aircraft because

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- 53 **Gray Eagle** training has two frequently changing phases: currently they are an 8
- week **Gray Eagle** course. On completion of the initial phase, the soldiers possess

Page : 839

- the **Gray Eagle**. Upon graduation of either track, UAS students are expected to
- The **Gray Eagle** course consists of 8 modules and 680 hours of academic and flight

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- : **Gray Eagle** Training Modules (Source: 2-13th Catalogue. 15W Common
- , **Gray Eagles** operate exclusively in combat zones or restricted airspace unless granted a domestic
- enlisted **Gray Eagle** operators. The schoolhouse conducts four week courses to transform incoming lieutenants

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- the **Gray Eagle**, to operate its payloads, to conduct certain maintenance items,

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- for **Gray Eagle**, Shadow UAS, and other small UAS into the system.

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- between **Gray Eagle** or Shadow operators. Finally, distilling the cost of just flight

Page : 864

- and **Gray Eagle** qualification course. Several quick-reference figures and tables are included

Page : 865

- . **Gray Eagle** training includes airfield operations, deployed setup and disassembly, and launch
- The **Gray Eagle** course introduces basic gunnery and then allows follow on units to tailor

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- include **Gray Eagle** and Shadow UAS operators that function as both pilots and sensor operators
- and **Gray Eagle** courses is $157k. Table 1: RPA/UAS Hours
- as **Gray Eagle** at $33/hr. Flight hour cost of $4762
- Core **Gray Eagle** Academic Training Course Hours 273: 62/133/78 157.5

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- Army **Gray Eagles** fold into the Global Force Management Allocation Plan (GFMAP) and

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- and **Gray Eagle** course. With the comparison as a backdrop, a Focused,

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- its **Gray Eagle** course to focus on aircraft systems and employment. Overtraining Shadow UAS

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- the **Gray Eagle**, to operate its payloads, to conduct certain maintenance items,

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- Army **Gray Eagles**, skill differentiation is called into question. Moreover, three emerging

Page : 892

- Regiment **Gray Eagle** Program Manager 6. Mark Farrar, MSgt, USA (ret

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- and **Gray Eagle** systems. These systems are all fixed-wing, have limited

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- Gray **Eagle is a much** larger UAS that can carry Hellfire missiles as well as an ISR

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- and **Gray Eagle** systems. These systems are all fixed-wing, have limited
- although **Gray Eagle** can carry Hellfire missiles in addition to ISR payloads). Currently
- and **Gray Eagle** flight path and payload (but not takeoff or landing).

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- and **Gray Eagle** systems. These systems are all fixed wing, have limited autonomy
- although **Gray Eagle** can carry Hellfire missiles in addition to ISR payloads). Currently
- and **Gray Eagle**. Collaboration by means of MUM-T is constrained by lack

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- . **Gray Eagle** is currently the only unmanned aircraft system deployed by the Army that

Page : 952

- and **Gray Eagle** flight path and payload. In addition to enhancing Army Aviation survivability

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- • **Gray Eagle** – Predator upgrade, 3,600 lb max takeoff Figure E-4

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- and **Gray Eagle**) and that it is assumed that industry will drive the S
- and **Gray Eagle** have unique operating systems and mission packages. While the GCS for
- and **Gray Eagle** is called a Universal Ground Control System (UGCS), it
- the **Gray Eagle** GCS has functions to control SATCOM and Link-16 communications,

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-) **Gray Eagle** MQ-1C USA 2009 ISR Pod / Hellfire 3,600 lb 150
- Improved **Gray Eagle** Gray Eagle Upgrade 2017 ISR Pod / Hellfire 4,200 lb 167 kt
- Eagle **Gray Eagle** Upgrade 2017 ISR Pod / Hellfire 4,200 lb 167 kt max /

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- /**Gray Eagle** • MQ-9 Reaper • RQ-4A and RQ-

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- 12 **Gray Eagles**, 32 Shadows, 224 Ravens, and 7 Pumas, which

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- 1C **Gray Eagle**. Source: [7]. .....

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- 1C **Gray Eagle** (Figure 2) fielded at the division-level. This
- 1C **Gray Eagle**. Source: [7].

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- new **Gray Eagle attack** drone system in South Korea," Stars and Stripes, Mar

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- "**Gray Eagle** UAS," General Atomics Aeronautical. Accessed April 28, 2018

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- 1C **Gray Eagle**. Source: [7]. .....

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- 1C **Gray Eagle** (Figure 2) fielded at the division-level. This
- 1C **Gray Eagle**. Source: [7].

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- new **Gray Eagle attack** drone system in South Korea," Stars and Stripes, Mar

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- "**Gray Eagle** UAS," General Atomics Aeronautical. Accessed April 28, 2018

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- . **Gray Eagle** Contested Airspace Operations. "Gray Eagle in Large Scale Combat Operations
- "**Gray Eagle** in Large Scale Combat Operations," 32....

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- Range **Gray Eagle** UAS," Army Aviation (November 2018): 52-

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- the **Gray Eagle**. The coordination of the UAS and AH-64 also extends

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- range **Gray Eagle** underwent an extensive fourty-two day training mission with F Company

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- Range **Gray Eagle** UAS," 52-53. 45 William Lewis and Carvil

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- the **Gray Eagle** UAS." The first and second issues are due to the

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- . **Gray Eagle** Contested Airspace Operations. "Gray Eagle in Large Scale Combat Operations
- "**Gray Eagle** in Large Scale Combat Operations," 32. Conclusion Aviation is

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- "**Gray Eagle** in Large Scale Combat Operations: Can It Only Survive in COIN
- Range **Gray Eagle** UAS." Army Aviation (November 2018): 52-

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- 1C **Gray Eagle** UAS unit in the Army. The Army Special Operations Aviation (
-) **Gray Eagle** unit is organized, trained, and equipped in an almost identical
-) **Gray Eagle** units. Conversely, the rotary wing units within ARSOA are organized
- ARSOA **Gray Eagle** unit. A comparative analysis of ARSOA rotary wing units in relation

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- 1C **Gray Eagle** UAS unit in the Army. The Army Special Operations Aviation (
-) **Gray Eagle** unit is organized, trained, and equipped in an almost identical
-) **Gray Eagle** units. Conversely, the rotary wing units within ARSOA are organized
- ARSOA **Gray Eagle** unit. A comparative analysis of ARSOA rotary wing units in relation

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- 1C **Gray Eagle** Unmanned Aircraft System (UAS), hereafter referred to as Gray
- as **Gray Eagle**, in support of special operations around the globe. Unlike the
- ARSOA **Gray Eagle** unit is manned, trained, and equipped from that of the
-) **Gray Eagle** units. Conversely, the rotary wing units within ARSOA have major
- ARSOA **Gray Eagle** unit is manned, trained, and equipped, in comparison to
- CF **Gray Eagle** units, then what unique capability does the ARSOA Gray Eagle unit
- ARSOA **Gray Eagle** unit provide SOA? Of note, the terms manning and equipping

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- the **Gray Eagle** for more than a decade, but it was not until 2013
- aviation **Gray Eagle** company within the Army. Before that time Quick Reaction Capability Companies
- ARSOA **Gray Eagle** operations within SOA has not been written to capture the unique

Page : 1311

- second **Gray Eagle** company (USA UAS COE 2010, 4-6).
- ARSOA **Gray Eagle** company appears to be a stable and growing capability, it is
- the **Gray Eagle** like a CF UAS unit. However, the ARSOA Gray Eagle
- ARSOA **Gray Eagle** company is manned, trained, and equipped in almost an identical
- ARSOA **Gray Eagle** unit from providing a unique SOA capability? This study will illustrate
- the **Gray Eagle**’s capabilities and meet SOF needs. Only by conducting a
- their **Gray Eagle** units. Primary Research Question In order to answer the primary question

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- ARSOA **Gray Eagle** organization when compared to the rotary wing ARSOA units? 3.
- the **Gray Eagle** and the near-term fielding of the MQ-1C Extended
- Range **Gray Eagle** UAS are the only Group 4 UAS platforms employed by ARSOA within
- the **Gray Eagle** company within the 160th Special Operations Aviation Regiment (160th SOAR)
- CF **Gray Eagle** community;

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- ARSOA **Gray Eagle** community. Definitions and Terms The Unmanned Aircraft System (UAS)
- 1C **Gray Eagle**, the ground control station (GCS), and the communications

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- ARSOA **Gray Eagle** unit of study in this thesis. The study may not clearly

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- the **Gray Eagle** provides SOA with a unique UAS capability. Specific DOTMLPFP domains that
- ARSOA **Gray Eagle** unit, in relation to UAS employment by the CF. This
- ARSOA **Gray Eagle** units are not vulnerable to changes in the CF’s force

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- ARSOA **Gray Eagle** as beginning with the creation of E/160 in 2013.
- the **Gray Eagle** within special operations during the operations of the Quick Reaction Capability Companies
- ARSOA **Gray Eagle** and the CF Gray Eagle units, in comparison to ARSOA and
- CF **Gray Eagle** units, in comparison to ARSOA and CF rotary wing units.
- ARSOA **Gray Eagle** unit that may prevent it from providing a unique UAS SOA capability
- CF **Gray Eagle** unit, by comparing the similarities and differences between the ARSOA and
- CF **Gray Eagle** units. The study will then look to the ARSOA rotary wing

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- ARSOA **Gray Eagle** unit from providing a unique SOA capability? The author developed this
- ARSOA **Gray Eagle** company, E/160, as the executive officer just prior
- the **Gray Eagle**, its role within the 160th SOAR, and the Soldiers who
- the **Gray Eagle**. With that understanding, the author believes there are capability gaps

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- The **Gray Eagle** is still within its first five years of employment within ARSOA,
- second **Gray Eagle** company is currently being fielded with an August 2018 activation date.
- ARSOA **Gray Eagle** is going to increase, as evidenced by the fielding of a
- second **Gray Eagle** company within the 160th SOAR. Additionally, the Department of Defense
- the **Gray Eagle** with the production of the Extended Range (ER) Gray Eagle
-) **Gray Eagle**, which is scheduled to undergo initial operational testing and evaluation (

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- CF **Gray Eagle** units. After gathering the right data, an applied professional case

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- ARSOA **Gray Eagle** unit has enabled special operations across the globe with phenomenal results.
- 1C **Gray Eagle** company within ARSOA. This chapter discussed the background, the problem

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- ARSOA **Gray Eagle** unit to meet special operations specific requirements, and to persuade the

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- 1C **Gray Eagle** aerial vehicle. One of which is the Direct Attack Guided Rocket
- 1C **Gray Eagle** to carry up to four times as much payload as its current
- 1C **Gray Eagle** Selected Acquisition Report (SAR), as of the FY2017 President
- of **Gray Eagle** units in terms of organization. Specifically, it addresses how the

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- to **Gray Eagle** crewmembers and their commanders. The purpose of this document is to

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- the **Gray Eagle** specific aircrew training program and the commander’s aircrew training program
- to **Gray Eagle** operations. This is significant because this study will examine the corresponding
- ARSOA **Gray Eagle** units both use this same document. The aircrew training program outlined
- the **Gray Eagle**, criteria for readiness level progression,

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- a **Gray Eagle** company commander to execute the aircrew training program that covers everything from
- the **Gray Eagle** and is the basis for the crewmember’s training from the

- and **Gray Eagle** crewmembers. It does not apply to ARSOA MH-47G crewmembers

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- ARSOA **Gray Eagle** crewmembers. This reference covers much of the same material as the
- ARSOA **Gray Eagle** crewmembers only have the designations of AO and AC. The ARSOA

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- a **Gray Eagle** operator would be to operate synthetic aperture radar, task #2305

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- the **Gray Eagle** community, UAS crewmembers (UACs) have the following designations;
- approved **Gray Eagle** qualification course and designation in writing from the aircrew training program commander

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- Army **Gray Eagle** Instructor Operator (IO) course to undergo training. Of note

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- the **Gray Eagle** is not rated for IFR flight, and because of that,

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- and **Gray Eagle**) to meet joint expeditionary tactics, techniques, procedures, forward

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- USASOC **Gray Eagle** units (F102Ra 2017, 2). The USASOAC Commander,
- ARSOA **Gray Eagle** organization when compared to the rotary wing ARSOA units? (3
- ARSOA **Gray Eagle** units' domains of manning, training, and equipping, needed

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- ARSOA **Gray Eagle** unit. These capability gaps were based on capabilities provided by ARSOA

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- ARSOA **Gray Eagle**

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- the **Gray Eagle** company within special operations (Hancock and Algozzine 2011; Gagnon 2010

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- 15W **Gray Eagle** operators. Army and Joint doctrine also provide the condition for this

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- 1C **Gray Eagle** units. To determine the standard for the FAA, this study

- ARSOA **Gray Eagle** in relation to CF Gray Eagle formations. This established the standard
- CF **Gray Eagle** formations. This established the standard set for this study. The
- 1C **Gray Eagle** 15W operators, are more senior in ARSOA rotary wings units compared
- ARSOA **Gray Eagle** operators. The number of personnel must be taken into account when

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- senior **Gray Eagle** operators than CF Gray Eagle units. Part of ARSOA's
- CF **Gray Eagle** units. Part of ARSOA's ability to provide a unique

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- enlisted **Gray Eagle** 15W operators in the grades of E5, E6, and E7

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- 15W **Gray Eagle** operators. The ARSOA rotary wings units have a unique training and
- conventional **Gray Eagle** units and does not have unique, special operations aviation specific aircrew
- unique **Gray Eagle** capability, and part of that expectation involves uniquely trained 15W operators

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- operations **Gray Eagle** capability to the ground force commander that would enable them to control

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- CFs **Gray Eagle** units, there is no specialized equipment that enables E/160
- The **Gray Eagle** employed by E/160 is identical to the one employed by
- CF **Gray Eagle** unit, B/101. Given the results of this comparison
- CF **Gray Eagle** units. The risk associated with the identified equipment capability gap is
- s **Gray Eagle** capability. Special operations

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- the **Gray Eagle** to provide a unique UAV platform capability specifically designed to support the
- current **Gray Eagle** company equipment resources to enhance its ability to support special operations.
- the **Gray Eagle** to improve the company's expeditionary capability. R2: The

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- ARSOA **Gray Eagle** unit to provide the unique capabilities required by the special operations community
- CF **Gray Eagle** company to an ARSOA Gray Eagle company and comparing them to the

- ARSOA **Gray Eagle** company and comparing them to the similarities and differences between a CF
- ARSOA **Gray Eagle** company. Specifically, the manned ARSOA rotary wing company analyzed in
- 1C **Gray Eagle** company in comparison to the CF MQ-1C Gray Eagle company
- 1C **Gray Eagle** company. This new knowledge and understanding led the author to update

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- ARSOA **Gray Eagle** unit from providing a unique special operations aviation capability? During the
- ARSOA **Gray Eagle** company, Company F, 160th Special Operations Aviation Regiment, scheduled
- ARSOA **Gray Eagle** company, F/160, is scheduled to activate in August
- ARSOA **Gray Eagle** companies within a five-year period. This highlights the importance
- ARSOA **Gray Eagle** company. The primary sources of data for this study were DOD

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- ARSOA **Gray Eagle** companies in relation to the ARSOA and CF rotary wing companies.
- 1C **Gray Eagle** company. The MTOE narrative and aircrew training publications provided the necessary
- ARSOA **Gray Eagle** company in comparison to the CF's UAS company. In

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- the **Gray Eagle** within ARSOA, which is focused on the Army and its mission
- ARSOA **Gray Eagle** needs to provide a unique UAS capability to enhance ARSOA before these
- and **Gray Eagle**) to meet joint expeditionary tactics, techniques, procedures, forward

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- ARSOA **Gray Eagle** unit from providing a unique special operations aviation capability? The primary

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- its **Gray Eagle** assets. The author's personal operational experience attests that DOD

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- 15W **Gray Eagle** operators. The proposed non-materiel solution to this capability gap
- the **Gray Eagle** to provide a unique aviation capability. The author recommended a modification
- the **Gray Eagle** that increases its expeditionary capability by reducing the

hysi**cal size o**f the

Page : 1372

- the **Gray Eagle**. The CDM would agree with the author’s recommendation to
- the **Gray Eagle** to increase its expeditionary capability. This recommendation is in-line
- and **Gray Eagle**) to meet joint expeditionary tactics, techniques, procedures, forward

Page : 1375

- ARSOA **Gray Eagle** units would be a fairly simple change to make. This is

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- ARSOA **Gray Eagle** units. It is once again important to note that the author
- ARSOA **Gray Eagle** company, F/160, with an activation date set for
- ARSOA **Gray Eagle** company, E/160, is viewed as a critical capability
- ARSOA **Gray Eagle** community as it is for the ARSOA rotary wing community. After

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- 1C **Gray Eagle** Extended Range UAS in July of 2018. This new version of
- the **Gray Eagle** will provide additional capabilities and, because of this, it is
- the **Gray Eagle** until the added benefits of this new version are fully understood.
- 1C **Gray Eagle** Extended Range UAS, this new version will be fielded to both
- CF **Gray Eagle** units and the new capability will not be unique to the SOF
- the **Gray Eagle** should be the focus of a follow-on study. Based
- the **Gray Eagle**. This proposed solution was recommended because it is nested within the
- and **Gray Eagle**) to meet joint expeditionary tactics, techniques, procedures, forward

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- ARSOA **Gray Eagle** units. Unlike the proposed short term solution, the identified long
- the **Gray Eagle** was based upon the needs of the CF, and that a
- the **Gray Eagle** by reducing the size of the ground control station, satellite and
- the **Gray Eagle**. The study would need to focus on the current breakdown and
- the **Gray Eagle** in its current configuration as well as the amount of pallet space
- one **Gray Eagle** flight platoon from one location to another. The study would then

Page : 1380

- the **Gray Eagle** to address the capability gap in supporting this USSOCOM mission set.
- ARSOA **Gray Eagle** units to exclusively train at their home base or incur the high

Page : 1381

- The **Gray Eagle** needs to have the ability to tailor its payload based on the
- the **Gray Eagle** other than its current restriction to the Hellfire missile. This is
- the **Gray Eagle**, but in its current configuration, it can only carry up
- the **Gray Eagle** an alternate, lighter, precision guided munition that would provide the
- upgraded **Gray Eagle** materiel solution? (2) Perform a manpower grade analysis to

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- ARSOA **Gray Eagle** units, and more importantly, an understanding of the current capability
- ARSOA **Gray Eagle** company, F/160. Additionally, by focusing this study
- The **Gray Eagle** platform was designed to meet the needs of the CF and this
- ARSOA **Gray Eagle** units need to begin making the same organizational, training, and

Page : 1383

- “**Gray Eagle** UAS.” Accessed September 21, 2017. http:/

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- 1C **Gray Eagle** UAS unit in the Army. The Army Special Operations Aviation (
-) **Gray Eagle** unit is organized, trained, and equipped in an almost identical
-) **Gray Eagle** units. Conversely, the rotary wing units within ARSOA are organized
- ARSOA **Gray Eagle** unit. A comparative analysis of ARSOA rotary wing units in relation

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- 1C **Gray Eagle** UAS unit in the Army. The Army Special Operations Aviation (
-) **Gray Eagle** unit is organized, trained, and equipped in an almost identical
-) **Gray Eagle** units. Conversely, the rotary wing units within ARSOA are organized
- ARSOA **Gray Eagle** unit. A comparative analysis of ARSOA rotary wing units in relation

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- 1C **Gray Eagle** Unmanned Aircraft System (UAS), hereafter referred to as Gray
- as **Gray Eagle**, in support of special operations around the globe. Unlike the
- ARSOA **Gray Eagle** unit is manned, trained, and equipped from that of the
-) **Gray Eagle** units. Conversely, the rotary wing units within ARSOA have major
- ARSOA **Gray Eagle** unit is manned, trained, and equipped, in comparison to
- CF **Gray Eagle** units, then what unique capability does the ARSOA Gray Eagle unit
- ARSOA **Gray Eagle** unit provide SOA? Of note, the terms manning and

quippi**ng**

Page : 1394

- the **Gray Eagle** for more than a decade, but it was not until 2013
- aviation **Gray Eagle** company within the Army. Before that time Quick Reaction Capability Companies
- ARSOA **Gray Eagle** operations within SOA has not been written to capture the unique

Page : 1395

- second **Gray Eagle** company (USA UAS COE 2010, 4-6).
- ARSOA **Gray Eagle** company appears to be a stable and growing capability, it is
- the **Gray Eagle** like a CF UAS unit. However, the ARSOA Gray Eagle
- ARSOA **Gray Eagle** company is manned, trained, and equipped in almost an identical
- ARSOA **Gray Eagle** unit from providing a unique SOA capability? This study will illustrate
- the **Gray Eagle**'s capabilities and meet SOF needs. Only by conducting a
- their **Gray Eagle** units. Primary Research Question In order to answer the primary question

Page : 1396

- ARSOA **Gray Eagle** organization when compared to the rotary wing ARSOA units? 3.
- the **Gray Eagle** and the near-term fielding of the MQ-1C Extended
- Range **Gray Eagle** UAS are the only Group 4 UAS platforms employed by ARSOA within
- the **Gray Eagle** company within the 160th Special Operations Aviation Regiment (160th SOAR)
- CF **Gray Eagle** community;

Page : 1397

- ARSOA **Gray Eagle** community. Definitions and Terms The Unmanned Aircraft System (UAS)
- 1C **Gray Eagle**, the ground control station (GCS), and the communications

Page : 1404

- ARSOA **Gray Eagle** unit of study in this thesis. The study may not clearly

Page : 1405

- the **Gray Eagle** provides SOA with a unique UAS capability. Specific DOTMLPFP domains that
- ARSOA **Gray Eagle** unit, in relation to UAS employment by the CF. This
- ARSOA **Gray Eagle** units are not vulnerable to changes in the CF's force

Page : 1406

- ARSOA **Gray Eagle** as beginning with the creation of E/160 in 2013.
- the **Gray Eagle** within special operations during the operations of the Quick Reaction Capability Companies
- ARSOA **Gray Eagle** and the CF Gray Eagle units, in comparison to ARSOA and
- CF **Gray Eagle** units, in comparison to ARSOA and CF rotary wing units.
- ARSOA **Gray Eagle** unit that may prevent it from providing a unique UAS SOA capability
- CF **Gray Eagle** unit, by comparing the similarities and differences between the ARSOA and
- CF **Gray Eagle** units. The study will then look to the ARSOA rotary wing

Page : 1407

- ARSOA **Gray Eagle** unit from providing a unique SOA capability? The author developed this
- ARSOA **Gray Eagle** company, E/160, as the executive officer just prior
- the **Gray Eagle**, its role within the 160th SOAR, and the Soldiers who
- the **Gray Eagle**. With that understanding, the author believes there are capability gaps

Page : 1408

- The **Gray Eagle** is still within its first five years of employment within ARSOA,
- second **Gray Eagle** company is currently being fielded with an August 2018 activation date.
- ARSOA **Gray Eagle** is going to increase, as evidenced by the fielding of a
- second **Gray Eagle** company within the 160th SOAR. Additionally, the Department of Defense
- the **Gray Eagle** with the production of the Extended Range (ER) Gray Eagle
-) **Gray Eagle**, which is scheduled to undergo initial operational testing and evaluation (

Page : 1409

- CF **Gray Eagle** units. After gathering the right data, an applied professional case

Page : 1410

- ARSOA **Gray Eagle** unit has enabled special operations across the globe with phenomenal results.
- 1C **Gray Eagle** company within ARSOA. This chapter discussed the background, the problem

Page : 1411

- ARSOA **Gray Eagle** unit to meet special operations specific requirements, and to persuade the

Page : 1414

- 1C **Gray Eagle** aerial vehicle. One of which is the Direct Attack Guided Rocket

- 1C **Gray Eagle** to carry up to four times as much payload as its current
- 1C **Gray Eagle** Selected Acquisition Report (SAR), as of the FY2017 President
- of **Gray Eagle** units in terms of organization. Specifically, it addresses how the

Page : 1415

- to **Gray Eagle** crewmembers and their commanders. The purpose of this document is to

Page : 1416

- the **Gray Eagle** specific aircrew training program and the commander's aircrew training program
- to **Gray Eagle** operations. This is significant because this study will examine the corresponding
- ARSOA **Gray Eagle** units both use this same document. The aircrew training program outlined
- the **Gray Eagle**, criteria for readiness level progression,

Page : 1417

- a **Gray Eagle** company commander to execute the aircrew training program that covers everything from
- the **Gray Eagle** and is the basis for the crewmember's training from the
- and **Gray Eagle** crewmembers. It does not apply to ARSOA MH-47G crewmembers

Page : 1418

- ARSOA **Gray Eagle** crewmembers. This reference covers much of the same material as the
- ARSOA **Gray Eagle** crewmembers only have the designations of AO and AC. The ARSOA

Page : 1421

- a **Gray Eagle** operator would be to operate synthetic aperture radar, task #2305

Page : 1422

- the **Gray Eagle** community, UAS crewmembers (UACs) have the following designations;
- approved **Gray Eagle** qualification course and designation in writing from the aircrew training program commander

Page : 1423

- Army **Gray Eagle** Instructor Operator (IO) course to undergo training. Of note

Page : 1426

- the **Gray Eagle** is not rated for IFR flight, and because of that,

Page : 1431

- and **Gray Eagle**) to meet joint expeditionary tactics, techniques, procedures, forward

Page : 1432

- USASOC **Gray Eagle** units (F102Ra 2017, 2). The USASOAC Commander,
- ARSOA **Gray Eagle** organization when compared to the rotary wing ARSOA units? (3
- ARSOA **Gray Eagle** units' domains of manning, training, and equipping, needed

Page : 1433

- ARSOA **Gray Eagle** unit. These capability gaps were based on capabilities provided by ARSOA

Page : 1434

- ARSOA **Gray Eagle**

Page : 1436

- the **Gray Eagle** company within special operations (Hancock and Algozzine 2011; Gagnon 2010

Page : 1441

- 15W **Gray Eagle** operators. Army and Joint doctrine also provide the condition for this

Page : 1442

- 1C **Gray Eagle** units. To determine the standard for the FAA, this study
- ARSOA **Gray Eagle** in relation to CF Gray Eagle formations. This established the standard
- CF **Gray Eagle** formations. This established the standard set for this study. The
- 1C **Gray Eagle** 15W operators, are more senior in ARSOA rotary wings units compared
- ARSOA **Gray Eagle** operators. The number of personnel must be taken into account when

Page : 1443

- senior **Gray Eagle** operators than CF Gray Eagle units. Part of ARSOA's
- CF **Gray Eagle** units. Part of ARSOA's ability to provide a unique

Page : 1444

- enlisted **Gray Eagle** 15W operators in the grades of E5, E6, and E7

Page : 1445

- 15W **Gray Eagle** operators. The ARSOA rotary wings units have a unique training and
- conventional **Gray Eagle** units and does not have unique, special operations aviation specific aircrew
- unique **Gray Eagle** capability, and part of that expectation involves uniquely trained 15W operators

Page : 1446

- operations **Gray Eagle** capability to the ground force commander that would enable them to control

Page : 1447

- CFs **Gray Eagle** units, there is no specialized equipment that enables E/160
- The **Gray Eagle** employed by E/160 is identical to the one employed by
- CF **Gray Eagle** unit, B/101. Given the results of this comparison
- CF **Gray Eagle** units. The risk associated with the identified equipment capability gap is
- s **Gray Eagle** capability. Special operations

Page : 1448

- the **Gray Eagle** to provide a unique UAV platform capability specifically designed to support the
- current **Gray Eagle** company equipment resources to enhance its ability to support special operations.
- the **Gray Eagle** to improve the company's expeditionary capability. R2: The

Page : 1449

- ARSOA **Gray Eagle** unit to provide the unique capabilities required by the special operations community
- CF **Gray Eagle** company to an ARSOA Gray Eagle company and comparing them to the
- ARSOA **Gray Eagle** company and comparing them to the similarities and differences between a CF
- ARSOA **Gray Eagle** company. Specifically, the manned ARSOA rotary wing company analyzed in
- 1C **Gray Eagle** company in comparison to the CF MQ-1C Gray Eagle company
- 1C **Gray Eagle** company. This new knowledge and understanding led the author to update

Page : 1450

- ARSOA **Gray Eagle** unit from providing a unique special operations aviation capability? During the
- ARSOA **Gray Eagle** company, Company F, 160th Special Operations Aviation Regiment, scheduled
- ARSOA **Gray Eagle** company, F/160, is scheduled to activate in August
- ARSOA **Gray Eagle** companies within a five-year period. This highlights the importance
- ARSOA **Gray Eagle** company. The primary sources of data for this study were DOD

Page : 1451

- ARSOA **Gray Eagle** companies in relation to the ARSOA and CF rotary wing companies.
- 1C **Gray Eagle** company. The MTOE narrative and aircrew training publications provided the necessary
- ARSOA **Gray Eagle** company in comparison to the CF's UAS company. In

Page : 1452

- the **Gray Eagle** within ARSOA, which is focused on the Army and its mission
- ARSOA **Gray Eagle** needs to provide a unique UAS capability to enhance ARSOA before these
- and **Gray Eagle**) to meet joint expeditionary tactics, techniques, procedures, forward

Page : 1453

- ARSOA **Gray Eagle** unit from providing a unique special operations aviation capability? The primary

Page : 1454

- its **Gray Eagle** assets. The author’s personal operational experience attests that DOD

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- 15W **Gray Eagle** operators. The proposed non-materiel solution to this capability gap
- the **Gray Eagle** to provide a unique aviation capability. The author recommended a modification
- the **Gray Eagle** that increases its expeditionary capability by reducing the physical size of the

Page : 1456

- the **Gray Eagle**. The CDM would agree with the author’s recommendation to
- the **Gray Eagle** to increase its expeditionary capability. This recommendation is in-line
- and **Gray Eagle**) to meet joint expeditionary tactics, techniques, procedures, forward

Page : 1459

- ARSOA **Gray Eagle** units would be a fairly simple change to make. This is

Page : 1460

- ARSOA **Gray Eagle** units. It is once again important to note that the author
- ARSOA **Gray Eagle** company, F/160, with an activation date set for
- ARSOA **Gray Eagle** company, E/160, is viewed as a critical capability
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Page : 1462

- 1C **Gray Eagle** Extended Range UAS in July of 2018. This new version of
- the **Gray Eagle** will provide additional capabilities and, because of this, it is
- the **Gray Eagle** until the added benefits of this new version are fully understood.
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- the **Gray Eagle** should be the focus of a follow-on study. Based

- the **Gray Eagle**. This proposed solution was recommended because it is nested within the
- and **Gray Eagle**) to meet joint expeditionary tactics, techniques, procedures, forward

Page : 1463

- ARSOA **Gray Eagle** units. Unlike the proposed short term solution, the identified long
- the **Gray Eagle** was based upon the needs of the CF, and that a
- the **Gray Eagle** by reducing the size of the ground control station, satellite and
- the **Gray Eagle**. The study would need to focus on the current breakdown and
- the **Gray Eagle** in its current configuration as well as the amount of pallet space
- one **Gray Eagle** flight platoon from one location to another. The study would then

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- the **Gray Eagle** to address the capability gap in supporting this USSOCOM mission set.
- ARSOA **Gray Eagle** units to exclusively train at their home base or incur the high

Page : 1465

- The **Gray Eagle** needs to have the ability to tailor its payload based on the
- the **Gray Eagle** other than its current restriction to the Hellfire missile. This is
- the **Gray Eagle**, but in its current configuration, it can only carry up
- the **Gray Eagle** an alternate, lighter, precision guided munition that would provide the
- upgraded **Gray Eagle** materiel solution? (2) Perform a manpower grade analysis to

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- ARSOA **Gray Eagle** units, and more importantly, an understanding of the current capability
- ARSOA **Gray Eagle** company, F/160. Additionally, by focusing this study
- The **Gray Eagle** platform was designed to meet the needs of the CF and this
- ARSOA **Gray Eagle** units need to begin making the same organizational, training, and

Page : 1467

- “**Gray Eagle** UAS.” Accessed September 21, 2017. http:/

Page : 1471

- a **Gray Eagle** unmanned aircraft system (UAS). Sound levels inside of Universal
- The **Gray Eagle** operators did not wear hearing protection and it is recommended that they

- , **Gray Eagle,** sound level, UGCS

Page : 1473

- 1C **Gray Eagle**. The RQ-7 Shadow Tactical Unmanned Aircraft System (TUAS
- 1C **Gray Eagle** is a mediumaltitude, long-endurance (MALE) UAS and
- and **Gray Eagle** require the use of hearing protection per Section 7-13 of
- that **Gray Eagle** operators use some sort of hearing protection. The sound levels in

Page : 1477

- 10 **Gray Eagle** .....
- 1C **Gray Eagle** unmanned aircraft system (UAS). .....
- the **Gray Eagle**. .....
- . **Gray Eagle** UAS with first three microphone positions. .....
- . **Gray Eagle** UGCS dimensions and microphone placement. .....
- in **Gray Eagle** UGCS. .....
- . **Gray Eagle** UAS. .....
- . **Gray Eagle** UAS sound levels .....
- in **Gray Eagle** UGCS .....

Page : 1479

- 1C **Gray Eagle** is a mediumaltitude, long-endurance (MALE) UAS and
- and **Gray Eagle** unmanned aircraft systems. Built on a flexible crew station architecture,

Page : 1480

- 1C **Gray Eagle** unmanned aircraft system (UAS). Universal ground control stations (

Page : 1481

- 1C **Gray Eagle** UAS vehicles at Fort Huachuca, AZ in July 2019. Measurements
- and **Gray Eagle** UAS sound level measurements. Due to a limited opportunity to collect
- the **Gray Eagle** UAS which was 4 feet high. The relative microphone positions for
- the **Gray Eagle**. Table 1. Microphone distances from the aircraft centerline in feet

Page : 1482

- 4 **Gray Eagle** UAS with first three microphone positions. Shadow UAS on launcher showing

Page : 1484

- the **Gray Eagle** UGCS. Figure 9 shows the dimensions and microphone layout for the
- the **Gray Eagle** UGCS. Microphone 1 and Microphone 2 were placed on the

hair**s**

- the **Gray Eagle** UGCS. Gray Eagle UGCS dimensions and microphone placement. Microphone positions
- . **Gray Eagle** UGCS dimensions and microphone placement. Microphone positions one, two,
- in **Gray Eagle** UGCS.

Page : 1489

- 72.8 **Gray Eagle** Gray Eagle UAS. Measurements were conducted prior to launch while the
- Eagle **Gray Eagle** UAS. Measurements were conducted prior to launch while the Gray Eagle
- the **Gray Eagle** UAS idled on the tarmac. The results are shown in Table

Page : 1490

- . **Gray Eagle** UAS sound levels dB(A) Gray Eagle UAS Sound Levels
-) **Gray Eagle** UAS Sound Levels Low Idle High Idle Mic 1 78.7 103 Mic
- the **Gray Eagle** UGCS are shown in Table 5. Each measurement sample was one
- in **Gray Eagle** UGCS dB(A) Gray Eagle UGCS Sound Levels Sample 1
-) **Gray Eagle** UGCS Sound Levels Sample 1 Sample 2 Sample 3 Mic 1 76.2

Page : 1492

- The **Gray Eagle** Operator did not wear hearing protection. For the majority of time
- the **Gray Eagle** UAS was on the tarmac it was at low idle and the

Page : 1637

- 1C **Gray Eagle** represent a sampling of the updated and emerging capabilities at echelons above

Page : 1686

- 1C **Gray Eagle** UAS. These MQ-1C Gray Eagle UAS are often reserved
- 1C **Gray Eagle** UAS are often reserved for divisional control as dedicated collection platforms.
- 1C **Gray Eagles** and the RQ-7 Shadows within the Combat Aviation Brigade lies
- 1C **Gray Eagles** operate as a separate company within the Attack Reconnaissance Battalion.118F12
- 1C **Gray Eagle** UASs. The key point for the division echelon is, barring

Page : 1801

- 1C **Gray Eagle** was cited at $26.5M with an average yearly operations and support

Page : 1802

- Gray **Eagle and MQ-**9 Reaper are used specifically for combat, like the F-

- Gray **Eagle and MQ-**9 Reaper have an available ECM payload (Air Force Technology n

Page : 1890

- 1C **Gray Eagle** was cited at $26.5M with an average yearly operations and support

Page : 1891

- Gray **Eagle and MQ-**9 Reaper are used specifically for combat, like the F-
- Gray **Eagle and MQ-**9 Reaper have an available ECM payload (Air Force Technology n

Page : 1911

- . **Gray Eagle** .....
- . **Gray Eagle** T&E Test Methodology.....

Page : 1913

- UAS **Gray Eagle**. Source: SAR (2010). ....
- . **Gray Eagle** RDT&E Funding. Adapted from SAR (2010).

Page : 1915

- 1C **Gray Eagle**'s Schedule. Adapted from SAR (2010) and SAR

Page : 1930

- . **Gray Eagle** According to the Selected Acquisition Report (SAR) (2010)
-) **Gray Eagle** or MQ-1C Unmanned Aircraft System (UAS) program is
- . **Gray Eagle** Quick Reaction Capability (QRC) 2 Units are capable of autonomous
- the **Gray Eagle** was initiated in April 2005 at milestone (MS) B and
- prototype **Gray Eagle** UAS equipment to support the war in Iraq. QRC Gray Eagle
- , **Gray Eagle** was re-designated as an ACAT 1D and by March of

Page : 1931

- allowable **Gray Eagles** within a platoon to 3 per company, which was a total
- 17 **Gray Eagle** UAS companies. According to the SAR report PM-UAS performed
- UAS **Gray Eagle**. Source: SAR (2010). 2. Autonomous Mobility

Page : 1938

- , **Gray Eagle** is a major defense acquisition program (MDAP) that was required
- . **Gray Eagle**'s autonomous functionality includes a system capable of automatic take-
- includes **Gray Eagle**'s acquisition program baseline (APB) and the project management
- includes **Gray Eagle**'s acquisition program baseline (APB) and the project management
- with **Gray Eagle**'s annual funding in Table 2 and surmise how much money

Page : 1939

- 1C **Gray Eagle**’s Schedule. Adapted from SAR (2010) and SAR
- verify **Gray Eagle**’s ability to autonomously take-off and land to ensure
- 1C **Gray Eagle** 2016 SAR (Table 1), confirmed Gray Eagle’s
- confirmed **Gray Eagle**’s IOTE was scheduled to begin in September of 2011 and
- during **Gray Eagle**’s engineering maturation phase as shown in Table 2 SAR (

Page : 1940

- . **Gray Eagle** RDT&E Funding. Adapted from SAR (2010).

Page : 1941

- the **Gray Eagle** program spent the largest amount of RDT&E funds during the
- to **Gray Eagle**’s budget and IOT&E cannot be discerned from just
- verify **Gray Eagle**’s autonomous capability in an operational environment was the cost driver

Page : 1942

- . **Gray Eagle** T&E Test Methodology According to the (DOT&E
- , **Gray Eagle** utilized computer-based simulation training for Gray Eagle operators and actual
- for **Gray Eagle** operators and actual test flight in both the continental United States and
- train **Gray Eagle** operators with monitoring flight systems, air traffic and communication systems with

Page : 1943

- During **Gray Eagle** operational testing, autonomous systems are verified and validated using continuous software
- Since **Gray Eagle** is an ACAT 1D program, the low rate initial production (
- test **Gray Eagle**’s sensors and autonomous capabilities against foreign threats. 3.

Page : 1945

- s **Gray Eagle** utilizes Edwards Air Force Base in California and the National Training Center

Page : 1957

- , **Gray Eagle**, Project Perdix and the AMAS system) alongside similar industry systems

Page : 1960

- ; **Gray Eagle** is tested in airspace used to qualify the military’s fleet

Page : 1963

- . **Gray Eagle** was similarly developed with the same methodology. Government test and evaluators
- the **Gray Eagle** after the capability was complete and real-world data could be

- train **Gray Eagle** operators, but virtual testing could have been utilized to mitigate reliability

Page : 1965

- the **Gray Eagle**’s autonomous liftoff and landing capability could have reduced the time

Page : 1967

- (**Gray Eagle**, SREHD, and AMAS & Project Perdix) and identify corresponding

Page : 1971

- like **Gray Eagle**, have a process in place to incrementally add enhancements but the

Page : 1973

- 1C **Gray Eagle.** Defense Modeling & Simulation Coordination Office. (2019, December 13
- , **Gray Eagle UAS** Completes 20,000 Automated Takeoffs and Landings. http://www

Page : 2007

- two **Gray Eagle** (GE) MQ-1Cs, one Shadow (SH)

Page : 2029

- GE **Gray Eagle** GFC Ground Force Commander HAI Human-Autonomy Interface HOTAS Hands-

Page : 2053

- 1C **Gray Eagle**, the RQ-7B Shadow, and AH-64 Apache

Page : 2137

- 81 **Gray Eagle** Unmanned Aircraft System 83 HC/MC-130 Recapitalization Program 85

Page : 2148

- The **Gray Eagle** unmanned aircraft program changed how it calculates quantities for the 2010 SAR

Page : 2223

- : **Gray Eagle** Page 83 GAO-12-400SP Assessments of Selected Weapon Programs
- Programs **Gray Eagle** Unmanned Aircraft System The Army’s MQ-1C Gray Eagle
- 1C **Gray Eagle** will perform reconnaissance, surveillance, target acquisition, and attack missions
- The **Gray Eagle** program began production in February 2010 with three of its five critical

Page : 2224

- : **Gray Eagle** Page 84 GAO-12-400SP Assessments of Selected Weapon Programs

- Programs **Gray Eagle** Program Technology Maturity The Gray Eagle entered production in February 2010 without
- The **Gray Eagle** entered production in February 2010 without all five of its critical technologies
- controlling **Gray Eagle**. However, the tactical common data link is still not fully
- the **Gray Eagle** design is currently stable; however, the program has experienced a
- Maturity **Gray Eagle** began production in February 2010 with manufacturing processes that had been demonstrated
- the **Gray Eagle**'s production processes. If tooling or other manufacturing changes are
- the **Gray Eagle** baseline design is mature. The program also indicated that changes to
- the **Gray Eagle** baseline design mature, but the tactical common data link's

Page : 2315

- UAS **Gray Eagle** 5,159 1,015 408.2 2.0 159.9 Multifunctional Information Distribution System (MIDS)

Page : 2325

- . **Gray Eagle** Unmanned Aircraft System Tana M. Davis Ground Combat Vehicle (GCV

Page : 2335

- 1C **Gray Eagle** .....

Page : 2339

- 1C **Gray Eagle**). PERFORMANCE AND COST ASSESSMENT No single platform was clearly superior

Page : 2341

- 1C **Gray Eagle.** Survey Methods The DPG Team conducted weekly golden eagle nest surveys on

Page : 2362

- 1C **Gray Eagle** was also used when available for nest monitoring in both the 2019
- The **Gray Eagle** fleet on DPG underwent a significant upgrade to their payload systems during
- the **Gray Eagle** platform were also intriguing as a method of detecting chicks (before
- the **Gray Eagle** was not always available for monitoring, it was difficult to obtain
- 1C **Gray Eagle** Although not specifically included in the demonstration, helicopters can also be

Page : 2501

- a **Gray Eagle** Company directly assigned at the brigade level. The current associated TOE

- alone **Gray Eagle** Company suggests that such an organization would include its own flight operations
- the **Gray Eagle** has a flight endurance of over 27 hours at an altitude of
- the **Gray Eagle** intended for Multi-Domain operation provides an extended endurance of up
- the **Gray Eagle**, which Armada International calculates at up to 387 kilometers using a
- 01707K000 **Gray Eagle** UAS Company (MQ-1C) (SEP) TOE Narrative
- 1C **Gray Eagle** Unmanned Aircraft System (UAS)," U.S.
- "**Gray Eagle** Extended Range (GE-ER)," General Atomics Aeronautical

Page : 2502

- the **Gray Eagle** that the MDTF uses, either platform provides the capability of providing
- the **Gray Eagle** does not currently possess is an anti-submarine capability. This
- the **Gray Eagle** and has a correspondingly higher carrying capacity, a similar system could

Page : 2503

- s **Gray Eagle** Company, which can provide targeting information using over the horizon and

Page : 2516

- the **Gray Eagle** is not included on these diagrams as the system's range

Page : 2518

- the **Gray Eagle**'s surveillance capability. Using the HIMARS to its maximum range

Page : 2521

- s **Gray Eagle** company to its limits, requiring careful selection of surveillance locations to

Page : 2532

- s **Gray Eagle** or replace a portion of the Gray Eagle platforms with MQ-
- the **Gray Eagle** platforms with MQ-9B platforms with that package. 4.

Page : 2541

- 1C **Gray Eagle** Unmanned Aircraft System (UAS)." Accessed 13 March 2022

Page : 2547

- 01707K000 **Gray Eagle** UAS Company (MQ-1C) (SEP) TOE Narrative

Page : 2548

- "**Gray Eagle** Extended Range (GE-ER)." Accessed 13 March

Page : 2601

- /**Gray Eagle** .....

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/ **Gray Eagle**.....

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/**Gray Eagle** (Headquarters, Department of the Army 2006a, 21).

Page : 2646

/**Gray Eagle** The MQ-1C Gray Eagle, produced by General Atomics Aeronautical

1C **Gray Eagle**, produced by General Atomics Aeronautical Systems, is an upgrade of

Page : 2647

the **Gray Eagle** (Jensen 2010). Production of the MQ- 1C is

The **Gray Eagle** is capable of either LOS or BLOS communications using Ku-band

Page : 2648

/ **Gray Eagle** Source: FY2009–2034 Unmanned Systems Integrated Roadmap, DOD (

Page : 2791

and **Gray Eagle** UAS are weaponized to conduct offensive operations, irregular warfare, and

Page : 2792

1C **Gray Eagle** US Army BA ISR/RSTA, C3, Log, PS

Page : 2835

, **Gray Eagle**, and Global Hawk) utilize both LOS and BLOS communications,

Page : 2883

a **Gray Eagle** UAV (MUM concept) .....

Page : 2911

a **Gray Eagle** UAV (MUM concept) Source: Defense Update, http:

Page : 2979

Army **Gray Eagle** and DHS's Predator optimized for marine environments; Northrop Grumman

Page : 2981

1C **Gray Eagle** 26 24 Army ISR/Reconnaissance, Surveillance, and Target Acquisition

Page : 3026

5B **Gray Eagle** MQ-1C Corps Level Division Level Brigade Level Battalion Level Puma

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Hunter **Gray Eagle** Remote Video Terminal (RVT) Ground Control Station (GCS)

Page : 3028

- Hunter **Gray Eagle** (all variants) Total UAS OIF/OND Hours (EOM

Page : 3043

- 1C **Gray Eagle**

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- UNCLASSIFIED **Gray Eagle** System Characteristics 21 21 12 Unmanned Aircraft 6 Control Stations 9 TCDL

Page : 3045

- UNCLASSIFIED **Gray Eagle** RF Spectrum Requirements 22 System Component Frequencies Used Manufacturer Quantity Location J

Page : 3046

- UNCLASSIFIED **Gray Eagle** RF Spectrum Requirements 23 System Component Frequencies Used Manufacturer Quantity Location J

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- UNCLASSIFIED **Gray Eagle** RF Spectrum Requirements 24 System Component Frequencies Used Manufacturer Quantity Location J

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- UNCLASSIFIED **Gray Eagle** RF Spectrum Requirements 25 System Component Frequencies Used Manufacturer Quantity Location J

Page : 3049

- /**Gray Eagle**. • Army has transitioned test activities from ELMO to Dugway Proving
- five **Gray Eagle** sites. • Interoperability and Technology demos utilizing the DPG testbed currently

Page : 3199

- first **Gray Eagle** UAS with the Common Sensor Payload (CSP), Full Motion

Page : 3200

- the **Gray Eagle** platform with day / night capability to collect and display continuous imagery

Page : 3203

- fund **Gray Eagle** UAS production. Table 5. Aviation Portfolio (see Acronym glossary

Page : 3205

- 1C **Gray Eagle** Unmanned Aircraft and the associated ground support equipment ($456M)
- . **Gray Eagle** missions include Reconnaissance, Surveillance, Target Acquisition, Armed Reconnaissance,
- two **Gray Eagle** Quick Reaction Capability platoons equipped with four aircraft each (one was
- 1C **Gray Eagle** Company to the 1st Infantry Division CAB in the 3rd quarter of
- 17 **Gray Eagle** Companies; two fully equipped companies within the Special

per**ations Com**mand;

Page : 3206

- 1C **Gray Eagle** program by procuring 36 MQ-1C aircraft, 18 ground control

Page : 3237

- (**Gray Eagle**) Enhanced Situational Awareness Expeditionary Signal Battalion Field Artillery Functional Area Assessment

Page : 3256

- 1C **Gray Eagle** Unmanned Aircraf

Page : 3263

- 1 **Gray Eagle** (GE) Unmanned Aircraft System (UAS) TEMP MQ-

Page : 3264

- 1C **Gray Eagle** Unmanned Aircraft System IOT&E OTA Test Plan MQ-9

Page : 3266

- 1C **Gray Eagle** Unmanned Aircraft System (UAS) OT Report April 2012 Department of

Page : 3270

- System **Gray Eagle** Nett Warrior One System Remote Video Terminal (OSRVT) Paladin/

Page : 3274

- Gray **Eagle and** JTRS HMS Manpack Radio. Despite the recommendation, both of these
- Gray **Eagle performed** well in IOT&E despite DT results suggesting poor reliability that
- Gray **Eagle Unmanned** Aircraft System (UAS) C-130 Avionics Modernization Program (

Page : 3275

- Gray **Eagle Unmanned** Aircraft System (UAS) E-2D Advance Hawkeye MQ-

Page : 3347

- with **Gray Eagle** to receive UAS video. Crews had some difficulty establishing and maintaining
- the **Gray Eagle** sensor. • There is a pilot confidence concern with the AB3

Page : 3368

- 1C **Gray Eagle** 103 Memorandum, the project manager for UAS requested the Army Aviation
- The **Gray Eagle** UAS participated in the Apache Block 3 IOT&E in March
- single **Gray Eagle** UAS with associated flight crew and personnel provided mission support to the
- employ **Gray Eagle** Companies to execute Reconnaissance, Surveillance, Security, Attack, and
- the **Gray Eagle** IOT&E at Edwards AFB, California, and the National

- the **Gray Eagle** Full-Rate Production decision planned for April 2013. In that
- the **Gray Eagle**-equipped unit was effective at operating the MQ-1C system
- The **Gray Eagle** system is operationally suitable. The Gray Eagle meets its crew force
- The **Gray Eagle** meets its crew force protection survivability requirements by providing up-armored
- The **Gray Eagle** aircraft is not survivable in a mid- to high-threat
- The **Gray Eagle** Unmanned Aircraft System (UAS) is composed of the following major
- 1C **Gray Eagle** Unmanned Aircraft System (UAS)

Page : 3369

- 1C **Gray Eagle** • The Army conducted the Gray Eagle IOT&E at Edwards
- the **Gray Eagle** IOT&E at Edwards AFB, California, and the NTC
- the **Gray Eagle** provided the lasing of the target and launched the missile on its
- the **Gray Eagle**-equipped unit was effective at operating the MQ-1C system
- of **Gray Eagle** into employment concepts, and development of tactics, techniques, and
- The **Gray Eagle** system has more capability and functionality today than it demonstrated in previous
- The **Gray Eagle** system is operationally suitable. During IOT&E, the Gray
- the **Gray Eagle** unit demonstrated its ability to meet its operational tempo requirement to provide
- The **Gray Eagle** system demonstrated a Combat Availability of 81 percent, exceeding the Sustainment
- the **Gray Eagle** demonstrated KSA Mean Time Between System Abort (MTBSA) compared to
- The **Gray Eagle** Company depended heavily on the maintenance expertise of Contractor Field Service Representatives
- the **Gray Eagle** to the One System Remote Video Terminal (OSRVT) was generally
- the **Gray Eagle** with a reliable remote video display system is not complete. •
- the **Gray Eagle** system when using the TCDL and SATCOM datalinks. The Army has
- The **Gray Eagle** is vulnerable to computer network attack. • The Gray Eagle meets
- The **Gray Eagle** meets its crew force protection survivability KPP requirement by providing up-

Page : 3370

- 1C **Gray Eagle** 105 - Procedures for operators to establish SATCOM and ADR datalinks are
- the **Gray Eagle** unit into combat operations. - Train operators on fundamentals

f re**connaissan**ce
- the **Gray Eagle**. - Continue to develop and publish standardized procedures for distribution of
- of **Gray Eagle** video to OSRVT and institute training across the Army to facilitate integration
- of **Gray Eagle** into supported unit operations. - Revise and expand the training program

Page : 3615

-) **Gray Eagle** (see MQ-1C Gray Eagle) Ground-Based Midcourse
- 1C **Gray Eagle**) Ground-Based Midcourse Defense (GMD)...

Page : 3616

- 1C **Gray Eagle** Unmanned Aircraft System (UAS) .....

Page : 3728

- Army **Gray Eagle** in flight. From [14] . . . . .

Page : 3747

- 1C **Gray Eagle** The MQ-1C Gray Eagle (also known as “Warrior
- 1C **Gray Eagle** (also known as “Warrior”) belongs in the Group

Page : 3751

- Army **Gray Eagle** in flight. From [14] Figure 2.7: MQ-

Page : 3858

- . **Gray Eagle** Armed Persistence Data Sheet. Poway: CA, G.A
- 30m **gray eagle** contract. (2012). [Online]. Available:

Page : 3901

- and **Gray Eagle** UAS are weaponized to conduct offensive operations, irregular warfare, and

Page : 3924

- s **Gray Eagle** efforts are already moving in this direction. Such hardware will allow

Page : 3967

- Army **Gray Eagle** at Fort Hood, Texas. The Gray Eagle currently requires a
- The **Gray Eagle** currently requires a COA to transit from Joint use Class D airspace
- the **Gray Eagle** vehicle must be certified as airworthy and properly equipped to fly in
- the **Gray Eagle** to manned aircraft

Page : 3968

- the **Gray Eagle** will fly perpendicular to the road and take other similar precautions.

Page : 3977

- s **Gray Eagle** program will use the Navy’s Fleet Repair Center Southeast,

Page : 3981

- 1C **Gray Eagles.** The 2nd Battalion, 13th Aviation Regiment (2–13th Aviation
- and **Gray Eagle maintenance**. Additionally, 2-13th Aviation supports the Joint community by

Page : 4020

- Army **Gray Eagle** program to identify opportunities for leveraging similar efforts. The programs are
- Army **Gray Eagle** program’s research of the Government’s rights. The

Page : 4035

- Gray **Eagle Unmanned** Aircraft System (MQ-1C Gray Eagle) 99
- Gray **Eagle) 99**

Page : 4139

- 1C **Gray Eagle** Page 99 GAO-14-340SP Assessments of Major Weapon Programs
- 1C **Gray Eagle** Unmanned Aircraft System (MQ-1C Gray Eagle) The Army
- 1C **Gray Eagle**) The Army's MQ-1C Gray Eagle unmanned aircraft
- 1C **Gray Eagle** unmanned aircraft system (UAS) will perform reconnaissance, surveillance,
- The **Gray Eagle** program received approval to begin full-rate production in June 2013

Page : 4140

- 1C **Gray Eagle** Page 100 GAO-14-340SP Assessments of Major Weapon Programs
- 1C **Gray Eagle** Program Technology and Design Maturity The Gray Eagle program reported that all
- The **Gray Eagle** program reported that all five of its critical technologies are mature and
- entire **Gray Eagle** fleet, although it would provide increased reliability and endurance. A
- The **Gray Eagle**'s 2013 production readiness assessment reported that its manufacturing processes are
- the **Gray Eagle** prime contractor is currently flight testing a new aircraft engine to replace
- The **Gray Eagle** system completed initial operational test and evaluation in August 2012. DOD
- train **Gray Eagle** operators on the new system. Program Office Comments In commenting on

Page : 4202

- 1C **Gray Eagle Unmanned** Aircraft System (MQ-1C Gray Eagle) 4,951 1,068 363.6

- 1C **Gray Eagle)** 4,951 1,068 363.6 2.1 94.3 MQ-4C Triton Unmanned Aircraft System

Page : 4210

- Gray **Eagle Unmanned** Aircraft System (MQ-1C Gray Eagle) 6 5 MQ
- Gray **Eagle) 6** 5 MQ-4C Triton Unmanned Aircraft System (MQ-4C

Page : 4214

- 1C **Gray Eagle**) Deanna Laufer, James S. Kim MQ-4C Triton

Page : 4225

- 1C **Gray Eagle** Unmanned Aircraft System Decrease Decreased requirements for the removal and replacement of

Page : 4307

- 1C **Gray Eagle** or man-portable electronic jammers are intended to deploy as part

Page : 4310

- 1C **Gray Eagle**. A variant of the General Atomics MQ-1 Predator,
- the **Gray Eagle is** a 3,600-pound airplane with a 56-foot wingspan,
- 12 **Gray Eagles.4** Ultimately, these aircraft achieve a true multirole operational capability, including
- the **Gray Eagle flies** above the coordinating altitude in joint airspace, we already face the
- the **Gray Eagle as** a joint operational asset will require putting in place the same type

Page : 4311

- 1C **Gray Eagle** Recent Conflicts and the Need for Joint Flexibility The recent operation in

Page : 4325

- as **Gray Eagle** companies take on the task of preparing to function as joint air

Page : 4330

- Upgrading **Gray Eagle Fleet**," US Army, 28 June 2012, http:/
- MP **Gray Eagle:** Enhanced MQ-1C Predators for the Army," Defense Industry

Page : 4437

- and **Gray Eagle** UAVs . . . . . .

Page : 4441

- and **Gray Eagle** systems. Training for the Raven UAS, which is about the
- training **Gray Eagle** Gray Eagle All: large systems usually simulated for leader training All
- Eagle **Gray Eagle** All: large systems usually simulated for leader training All: large
- possibly **Gray Eagle** Shadow and Raven Predator, Reaper Predator, Reaper Predator, Reaper

Page : 4472

- training **Gray Eagle** Gray Eagle All: large systems usually simulated for leader training All
- Eagle **Gray Eagle** All: large systems usually simulated for leader training All: large
- possibly **Gray Eagle** Shadow and Raven Predator, Reaper Predator, Reaper Predator, Reaper

Page : 4473

- the **Gray Eagle** UAS. In some instances—these have historically been very rare
- flying **Gray Eagle**, when available. In addition, it is at this level

Page : 4478

- , **Gray Eagle,** and Shadow UASs Training for Army UAS operators—pilots and payload

Page : 4479

- for **Gray Eagle** classes. After completing Phase II, the UAS operators earn their
- , **Gray Eagle**, and Shadow UASs The Army UAS maintainers take the MOS 15E
- and **Gray Eagle**. The additional training takes ten weeks for Hunter and 18 weeks
- for **Gray Eagle**. Army Raven Operators Without a dedicated MOS, the development and
- hours **Gray Eagle** 25 weeks 71 ight hours 60 sim hours RSTA-I

Page : 4480

- and **Gray Eagle** UAVs SOURCE: DoD. SOURCE: U.S. Army

Page : 4482

- s **Gray Eagle** UAS has its own simulator capability built into the operating hardware.

Page : 4484

- and **Gray eagle** platforms evolve. Fort A. p. hill During landings the

Page : 4487

- as **Gray Eagle**, Predator, and Reaper, in home-station training events
- especially **Gray Eagle**, will be contiguous with the training areas in which they are

Page : 4500

- the **Gray Eagle** is similar to the costs the Air Force reported for Predator at

Page : 4505

- is **Gray Eagle** an ISR asset or an armed reconnaissance system? Doctrine development efforts
- with **Gray Eagle** took place in summer 2011, but GBSAA is not expected to

Page : 4534

- 1C **Gray Eagle**. The training pipeline for each of these was described in the

Page : 4535

- . **Gray Eagle** training takes place at Libby Army Airfield. Expansion Potential The IQT
- The **Gray Eagle** course is just beginning, and the Hunter course is winding down
- . **Gray Eagle** and Warrior Alpha vehicles are flown out of Libby Army Airfield.

Page : 4558

- and **Gray Eagle** UAVs . . . . . .

Page : 4562

- and **Gray Eagle** systems. Training for the Raven UAS, which is about the
- training **Gray Eagle** Gray Eagle All: large systems usually simulated for leader training All
- Eagle **Gray Eagle** All: large systems usually simulated for leader training All: large
- possibly **Gray Eagle** Shadow and Raven Predator, Reaper Predator, Reaper Predator, Reaper

Page : 4593

- training **Gray Eagle** Gray Eagle All: large systems usually simulated for leader training All
- Eagle **Gray Eagle** All: large systems usually simulated for leader training All: large
- possibly **Gray Eagle** Shadow and Raven Predator, Reaper Predator, Reaper Predator, Reaper

Page : 4594

- the **Gray Eagle** UAS. In some instances—these have historically been very rare
- flying **Gray Eagle**, when available. In addition, it is at this level

Page : 4599

- , **Gray Eagle,** and Shadow UASs Training for Army UAS operators—pilots and payload

Page : 4600

- for **Gray Eagle** classes. After completing Phase II, the UAS operators earn their
- , **Gray Eagle**, and Shadow UASs The Army UAS maintainers take the MOS 15E
- and **Gray Eagle**. The additional training takes ten weeks for Hunter and 18 weeks
- for **Gray Eagle**. Army Raven Operators Without a dedicated MOS, the development and
- hours **Gray Eagle** 25 weeks 71 ight hours 60 sim hours RSTA-I

Page : 4601

- and **Gray Eagle** UAVs SOURCE: DoD. SOURCE: U.S. Army

Page : 4603

- s **Gray Eagle** UAS has its own simulator capability built into the operating hardware.

Page : 4605

- and **Gray eagle** platforms evolve. Fort A. p. hill During landings the

Page : 4608

- as **Gray Eagle**, Predator, and Reaper, in home-station training events
- especially **Gray Eagle**, will be contiguous with the training areas in which they are

Page : 4621

- the **Gray Eagle** is similar to the costs the Air Force reported for Predator at

Page : 4626

- is **Gray Eagle** an ISR asset or an armed reconnaissance system? Doctrine development efforts
- with **Gray Eagle** took place in summer 2011, but GBSAA is not expected to

Page : 4655

- 1C **Gray Eagle**. The training pipeline for each of these was described in the

Page : 4656

- . **Gray Eagle** training takes place at Libby Army Airfield. Expansion Potential The IQT
- The **Gray Eagle** course is just beginning, and the Hunter course is winding down
- . **Gray Eagle** and Warrior Alpha vehicles are flown out of Libby Army Airfield.

Page : 4683

- 1C **Gray Eagle**, a Predator variant that the Army continues to improve and field
- s **Gray Eagle**," Defense Update, 30 July 2013, http:/

Page : 4713

- and **Gray Eagle hours**, which represent the overwhelming majority of statistically tracked UAS flight hours

Page : 4715

- A **Gray Eagle** platoon of four aircraft and all support equipment costs $153.1 million

Page : 4756

- s **Gray Eagle** (MQ-1C)." Defense Update, 30 July

Page : 4764

- 1C **Gray Eagle** Unmanned Aircraft System (MQ-1C Gray Eagle) As of
- 1C **Gray Eagle**) As of FY 2015 President's Budget Defense Acquisition Management

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- 1C **Gray Eagle** Unmanned Aircraft System (MQ-1C Gray Eagle) 5a.
- 1C **Gray Eagle**) 5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** Unmanned Aircraft System (MQ-1C Gray Eagle) DoD Component
- 1C **Gray Eagle**) DoD Component Army Responsible Office Colonel Timothy R. Baxter Unmanned
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** Unmanned Aircraft System (MQ-1C Gray Eagle) provides the
- 1C **Gray Eagle**) provides the Division Commander a dedicated, assured, multi-
- 1C **Gray Eagle** will also be assigned to Army Special Operations Forces and the Aerial
- 1C **Gray Eagle** provides reconnaissance, surveillance, and target Acquisition; command and control
- 1C **Gray Eagle** is balanced platoons, each with four aircraft and associated support equipment
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** program continues with development, integration, testing, training, production
- 1C **Gray Eagle** Quick Reaction Units (four aircraft each and associated support equipment)
- 1C **Gray Eagle** Company (12 aircraft and 128 Soldiers) deployed in support of
- 1C **Gray Eagle** Initial Operational Test and Evaluation completed in August 2012. Developmental testing
- 1C **Gray Eagle** fielding configuration to provide greater capability across the Army. The EXORD
- 1C **Gray Eagle** companies to ten Army Divisions, one to the National Training Center
- full **Gray Eagle** System equipment strength (12 aircraft and associated ground support equipment)
- 1C **Gray Eagle** program. The ADM changed the program classification from ACAT ID to
- 1C **Gray Eagle** has demonstrated meeting six of seven Key Performance

ara**meters (KP**P)

1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** systems allocated among Base Engineering Service Memoranda. ● Modification to the

1C **Gray Eagle** at the FY 2014 PB request of $10.9M. However,

1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle December** 2013 SAR April 16, 2014 16:39:20 UNCLASSIFIED

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1C **Gray Eagle December** 2013 SAR April 16, 2014 16:39:20 UNCLASSIFIED

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** program baseline includes the Common Sensor Payload (CSP) procurement,

1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** program Milestone C decision, like all life cycle cost estimates previously

1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** is balanced Platoons, each with four aircraft and associated support equipment

1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** capability entrance into theater as quickly as possible. Initial LRIP Decision

1C **Gray Eagle** systems which equates to six platoon sets (24 aircraft).

1C **Gray Eagle** systems which equates to 18 platoon sets and includes LRIP I (

1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** has one inquiry for Pricing and Availability from the Government of Poland

1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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1C **Gray Eagle**. (Estimating) +126.1 +148.6 MILCON Subtotal +130.0

- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- Name **Gray Eagle** PBL Contractor General Atomics - Aeronautical Systems, Inc. Contractor Location
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle December** 2013 SAR April 16, 2014 16:39:20 UNCLASSIFIED

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle December** 2013 SAR April 16, 2014 16:39:20 UNCLASSIFIED

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** Assumptions and Ground Rules Cost Estimate Reference: The O&S
- 1C **Gray Eagle** program in accordance with the program schedule which includes a total approved
- 1C **Gray Eagle** is balanced Platoons, each with four aircraft and associated support equipment
- 1C **Gray Eagle** aircraft for conventional companies (non-deployed) and when deployed
- 1C **Gray Eagle** companies with a 20-year service plus one training base with
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** Average annual cost per company No Antecedent (Antecedent) N/
- 1C **Gray Eagle** MQ-1C Gray Eagle No Antecedent (Antecedent) Base Year
- 1C **Gray Eagle** No Antecedent (Antecedent) Base Year 7357.3 8093.0 7357.3 N/
- 1C **Gray Eagle** system was $31.84M. 2) Ownership Cost Key System Attribute
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** Unmanned Aircraft System (MQ-1C Gray Eagle) As of
- 1C **Gray Eagle**) As of FY 2015 President's Budget Defense Acquisition Management

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- 1C **Gray Eagle** Unmanned Aircraft System (MQ-1C Gray Eagle) 5a.
- 1C **Gray Eagle**) 5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** Unmanned Aircraft System (MQ-1C Gray Eagle) DoD Component
- 1C **Gray Eagle**) DoD Component Army Responsible Office Colonel Timothy R. Baxter Unmanned
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** Unmanned Aircraft System (MQ-1C Gray Eagle) provides the
- 1C **Gray Eagle**) provides the Division Commander a dedicated, assured, multi-
- 1C **Gray Eagle** will also be assigned to Army Special Operations Forces and the Aerial
- 1C **Gray Eagle** provides reconnaissance, surveillance, and target Acquisition; command and control
- 1C **Gray Eagle** is balanced platoons, each with four aircraft and associated support equipment
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** program continues with development, integration, testing, training, production
- 1C **Gray Eagle** Quick Reaction Units (four aircraft each and associated support equipment)
- 1C **Gray Eagle** Company (12 aircraft and 128 Soldiers) deployed in support of
- 1C **Gray Eagle** Initial Operational Test and Evaluation completed in August 2012. Developmental testing
- 1C **Gray Eagle** fielding configuration to provide greater capability across the Army. The EXORD
- 1C **Gray Eagle** companies to ten Army Divisions, one to the National Training

ent**er**

- full **Gray Eagle** System equipment strength (12 aircraft and associated ground support equipment)
- 1C **Gray Eagle** program. The ADM changed the program classification from ACAT ID to
- 1C **Gray Eagle** has demonstrated meeting six of seven Key Performance Parameters (KPP)
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** systems allocated among Base Engineering Service Memoranda. ● Modification to the
- 1C **Gray Eagle** at the FY 2014 PB request of $10.9M. However,
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- Gray **Eagle December** 2013 SAR April 16, 2014 16:39:20 UNCLASSIFIED

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- Eagle **December** 2013 SAR April 16, 2014 16:39:20 UNCLASSIFIED

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- 1C **Gray Eagle December** 2013 SAR April 16, 2014 16:39:20 UNCLASSIFIED

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- 1C **Gray Eagle December** 2013 SAR April 16, 2014 16:39:20 UNCLASSIFIED

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- Eagle **December** 2013 SAR April 16, 2014 16:39:20 UNCLASSIFIED

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** program baseline includes the Common Sensor Payload (CSP) procurement,
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** program Milestone C decision, like all life cycle cost estimates previously
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** is balanced Platoons, each with four aircraft and associated support equipment
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** capability entrance into theater as quickly as possible. Initial LRIP Decision
- 1C **Gray Eagle** systems which equates to six platoon sets (24 aircraft).
- 1C **Gray Eagle** systems which equates to 18 platoon sets and includes LRIP I (
- 1C **Gray Eagle** December 2013 SAR April 16, 2014 16:39:20

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- 1C **Gray Eagle** has one inquiry for Pricing and Availability from the Government of Poland
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1C **Gray Eagle**. (Estimating) +126.1 +148.6 MILCON Subtotal +130.0

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Name **Gray Eagle** PBL Contractor General Atomics - Aeronautical Systems, Inc. Contractor Location

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1C **Gray Eagle** Assumptions and Ground Rules Cost Estimate Reference: The O&S

1C **Gray Eagle** program in accordance with the program schedule which includes a total approved

1C **Gray Eagle** is balanced Platoons, each with four aircraft and associated support equipment

1C **Gray Eagle** aircraft for conventional companies (non-deployed) and when deployed

1C **Gray Eagle** companies with a 20-year service plus one training base with

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1C **Gray Eagle** Average annual cost per company No Antecedent (Antecedent) N/

- 1C **Gray Eagle** MQ-1C Gray Eagle No Antecedent (Antecedent) Base Year
- 1C **Gray Eagle** No Antecedent (Antecedent) Base Year 7357.3 8093.0 7357.3 N/
- 1C **Gray Eagle** system was $31.84M. 2) Ownership Cost Key System Attribute
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United States Government Accountability Office



Testimony

Before the Airland Subcommittee, Armed Services Committee, U.S. Senate

For Release on Delivery
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UNMANNED AERIAL SYSTEMS

Further Actions Needed to Fully Address Air Force and Army Pilot Workforce Challenges

Statement of Brenda S. Farrell, Director, Defense Capabilities and Management

GAO-16-527T

DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

GAO Highlights

Highlights of GAO-16-527T, a testimony before Subcommittee on Airland, Committee on Armed Services, U.S. Senate

March 16, 2016

UNMANNED AERIAL SYSTEMS

Further Actions Needed to Fully Address Air Force and Army Pilot Workforce Challenges

Why GAO Did This Study

In recent years, the size, sophistication, and cost of the Department of Defense's (DOD) UAS portfolio has grown considerably, as has the demand for trained UAS pilots.

This testimony discusses, among other things, DOD's progress in (1) taking actions to strengthen the management of Air Force UAS pilots and (2) addressing challenges the Army faces to ensure that its UAS pilots complete their required training and receive high-quality training.

GAO's statement is based on information from its reports issued in April 2014 on the Air Force UAS pilots and May 2015 on Army and Air Force UAS pilot training. For those reports, GAO reviewed DOD guidance on training UAS pilots and other relevant documents, examined nongeneralizeable training records of Air Force UAS units, conducted nongeneralizeable focus groups with active duty UAS pilots who were selected to cover a range of ranks and other factors at 6 installations, and interviewed DOD and military services officials. GAO obtained updates from DOD and military services officials for this statement.

What GAO Recommends

In April 2014 and May 2015, GAO made ten recommendations to DOD to improve the Air Force's management of UAS pilots, address Army UAS pilot training challenges, and enhance DOD coordination of UAS pilot training. DOD initiated action on most of these recommendations.

View GAO-16-527T. For more information, contact Brenda S. Farrell at (202) 512-3604 or farrellb@gao.gov.

What GAO Found

In April 2014, GAO reported on several issues the Air Force faced in managing its UAS pilots, and while the Air Force has taken some actions since then, it has not fully implemented GAO's recommendations to strengthen its management.

- **Personnel Requirements**: GAO reported that the Air Force had not accurately identified the number of UAS pilots required to accomplish its mission nor had it established a minimum number of pilots needed. As of March 2016, the Air Force had not updated personnel requirements and until it does, the Air Force will not know if it is assuming unacceptable levels of risk to accomplishing the mission and ensuring pilot safety.
- **Recruiting and Retaining**: GAO reported that the Air Force had faced challenges recruiting UAS pilots and might also face retention challenges in the future. The Air Force has taken steps to recruit more UAS pilots and offers a monthly assignment incentive pay to help retain pilots, but issues related to recruiting UAS pilots may warrant the Air Force's attention.
- **Alternative Sources**: GAO reported that the Air Force had not evaluated the use of alternative personnel populations such as enlisted or civilian personnel to help it sustain required UAS pilot staffing levels. In 2015, the Air Force announced it would test using enlisted personnel but has not formally evaluated using DOD civilian personnel as UAS pilots and thus may lack information on potential options for meeting personnel requirements.
- **Training**: GAO reported that the Air Force had faced challenges training its UAS pilots due to UAS pilot shortages, which impacted its ability to produce new pilots. Fully implementing GAO's recommendations pertaining to management of UAS pilots would better position the Air Force to address its training challenges.
- **Promotions**: GAO reported that the Air Force monitors the promotion rates of UAS pilots but had not analyzed factors that may relate to their low promotion rates. Until the Air Force does this analysis, it is unclear whether its actions to raise promotion rates are appropriate.

The Army has initiated steps to address challenges related to UAS pilots completing their required training and its use of less experienced instructors, which could affect training quality. In May 2015, GAO found that Army unit status reports did not require UAS pilot training information, and thus the Army did not know the extent pilots had been trained and were ready to deploy. GAO recommended that the Army require unit status reports to include UAS pilot readiness information. In March 2016, officials stated that the Army had taken steps to implement the recommendation, but its efforts are ongoing and thus it is too early to know their impact. Also, the Army had waived course prerequisites for about 40 percent of the UAS pilots attending a course to become instructor pilots from the beginning of fiscal year 2013 through February 2015. As a result, Army UAS pilots may not have been receiving the highest caliber of training to prepare them for UAS missions. GAO recommended in May 2015 that the Army mitigate risks posed by waiving prerequisites for less experienced UAS pilots, and in March 2016, Army officials stated that they have addressed the underlying causes that led it to waive the prerequisites, but they did not provide information for GAO to be able to determine whether they were continuing to waive these prerequisites.

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Chairman Cotton, Ranking Member Manchin, and Members of the Subcommittee:

Thank you for the opportunity to be here today to discuss some of the unmanned aerial systems (UAS) pilot personnel challenges that the Department of Defense (DOD) faces. In recent years, the size, sophistication, and cost of DOD's UAS[1] portfolio has grown considerably, as has the demand for trained UAS pilots.[2] Each of the services flies various types of UAS. The Air Force flies the MQ-1 (Predator), the MQ-9 (Reaper), and the RQ-4 (Global Hawk) while the Army flies the RQ-7 (Shadow), the MQ-5 (Hunter) and the MQ-1C (Gray Eagle).

We found in our prior work that in recent years, the Air Force has not provided a sufficient number of UAS pilots to meet requirements due to several factors including most notably the increase in demand for intelligence, surveillance, and reconnaissance.[3] As a result, the UAS workload has been performed by fewer pilots working more hours to accomplish the Air Force mission. In additional in our prior work, we found that the Army has faced challenges ensuring that its pilots in UAS units that are not deployed conduct unit training to prepare them to perform their missions.[4] In April 2014 and May 2015, we reported on these other issues and made ten recommendations to DOD to improve the Air Force's management of UAS pilots, address Army UAS pilot training challenges, and enhance DOD coordination of UAS pilot training.[5]

I will focus my remarks today on DOD's progress in (1) taking actions to strengthen the management of Air Force UAS pilots, (2) addressing challenges the Army faces to ensure that its UAS pilots complete their

[1]DOD defines an unmanned aerial system (UAS) as a system whose components include the necessary equipment, networks, and personnel to control an unmanned aircraft—that is, an aircraft that does not carry a human operator and is capable of flight under remote control or autonomous programming.

[2]DOD, *Unmanned Systems Integrated Roadmap* FY2013-2038.

[3]GAO, *Air Force: Actions Needed to Strengthen Management of Unmanned Aerial System Pilots*, GAO-14-316 (Washington, D.C.: Apr. 10, 2014).

[4]GAO, *Unmanned Aerial Systems: Actions Needed to Improve DOD Pilot Training*, GAO-15-461 (Washington, D.C.: May 14, 2015).

[5]GAO-15-461 and GAO-14-316.

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required training and receive high-quality training, and (3) coordinating the training of UAS pilots within DOD.

My testimony is primarily based on reports we issued on UAS personnel issues in May 2015 and April 2014.[6] For those reports, we reviewed service guidance on training UAS pilots and other relevant documents, examined nongeneralizeable training records of Air Force UAS units, conducted nongeneralizeable focus groups at 6 installations with active duty UAS pilots from a range of ranks, and interviewed DOD and military services officials. We also followed up with OSD, Air Force and Army officials to determine what actions they had taken in response to the recommendations we have made. All work on which this testimony is based was performed in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Air Force Has Made Efforts to Manage UAS Pilots But Further Actions are Needed

The Air Force has made efforts to manage its UAS pilots but has not fully addressed issues related to: identifying personnel requirements, recruiting and retention difficulties, the potential use of DOD civilians as pilots, pilots completing their required training, moving pilots through the training pipeline, and analyzing pilot promotion rates.

Air Force Has Not Accurately Identified the Number of UAS Pilots Required to Accomplish Its Mission

We found in April 2014 that the Air Force had not accurately identified optimum personnel requirements, or the crew ratio, for the number of UAS pilots it requires. As a result, Air Force UAS units may be operating at personnel levels that are too low, which may diminish the combat capability and flight safety of these units. The Air Force conducted a study in 2008 to determine the appropriate crew ratio for MQ-1 Predator squadrons but did not account for all of the flying and administrative tasks required of those squadrons due to the study's reporting timeframes. Based on the study, the Air Force concluded that the crew ratio for MQ-1

[6]GAO-15-461 and GAO-14-316.

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Predator squadrons should be 10:1, which calls for 10 UAS pilots to support one near-continuous 24-hour flight presence of an Air Force UAS over a particular geographic location. Headquarters Air Force officials stated that, because of the omitted tasks, the study's recommended 10:1 crew ratio probably did not provide enough pilots to perform the work in an MQ-1 squadron. In addition, some UAS unit commanders and UAS pilots in some of the 10 focus groups we conducted at three Air Force bases said that the 10:1 crew ratio was too low.[7] High-performing organizations use complete and current data to inform their strategic human capital planning and remain open to reevaluating workforce planning efforts. Consequently, we recommended that the Air Force update crew ratios for UAS units to help ensure that the Air Force establishes a more-accurate understanding of the required number of UAS pilots in its units, and the Air Force concurred with our recommendation.

The Air Force has taken some actions in response to our recommendation, but Air Force officials told us that as of March 2016, the Air Force has not updated its UAS unit crew ratio. In our May 2015 report, we found that the Air Force had a three-phase personnel requirements study underway that was designed to update the UAS unit crew ratio. Air Force officials stated that the preliminary results of the study pointed to updating the UAS unit crew ratio and increasing the required number of pilots in UAS units. In May 2015, the officials also stated that they expected to update the UAS unit crew ratio later in 2015 but has not yet done so. Without an updated crew ratio, the Air Force lacks information needed to accurately identify the number of Air Force UAS pilots it requires and may need additional pilots.

As we also found in April 2014, Air Force documentation showed that crew ratios in UAS units had not met the 10:1 crew ratio identified in the 2008 study and instead fluctuated between 7:1 and 8.5:1, indicating that between 7 and fewer than 9 UAS pilots were used to sustain 24 hours of Predator operations rather than the 10 pilots recommended by the study. We found that the Air Force operated at these levels in order to provide a

[7]We conducted 10 focus group meetings with active-duty RPA pilots during site visits to Beale, Cannon, and Creech Air Force Bases. We decided to visit these three bases because more RPA pilots are stationed at these bases than other Air Force bases. We use the term "some," as in "pilots in some focus groups," to report topics that were discussed by UAS pilots in two to four of our focus groups.

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higher number of CAPs to meet the requests made by combatant commanders. An Air Force instruction states that a crew ratio establishes the number of personnel required to support a unit mission and that if a ratio is too low, combat capability is diminished and flight safety suffers.[8] We recommended at that time that the Air Force establish a minimum crew ratio in Air Force policy below which UAS units cannot operate without unacceptable levels of risk to mission accomplishment and safety. The Air Force concurred with our recommendation and in comments on our report the Air Force stated that it anticipated that it would implement our recommendation by February 2015.

We reported in May 2015 that the three-phase personnel requirements study would also address the recommendation to establish a minimum crew ratio, but according to Air Force officials that study has not been finalized. In February 2016, the Air Force Deputy Chief of Staff of Operations directed that the Air Force use the 10:1 crew ratio as the minimum. However Air Force officials stated that due to personnel shortages, that ratio has not been enforced. As of February 2016, UAS units had been operating at a 9.4:1 crew ratio, meaning that between 9 and 10 UAS pilots were used to sustain 24 hours of Predator operations rather than the 10 pilots recommended by the study. Without a minimum crew ratio established in Air Force policy, the Air Force lacks information needed to determine when UAS units are operating at crew ratio levels that expose the Air Force to unacceptable levels of risk to accomplishing its mission and ensuring safety. In addition, UAS pilots may continue to experience a high pace of operations that limits their time for training and impacts their quality of life.

[8]Air Force Instruction 65-503, *Authorized Aircrew Composition-Active Forces*, table A36-1 (Feb. 1, 2012).

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The Air Force Has Taken Steps to Recruit More UAS Pilots, but May Face Retention Challenges and Continues to Rely on Pilots Trained on Manned Aircraft to Meet Requirements

We found in April 2014 that the Air Force faced challenges recruiting UAS pilots and had not achieved its recruiting goals for UAS pilots in fiscal years 2012 and 2013. Air Force officials cited a number of reasons for missing the targets, including that potential UAS pilot recruits had a limited understanding of the UAS mission because the Air Force lacked recruiting officials with UAS experience. High-performing organizations tailor their strategies to the specific needs and challenges of the workforce to recruit high-quality personnel with critical skills, but the Air Force had not developed a strategy to address recruiting and retention of UAS pilots, including increasing the appeal of the UAS pilot career to potential recruits. As a result, the Air Force risked personnel shortages and continued reliance on manned-aircraft pilots to fill its personnel requirements. We recommended that the Air Force develop such a tailored strategy to recruiting and retaining UAS pilots to help ensure that the Air Force can meet and retain required staffing levels, and the Air Force concurred.

In 2015, Air Force senior leadership and headquarters officials stated that the Air Force was in the process of developing strategies to recruit UAS pilots. The Air Force has taken a number of actions that officials say have helped improve UAS pilot recruiting. For example, Air Force officials stated that Headquarters Air Force has efforts underway to educate potential recruits at the commissioning sources such as the Air Force Academy on the UAS mission. Officials told us that the Air Force is providing cadets information on the UAS pilot career and it is assigning UAS pilots to the Academy so that they can share their on-the-job experiences with cadets who may be interested in becoming a UAS pilot In addition, the Air Force began requiring cadets to volunteer to serve in any of the four aviation-related careers rather than applying for one specific career. This process allows the Air Force to assign cadets to any of the four careers based on Air Force needs, among other factors. Air Force officials stated that the Air Force has also opened up eligibility for becoming a UAS pilot by removing age requirements and granting waivers for certain medical requirements.

In April 2014 we also found that the Air Force may face challenges retaining UAS pilots. Pilots in 7 of the 10 focus groups we conducted at three Air Force bases indicated that retention of UAS pilots is or will be a challenge and UAS unit commanders in one location we visited and other Air Force officials stated that they were concerned with future retention rates of UAS pilots. As mentioned above, we recommended that the Air Force develop a tailored strategy that addresses both recruiting and retention of UAS pilots and the Air Force concurred.

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To retain pilots, officials stated that the Air Force pays UAS pilots a monthly assignment incentive pay which is equivalent to the amount that manned pilots receive in aviation pay. Also, the National Defense Authorization Act for Fiscal Year 2016 granted the Air Force the authority to increase the annual amount that it pays UAS pilots in a retention bonus from $25,000 to $35,000. A Headquarters Air Force official told us in January 2016 that the Air Force has not used this authority to pay UAS pilots the increased amount of this retention bonus for two reasons. First, OSD has not yet issued related policy that the act required be issued before the Air Force could begin paying this increased amount. Second, the Air Force does not have enough data to determine what the retention patterns of this population will be because most of the pilots who specialize in flying UAS have not reached the end of their six-year service commitment. The official stated that the Air Force would like to determine if retention of this population is a concern before exercising the authority to offer these pilots the increased retention bonus amount.

Further, the Chief of Staff of the Air Force testified that the Air Force was not using the increased amount of the retention bonus. Specifically, he stated that the Air Force did not use that increased bonus for UAS pilots because the current amount was commensurate with that of other critically manned pilot categories. He further stated that the Air Force has other pilot categories that are even in more crisis than UAS at this point in time. We will be exploring further with the Air Force their plan to use this bonus and UAS pilot retention rates. The Air Force is pursuing initiatives to address shortages in the MQ-1 and MQ-9 pilot community that Air Force officials say will have a positive impact on retention. For example, the Air Force is supplementing its UAS pilot population with the Air Force Reserve and contractor support.

The Air Force has taken positive steps toward improving recruiting and, according to Air Force officials, has met or nearly met its UAS pilot recruiting goals for fiscal years 2014 and 2015, which shows progress toward resolving the recruiting challenges we found in 2014. At the same time, issues related to recruiting UAS pilots may warrant the Air Force's attention. In particular, the recruiting goals themselves may not be appropriate because, as previously discussed, the crew ratio has not yet been updated and the crew ratio is used to determine the total number of UAS pilots the Air Force requires. In addition, in April 2014, we also found that 42 percent of Air Force pilots flying UAS were manned-aircraft pilots and manned-aircraft pilot training graduates. Both of those groups are temporary UAS pilots who serve only one assignment in a UAS squadron. Air Force officials stated that as of March 2016, those groups represented

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around one-third of Air Force UAS pilots. They also stated they anticipate they will not need to use any manned-aircraft pilot training graduates in fiscal year 2016 based on the number new UAS pilots that the Air Force anticipates will join the Air Force in fiscal year 2016. However, if the Air Force updates the crew ratio and finds it needs to increase the number of UAS pilots it requires, the Air Force may need to continue relying on manned aircraft pilots, indicating the continued importance of a strategic approach to recruiting and retention that is tailored to the needs of the UAS pilot workforce.

The Air Force Is Planning to Use Enlisted Personnel to Operate the Global Hawk but has not Evaluated the Possible Use of DOD Civilians

In April 2014, we found that the Air Force had not evaluated whether using alternative personnel populations such as enlisted or civilian personnel as UAS pilots is a viable option to help it meet and sustain required UAS pilot staffing levels. Headquarters Air Force officials had stated that they had, at times, considered the use of enlisted or civilian personnel but had not initiated formal efforts to evaluate the potential use of alternative personnel populations as UAS pilots. We recommended that the Air Force conduct such an evaluation to identify whether such alternative populations could help the Air Force meet and sustain required UAS pilots staffing levels. The Air Force partially concurred with our recommendation, stating that the Air Force had considered assigning enlisted personnel as UAS pilots but had decided that the responsibilities of piloting a UAS were commensurate with the rank of officers.

Subsequently, the Air Force has made progress toward implementing our recommendation. Even though the Air Force commented on our recommendation that the responsibilities of piloting a UAS were commensurate with the rank of officers, the Chief of Staff of the Air Force directed Headquarters Air Force staff to evaluate the potential of using enlisted personnel as UAS pilots in fall 2014. Further, the Air Force announced in December 2015 that it would integrate enlisted personnel into flying operations for the RQ-4 Global Hawk UAS. In December 2015, the Secretary of the Air Force and Chief of Staff of the Air Force stated that the goal of the initiative is to provide an additional avenue for capability growth and directed development of an implementation plan to use enlisted personnel to operate the Global Hawk by May of 2016. However, as of March 2016, Air Force officials stated that the Air Force has not formally evaluated using DOD civilian personnel as UAS pilots, as we recommended. Without also evaluating DOD civilian personnel, the Air Force may lack valuable information on whether additional options exist for meeting personnel requirements.

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Air Force UAS Pilots Do Not Complete the Majority of Their Continuation Training

In April 2014, we found that the high pace of operations limited the time the UAS pilot workforce could put toward training and development. In addition, in May 2015, we found that Air Force UAS pilots do not complete the majority of their continuation training because they spend most of their time conducting operational missions due to shortages of UAS pilots and high workloads. Continuation training includes all training that takes place once a servicemember reaches their operational unit and finishes the training required to be considered qualified to perform the unit's mission. A core characteristic of a strategic training framework is that agency leaders and managers consistently demonstrate that they support and value continuous learning. We found that a nongeneralizable sample of training records for seven Air Force UAS units showed that, on average, 35 percent of the pilots in these units completed the continuation training for all of their seven required missions in fiscal year 2014. In March 2016, Air Force officials stated that UAS units make efforts to dedicate time to continuation training but the majority of their time is still devoted to combat missions based on personnel shortages and high demand. However, as we noted in May 2015, fully implementing all four recommendations we made in our April 2014 report pertaining to management of Air Force UAS pilots should better position the Air Force to address the UAS pilot shortages that contribute to training challenges.

The Air Force Faces Challenges Moving UAS Pilots Through the Training Pipeline

In April 2014 we found that the Air Force had reduced the capacity of its training units by moving instructor pilots to operational units to react to increasing demand for UAS capabilities. A core characteristic of a strategic training framework is that agencies should provide appropriate resources for its training programs. However, In May 2015, we found that the Air Force had staffed its UAS training squadrons at Holloman Air Force Base at 63 percent of their planned staffing levels due to shortages of UAS pilots across the Air Force, which Air Force officials stated in turn impacted the Air Force's ability to produce new pilots. We also reported actions the Air Force was taking to increase the number of instructor pilots, including studying the personnel requirements for the formal training unit. Air Force officials stated that as of February 2016, the Air Force had filled 84 percent of its instructor pilot positions at Holloman. These officials said that there is still a need to increase the number of instructor pilots, and the Air Force goal is to fill 100 percent of the instructor pilot slots by fiscal year 2017. Fully implementing our recommendations pertaining to management of UAS pilots should better position the Air Force to address the need to increase the number of instructor pilots.

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The Air Force Monitors UAS Pilot Promotion Rates but Has Not Analyzed Factors Related to Those Rates

In April 2014, we found that the Air Force monitors the promotion rates of UAS pilots but had not analyzed factors that may relate to their low promotions rates. The Air Force had found that UAS pilots were promoted below the average rate for active-duty line officers on 20 of 24 officer promotion boards between 2006 and 2012 and 2013, depending on rank. We also found that UAS pilots were promoted at the lowest rate of any career field on 9 of the 24 boards. Statistical principles call for researchers to account for potential key factors in analysis because when they omit key factors, the relationships between other factors may not be accurately estimated. The Air Force analyzed promotions across a group of officers –or the Line of the Air Force—including UAS pilots, and found factors that related to promotions in general. However, the Air Force had not analyzed the factors related to UAS pilots' promotions specifically and, as a result, it did not have the information to determine what factors may affect their promotions. We recommended that the Air Force include the career field effect of being a UAS pilot into its analysis to determine whether and how being a UAS pilot is related to promotions and determine whether the factors identified in the analysis of Line of the Air Force officers are also related to UAS pilot promotions.

The Air Force partially concurred with our recommendation, stating that because the UAS career field is a subsection of the Line of the Air Force, the factors identified in analysis of the Line of the Air Force are directly related to UAS pilot promotions, which we acknowledged in our report. As of January 2016, the Air Force had not taken any steps to implement our recommendation and when we sought additional information in March 2016, the Air Force did not respond in time for this statement. Without including the career field effect in its analysis, the Air Force may not be targeting actions it is taking to raise UAS pilots promotion rates at the appropriate factors, and information it has reported to Congress may not be accurate.

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Army Has Not Fully Addressed Challenges Related to UAS Pilots Completing Required Training and the Use of Less Experienced Instructors

The Army has not fully addressed challenges related to UAS pilots completing their required training and its use of less experienced instructors, which could affect training quality.

Army UAS Pilots in Shadow Units that are Not Deployed Are Not Completing Continuation Training

In May 2015, we found that a 2015 Army review showed that pilots in most of the Army's Shadow units did not complete training in their units in fiscal year 2014.[9] We previously developed a set of core characteristics for assessing strategic training programs in the federal government.[10] One of these characteristics calls for agency leaders to demonstrate that they value continuous learning. [11] In January 2015, the Chief of Staff of the Army directed the Army Training and Doctrine Command to evaluate if unit training was a factor that caused UAS mishaps in combat. The Army reviewed this issue from January 2015 through March 2015 and found that UAS pilots in 61 of the 65 RQ-7B Shadow units that were not deployed in fiscal year 2014 had flown an annual unit average of 150 hours of training,[12] which is about 200 hours less than minimum amount of training flight hours that an Army unit is required to fly according to the review. In addition, the review included recommendations to increase emphasis on training in UAS units including that the Army should (1) issue guidance to unit commanders on UAS training; (2) ensure that UAS

[9]Army Shadow units operate the RQ-7 Shadow UAS.

[10]GAO, *A Guide for Assessing Strategic Training and Development Efforts in the Federal Government*, GAO-04-546G (Washington, D.C.: Mar. 2004). To develop these characteristics, we consulted government officials and experts in the private sector, academia, and nonprofit organizations; examined laws and regulations related to training and development in the federal government; and reviewed literature on training and development issues, including previous GAO products on a range of human capital topics.

[11]GAO-04-546G.

[12]This measure shows an average of the total amount of training time that all pilots in each unit flew in fiscal year 2014.

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warrant officers are qualified on their UAS; (3) Increase the amount of home station training for UAS units; and (4) establish a system to report UAS training readiness on unit status reports.

We corroborated the Army's findings in focus groups discussions[13] with Army UAS pilots and in responses to a questionnaire that UAS unit commanders provided. Specifically, we found that pilots in all eight of the focus groups we conducted with Army UAS pilots stated that they cannot complete training in their units. For example, a pilot in one of 8 focus groups stated that during his 3 years as a UAS pilot, he had been regularly tasked to complete non-training-related activities, and as a result he completed a total of 36 training flight hours even though the requirement is that he should have completed 72 flight hours during those three years. Further, Army UAS pilots in each of the 8 focus groups we conducted stated that they had difficulty completing UAS pilot training in units because they spend a significant amount of time performing additional duties such as lawn care, janitorial services, and guard duty. Additionally, five of the six Army UAS units that responded to a questionnaire we administered indicated that their units faced challenges completing training in their units.

At the time, we did not make any recommendations on this issue. We noted that while the Army review and our analysis showed that most Army UAS pilots were not completing training in their units, the Army's training shortfalls might be addressed by the high-level interest expressed by the Chief of Staff of the Army and the recommendations in the Training and Doctrine Command review, if implemented. We asked the Army to provide information to update our May 2015 report to show (1) the amount of unit training that UAS pilots completed in fiscal year 2015, and (2) actions the Army had taken in response to its internal recommendations to increase emphasis on unit training. Finally, the Army

[13]We conducted 8 focus groups with Army UAS pilots at Ft. Huachuca, AZ and Ft. Hood, TX. We selected these locations on the basis of several factors including the type and size of UAS flown in the unit; missions of the unit; whether or not the unit is deployed (we did not meet with units who were deployed); number of UAS pilots in the unit; the major command of the unit; and location of the unit. We conducted focus groups with active-duty UAS pilots at these locations to gain their perspectives on the Army's UAS training efforts. To select specific UAS pilots to participate in our focus groups, we worked with officials at each of the instillations to develop a diverse group of active-duty UAS pilots. To obtain a variety of perspectives, we selected UAS pilots with varying amounts of experience flying UASs and additional duties in their units. The opinions of UAS pilots we obtained during our focus groups are not generalizable to the populations of all UAS pilots in the Army.

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did not respond to our request to provide updated information on these topics for this statement.

Army Does Not Have Visibility over the Amount of Training that Pilots in Some UAS Units Have Completed

In May 2015, we also found that the Army does not have visibility over the amount of training that pilots in some Army UAS units have completed. Another core characteristic of a strategic training framework highlights the importance of quality data regarding training.[14] However, we found that Army does not have access to data that would allow it to measure the amount of training that UAS pilots have completed in Army UAS units. Army Forces Command officials stated that they need information about the readiness level of pilots in UAS units to determine if a unit is ready to deploy and perform its mission. These officials stated that they review Army unit status reports to determine if a unit is prepared to deploy. However, officials from Army Headquarters, Army Forces Command and the Army Aviation Center of Excellence both stated that these reports do not provide any information on the readiness levels of the UAS pilots in UAS units because the reports are not required to include this information. Officials at Forces Command stated that, using these reports, they have designated units as available for deployment and later learned that a significant portion of the pilots in those units had not completed their readiness level training. Without requiring information on the readiness level of pilots in UAS units as part of unit status reports, Army Forces Command will continue to lack visibility over the amount of training that UAS pilots have completed in units. To provide greater visibility over the extent to which Army UAS units have completed required training to leaders responsible for deployment decisions, we recommended that the Army require unit status reports to include information on the readiness levels of UAS pilots in UAS units and the Army concurred.

Since we issued our report in May 2015, Army Headquarters officials stated that the Army had drafted an update to Department of the Army Pamphlet 220-1 that would require UAS units to report the readiness levels of the UAS pilots in UAS units.[15] In addition, these officials stated that the Army was working on updating the unit status reporting software

[14] GAO-04-546G.

[15] Army Pamphlet 220-1, *Defense Readiness Reporting System-Army Procedures*, (November 16, 2011).

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to enable units to comply with the planned update to the Army pamphlet. While the steps that Army has taken to date should address our recommendation, its efforts are ongoing and thus it is too early to know their impact.

The Army Has Taken Action to Increase the Number of Instructors, but Its Use of Less Experienced Instructors Could Affect the Quality of UAS Pilot Training

In May 2015, we found that the Army had taken actions to increase the number of UAS instructors, but it had not fully addressed the risks associated with using less experienced instructors. In order to increase the number of its instructors in response to an increase in the number of UAS units, the Army waived course prerequisites for about 40 percent of the UAS pilots attending the course to become instructor pilots from the beginning of fiscal year 2013 through February 2015.These prerequisites—such as a minimum number of flight hours— are important because they help ensure that UAS pilots volunteering to become instructors to help ensure that instructors are fully trained and ready to instruct UAS pilots.

In May 2015, we found that the Army had taken steps to mitigate the risks of using less proficient UAS instructors. For example, in fiscal year 2015, the Army stopped waiving course prerequisites related to proficiency, according to Army Aviation Center of Excellence officials. However, the Army could continue to waive prerequisites related to experience. As a result, we found that Army UAS pilots may not have been receiving the highest caliber of training needed to prepare them to successfully perform UAS missions. To help ensure that Army UAS pilots receive the highest caliber of training, we recommended, in May 2015, that the Army take additional steps to mitigate potential risks posed by waiving course prerequisites for less experienced UAS pilots attending the course to become instructors and the Army concurred.

In February 2016, Army Headquarters officials stated that the Army has taken additional steps to mitigate potential risks posed by waiving course prerequisites for less experienced UAS pilots attending the course to become instructors. However, the Army did not respond to requests we made in March 2016 for it to explain these additional steps; nor did the Army respond to requests we made for it to provide updated statistics to determine if the Army was continuing to waive these prerequisites. In addition, an Army official from Training and Doctrine Command stated that the Army had not provided additional training or preparation for instructors who previously received a waiver of one of the course prerequisites to attend the instructor course as we had recommended.

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DOD is Coordinating on Some Aspects of UAS Pilot Training But Still Lacks a Department-Wide Strategy

Some coordination is occurring among the services with respect to UAS pilot training but DOD has not yet developed a department-wide UAS training strategy. In May 2015, we found that the actions that the services had taken were either partially consistent or inconsistent with the key practices to enhance and sustain agency coordination.[16] We previously reported that agencies face a range of barriers when they attempt to collaborate with other agencies. To help agencies overcome these barriers, we developed a set of key practices that can help enhance and sustain federal agency collaboration.[17] According to these key practices, federal agencies can enhance and sustain their coordination if they take a number of actions including the following.[18]

- Agencies should identify the human, information technology, physical, and financial resources needed to initiate or sustain their coordinated effort. In May 2015, we found that DOD actions were partially consistent with this principle. For instance, the Air Force and the Army provide resources to train all Marine Corps UAS pilots. However, as we found in May 2015, both the Army and the Air Force are working on addressing UAS personnel shortages and such shortages may negatively affect their ability to continue to train Marine Corps UAS pilots.
- Agencies should agree on their roles and responsibilities, including how the coordinated effort will be led. In May 2015, we found the Office of the Deputy Assistant Secretary of Defense (Readiness) and the services have not agreed on roles or responsibilities for any of the services for coordinating on UAS pilot training. The Office of the

[16]GAO-15-461

[17]We reported these key practices in *Results-Oriented Government: Practices That Can Help Enhance and Sustain Collaboration among Federal Agencies*, GAO-06-15 (Washington, D.C.: Oct. 21, 2005). For our 2005 report, we derived these practices by reviewing academic literature and prior GAO and Congressional Research Service reports; and interviewing experts in coordination, collaboration, partnerships, and networks from the National Academy of Public Administration, the IBM Center for The Business of Government, and the University of California, Berkeley.

[18]While these practices address interagency collaboration, we believe these practices apply to intra-agency coordination in DOD because multiple departments within DOD are responsible for UAS pilot training programs. Further, we reviewed these practices with officials from the Office of the Assistant Secretary of Defense for Readiness and these officials agreed that the practices applied in the context of our review. In addition, we confirmed these practices and reported on mechanisms for implementing collaborative efforts in Managing For Results: Key Considerations for Implementing Interagency Collaborative Mechanisms, GAO-12-1022 (Washington, D.C.: Sept. 27, 2012).

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Under Secretary of Defense for Acquisitions, Technology, and Logistics established a UAS Task Force in 2007, and its charter states that its mission is to coordinate critical DOD UAS issues. However, a task force official stated that the task force does not play a role in coordinating UAS pilot training among the services.

- Agencies should define a clear and compelling rationale for coordination. In March 2010, we found that DOD had begun to address UAS training challenges, but had not developed a strategy to prioritize and synchronize these efforts. We recommended that DOD establish a DOD-wide UAS training strategy to resolve challenges that affect the ability of the Air Force and the Army to train personnel for UAS operations and DOD concurred with that recommendation.[19] The Office of the Deputy Assistant Secretary of Defense (Readiness) tasked the RAND Corporation to draft a DOD-wide UAS training strategy and provided RAND with guidelines about the content and purpose of the strategy. [20] However, these guidelines did not discuss if or how the services should coordinate on UAS pilot training. In September 2014, RAND provided a draft of a UAS training strategy to the Office of the Deputy Assistant Secretary of Defense (Readiness), but the draft did not define a rationale for the services to coordinate on training UAS pilots nor did it more generally discuss service coordination on training UAS pilots.

In our May 2015 report we noted that the Acting Deputy Assistant Secretary of Defense (Readiness) had stated, in January 2015, that the services should coordinate their efforts to train UAS pilots and that the services may have valuable training lessons to share with one another because the services fly similar UAS. He cited similarities between the Air Force's Predator and the Army's Gray Eagle and between the Air Force's Global Hawk and the Navy's Triton. He stated that if the services coordinated on training their UAS pilots the department as a whole may be able to train its UAS pilots more effectively and efficiently. However, as

[19]GAO, *Unmanned Aircraft Systems: Comprehensive Planning and a Results-Oriented Training Strategy Are Needed to Support Growing Inventories*, GAO-10-331 (Washington, D.C.: Mar. 26, 2010).

[20]In 2010, we found that DOD had commenced initiatives to address training challenges, but had not developed a results-oriented strategy to prioritize and synchronize these efforts. We recommended that DOD establish a UAS training strategy to comprehensively resolve challenges that affect the ability of the Air Force and the Army to train personnel for UAS operations and DOD concurred with our recommendation. See Unmanned Aircraft Systems: Comprehensive Planning and a Results-Oriented Training Strategy Are Needed to Support Growing Inventories, GAO-10-331 (Washington, D.C.: Mar. 26, 2010).

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we found in May 2015, without a DOD-wide UAS training strategy that addresses if and how the services should coordinate with one another on training UAS pilots, the services may miss opportunities to improve the effectiveness and efficiency of this training and may waste scarce funds on training UAS pilots. We therefore recommended that the Office of the Under Secretary of Defense for Personnel and Readiness address how the services should coordinate with one another in the DOD-wide UAS training strategy the office was drafting at the time we issued our report, and DOD concurred with this recommendation.

In March 2016, the Director of Force Training in the Office of the Assistant Secretary of Defense (Readiness) stated that DOD had not yet published the DOD-wide UAS training strategy but the strategy was in the final drafting phase. He stated that his office held a summit in October 2015 with each of the services and during this summit representatives from each of the services discussed the draft strategy and how to incorporate our recommendation into the strategy. He stated that his office was collecting the services' comments on the draft strategy and would provide them to RAND and that RAND is currently revising the strategy. The Director stated that the current version of the strategy addresses our recommendation and provides detail on how the services could coordinate with one another during sustainment and mission readiness training. However, as of March 2016, the Office of the Assistant Secretary of Defense (Readiness) has not yet issued the DOD-wide UAS training strategy.

In summary, the Air Force and the Army have taken actions to implement the recommendations that we made to address some of the UAS workforce challenges we identified in 2014 and 2015. However, none of the recommendations that we have discussed today have been fully implemented. As you know, in June 2014 the Senate Armed Services Committee directed the Air Force to implement three of our recommendations—which address the UAS unit crew ratio, recruiting, and retention—that we discussed today. In addition, the Committee Chair and Ranking Member have urged the Secretary of Defense to focus senior leaders in the department on the UAS pilot training shortfalls in the Army and Air Force that we also discussed today. Fully implementing our recommendations would set the Air Force on a positive course toward helping ensure the high-demand UAS pilot workforce has sufficient numbers and is well trained. Similarly, as we recommended, greater visibility over the extent to which Army UAS units have completed required training and additional training for instructors who previously received a waiver of one of the course prerequisites would help ensure a

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highly skilled future Army UAS workforce. However, without addressing if and how the services can enhance their coordination efforts on training UAS pilots in DOD's forthcoming training strategy, the services may not be able to achieve additional benefits to the efficiency and effectiveness of UAS pilot training across the department.

Chairman Cotton, Ranking Member Manchin, and Members of the Subcommittee, this concludes my prepared testimony. I look forward to answering any questions.

GAO Contact and Staff Acknowledgments

If you or your staff have any questions about this testimony, please contact Brenda S. Farrell, Director, Defense Capabilities and Management at (202) 512-3604 or FarrellB@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this statement. GAO staff who made key contributions to this testimony are Lori Atkinson, (Assistant Director), James P. Klein, Kelly Liptan, Felicia Lopez, Mike Silver, and Erik Wilkins-McKee.

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Travis L. Norton, Lt. Col., USAF

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Travis L. Norton, Lt. Col., USAF

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Executive Summary

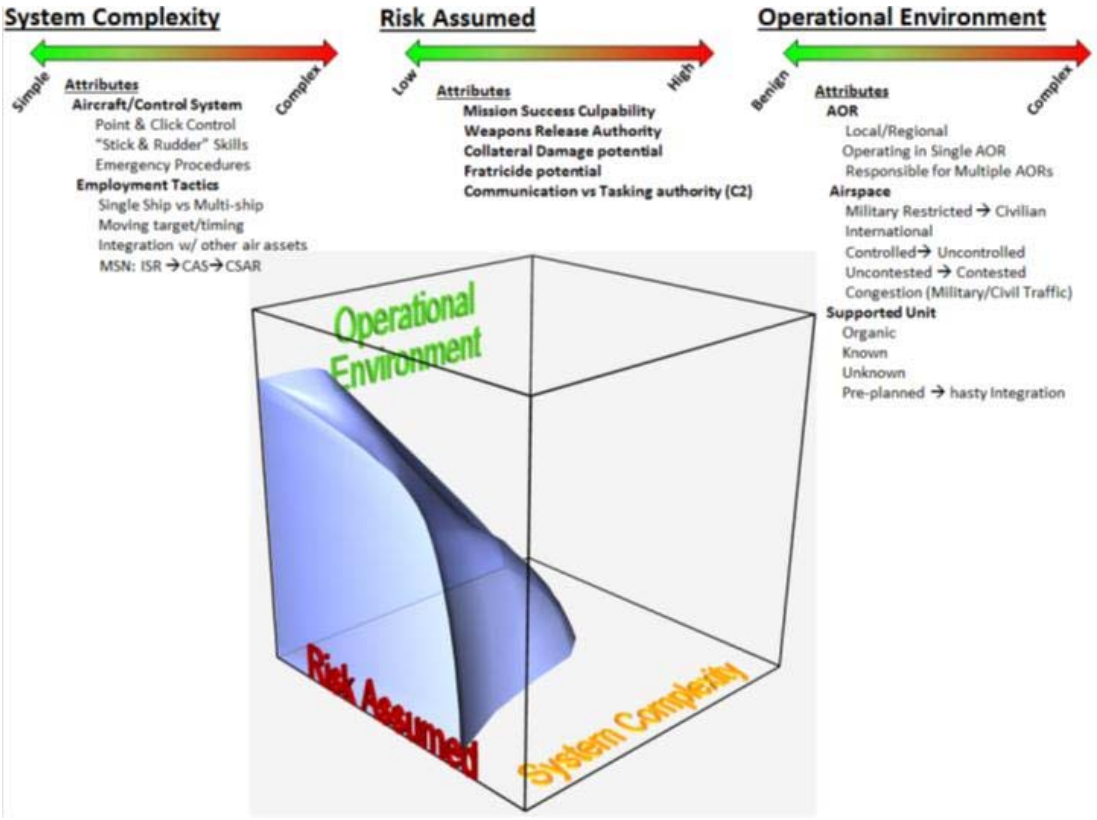
Within the last two decades, Unmanned Aircraft Systems (UAS) have undergone tremendous development and have become an integral part of joint military operations. Based on the unique capabilities and force multiplying effects of the UAS, each military Service has applied them across the spectrum of military operations. With the rapid development and adoption of this technology, a lack of an overall unifying effort to synchronize programs has led to several Service-unique staffing methodologies across the UAS enterprise. In turn, this has led to several manpower challenges across the Department of Defense's (DoD) UAS enterprise, which the department must address immediately if it is to preserve current UAS capability. While addressing these challenges the department must look to the future, as UAS will inevitably increase in both capability and number across the battlespace, a combination for which current staffing principles will prove unsupportable. This paper assesses the DoD's UAS operations to identify commonalities and differences while developing potential alternatives to standardize staffing methodologies where appropriate and maximizing manpower cost savings and mission effectiveness.

This paper analyzes each of the categories of performers available to DoD's UAS enterprise. These performers include not only uniformed military personnel and contractors, but also government service civilians, who are not currently used. Using existing statutory guidance, a framework for analysis is provided to distill mission requirements and identify who is authorized to conduct operations. In some cases, specifically with larger UAS (e.g., MQ-1, MQ-9, RQ/MQ-4), it was discovered that if mission elements are segregated (i.e., launch and recovery, transit, surveillance, weapons employment), opportunities to use a true workforce mix of individuals presents itself. When specifically looking at cost savings, the opportunity to use government service civilians to conduct appropriate mission elements is also available. This opportunity, in turn, decreases uniformed military personnel requirements and enables them to focus on combat-specific elements.

A common point raised when assessing differences between Service UAS programs was the role of enlisted members vs. officers. Regardless of how manpower costs are calculated, using an enlisted military member always costs less than using an officer. Similarly, when assessing the officer corps, warrant officers will always cost less than utilizing the "traditional" officers. Addressing concerns associated with this debate, this paper avoids a binary application for categories of performers (i.e., all pilots should be enlisted or officer). Rather, an illustrative model was designed to remove emotion and cultural bias from this discussion and enable an analysis of mission requirements based upon system complexity, risk assumed, and the operational environment (see illustrative

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figure on following page). When looking at UAS operations in this way, it is apparent that while manpower efficiencies are available across each of the Service's programs, the individual Services do—and should—maintain some unique staffing methodologies based upon their specific mission requirements.



In assessing where associated manpower efficiencies are available, analysis identified several common "business rules" built upon common lessons learned and associated best practices. Where these business rules did not apply, this paper identifies several observations on the rationale applied to a Service's staffing determination. Using these business rules and observations enabled the follow-on assessment of individual UAS mission elements, thereby identifying potential staffing alternatives for cost analysis, which remained platform agnostic rather focusing on mission requirements.

In total, the greatest manpower cost savings were available through the use of government civilians to conduct non-kinetic UAS operations. Applying a mix of government civilians and uniformed military to the Air Force MQ-1/9 launch and recovery force saves approximately $25.65 million across the Future Years Defense Program (FYDP). If government civilians are integrated into Continental United States (CONUS)-based operations (e.g., to transit the UAS), the Air Force could save another $68.3 million across the FYDP. Although these savings are Air Force unique, they highlight potential savings opportunities within similar sister-Service operations. It is also acknowledged that these

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savings are conservative in nature as this paper only analyzed annual savings versus the larger life-cycle costs associated with career development and retention initiatives. This paper suggests an alternative analysis by providing several related areas that are recommended for further research. These areas include additional manpower studies for maintenance and intelligence support personnel associated with UAS operations and the impact associated with the rapid maturation of technology on Service force presentation and staffing methodologies.

While this paper provides preliminary estimates of cost savings, the framework used identifies these potential savings not only in terms of cost, but also as providing an opportunity to decrease the overall requirement for uniformed military personnel. The rapid growth associated with DoD's UAS enterprise, coupled with the combatant commanders' insatiable demand for UAS capabilities, has led each Service to drive aggressively toward fielding these crucial platforms. As this paper shows, now is the time to reassess that growth across the entirety of DoD to capitalize on best practices, integrate efforts, and standardize staffing practices where appropriate. Not only will such efforts improve both current mission effectiveness and cost value of manpower, but they can also address the inevitable challenges faced with this rapidly expanding career field.

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1. Introduction

The purpose of this study is to identify alternative staffing strategies that would enable the Department of Defense's (DoD) to accomplish its Unmanned Aircraft System (UAS)-related missions in a more cost-effective way. This paper will analyze DoD's mission requirements against the individual Service's approach to UAS staffing and will identify common practices and differences. After gaining an understanding of the operational and cultural factors associated with UAS employment, several alternative staffing methodologies will be provided.

A. UAS Definitions

Joint Publication 1-02 lays the foundation by defining a UAS as "an aircraft or balloon that does not carry a human operator and is capable of flight under remote control or autonomous programming."[1] DoD defines a UAS as a "system whose components include the necessary equipment, network, and personnel to control an unmanned aircraft."[2] DoD categorizes UAS based upon weight, operating altitude, and airspeed, as depicted in Figure 1. The Air Force goes one step further and defines Groups 1 through 3 as small unmanned aircraft systems (SUAS) and Groups 4 and 5 as remotely piloted aircraft (RPA).[3] Although there is much debate across the community on the specific terminology, this paper will use the term UAS.[4]

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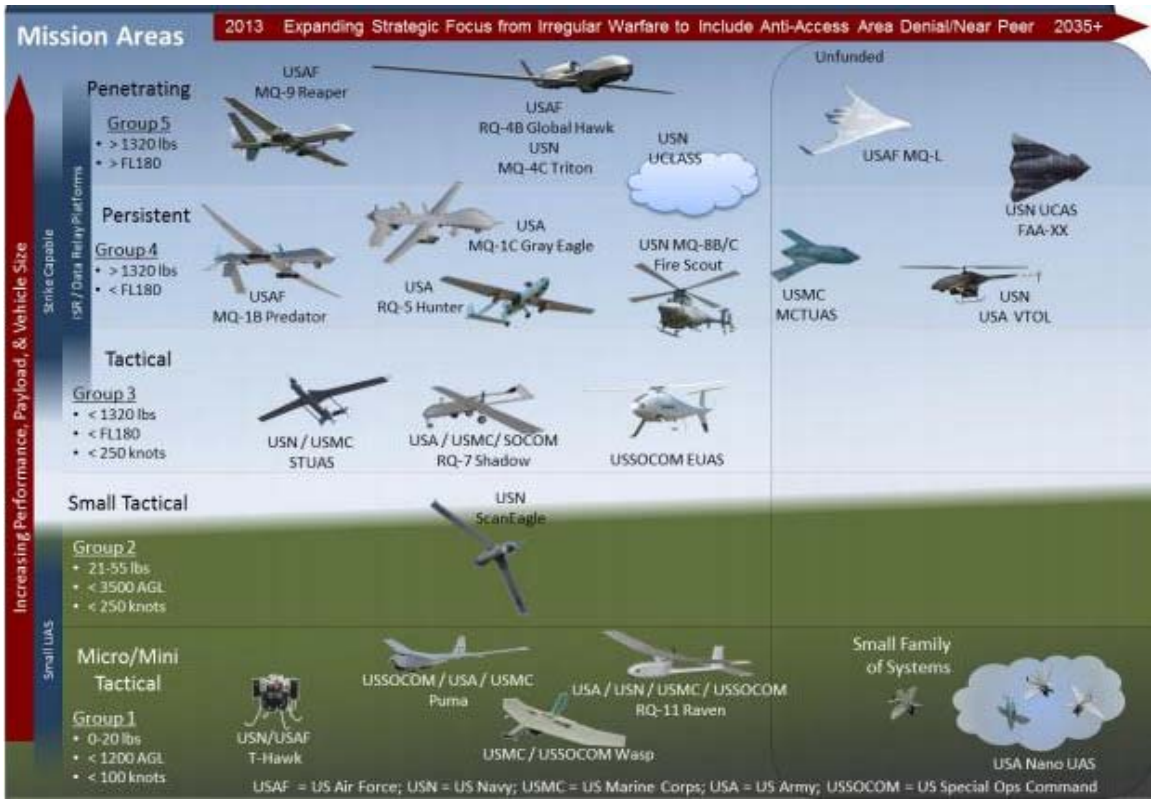
1 Joint Chiefs of Staff, *Department of Defense Dictionary of Military and Associated Terms*, Joint Publication 1-02 (Washington, DC: Department of Defense, November 2010 (as amended through 31 January 2011)), 388, http://ra.defense.gov/Portals/56/Documents/rtm/jp1_02.pdf.

2 Department of Defense, *Unmanned Systems Integrated Roadmap FY2013–203*8 (Washington, DC: Office of the Secretary of Defense, 2013), 4, http://www.defense.gov/pubs/DoD-USRM-2013.pdf.

3 United States Air Force, *RPA Vector: Vision and Enabling Concepts 2013–2038* (Washington, DC: Headquarters, United States Air Force, February 17, 2014), 13, http://www.defenseinnovationmarketplace.mil/resources/USAF-RPA_VectorVisionEnablingConcepts2013-2038_ForPublicRelease.pdf.

4 It is appropriate to note the Chairman of the Joint Chiefs of Staff's comment, "You will never hear me use the word 'drone,' and you will never hear me use the term 'unmanned aerial systems.' Because they are not. They are Remotely Piloted Aircraft" (see Kevin McCaney, "A Drone by Any Other Name Is … an RPA?," *Defense Systems*, May 23, 2014, http://defensesystems.com/articles/2014/05/23/dempsey-rpa-drones-uas.aspx). However, for consistency with the initial tasking of this paper and to stay in line with current documented government publications, this paper will use the term UAS, except when referring directly to the Air Force's aircraft.

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Source: Department of Defense, Unmanned Systems Integrated Roadmap FY2013–2038 (Washington, DC: Office of the Secretary of Defense, 2013), 6, http://www.defense.gov/pubs/DoD-USRM-2013.pdf.

Note: Although this grouping is convenient for current missions, technology advances and the expanding growth of UAS employment will blur the lines between the UAS groups. The implications associated with this maturation of technology are not addressed in this paper; however, further research is recommended.

Figure 1. DoD UAS

To set a baseline, the basic components of UAS are as follows:[5]

- An unmanned aircraft (UA) that flies without a person on board. This definition includes fixed-wing, rotary wing, and lighter-than-air vehicles.
- A mechanism for launching and retrieving the UA.
- A ground control station (GCS) to provide the means for a pilot/operator to control the flight of the UA by transmitting signals to it and receiving position, condition, and other telemetry. A communications terminal to receive signals from the UA and relay these signals to the GCS and other selected users.

[5] U.S. Army, *Unmanned Aircraft Systems Roadmap 2010–2035* (Fort Rucker, AL: U.S. Army UAS Center of Excellence, n.d.), 8, http://www-rucker.army.mil/usaace/uas/US%20Army%20UAS%20RoadMap%202010%202035.pdf; United States Air Force, *RPA Vector: Vision and Enabling Concepts 2013–2038*, 13.

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- A sensor suite installed on the UA to provide data and images to the GCS.
- For armed UA, missiles, bombs, or other munitions and weapons attached to the aircraft and used to strike targets.

B. UAS Missions

The inherent flexibility of aviation, combined with the technological advances in UAS, enable them to facilitate a myriad of military missions. Joint doctrine articulates six specific Joint functions as "related capabilities and activities grouped together to help JFCs [Joint Force Commanders] integrate, synchronize, and direct joint operations."[6] These functions are C2 [command and control], intelligence, fires, movement and maneuver, protection, and sustainment.[7] While traditionally viewed as an Intelligence, Surveillance, and Reconnaissance (ISR) asset, UAS are used by each of the Services across all six Joint functions with mission opportunities continuing to expand as UAS capacity/capability matures. Individual Services, however, label their missions in a manner consistent with their respective charters. Chapters 5 and 6 of this paper analyze these missions and the Services' UAS applications. Through this analysis, the importance behind mission task and level of warfare supported (e.g., tactical, strategic) becomes evident in the overall Services' approach to their staffing methodology.

C. Generic UAS Personnel Requirements

Although each Service has unique operational approaches to its respective UAS programs, generic roles and responsibilities are associated with all current systems. These generic roles and responsibilities are distilled into the following generic personnel requirements:

- **Pilot/operator.** Responsible for controlling the flight of a UAS to include, in the absence of automatic systems, taking off and landing.
- **Sensor operator.** Controls on-board sensors and receives data and images. For many smaller UAS, this role is combined with that of the pilot/operator.
- **Intelligence analyst.** Responsible for the exploitation of the data/signals that the UAS collects. This role also has multiple analyst subsets, including video imagery, all-source intelligence, signals intelligence, and so forth. For larger UAS (Group 4/5), these roles are typically performed by an element of the processing, exploitation, and dissemination (PED) intelligence community.

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[6] Joint Chiefs of Staff, *Joint Operation*, Joint Publication 3-0 (Washington, DC: Department of Defense, 11 August 2011), III-1, http://www.dtic.mil/doctrine/new_pubs/jp3_0.pdf.

[7] Ibid.

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- **Maintainer.** Responsible for repairing and servicing the UAS and associated equipment within the UAS. Several technicians are associated with this category, including aircraft, control station, payload, weapons, communication, data link, and so forth.

In scoping this study, analysis was not conducted on maintenance or intelligence professionals. Although crucial to the overall UAS operations, this requirement would have been beyond the scope of this study. This study also did not address manning requirements associated with support functions that are provided from either supported units and/or higher headquarters (acquisition, security, transportation, personnel services, and so forth). However, several observations from our analysis are included under recommended areas for further research.

D. Organization and Methodology

This paper has three main components, which cover existing practices and guidance, analysis, and supporting documentation. Chapters 2–4 will address the categories of performers within UAS operations, summarize applicable statutory guidance responsible for manpower decisions, and outline each of the Service's current staffing practices for its UAS program. The next three chapters will focus on the analysis of these data by first defining the baseline of apparent "business rules" used across the Services. Analysis then turns toward identifying the differences between Service staffing methodologies to provide context and to identify opportunities within the enterprise. After looking at current staffing strategies, the individual elements of a UAS mission are analyzed to identify additional opportunities. Finally, this information is combined to outline potential staffing alternatives and provide initial cost analysis to inform decision makers on the need for further research.[8]

While manpower costs associated with staffing methodologies provided the genesis for this paper and hold ever-increasing importance in this era of diminishing budgets, the analysis must acknowledge that this paper deals with a combat-related capability and that the risk to people and missions must be addressed. Analysis was driven by two guiding principles outlined in DoD manpower directives/instructions: "National military objectives shall be accomplished with a minimum of manpower that is organized and employed to provide maximum effectiveness and combat power,"[9] and "Risk mitigation shall take

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[8] Appendices provide greater detail and supporting documentation, as required.

[9] Department of Defense, "Guidance for Manpower Management," DoDD 1100.4 (Washington, DC: USD(P&R), February 12, 2005), 2, http://www.dtic.mil/whs/directives/corres/pdf/110004p.pdf.

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precedence over cost savings when necessary to maintain appropriate control of Government operations and missions … and to maintain core capabilities and readiness."[10]

During the research for this paper, a common point raised rested upon a rather binary decision concerning enlisted vs. officers. Regardless of how manpower costs are calculated, if an officer is replaced with an enlisted military member, the program instantly costs less. As Table 1 depicts, when comparing the delta between annual costs, even greater savings can be obtained when civilians are included. Because of this implicit relationship between rank and annual cost, analysis avoids the binary application for category of performers (i.e., all pilots should be enlisted or officer). Rather, work-force staffing methodologies are analyzed based upon a business case analysis that combines variables such as mission risk, authorities, and the determination of inherently governmental (IG) activities.

Table 1. Delta between Rank/Pay Grades Annual Total Cost

	O-4	O-3	W-3	W-2	E-7	E-5
O-3	34,202					
W-3	43,334	9,132				
W-2	60,108	25,906	16,774			
E-7	63,438	29,236	20,104	3,330		
E-5	91,081	56,879	47,747	30,973	27,643	
GS-12	96,049	61,847	52,715	35,941	32,611	4,968
GS-11	114,141	79,939	70,807	54,033	50,703	23,060
GS-7	143,688	109,485	100,354	83,580	80,249	52,607
GS-5	155,550	121,348	112,216	95,442	92,112	64,469

While some of the overall assumptions used—specifically, officer vs. enlisted—may be contentious among the Services, the methodology used in the analysis frames the issues in such a manner that if someone decides to adjust the assumption, the subsequent analysis and methodology remain the same. To provide a standard baseline for calculating costs across staffing methodologies, this analysis used DoD's Cost Assessment and Program Evaluation (CAPE) Full Cost of Manpower (FCoM) tool as directed by Department of Defense Instruction (DoDI) 7041.04.[11] FCoM provides annual costing data only and does

[10] Department of Defense, "Policy and Procedures for Determining Workforce Mix," DoDI 1100.22 (Washington, DC: USD(P&R), April 12, 2010), 15, http://www.dtic.mil/whs/directives/corres/pdf/110022p.pdf.

[11] Department of Defense, "Estimating and Comparing the Full Costs of Civilian and Active Duty Military Manpower and Contract Support," DoDI 7041.04 (Washington, DC: CAPE, July 3, 2013), 2; "FCoM [Full Cost of Manpower]," accessed October 2, 2014, https://fcom.cape.osd.mil/.

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not include the full life-cycle costs associated with individual military occupational specialty/Air Force Specialty Code (MOS/AFSC) training and retention factors.

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2. Categories of Performers

When analyzing staffing strategies, it is crucial to first answer the question of who is *authorized* to conduct the desired operations. The first step in this process requires an understanding of which individuals—"categories of performers"—are available. This chapter sets the foundational knowledge by breaking down each category of performer as outlined by U.S. Code (U.S.C.) Title 10 (hereafter referred to as "Title 10"), DoDIs, and/or Department of Defense Directives (DoDDs). For this paper, three primary categories were analyzed: (1) uniformed military personnel, (2) government service civilian (i.e., "GS") and (3) contracted support (i.e., "contractor"). Military personnel include the subcategories of enlisted and officer.[12] A basic understanding is required before Chapter 3's review of statutory guidance and legal constraints to provide a foundation for future analysis. For those intimately familiar with these categories, the summary of this chapter provides several key takeaways applicable to the further analyses within this paper.

A. Uniformed Military Personnel

In general, uniformed military personnel must be physically qualified for active service and be of good moral character.[13] Albeit somewhat vague in concept, DoDI 1304.26 does outline specific requirements and/or further references for each of these criteria. The following paragraphs provide specific requirements for each of the military personnel subsections.

1. Enlisted

The enlisted force establishes the backbone of the Service because it consists of the majority of each Service's respective force structure. Requirements for enlistment are designed as inclusive, while primarily targeting young adults about to begin their careers (eligibility starts at 17 years old). The door for citizenship is also opened, allowing not only American citizens, but also those "lawfully admitted to the United States for permanent residence" or those described in one of several "compacts" (i.e., international agreements (IAs)).[14] These compacts include "… the Compact of Free Association between the Federated States of Micronesia and the United States, the Compact of Free Association

[12] Officers include the subcategories of limited duty officer (LDO) and warrant officer (WO).

[13] Department of Defense, "Qualification Standards for Enlistment, Appointment, and Induction," DoDI 1304.26 (Washington, DC: USD(P&R), September 20, 2005), 8, http://dopma-ropma.rand.org/pdf/DODI-1304-26.pdf. The reason for good moral character is defined as follows: "The military Services are responsible for the defense of the nation and should not be viewed as a source of rehabilitation for those who have not subscribed to the legal and moral standards of society at large."

[14] Ibid., 7.

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between the Republic of the Marshall Islands and the United States, or the Compact of Free Association Between Palau and the United States. However, the Secretary concerned may authorize the enlistment of a person not described above if the Secretary determines that such enlistment is vital to the national interest."[15] In terms of education, "a high school diploma is desirable, although not mandatory, for enlistment."[16]

2. Officer

While the employment and management of officers vary between the Services, only an officer can command troops and exercise associated command authorities.[17] As defined by DoDI 1310.02, a Commissioned Officer is defined as "An officer in any of the military Services in the Department of Defense who holds a grade and an office under a commission signed by Presidential authority, and who is appointed as a Regular or a Reserve officer."[18] Officers must be a citizen of the United States and be able to complete 20 years of active commissioned service prior to their 62nd birthday.[19] With a few rare exceptions, a baccalaureate degree is also a prerequisite for officers.[20]

a. Navy Limited Duty Officer (LDO)

As a subset of the officer corps, the Navy's LDO corps includes ranks of O-1 to O-6. However, while these officers fill management, leadership, and command positions commensurate with their rank, their associated career fields require technical background and skills that cannot be attained through normal development.[21] LDOs are currently

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[15] Ibid., 7.

[16] "A person who is not a high school graduate may not be accepted for enlistment in the Armed Forces unless the score of that person on the Armed Forces Qualification Test (AFQT) is at or above the thirty-first percentile; however, a person may not be denied enlistment in the Armed Forces solely because he or she does not have a high school diploma if his enlistment is needed to meet established strength requirements." See Armed Forces, 10 U.S.C., Volume I § 520 (Washington, DC: U.S. Government Printing Office, July 2011), http://armedservices.house.gov/index.cfm/files/serve?File_id=7C199E0E-1614-497F-A818-B5D5B4BF33B5.

[17] Ibid.

[18] Department of Defense, "Appointing Commissioned Officers," DoDI 1310.02 (Washington, DC: USD(P&R), May 8, 2007), 9, http://dopma-ropma.rand.org/pdf/DODI-1310-02.pdf.

[19] Armed Forces, 10 U.S.C., Volume I § 532. (With respect to a person who has been lawfully admitted to the United States for permanent residence or for a United States national otherwise eligible for appointment as a cadet or midshipman when the Secretary determines that the national security so requires, but only for an original appointment in a grade below O-4).

[20] Department of Defense, "Qualification Standards for Enlistment, Appointment, and Induction," DoDI 1304.26, 7. US Code Title 10, section 12205 states Baccalaureate degree is required for Reserve and National Guard officers O-2 and above.

[21] United States Navy, *The Limited Duty Officer and Chief Warrant Officer Professional Guidebook,* NAVPERS 15627A (Arlington, VA: Bureau of Naval Personnel, 2011 Edition (Updated 2013)), 2-1,

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chosen from the enlisted ranks and must first demonstrate technical proficiency in their respective career fields. Sailors are not eligible to become an LDO until they are at least an E-6 for a period of 1 year (and with all E-7 eligibility requirements met).[22] Since they are selected from the enlisted corps, LDOs do not necessarily require a baccalaureate degree and though current policy restricts LDO accession from the enlisted ranks, this is not required by law.[23]

b. Warrant Officer (WO)

Another technically focused subset of the officer corps is the WO. As described by the Department of the Army, WOs make up the technical foundation of the associated Service; however, unlike traditional commissioned officers who focus on commanding troops and who staff duty positions, WOs are solely focused on their chosen career specialty.[24] In Navy parlance, "Warrant officers 'bridge the gap' between the enlisted and technician level and other officers, thereby improving the efficiency and effectiveness of the organization."[25] Sitting within the force structure between the most senior non-commissioned officer (NCO) (E-9) and the most junior commissioned officer (O-1), an appointment as a WO holds similar requirements to that of a commissioned officer.[26] A WO is typically appointed to rank of W-1 while the ranks of Chief Warrant Officer (W-2 through W-5) receive commissions similar to the traditional officer corps.[27] Under Title 10 authority, "… a warrant officer may be assigned to perform duties that necessarily include those normally performed by a commissioned officer."[28] Therefore, a WO can hold the position of command and exercise the associated authorities of that command.

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http://www.public.navy.mil/bupers-npc/officer/communitymanagers/ldo_cwo/Pages/GUIDEBOOK.aspx.

[22] Ibid., 2-2.

[23] Ibid., 2-1.

[24] U.S. Army Website, "Career & Jobs: Warrant Officer," accessed August 25, 2014, http://www.goarmy.com/careers-and-jobs/current-and-prior-service/advance-your-career/warrant-officer.html.

[25] United States Navy, *The Limited Duty Officer and Chief Warrant Officer Professional Guidebook*, 2-4.

[26] Armed Forces, 10 U.S.C., Volume III § 3310 (Washington, DC: U.S. Government Printing Office, July 2011). http://armedservices.house.gov/index.cfm/files/serve?File_id=FC0173D5-F7D3-4D74-8D42-1B9E185B7C6B. This paragraph outlines the rank structure. Additional requirements are outlined in terms of education (a baccalaureate degree is not mandatory, although, in practice, it is common).

[27] Armed Forces, 10 U.S.C., Volume I § 571.

[28] Armed Forces, 10 U.S.C., Volume III § 3548.

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1) Army

Comprising 15% of its officer corps, the Army represents the largest WO corps within DoD.[29] Although WOs are typically selected from the non-commissioned officer corps (usually Sergeant, E-5 and above) direct accessions are possible (e.g., aviation).[30]

2) Navy

Selected from the senior enlisted force, Sailors are only eligible upon serving time as a Chief Petty Officer (E-7 through E-9).[31] In contrast to the Army's WO program, the Navy abolished the rank of W-1, and Sailors are commissioned directly into the rank of Chief Warrant Officer-2 (CWO-2).[32] Also of note, the Navy had a flying WO program that targeted younger enlisted Sailors; however, in 2013, it was terminated after 6 years when it was deemed that the needs of the Navy had changed and that "the long-term impact of keeping it going would hurt both the people and the Service."[33]

3) Air Force

While the Air Force discontinued its WO program in 1959 for a myriad of reasons, including the reduction overhead/gaining efficiencies within the Air Force technical structures by eliminating an entire personnel management system, the WO ranks are still authorized by Title 10.[34] This current IDA paper acknowledges the lack of an Air Force WO force structure, along with the additional overhead required to establish such a program. Although options to use WOs within an UAS program are analyzed, the constraints associated with the Air Force's force structure are applied to the subsequent cost/benefit analysis.

B. DoD Civilian

A DoD civilian is typically defined as a federally appointed employee by U.S.C. Title 5, Government Organization and Employees. These individuals are appointed into the civil

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[29] U.S. Army Website, "United States Army Warrant Officer Recruiting," accessed August 25, 2014, Website. http://www.usarec.army.mil/hq/warrant/.

[30] Ibid.

[31] United States Navy, *The Limited Duty Officer and Chief Warrant Officer Professional Guidebook*, 2-5.

[32] Ibid., 1-5.

[33] Mark D. Faram, "Flying Warrant Program Gets the Ax," *Navy Times*, August 24, 2013, http://www.navytimes.com/article/20130824/CAREERS/308240003/Flying-warrant-officer-program-gets-ax.

[34] Warrant Officer Historical Foundation Website, "Warrant Officer Programs of the Other U.S. Uniformed Services: U.S. Air Force," accessed August 25, 2014, https://warrantofficerhistory.org/WO_Prog_Other_Svc.htm; Armed Forces, 10 U.S.C., Volume III § 8575.

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service and are "engaged in the performance of a Federal function under authority of law or an Executive act" and, for this paper, are subject to the supervision of either a member of a uniformed Service and/or another government civilian while in this role.[35] It is also important to note, that in some cases (e.g., defense intelligence activities) government civilians are also appointed under Title 10 authorities.

DoDD 1404.10 outlines a specific subcategory of DoD civilians who are "typically away from normal work location of DoD civilians, or in situations where other civilians may be evacuated to assist military forces where the use of DoD civilians is appropriate."[36] These civilians are members of the DoD expeditionary workforce. The directive states further that this portion of the workforce "shall be organized, trained, cleared, equipped, and ready to deploy in support of combat operations by the military; contingencies; emergency operations; humanitarian missions; disaster relief; restoration of order; drug interdiction; and stability operations …."[37]

Statutory guidance directs the expeditionary workforce to be organized, trained, and equipped for contingency operations. However, research revealed that while this category of performer is extremely relevant to UAS operations, in many cases the current expeditionary workforce structure is based upon a loose collection of volunteers who are needed to fill deployed administrative functions and who are trained on an add-needed basis.[38] Despite the apparent discourse between reality and statutory guidance, subsequent analysis will focus on the applicability of such a workforce to UAS operations.

C. DoD Contractor

U.S.C. Title 5 defines a DoD contractor as an independent individual and/or company that has been contracted by or on behalf of DoD to accomplish a DoD-related function.[39]

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[35] Government Organization and Employees, 5 U.S.C. § 2105 (Washington, DC: U.S. Government Printing Office, March 2008), http://www.gpo.gov/fdsys/pkg/CPRT-110HPRT38035/pdf/CPRT-110HPRT38035.pdf. Other supervisors listed by Title 5 include the President, Members of Congress, heads of Government-controlled corporations, or an adjutant general designated by the concerned Secretary under section 709(c) of title 32.

[36] Department of Defense, "DoD Civilian Expeditionary Workforce," DoDD 1404.10 (Washington, DC: USD(P&R), 29 January 2009) 1, http://www.dtic.mil/whs/directives/corres/pdf/140410p.pdf.

[37] Ibid. In DoDD 1404.10, this sentence concludes with "… of the Department of Defense in accordance with DoDD 3000.05." DoDD 3000.05 was superseded by DoDI 3000.05 in September 2009.

[38] Office of the Under Secretary of Defense for Personnel and Readiness (OUSD/P&R), in discussion with the author, October 23, 2014.

[39] Government Organization and Employees, 5 U.S.C. § 552a (3)(m)(1). Although this section deals with administrative records-keeping, it provides a simple and clear definition of a government contractor.

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D. Summary

While the delineations outlined in this chapter are relatively well known, the following points are key takeaways applicable to the further analyses provided in this paper:

- Only uniformed military officers can hold positions of command (this includes LDOs and WOs).
- LDOs and WOs are subcategories of the officer corps used by some Services to focus on and capture long-term technical expertise.
- The Air Force lacks a WO force structure and, although authorized by Title 10, requires additional overhead to establish such a program. Similarly, the Navy lacks a flight WO program.
- The DoD expeditionary workforce is defined as a DoD civilian subcategory that is organized, trained, and equipped for expeditionary operations.

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3. Statutory Guidance Review: Workforce Mix

This chapter summarizes the analysis of standing statutory guidance to help answer the question of who is *authorized* to conduct DoD UAS operations.[40] Many assume that since DoD already uses uniformed military personnel and contractors for UAS operations, this question is a moot point. However, as outlined in Chapter 1, possible UAS missions are so broad in scope that there may be potential to structure a force by delineating categories of performers and mission requirements. Therefore, it is imperative that we understand the statutory and legal rationale. Specifically, analysis will develop a framework for UAS workforce determination, address concerns about which part of the operation/task is inherently governmental (IG), discuss how military incumbency is determined, and finally show how risk mitigation factors into the decision making process.

A. Workforce Mix Determination Framework

To answer the *who* question requires not only understanding the category of performers, as described previously, but also a working understanding of the associated DoD force structure constraints. Phrased as the "Workforce Mix," statutory guidance is primarily provided from Title 10, DoDD 1100.4 ("Guidance for Manpower Management"), and DoDI 1100.22 ("Policy and Procedures for Determining Workforce Mix"). While Title 10 outlines specific requirements in terms of generic missions (armor, infantry, strategic airlift, and so forth), it does not direct any one Service to specifically maintain a UAS capability.[41] Also, Title 10 does not direct a specific category of performer to conduct UAS operations.[42]

[40] Appendix A provides the additional detailed background analysis.

[41] Example: Title 10, Volume III § 3062 and § 8062 outline Congress' intent for the Army and Air Force, respectively, and, in some cases, outline generic structure (e.g., Army branches). However, it does not dictate a UA program. See Armed Forces, 10 U.S.C., Volume III § 3062 and § 8062.

[42] For example Title 10 § 8067 dictates that Medical, Judge Advocate, and Chaplain services be performed by officers. There is no such designation for UA programs or even for pilots in general. This current IDA paper does not advocate for such direction, but rather highlights the lack of Title 10 restrictions for an unrestricted development of alternative strategies within the constraints of existing generic manpower guidance. See Armed Forces, 10 U.S.C., Volume III § 8067

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Title 10

- Does NOT direct any singular Service to maintain a UAS program
- Does NOT direct a specific category of performer to conduct UAS operations.
- Does NOT prescribe a percentage of force and/or rank to support UAS.

Lacking specific Title 10 guidance toward a UAS force structure, DoDD 1100.4 outlines how to implement Title 10 and congressional guidance when determining the appropriate category of performers for military operations. The document is based upon the following guiding principle:

> National military objectives shall be accomplished with a minimum of manpower that is organized and employed to provide maximum effectiveness and combat power.[43]

Manpower guidance found within DoD manning directives and instructions outline several requirements for analysts to follow when determining workforce mix. As part of these principles, the guidance directs analysts to not only consider mission requirements and associated risk, but also to consider all available sources of manpower and that "assigned missions shall be accomplished using the least costly ***mix*** of personnel."[44] For this paper, the previous guidance is distilled into three guiding principles:

UAS Program Alternative Staffing Guiding Principles

- Manpower costs should be minimized to provide optimal effectiveness and combat power.
- Risk mitigation takes precedence over cost savings when necessary to maintain control, capabilities, and/or readiness.
- No single category of performer solution necessarily works best. A ***mix*** must be analyzed.

[43] Department of Defense, "Guidance for Manpower Management," DoDD 1100.4, 2.

[44] Ibid., (emphasis added).

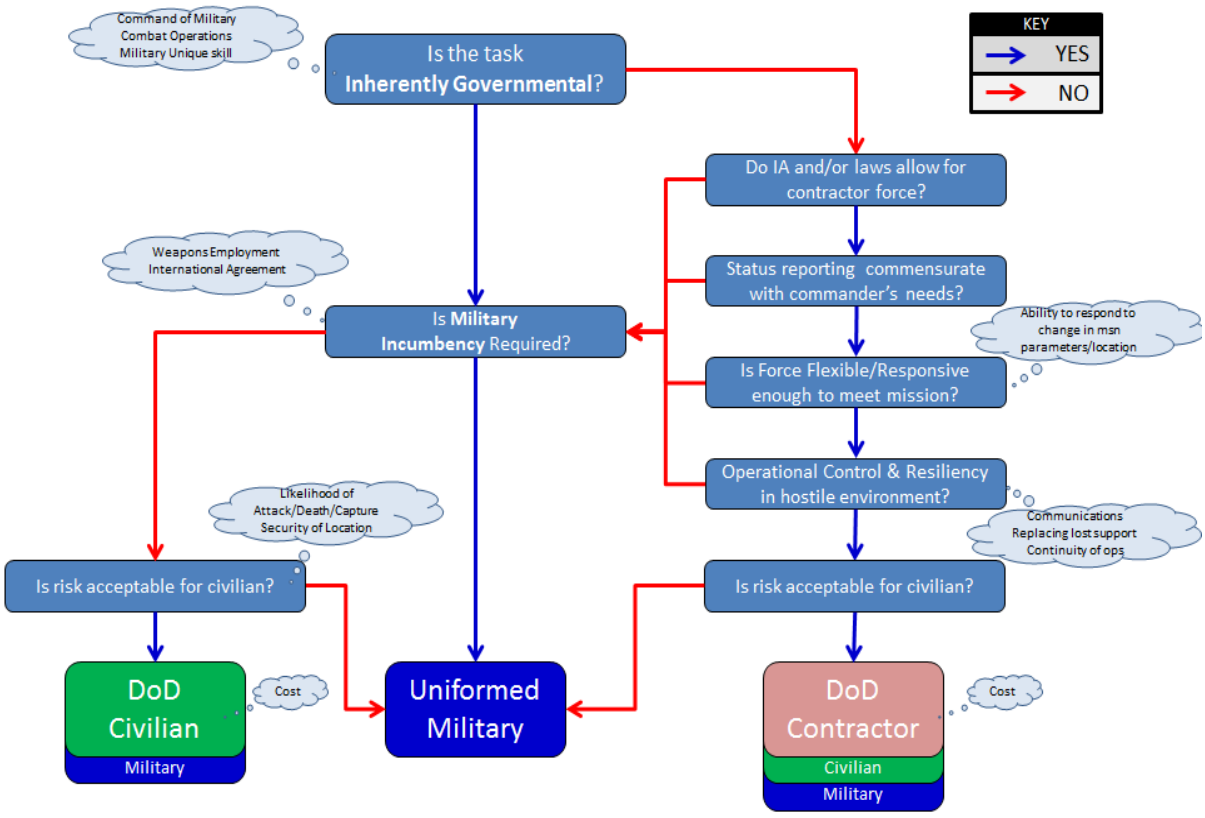
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While there are many intricacies associated with manpower analysis, this paper distills the applicable DoD statutory guidance into the following three overarching questions in terms of the UAS task in question:

Force mix Analysis Questions

- Is the task inherently governmental?
- Is military incumbency required?
- Is the level of risk to force acceptable for civilians?

Using these questions as a framework, the decision tree depicted in Figure 2 was developed to analyze potential staffing alternatives. While this generic roadmap is a simplification of the overall requirements, it will help find an appropriate balance across UAS missions and associated forces.



Note: Subsequent analysis further breakdowns the military component into officer and enlisted subcategories.

Figure 2. Category of Performer Decision Tree

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B. Inherently Governmental (IG)

As seen in the decision tree in Figure 2, the first determination made is whether the task at hand is IG. This determination is based on the DoDI 1100.4 constraint that states,

> Functions that are inherently governmental shall not be contracted.[45]

In an attempt to condense associated guidance, DoD updated DoDI 1100.22, "Policy and Procedures for Determining Workforce Mix," in 2010 as an attempt to clarify the "manpower mix criteria and guidance for risk assessments to be used to identify and justify activities that are inherently governmental (IG)"[46] This guidance consolidated previous direction and stands as the DoD standard for determining what is IG.[47]

> ***Inherently Governmental (IG) Activities***
>
> In general, a function is IG if it is so intimately related to the public interest as to require performance by Federal Government personnel. IG functions shall include, among other things, activities that require either the exercise of substantial discretion when applying Federal Government authority, or value judgments when making decisions for the Federal Government ….[48]

While DoDI 1100.22 provides in-depth detail for manpower analysts to determine what is and is not IG, the following summary distills this information into issues applicable to this UAS study. Within this summary, key criteria elements are separated into those that are mission related and those that are risk related.

[45] Ibid., 3.

[46] Department of Defense, "Policy and Procedures for Determining Workforce Mix," DoDI 1100.22, 1.

[47] Ibid., 2.

[48] Ibid., 13.

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Key Criteria: IG Determination[49]

- **Mission-Focused Criteria**
  - Command of military forces
  - Operational control of combat, combat support, and combat service support units
  - Conduct of combat operations
  - Peacetime commercial function that, in the event of a contingency, is required to mobilize and conduct an IG function
  - Ultimately accountable for accomplishment of missions and/or discretionary exercise of DoD authority
  - Military-unique knowledge and skills
- **Risk-Focused Criteria**
  - Security in hostile or volatile areas
  - Threat level could increase and military personnel would be needed on short notice to provide or augment a military capability
  - Unsafe number of personnel in hostile area who are not combatants
  - DoD civilians/contractors will not/cannot continue to perform work
  - Enemy or hostile force encounter would likely lead to hostilities
  - "Emergency-Essential" manpower … continuity of ops for essential functions

One caveat to the IG determination is for those tasks which are previously identified as core capabilities for critical operations. DoDI 1100.22 states, "…DoD Components shall review the function to verify whether the work should be performed by government personnel to provide a core capability for readiness or risk mitigation purposes, or for continuity of operations."[50] If a function is determined as such a core capability, the workforce mix determination is determined as inherently IG and the decision is then between DoD Civilian or uniformed military categories of performers.

When assessing UAS program manpower and the IG determination, one must keep in mind the UAS program alternative staffing guiding principle that states that "no single category of performer solution necessarily works best." Therefore, analysis will not only look at individual mission sets, but will also focus on individual tasks within those missions to analyze a mixed/total force options that will provide the appropriate balance of military, civilian, and contractor.[51]

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[49] Appendix A provides additional information describing the specific criteria.

[50] Department of Defense, "Policy and Procedures for Determining Workforce Mix," DoDI 1100.22, 49.

[51] While the Reserve Component plays a major role in the total force discussion, the analysis of an Active/Reserve mix was beyond the scope of this paper and has been covered in multiple other studies.

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C. Military Incumbency

As depicted in Figure 2, upon determination of a task as IG, military incumbency must be assessed. Contrasting the IG determination, the requirements supporting this decision are rather straightforward. The first step is determining the following: Is an IA in place (e.g., Status of Forces Agreement (SOFA)) that requires only uniformed military members to conduct this operation? Next, does the mission require the employment of, or terminal guidance of, kinetic weapons? Although the statutory guidance does allow for each category of performer to employ lethal force under certain conditions, for those personnel not in active military service, employing lethal force is limited to self-defense.[52] Since the employment of weapons in combat is IG, the following is a key tenet to the remainder of the paper:

> UAS Operations that include the employment of, and/or provide terminal guidance to, kinetic weapons require **uniformed military personnel**.

In addition to weapons employment, analysis indicates that UAS aircrew/operators who provide direct support to forces actively engaged in hostilities also requires support from uniformed military personnel.[53] Therefore, the following definition of military incumbency is used for the remainder of this analysis:[54]

> UAS military incumbency is indicated when an aircrew/operator position:
> - Requires **employment/terminal guidance** of kinetic weapons,
> - Provides **direct support** to forces that face the potential of, or are directly engaged in **armed hostilities** and/or
> - An **IA** requiring use of uniformed military members to conduct operations in host country.

[52] Although somewhat overly simplified, this paper will limit the discussion of UAS weapons employment to those weapons that are offensive in nature. Appendix A contains further background discussion on the use of Self-Defense Rules of Engagement (ROE).

[53] See Appendix A for background analysis.

[54] Although this somewhat oversimplifies the issue, other intricacies are addressed in the assumption of risk analysis. Appendix A provides additional information on what entails "direct support" for UAS aircrew/operators.

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D. Risk Assessment

Assessing the risk to the force is the most ambiguous decision of this analysis. While Figure 2 shows risk analysis as one of the final decision points, it is really imbedded throughout the decision tree. This risk analysis is based on the Commander's best military advice from the information that he/she is given at that time. DoDI 1100.22 stresses the importance of analyzing risk when determining the workforce mix.

> Risk mitigation shall take precedence over cost savings when necessary to maintain appropriate control of Government operations and missions … the Defense workforce shall have sufficient flexibility to reconstitute or expand the capabilities of the military Services on short notice to meet a resurgent or increased threat to U.S. national security. Accordingly, risk mitigation shall take precedence over cost savings when necessary to maintain core capabilities and readiness.[55]

With this in mind, the factors behind this decision could easily change during an operation, and that potential must also be included in the Commander's assessment. As such, the Commander is asking two questions: (1) What is the likelihood that this force will come under direct engagement with the enemy (i.e., risk of injury, death and/or capture), and (2) what is the likelihood that this force will have to pick up arms (includes self-defense considerations)? If either likelihood is "high" and/or in the Commander's belief is beyond the acceptable risk for a civilian force, uniformed military members are required.

DoDI 1100.22 also directs that when addressing the possible use of contractors, risk should be considered "to preclude ceding governmental control and authority of IG functions to the private sector where there is insufficient public **accountability and transparency**."[56] It also discusses analyzing the operational/logistical footprint associated with various workforce mix solutions since an overly large footprint could limit flexibility and introduce an unacceptable level of risk.[57] The following list summarizes the applicable risk factors to the analysis of UAS program staffing strategies.[58]

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[55] Department of Defense, "Policy and Procedures for Determining Workforce Mix," DoDI 1100.22, 2.

[56] Ibid., 46 (emphasis added).

[57] Ibid., 53.

[58] Appendix A provides additional information describing the specific criteria.

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IG Risk Assessment Factors

- Accountability and transparency
- Operational and logistical footprint
- Readiness reporting
- Replacing lost support
- Continuity of operations during hostilities
- Operational control in hostile environments
- Flexibility and responsiveness
- Discipline authority
- Restrictions due to laws and IAs

When looking down the "right side" of the category of performer decision tree (see Figure 2), risk must also be assessed in terms of the force's flexibility/responsiveness. While risk is inherent in deployed military operations, which include forward-deployed UAS elements, operating concepts enable some UAS to control missions from the Continental United States (CONUS) thereby decreasing the risk to force. It is important to understand not only who can deploy, but where and into what conditions each category of performer can deploy. While there are provisions that allow all three categories to deploy, there are key considerations for DoD civilians and DoD contractors.[59]

[59] The assumption is that uniformed military personnel are not restricted from deploying where tasked by DoD. Since all three categories of performers can deploy, "ability to deploy" is not included in the decision tree framework; however, elements of this factor must be included when considering both risk and cost.

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For civilians, DoDI 1404.10, "DoD Civilian Expeditionary Workforce," provides the primary statutory guidance associated with this category of individuals and states that they will be included in the DoD Global Force Management process and that it will reflect designation of:[60]

> **DoD civilian employees as the preferred sourcing solution** when appropriate for **non-warfighting** Combatant Command request for forces and requests for capabilities, and Joint Individual Augmentation requirements on Combatant Command Joint Manning Documents for r**ecurring and emergent mission requirements**.[61]

DoD contractors are also able to deploy in support of contingencies; however, the level of that support and associated responsiveness/robustness is often tied to significantly increased dollar amounts. DoDI 3020.41[62] is the primary source for using a contracted force in such operations. It outlines how "contracted services may be utilized in applicable contingency operations for all functions **not inherently governmental** [and that] contractor personnel may be utilized in support of such operations in a non-combat role as long as contractor personnel residing with the force in foreign contingencies have been designated as CAAF [contractors authorized to accompany the force] by the force they accompany ….[63] The CAAF designation provides contractor personnel Geneva Convention Prisoner of War protections in the event of capture; however, the instruction stresses the fact that such contractors face the "**risk of injury or death** incidental to enemy actions while supporting military operations."[64] Much of the subsequent discussion in this instruction (DoDI 3020.41) mirrors the factors discussed in the previous risk consideration. While contractors can provide support functions such as maintenance, private security (in

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[60] While DoDI 1404.10 provides the guidance for the Expeditionary workforce, as discussed in Chapter 2, there is an apparent discourse between reality and statutory guidance. The individuals are typically a loose collection of volunteers used to fill deployed administrative functions (trained on an as-needed basis) rather than specifically organized trained and equipped.

[61] Department of Defense, "DoD Civilian Expeditionary Workforce," DoDI 1404.10, 3 (emphasis added). Some associated constraints with this force are that those personnel designated as expeditionary workforce are susceptible to expeditionary assignments in 6-month rotational periods and that an individual's deployment tour shall not exceed 2 years. While this rotation is not significantly different from rotational goals associated with uniformed military personnel, it must be considered when assessing the right size and costs associated with the use of DoD civilian expeditionary workforce personnel.

[62] Department of Defense, "Operational Contract Support (OCS)," DoDI 3020.41 (Washington, DC: USD(AT&L), December 20, 2011), http://www.dtic.mil/whs/directives/corres/pdf/302041p.pdf.

[63] Ibid., 9 (emphasis added).

[64] Ibid., (emphasis added).The instruction does make a point that CAAF status does not apply to contractor personnel supporting domestic contingencies.

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some specific cases), billeting, and so forth, they are often bound by the laws of the host nation and could lose CAAF status depending "on where they are detailed to work by their employer or on the provisions of the contract."[65] Examples of limiting factors that a contracted force may be held to host nation laws include, "labor worker permits; workforce and hour restrictions; medical, life, and disability insurance coverage; taxes, customs, and duties; cost of living allowances; hardship differentials; access to classified information; and hazardous duty pay."[66] Finally the instruction highlights a key limiting factor for the contracted force, logistics:

> Contractors are generally responsible for providing their own logistical support. However, in austere, uncertain, and/or hostile environments, the DoD may provide logistical support to ensure continuation of essential contractor services.[67]

Armed with the basic framework outlined by the category of the performer decision tree (see Figure 2), Chapter 4 summarizes the current methodologies that each of the Services uses. Understanding what is currently used not only allows further analysis into any common practices applied among the Services, but also helps to identify associated gaps between statutory guidance and practice that the follow-on analysis of alternatives can address.

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[65] Ibid. Specific guidance on Private Security Contractors is provided by the Department of Defense, "Private Security Contractors (PSCs) Operating in Contingency Operations, Humanitarian or Peace Operations, or Other Military Operations or Exercises," DoDD 3020.50 CE-01(Washington, DC: DoD Directives Service, August 1, 2011).

[66] Ibid.

[67] Ibid., 2.

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4. Current Service Practices

Each Service has a unique perspective on the purpose and associated mission set of its UAS programs. This chapter will list each of the Services to show the missions associated with UAS, how the UAS are employed, and how each Service presents its UAS forces. Chapter 5 provides the analysis comparing these programs. Table 2 depicts the UAS programs analyzed in this paper.

Table 2. DoD UAS Programs Analyzed

Group	Air Force	Army	Navy	Marine Corps	SOCOM
Group 5 • > 1,320 lbs • > FL180	RQ-4 Global Hawk MQ-9 Reaper	NA	MQ-4 Triton	NA	MQ-9 Reaper
Group 4 • > 1,320 lbs • > FL180	MQ-18 Predator	MQ-1C Gray Eagle	MA-8 Fire Scout	NA	MQ-1B Predator MQ-1C Gray Eagle
Group 3 • < 1,320 lbs • < FL180 • < 250 kts	NA	RQ-7 Shadow	RQ-21 Blackjack	RQ-7 Shadow RQ-21 Blackjack	RQ-7 Shadow RQ-21 Blackjack
Group 2 • 21–55 lbs • < 3,500 AGL • < 250 kts	ScanEagle	NA	ScanEagle	ScanEagle	ScanEagle
Group 1 • 0–20 lbs • < 1,200 AGL • < 100 kts	RQ-11 Raven	RQ-11 Raven RQ-20 Puma	NA	WASP RQ-11 Raven RQ-20 Puma	WASP RQ-11 Raven RQ-20 Puma

Note: While this list is not all inclusive, it does incorporate the more prominent programs and constitutes a majority of DoD UAS programs of record.

Detailed analysis into the effectiveness of the Service's force presentation is not provided; however, this chapter concludes with a summary of common practices and/or associated gaps between the representative staffing methodologies.[68]

A. Joint UAS Requirements

While this paper refrains from an in-depth review of training and employment practices, a synopsis of the minimum joint UAS training standards is applicable to subsequent

[68] As with many rapidly developing programs, the exact numbers of aircraft and manpower associated with each program changed rapidly—even during the research for this paper. While the data contained within were current as of the research date, these changes are problematic for analyses when attempting to stick to specific manpower program levels. Therefore, this chapter and subsequent analyses will maintain a general program overview rather than chase "current" program levels. Specificity is provided where appropriate, but, for this paper, the importance lies in the analyses of the policies and their application to individual Service UAS programs to provide a long-term view applicable to all UAS programs, not just those currently in service.

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analyses. Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3255.1[69] is the guideline "to ensure the requisite knowledge, skills and abilities are addressed appropriately."[70] These standards were developed to meet or exceed Federal Aviation Administration (FAA) requirements in an effort "to facilitate UAS access into the National Airspace System (NAS)."[71] CJCSI 3255.01 guidance sets a basic UAS qualification (BUQ) and a joint mission qualification (JMQ). The BUQ details the "general aviation knowledge and UAS knowledge-based skills to operate a UAS safely as required by crew duties or position (i.e., Pilot/Aircraft Operator)."[72] The BUQ level directly correlates to the NAS and/or International Civil Aviation Organization (ICAO) airspace in which the pilot is expected to operate, depicted as follows:[73]

BUQ Level-I. Knowledge and knowledge-based skills required to fly VFR [Visual Flight Rules] in Class E, G, and Restricted/combat airspace <1,200 ft. AGL [altitude above ground level]. [**FAA Equivalent:** FAA requirements do not currently exist for this group of aircraft.]

BUQ Level-II. Knowledge and knowledge-based skills required to fly under VFR in Class D, E, G, and Restricted/combat airspace <18,000 ft. MSL [mean sea level]. [**FAA Equivalent:** Sport Pilot]

BUQ Level III. Knowledge and knowledge-based skills required to fly under VFR in all classes of airspace *except U.S. and ICAO Class A.* [**FAA Equivalent:** Private Pilot]

BUQ Level IV. Knowledge and knowledge-based skills required to fly *VFR/IFR [Visual Flight Rules/Instrument Flight Rules] in all weather conditions and classes of airspace up to FL600 [flight level 600]*. [**FAA Equivalent:** Private Pilot with Instrument rating]

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[69] Department of Defense, "Joint Unmanned Aircraft Systems Minimum Training Standards," CJCSI 3255.01 (Washington, DC: Joint Staff, 17 July 2009; CH 1, 31 October 2011; Directive Current as of 4 September 2012), http://www.dtic.mil/cjcs_directives/cdata/unlimit/3255_01.pdf.

[70] United States Air Force, *RPA Vector: Vision and Enabling Concepts 2013–2038*, 79.

[71] Department of Defense, "Joint Unmanned Aircraft Systems Minimum Training Standards," CJCSI 3255.01, 1.

[72] Ibid., 2.

[73] Ibid., A-2 (emphasis added). BUQs are cumulative (e.g., to achieve a BUQ III, a pilot must also meet BUQ I and II requirements). The BUQ requirements meet or exceed the requirements of their FAA equivalents (as described by the 14 Code of Federal Regulation (CFR).

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A detailed comprehension of airspace classification (A–G) is not necessary other than understanding that Class A is the most restrictive (e.g., international airports and civilian airliner airways), Class D is found at many smaller airports and military airfields, and Class G is the least restrictive (e.g., rural farm land).

CJCSI 3255.01 also dictates JMQs to "provide general knowledge of the UAS mission/objective … to ensure [that] the crews understand their role in accomplishing a larger military objective."[74] The three JMQ levels are as follows:[75]

> **JMQ-A.** These qualifications support **unit-level ISR and Fires** tasks in support of the JFC. Mission support with capabilities defined in the JMTL [Joint Mission Task List].
>
> **JMQ-B.** These qualifications support **theater-level advanced ISR/IAA [Intelligence, Surveillance, and Reconnaissance/Incident Awareness and Assessment]** mission support with defined capabilities in the JMTL of the JFC.
>
> **JMQ-C.** These qualifications support **strategic level Fires and CSAR/PR [combat search and rescue/personnel recovery]** tasks in support of the JFC as defined in the JMTLs.

The nuances between these (**bold texts**) are significant because they show the level of anticipated mission execution, which ties directly into how the Services view their respective UAS crew forces. Like the BUQs, the JMQs are cumulative in nature.

CJCSI 3255.1 goes one step further in tying the BUQ and the JMQ as minimum standards to each of the previously described UAS classifications (Groups 1–4).

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[74] Ibid., 2.

[75] Ibid., B-1 (emphasis added).

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Table 3 depicts the minimum standard required by the CJCSI for each of the UAS groups.[76]

Table 3. CJCSI 3255.1 Minimum Training Standards

Group	BUQ	Airspace	JMQ	Mission level
5	IV	VFR/IFR, all classes, all weather FL600	B	Theater ISR
4 3	III	VFR, All classes ***except*** U.S./ICAO Class A		
2	II	Restricted/combat <18,000 ft. MSL VFR, Class D, E, and G	A	Unit ISR/Fires
1	I	Restricted/combat <1,200 ft. AGL VFR, Class E and G		

B. Air Force

The Air Force's UAS efforts focus on Group 4/5 UAS, which the Air Force refers to as RPA.[77] The Air Force operates and maintains these assets within DoD and, as with most Air Force aircraft, RPAs are viewed as operational/strategic assets whose support is typically focused regionally rather than in a direct support role to any single unit.[78] While the focus of the Air Force is primarily on RPAs, the 2014 RPA Vector report does reemphasize "the inherent potential and emerging capabilities of small unmanned aircraft systems (SUAS),"[79] the term that the Air Force uses for UAS Groups 1–3. The overall vision is for the Air Force to tie RPAs and SUAS together into a family-of-systems approach that is agile and responsive to the JFCs requirements.

1. Applied Missions

The Air Force's five core missions are as follows:

- Air and Space Superiority,
- ISR

[76] JMQ C (strategic level fires and CSAR/PR) is not set as a minimum requirement by CJCSI 3255.1; however, it is used as the minimum standard for the Air Force MQ-1/9.

[77] United States Air Force, *RPA Vector: Vision and Enabling Concepts 2013–2038*, 13.

[78] While RPAs can indeed provide direct support to a specific unit, they are typically launched to support multiple units during a single sortie, thereby maximizing collection requirements within their area of responsibility.

[79] United States Air Force, *RPA Vector: Vision and Enabling Concepts 2013–2038*, 12.

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- Rapid Global Mobility,
- Global Strike, and
- C2.

While the primary focus of the Air Force's UAS program is focused on ISR and Global Strike, Air Force RPAs have a role in providing Air and Space Superiority and C2. The 2014 RPA Vector report depicts a vision in which these missions will continue to expand and in which future RPA programs will broaden to consider global mobility in missions such as cargo movement and air refueling.[80] While RPA have been used in "atypical" military missions, such as humanitarian relief and/or support to non-governmental agencies, the core Air Force missions flown today focus on close air support (CAS), ISR, CSAR, and strike coordination and reconnaissance (SCAR). While these missions are similar to those performed by UA in the other Services, the Air Force has a global commitment. Even when regionally assigned (e.g., Afghanistan), Air Force RPAs are tasked to support multiple teams during their often 20+-hour flights. These aircraft are also responsible for adjusting mission focus depending on which ground force they are supporting at that time. Within a single flight, Air Force RPAs can go from basic ISR collection, to convoy protection, to C2 relay, to providing CAS and associated precision weapons employment—all for several different ground component commanders.

In contrast, the Air Force's SUAS force is currently used at the tactical level in support of battlefield airmen and security forces. Similar to that of the other Services' tactical ground units, these UA are used for point security or short-duration missions to provide a unique vantage point typically unavailable at the small-team level. While the team missions can vary from humanitarian assistance to support of direct fire missions, SUAS are kept at the tactical unit support level.

2. Employment Concept

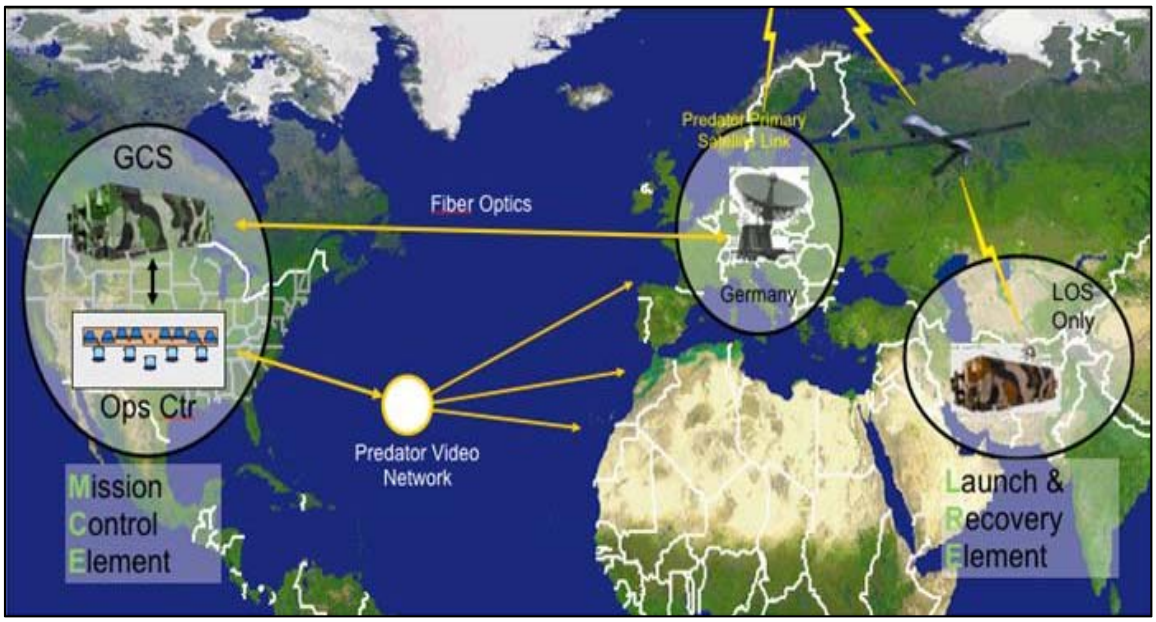
Air Force RPA fly in support of global operations 24 hours a day, 7 days a week, 365 days a year (24/7/365), primarily from bases stationed in CONUS. Figure 3 depicts this extensive communication infrastructure referred to as remote split operations (RSO). While a small contingent is required to deploy in support of launch and recovery operations, most of the Air Force RPA crew force remain CONUS. This approach provides the benefits of minimizing forward-deployed forces and decreasing the number of rotational forces required.[81]

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[80] Ibid., 18.

[81] "Deployed-in-garrison" construct was noted as creating challenges between balancing combat operations and typical in-garrison duties. While several studies address this topics, this paper will focus on the manning construct from an effectiveness, mission risk, and cost perspective.

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Source: 3rd Special Operations Squadron Unit Capabilities Brief, CAO February 2011 (author's personal files).

Figure 3. Air Force RPA RSO

3. Force Presentation Model: Uniformed Military

The Air Force uses the Squadron as the primary unit responsible for provided UAS capability to the JFC. Air Force RPA support is quantified by the number of Combat Air Patrols (CAPs) provided. A CAP is a singular aircraft that is airborne over a designated objective(s), where the measure of CAPs is typically assessed by how many CAPs can be provided globally at any one time.[82] The typical active duty MQ-1/9 Squadron construct is to support five CAPs, while the reserve component squadron construct can support up to three.[83] Since these operations run "24/7/365," the Air Force currently applies a 10:1 crew ratio to their MQ-1/9 pilot and sensor operator positions. This translates to 10 pilots and 10 sensor operators for each CAP for which a squadron is responsible.[84] For RQ-4

[82] Current Air Force program provides 65 total RPA CAPs, which includes MQ-1, MQ-9, and RQ-4.

[83] United States Air Force, *RPA Vector: Vision and Enabling Concepts 2013–2038*, 16.

[84] In trying to grasp the number of individuals associated with a single aircraft, it is helpful to see a single RPA aircrew as 20 people (10 pilots, 10 sensor operators who operate 24/7/365 operations), thereby manning Air Force RPA at a crew-to-CAP ratio of 1:1. In this manner, it becomes analogous to other aircraft (yet other aircraft provide significantly less time airborne and do not provide 24/7/365). For example, an AC-130H gunship has 14 crew members, and an E-8C Joint Surveillance Target Attack Radar System (JSTARS) has between 21 and 34 crew members, depending on mission length. Also of note, an Air-Force-conducted manpower study, which reportedly validates Air Force RPA crews' claims that an increase in the crew-to-CAP ratio is actually required, was expected for official release end of February/beginning of March 2015.

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operations, this ratio is 15:1.[85] While the RSO construct eliminates the need for rotational forces, this manpower ratio is still required to meet the requirements to enable leave, days off, administrative duties, continued professional development (e.g., professional military education), and so forth. Since the reserve component must maintain a balance between its full-time active guard and reserve (AGR) and part-time traditional reservist (TR) positions, the manning construct is somewhat different. A typical three-CAP squadron has 56 positions per crew, balanced between 15 AGR and 41 TR positions.

In terms of category of performers within the RPA force, the Air Force uses rated officers for pilots and enlisted personnel for sensor operators.[86] The Air Force contends that the level of responsibility placed upon its pilots is associated with those traits of a commissioned officer. Rated RPA pilots come from two sources: (1) the undergraduate RPA training pipeline or (2) those rated officers who completed the traditional undergraduate pilot training (UPT) and previously flew a manned platform before their RPA tour. The goal is for RPA training pipeline pilots, whose training presents a 95% cost savings over their traditionally trained pilot training counterparts, to eventually comprise most of the force.[87] This career field was developed not only to capitalize on the cost savings associated with shorter training timelines, but also to further professionalize and focus the rated RPA force.

The Air Force's view on RPA operational requirements mirrors that of those associated with typical manned platforms. This view also drives the requirement for RPA sensor operators, who are also awarded an aeronautical rating and associated wings, to train at a level commensurate with their career enlisted aviator counterparts.

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[85] Air Force/A2CU, e-mail correspondence with author.

[86] United States Air Force, *RPA Vector: Vision and Enabling Concepts 2013–2038*, 13.

[87] Air Education and Training Command, HQ AETC/FMATT, e-mail with author. Costing data from AFI 65-503, "Cost Factors," Table A34-2 *Representative Officer Aircrew Training Costs Variable and Fixed*, 5 March 2014. Air Force Personnel Center RPA managers stated that UPT for a fighter pilot costs approximately $1,463,797 per pilot (T-6, T-38, and Introduction to Fighter Fundamentals) while undergraduate RPA training (URT) only costs $70,446. The cost for UPT graduates designated to fly mobility or refueling aircraft cost $749,354 (URT is 91.6% less costly).

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As stated in the RPA vector,

> While RPA pilots and sensor operators face challenges operating aircraft from a remote shelter (e.g., C2 link latency), the majority of **aircrew skill sets** required (e.g., communication, multitasking, airmanship) **are no different from those required for manned aircraft.**[88]

With this in mind, the Air Force acknowledges that while DoD will determine where and how it will operate its aircraft, the individual Service is responsible for creating qualification training programs necessary to safely accomplish that assigned mission. In terms of UAS, the Air Force's RPA Vector report references the CJCSI 3255.1 standards discussed previously.[89] Based on the Air Force's global requirement, which requires flight within ICAO airspace and the often kinetic (i.e., weapons employment) nature of the RPA mission, Air Force RPA crews are trained at the highest (BUQ-V, JMQ-C) level, thereby exceeding FAA requirements and enabling integrated operations within the national/international airspace structure.

In contrast to the larger RPA, Air Force SUAS are operated at the tactical/team level. Although SUAS operators are individually certified through a unique training program, becoming an operator is a secondary duty for airmen. As stated by the RPA vector,

> SUAS operators (SUAS-O) are not rated pilots but function as the pilots in command (PIC) and are responsible for the safe ground and flight operation of the UA and onboard systems. Air Force SUAS-Os are selected, trained, and certified to act as the PICs of their UA based on mission requirements. SUAS-O qualification does not result in award of an Air Force Specialty Code (AFSC) or a Special Experience Identifier.[90]

Therefore, while SUAS operations come with additional training/currency requirements, these operations do not drive an inherent increase of manpower within the unit.[91] This situation is primarily true now within the Air Force due to the fact that Airmen are only

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[88] United States Air Force, *RPA Vector: Vision and Enabling Concepts 2013–2038*, 79 (emphasis added).

[89] Ibid.

[90] Ibid., 13.

[91] As technology and capability among the SUAS force increase, this situation could easily change. As described in the 2014 RPA Vector report, there is a reemphasis on SUAS. Elements within the Headquarters Air Force, which is currently drafting an SUAS vector to shape future efforts. As the systems mature, the need for designated SUAS operators (especially in Groups 2/3) could become a reality.

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operating Group 1 UA. Although not a requirement, SUAS operators within the Air Force are typically enlisted personnel, largely due to fact that the career field employing these aircraft (e.g., Security Forces, Battlefield Airmen) is primarily enlisted and is performing operations in local support of its specific unit/team. The Air Force centrally trains RQ-11 operators at a BUQ-II, while individual units assure JMQ-A qualification.[92]

4. Utilization of Contractors

While most of the Air Force UAS program is performed by uniformed military personnel, some support aspects use DoD contractor support. The most prevalent use of contractors is within the deployed maintenance of these systems; however, in some unique cases, the Air Force has contracted UAS flight operations in cases where the demand required an immediate increase in a capability that was not inherent within the existing UAS program. Most notably are those contracts used in support of UAS training operations and where certain special-mission RPA units use contractors to provide deployed launch and recovery operational support.[93] Increases in ISR demand have also led to an increase in government-owned, contractor-operated (GOCO) UAS operations in which the government is able to aptly supply the necessary hardware but is ultimately short the personnel required to conduct combat support operations. For Air-Force-flown aircraft, this situation has presented itself most recently in the use of GOCO MQ-9 operations.

C. Army

In contrast to the Air Force, the Army's UAS program focuses primarily on the smaller Group 1 and 3 aircraft. (The Army does not currently employ Group 2.) Although approximately 92% of the Army's UAS inventory consists of Group 1 UA, it does operate the Group 4 MQ-1C. While the MQ-1Cs are a small portion of the Army's overall fleet (approximately 2%), this capability plays a large part in the Army's overall UAS strategy and brings significant capability to commanders at the lowest level. The level of support varies depending upon the unit to which the UAS is assigned; however, Army UAS operations are typically employed at the tactical level and used in a similar manner to other organic maneuver and fire forces.

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[92] Air Force SUAS School House Det-Commander, e-mail with the author, February 13, 2015. USAF RQ-11s often operate within Class D airspace in support of the base defense mission.

[93] Multiple interviews with RPA Manpower and Career Development Tiger Team. Training operations at Randolph, Holloman, and Creech Air Force Bases (AFBs) use contractors to augment the active duty force to meet training requirements and increased demand for a larger RPA force. While many of the deployed launch and recovery flight operations are conducted by uniformed military, some Air Force RPA squadrons are supported by contracted launch and recovery elements.

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As documented in the Army UAS Roadmap report, the typical Army echelons are as follows:[94]

> **Battalion-level and lower:** close-range (less than 25 kilometers), short duration (one to two hours) missions that operate below the coordinating altitude and are thoroughly integrated with ground forces as an organic asset supporting tactical operations.
>
> **Brigade level: medium-range** (less than 125 kilometers), medium-duration (five to 10 hours) missions that integrate with ground forces and other aviation assets.
>
> **Division-level and higher:** extended range (200 kilometers or more), long duration (16 hours or more), missions in direct support (DS), or general support (GS) at the tactical or operational level.

1. Applied Missions

Army Doctrine Publication 1 states that "the Army's indispensable contributions to the joint force—the core competencies—are combined arms maneuver and wide area security."[95] These competencies are those in which UAS applied at the tactical level prove indispensable in today's combined arms warfare. While UAS can easily be employed throughout each of the Army's core competencies, the Army's Unmanned Roadmap report states the overall goal is to "focus Army investments in unmanned systems and technologies to meet the prioritized capability needs of the Warfighter that include the following missions": (1) Reconnaissance and Surveillance, (2) Security, (3) Attack, (4) Command, Control, and Communications Support, (5) Combat Support, and (6) Sustainment.[96] The roadmap further stresses the importance of UAS as the "Eyes of the Army" and that they specifically "support **tactical echelons** in Army and Joint operations and provide the Warfighter a tactical advantage through near real-time situational

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[94] U.S. Army, *Unmanned Aircraft Systems Roadmap 2010–2035,* 1 (emphasis added).

[95] U.S. Army, *ADP1: The Army* (Washington, DC: Headquarters, Department of the Army, September 2012), 3–4, http://armypubs.army.mil/doctrine/dr_pubs/dr_a/pdf/adp1.pdf.

[96] U.S. Army, *Unmanned Aircraft Systems Roadmap 2010–2035,* 3–4. Reconnaissance and surveillance include chemical biological, radiological, nuclear, and high-yield explosives reconnaissance and counter explosive hazards. Security includes preserving friendly force combat power and providing threat/terrain information. Attack includes close combat, interdiction attack, strike, and target identification and designation. Command, control, and communications (C3) support enables the commanders to broaden the communication network and improve C2. Combat support includes military intelligence, engineer, military police, chemical operations, and combat identification. Sustainment includes the delivery of supplies and materials to forward-deployed units and the extraction of wounded and enemy prisoners of war.

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awareness, multi-role capabilities on demand … and the ability to dynamically retask."[97] The roadmap further defines eight significant "takeaway themes" of the UAS strategy. The following five are applicable to this discussion:[98]

Army UAS Roadmap Takeaway Themes

- The Army's UAS strategy provides dynamically retaskable assets to ground commanders.
- The Army's UAS provide actionable intelligence to the lowest tactical level.
- The Army's UAS strategy shortens the "sensor-to-shooter" timeline.
- The Army's UAS support full spectrum operations.
- Allow commanders to employ a variety of capabilities.

2. Employment Concept

Army UAS, similar to their Air Force counterparts, are also currently employed 24/7/365; however, the significant difference between the programs is that the Army does not currently employ an RSO model. For most of the Army UAS force, this lack of an RSO model is a technical limitation, which applies to all military small UAS, since current Group 1 UAS are not equipped with beyond-line-of-sight (BLOS) satellite capabilities. In the cases where the UAS are capable of BLOS, the Army units capitalize on this capability. However, unlike the Air Force, which operates from CONUS, Army units remain deployed forward so that they can remain organic to the unit, with the idea they can respond better to the commander's need to "dynamically retask" assets as the tactical situation dictates.[99] In addition, the Army's MQ-1C Gray Eagle has several technical differences from its Air Force counterpart, the MQ-1B Predator. The Army's MQ-1C is equipped with an automatic takeoff and landing system, thereby reducing the launch and recovery operator requirements across the force.[100] It is also controlled via "point-and-click" software, while

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[97] Ibid., 1 (emphasis added).

[98] Ibid., 2 (emphasis added).

[99] Some of the systems that are capable of satellite BLOS operations often require some CONUS reach-back in terms of intelligence exploitation (e.g., video, signals, and so forth) because the deployed infra-structure is often unable to meet the volume of information collected.

[100] OSD Website, "MQ-1C Gray Eagle Unmanned Aircraft System," accessed September 10, 2014, http://www.dote.osd.mil/pub/reports/FY2010/pdf/army/2010mq1cgrayeagleuas.pdf.

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the Air Force's MQ-1B retains a stick and throttle in addition to its autopilot "point-and-click" functionality.

3. Force Presentation Model: Uniformed Military

Within the Army, the size/echelon of the primary UAS unit providing support depends on which echelon it summarily supports. For example, Group 1 UAS are typically provided by a UA Team to support an associated Battalion (see Table 4). For Group 3, a UAS Company supports the Brigade. Finally, a UAS Company typically provides MQ-1C Gray Eagle (Group 4) support to the Division. Rotational forces are not built within each of these units since they are inherently designed to deploy in-mass with their Higher Headquarters (HHQ) to provide direct support to the same ground force commander with whom they train while in-garrison. Table 5 and Table 6 depict the *typical* force structure for each of these UAS units. In general, the UAS Team consists of 2 operators, the Platoon consist of 27 soldiers (see Table 5), and the Company has approximately 128 total personnel (see Table 6, includes maintenance).[101] As for combat capacity, the Army's UAS program calls for the following aircraft inventory per unit level (typical): Group 1 Teams: 3 aircraft, Group 3 Platoons: 4 aircraft, and Group 4 Companies: 10–12 aircraft each. Unlike the Air Force presentation model, which refers to number of CAPs provided, Army UAS units use their aircraft inventory in a manner directed by the commander and in response to the tactical situation at hand. Simply put, the number of flights launched is a balance between crew/aircraft availability and tactical mission requirements.

[101] U.S. Army, *Unmanned Aircraft Systems Roadmap 2010–2035.* Passim and information provided by Mr James Ryan, Aviation Directorate Army Staff G-3/5/7, September 2013. Without maintainers, the company has 97 soldiers.

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Table 4. Allocation of Raven Teams and Personnel in an Army Infantry Brigade Combat Team (IBCT)

			Enlisted Personnel			
Unit	SUAS Teams	Ravens	Master Trainer	Master and Operator	Operator	Total
Infantry Battalion	4	12	1		8	9
Infantry Battalion	4	12	1		8	9
Infantry Battalion	4	12	1		8	9
Recon Squadron	3	9	1		6	7
Fires Battalion	2	6	1		4	5
Engineer Battalion	2	6		1	3	4
Support Battalion	1	3		1	1	2
Totals	20	60	5	2	38	45

Source: U.S. Army, *Unmanned Aircraft Systems Roadmap 2010–2035, 101.* Passim and information provided by Mr. James Ryan, Aviation Directorate, Army Staff G-3/5/7, September 2013.

Table 5. Organization and Staffing of the Army Tactical Unmanned Aerial Systems (TUAS) Platoon

	WO MOS O50U	Enlisted Operator MOS 15 W	Enlisted Repairer MOS 15E	Total
Platoon Headquarters	2	1		3
Mission Planning and Control Section		8	7	9
Launch and Recovery Section		7	8	15
Total Military Personnel	2	16	15	27

Source: U.S. Army, Unmanned Aircraft Systems Roadmap 2010–2035, 99.

Table 6. Composition of the Army Gray Eagle Company

		WO		Enlisted				
	Officer	MOS O50U	Other	Operations MOS 15P	Operator MOS 15W	Repairer MOS 15E	Other MOS	Total
HQ	1	4		5	1		35	46
Flight Platoon		6			45			51
Maintenance Platoon			1			26	4	31
Total Personnel	1	10	1	5	46	26	39	128

Source: U.S. Army, Unmanned Aircraft Systems Roadmap 2010–2035, 97.

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In terms of category of performers, the Army currently uses WOs and enlisted soldiers to operate their aircraft. Officer involvement comes with one officer position commanding the Group 4 UAS company[102] while UAS WOs command the Platoon. The Army does have a unique UAS military MOS for both WOs and enlisted soldiers, but does not have the same for the officers O-1 and above.

Although enlisted operators were used to operate the plethora of Groups 1–3 UA, much like the Air Force, the addition of Group 4 UAS capabilities and subsequent tactical capabilities drove the Army to integrate WOs and establish a unique Warrant UAS MOS. According to numbers within the Army's roadmap, WO positions still only comprise ~18% of the UAS Group 4 Companies and ~13% of the Group 3 Platoons. Except for the one Officer (Company Commander), all remaining operators in the units are enlisted soldiers.

4. Utilization of Contractors

The tactical forward-deployed nature of Army UAS tends to drive the requirement for uniformed military personnel. However, over the years, the Army, much like the other Services, has used contractors to provide UAS support and capability where there were associated capability gaps within the Army's programs. Similar to the Air Force, Army UAS contractors support functions such as maintenance and training. In addition, the constant increase in demand has also driven a requirement for MQ-1C GOCO operations.[103]

D. Navy

The Navy's UAS program[104] has focused on support to the Fleet and littoral regions. For this reason, the Navy invested early in Group 2 and has, within the past few years, added the Group 4, MQ-8 Fire Scout and the Group 5, MQ-4 Triton. With a long history of unmanned aviation development, Navy UAS efforts are rather diverse, focusing on the next-generation Unmanned Combat Air System (UCAS), designed to prove an autonomous capability to launch from an Aircraft Carrier, to a variety of rotary wing UAS, designed to deliver supplies to deployed forces with little more than 5 minutes of operator training and a mobile tablet device.[105]

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[102] U.S. Army, *Unmanned Aircraft Systems Roadmap 2010–2035*, Appendix D: UAS Organizations.

[103] Interview with AFSOC/A5K Staff members, January 7, 2015. Flown in support of United States Special Operations Command (USSOCOM).

[104] Although Marine programs fall under the Department of Navy, for this paper, the programs are separated based on differences in manning constructs.

[105] The Navy flew the first RPA, an N-9 named *The Wild Goose*, September 15, 1924 (see Angelina Long Callahan, "Reinventing the Drone, Reinventing the Navy (1919–1939)," *Naval War College Review* 67, no. 3 (Summer 2014): 98–122, https://www.usnwc.edu/getattachment/52d53799-ce32-4a36-bb08-

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1. Applied Missions

With the combined effects of the surface fleet and Naval Aviation, Navy UAS can span from tactically focused missions to the strategic. The missions associated with these levels of warfare currently trend down the same lines associated with the UAS "Groups." For example the Navy's Group 2 ScanEagle maintains an extremely unit-level tactical focus, whereas the MQ-4C is used in a more regional/strategic role akin to its Air Force counterpart, the RQ-4. The Navy, similar to the other Services, applies UAS capabilities across each of its designated mission sets:

ASUW – Anti-Surface Warfare
ASW – Anti-Submarine Warfare
BAMS – Broad Area Maritime Surveillance
BDA – Battle Damage Assessment
C3 – Command, Control, and Communications
EOD – Explosive Ordnance Disposal
EW – Electronic Warfare
FP– Force Protection
ISR – Intelligence Surveillance, and Reconnaissance
LG – Logistics (Cargo Resupply)
MDA – Maritime Domain Awareness
MIW – Mine Warfare
OMCM – Organic Mine Counter Measures
RSTA – Reconnaissance, Surveillance, and Target Acquisition
STRIKE – Precision Strike

2. Employment Concept

The Navy, similar to the other Services, currently employs Groups 1–3 UAS via line-of-sight (LOS) control with forward-deployed forces directly supporting the surface fleet commander or associated ground force commander (mission dependent). Currently, the smaller Group 2/3 aircraft are primarily flown in support of the Naval Special Warfare Command (NAVSPECWARCOM), while the larger Group 4/5 aircraft are flown in direct support of fleet operations.[106] Many of these UAS are operated directly off of the surface fleet ships where UAS crews conduct both launch and recovery and mission operations. In contrast the larger Group 5, MQ-4C Triton uses a RSO model similar to that of the Air

2425c045167a/Reinventing-the-Drone,-Reinventing-the-Navy--1919-.aspx; "Navy to Fly Drone Helicopters from Tablet App," *RT*, April 7, 2014, http://rt.com/usa/navy-aacus-helicopter-drone-941/).

[106] Interview with Navy UAS program staffers, January 9, 2015.

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Force, with forward-deployed launch and recovery bases supplying aircraft for CONUS-based units to conduct operations.

3. Force Presentation Model: Uniformed Military

For Group 1 aircraft, the Navy operates in a similar way to that of the Air Force and Army, with individuals trained as an additional duty, operating in 1- and 2-man teams. These teams are typically security or Sea, Air, Land (SEAL) teams supporting their associated tactical element. For Group 2/3 aircraft, the Navy has relied primarily on contracted services, or in some cases individual augmentees from within the Service to perform duties while deployed.[107] For Group 4/5 aircraft, the Navy has adopted the Squadron as the primary force provider for UAS capabilities.

The Navy's rationale for using previously rated aircrew for Group 4/5 UAS is that it requires less training and that associated operating risk is reduced based upon their existing knowledge of aviation fundamentals and mission execution. In short, the Navy contends that it is less costly and presents less risk to use previously rated individuals. While the Navy has adopted the squadron model for its larger UAS, some unique characteristics are associated with its programs. For the Group 4 MQ-8B Fire Scout, the squadron is actually a helicopter squadron containing manned and unmanned aircraft. The operating concept for these squadrons is that naval aviators assigned to operate manned helicopters operate the unmanned helicopters as an additional duty. According to Navy personnel, the largest driver for this concept is bed space available on the ship.[108] Limited space equates to limiting resources, so the combination of crews flying similar missions, albeit with different platforms, makes logistical sense.

The Navy had a similar mindset when establishing its unmanned patrol squadrons (VUPs) operating the Group 5 MQ-4 Triton. However, rather than dual-qualifying their crews, pilots assigned to the VUP are solely focused on Triton operations during their assignment. The Navy does not take any new accessions into the program but rather sources it from other patrol squadrons (VP) flying similar missions in aircraft such as the P-8 Poseidon. Since all Group 4/5 UAS Naval Aviators come from a previous manned flying background, they all maintain a minimum of a BUQ-V/JMQ-B joint training level.

As discussed in Chapter 2, the Navy gave consideration to a flying WO program; however, after 6 years, this program was terminated in 2013 when it was deemed

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[107] Interview with Navy UAS program staffers, January 9, 2015. IAs come from within the Navy uniformed Service members (Officers) and are provided the training necessary to perform duties while on a particular deployment or sea rotation. These "particular duties" are not their primary duties, and, upon completion of their rotation, they return to their normal specialty. They currently represent approximately 10% of the force used.

[108] Interview with Navy UAS program staffers, January 9, 2015.

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counterproductive to career progression goals of standing Navy programs.[109] In addition, while the Navy does have the LDO program, it does not currently include opportunities for naval aviators.[110]

4. Utilization of Contractors

As mentioned previously, the Navy has used service contracts for over a decade to obtain ISR capabilities using UAS such as the Group 2 ScanEagle. The contractor provided teams of four operators with unmanned aerial vehicles (UAVs), sensors, ancillary equipment, and support services. The teams were stationed on Navy ships and in combat zones on land. The use of service contracts was justified originally as necessary to meet an urgent operational need. From an operational standpoint, the results were reported as positive. Currently, the Navy is undergoing efforts to establish an in-house military infrastructure to operate and sustain the Group 3 RQ-21 Blackjack and to replace the primarily contracted Group 2 ScanEagle.

E. Marine Corps

Focused on the tactical employment of the Marine Air Ground Task Force (MAGTF), the Marine's UAS program consists primarily of Group 3 and smaller UA. Much like the Army, these systems are focused on tactical-level employment and direct integration with the supported ground force. Although the Marine UAS program is applied in a similar fashion to its ground counterpart in the Army, the programs have some differences in organizational structure. The Marine UAS program strives to ensure direct tactical support to the MAGTF while also ensuring complete integration with the larger joint force. Also, while the Marine UAS echelons depicted below describe the currently executed UAS program, the Marine Corps is looking at the maturation of Group 3 UAS to perform the missions/roles currently supported by the larger Group 4/5 aircraft. This effort shapes much of the way the Marines have staffed their UAS program.[111]

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109 Mark D. Faram, "Flying Warrant Program Gets the Ax."

110 U.S. Navy Website, "Limited Duty Office Designators," accessed September 17, 2014, http://www.public.navy.mil/bupers-npc/career/reservepersonnelmgmt/officers/Pages/LDOCWOCommunity.aspx. This website provides list of current LDO Designators. Naval Aviation is not included. Conjecture on the possibility for UA MOS LDO is that of the author.

111 Telephone interview with Lt Col (Ret) Kenneth Briggs, HAF/A2CU, recently retired Marine UA officer, September 19, 2014.

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Typical Marine UAS Echelons

Battalion-level and lower: Group 1
Regiment level: Group 2/3
Brigade/Joint Task Force: Group 4/5 (none currently in inventory)

1. Applied Missions

The roles of Marine UAS are not that different from the other Services' programs. Marine aviation doctrine summarizes UAS tasks as conducting ISR, target acquisition, and airborne surveillance for search and rescue and tactical recovery of aircraft and personnel; supporting vertical assaults (helicopter/tiltrotor); adjusting direct/indirect fire; and conducting battlefield damage assessments (BDAs).[112] The more recently published Marines UAS doctrine mirrors these tasks but also includes rear area security, training, and the ability to "provide a remote-receive station capability and liaison to designated units" (i.e., expand C2 communications).[113]

2. Employment Concept

Due to the tactical-level focus of the Marine UAS program, it is employed similarly to that of the Army—UAS pilots and operators deploy with and remain integrated with the overall MAGTF that they support. Like the Army concept, the goal is for the UAS operators to deploy with their home-station unit, thereby training in-garrison with those they will directly support during their deployment. All current UAS employed by the Marines are controlled via LOS communications; however, they are pursuing a BLOS capability for their Group 3 UAS.

3. Force Presentation Model: Uniformed Military

Group 1 UA are employed using the same two-man team concept as the other Services. Although trained to the joint standard, the Marines also view this two-man team concept as an additional duty and do not assign a special MOS for these smaller UA. However for Group 2 and Group 3, the Marines are organized into Marine unmanned air-

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112 U.S. Marine Corps, *Aviation Operations*, MCWP 3-2 (Quantico, VA: Marine Corps Combat Development Command, Doctrine Division, 9 May 2000), 2-8–2-9, http://www.marines.mil/Portals/59/Publications/MCWP%203-2%20Aviation%20Operations.pdf.

113 U.S. Marine Corps, *Unmanned Aerial Vehicle Operations*, MCWP 3-42.1 (Quantico, VA: Marine Corps Combat Development Command, Doctrine Division, 14 August 2003), 1-2, http://fas.org/irp/doddir/usmc/mcwp3-42-1.pdf. Note: While this doctrine is over a decade old, the mission sets and tasks remain apropos.

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craft squadrons (VMUs) assigned under the Marine aircraft wing of a Marine Expeditionary Force (MEF). The VMUs are organized into self-sufficient detachments that include intelligence, support personnel, enlisted UAS operators, and officer UAS aircraft/mission commanders. These detachments are designed to be assigned to the combat aviation element of an MEU or larger MAGTF. The VMUs currently operate Group 3 RQ-7B Shadows and have begun receiving the RQ-21A Blackjack. They are organized as depicted in Table 7.

Table 7. VMU Table of Organization

	Officers			Enlisted			
	Operators	**Other**	**Total**	**Operators**	**Other**	**Total**	**Total[Note1]**
Squadron Headquarters	2	5	7	2	38	40	47
Shadow Detachment 1	2		2	8	39	47	49
Shadow Detachment 2	2		2	8	39	47	49
Shadow Detachment 3	3		3	8	40	48	51
SUAS Detachment A	2		2	9	15	24	26
SUAS Detachment B	2		2	9	15	24	26
SUAS Detachment C	2		2	9	15	24	26
Grand Total VMU[Note 2]	15	5	20	53	201	254	274

Source: MGySgt Donald D. Phillips, Washington DC: Headquarters Marine Corps, March 4, 2014.
Note 1: This column is the sum of the total columns under officers and enlisted.
Note 2: This row is the sum of the rows above it.

Much like the Army, when the VMU launches its aircraft, it balances the combat requirements with aircraft/crew availability. While each of the Shadow detachments are currently responsible for operating a single UA at a time, the larger Group 3 detachment is suborganized into three sections, each of which is responsible for a single UA operation. All of the detachments have a mix of operators, intelligence personnel, and support personnel, so these detachments can be somewhat self-sufficient when task organized into MAGTFs. The Marines do also have a reserve component VMU, which maintains a similar force structure.[114]

Marine UAS were initially operated primarily by enlisted personnel and supervised by commissioned Marine aviators; however, as the demand and associated role of the UAS expanded across the MAGTF, it was decided to employ more officers in the leadership. Combat lessons learned continued to mature the Marine concept of UAS operations as a permanently established career field. A Marine lessons learned report covering

[114] Interview with MGySgt Donald D. Phillips, Washington DC: Headquarters Marine Corps, March 4, 2014.

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Afghanistan UAS operations[115] cited the lack of a UAS-specific MOS as degrading the community's capability to retain experience and corporate knowledge because augmentees from the manned aviation community departed after approximately a year and a half without returning to the UAS community for follow on assignments.

To address this challenge, the Marines, much like the Air Force, have since developed a specific UAS aircraft commander MOS. As the most recent FY15 UAS officer accession board announcement states, this effort is in line with "the larger UAS manpower strategy, focused on establishing a professional cadre of UAS officers."[116] Officers selected for this role actually attend the Air Force's Undergraduate RPA Training in Texas alongside their Air Force counterparts and then complete RQ-7 Shadow training from the Army training program.[117] The enlisted operators also attend the Army training program and initially are qualified as the air vehicle operator (AVO) (i.e., pilot). As their experience grows, they are further certified as mission payload operator (MPO) (equivalent to Air Force sensor operator).[118]

While enlisted operators are used to physically control Groups 1–3 UAS, officers fill the role of aircraft commander by planning and directing the mission, coordinating airspace, ensuring the integration with other airborne assets, and so forth.[119] Officers are initially qualified as an aircraft commander over a single mission, but, as their experience and capability increase, they are upgraded and certified as a mission commander with the ability to command several UA missions at once (all physically piloted by enlisted operators).[120] Since these UAS officers are graduates from the Air Force's Undergraduate RPA training course, they are all BUQ-IV qualified in accordance with CJCSI 3255.1. As the Marine Corps either matures its Group 3 capability into missions currently reserved for Group 4/5 (i.e., kinetic operations, strategic ISR, and so forth) and/or it acquires true Group 4 capability, these UAS officers will not only have prior experience, but will already be trained and qualified at the appropriate level to meet Chairman of the Joint Chiefs of Staff

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115 United States Marine Corps, *Unmanned Aerial Systems (UAS) Integrated Operations in Support of Regional Command Southwest (RC(SW))* (Quantico, VA: Center for Lessons Learned, 4 October 2011), 5, https://info.publicintelligence.net/MCCLL-UAS-RC-SW.pdf.

116 U.S. Marine Corps Website, "FY 15 Unmanned Aircraft System (UAS) Officer Primary MOS 7315 Field Accession Board 9–13 June 2014," MARADMIN 185/14 (April 8, 2014), http://www.marines.mil/News/Messages/MessagesDisplay/tabid/13286/Article/162217/fy15-unmanned-aircraft-system-uas-officer-primary-mos-7315-field-accession-boar.aspx.

117 Ibid.

118 There is no change in MOS. The AVO qualification is simpler than that of the MPO (pilots control Groups 1–3 with a "point-and-click" capability, while control of the sensor requires greater expertise).

119 Telephone interview with Lt Col (Ret) Kenneth Briggs, HAF/A2CU, recently retired Marine UA officer, September 19, 2014. In some cases, senior/experienced NCOs also fill the role of aircraft commander.

120 Ibid.

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(CJCS) and FAA requirements. The importance of this career field is highlighted by the recent United States Marine Corps (USMC) Deputy Commandant for Aviation decision to capitalize on the EA-6B community by transitioning EW officers into this new UAS Officer MOS as the program moves toward its Fiscal Year (FY) 2020 sunset.[121]

F. Special Operations Command

With a wide range of global operations, the Special Operations Command (SOCOM) operates the widest diversity of UAS. Although SOCOM executes Service-like functions, much of its equipment and capability comes from that already inherent within DoD. As such, SOCOM UAS units are staffed in manner similar to those described previously. Although Group 1 is conducted by operators trained as an additional duty and Group 2/3 are primarily contract support (initial Navy model), SOCOM does have dedicated UAS organizations in both the 160th Special Operations Aviation Regiment (Army) and 27th Special Operations Wing (Air Force). All of these units are staffed in a manner similar to their general-purpose force counterparts. SOCOM also uses the previously mentioned GOCO UAS to support its operations. This support includes everything from the Group 2 ScanEagle to the Army's Group 4 MQ-1C Gray Eagle and Air Force's Group 5 MQ-9 Reaper.

G. Summary

Based upon the review of individual Services, it is revealed that for the majority of the UAS Groups, the Services staff their programs with similar categories of performers but with some notable differences. Table 8 provides an overview of category of performers for the pilots/air vehicle operators of each group. One notable difference is reliance of the Army on WOs to provide leadership within their Group 3/4 UAS units, whereas the other Services rely on officers above the rank of O-1.

[121] Ibid.

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Table 8. Service Category of Performer Summary (Pilots)

Group	Air Force	Army	Navy	Marines
5	70% RPA AFSC	N/A		N/A
4	70% RPA AFSC	18% W.O.		N/A
3	N/A	13% W.O.	~10% IA	22% RPA Officer
2		N/A		
1				

KEY					
Officer (RPA/UAS MOS)	Officer (other)	W.O.	Enlisted	DOD Civilian	Contractor

AFSC: Air Force Specialty Code, IA: Individual Augmentees

Note: This table summarizes the primary focus of those used to control the aircraft. The Air Force and Navy have approximately one-half their Group 4/5 UAS force as enlisted sensor operators.

The other major difference between Services is that while the Air Force and Marines have a dedicated Officer corps for UAS, the Navy and Army do not. The Navy relies on the use of previously qualified pilots from similarly tasked aircraft, while the Army relies on its WOs as previously discussed. Table 9., Table 10., Table 11., Table 12., and Table 13. summarize each of the Services by UAS Group.

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Table 9. Summary of Group 1 UAS

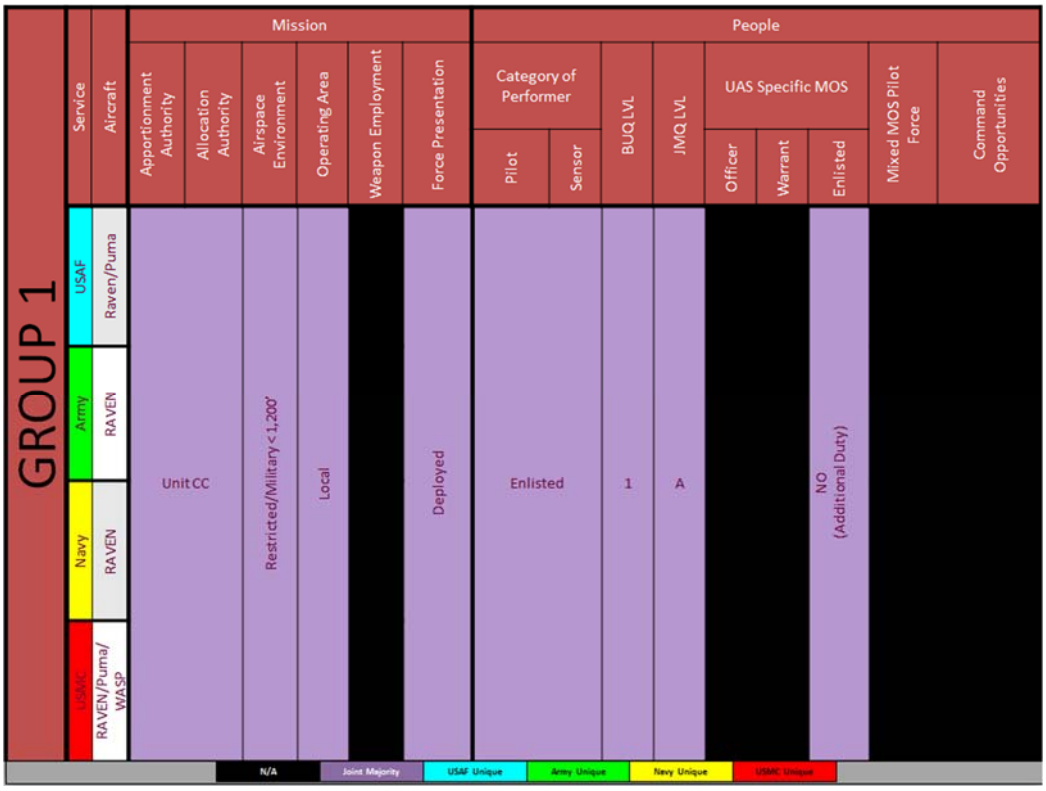
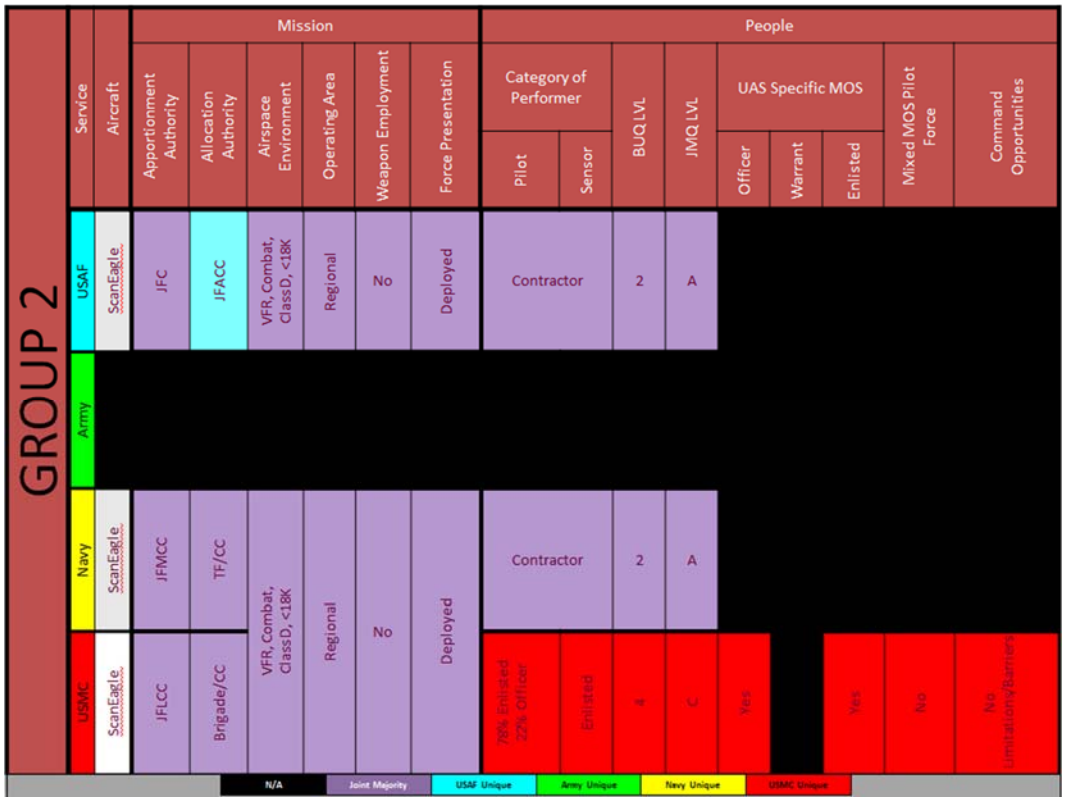


Table 10. Summary of Group 2 UAS



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Table 11. Summary of Group 3 UAS

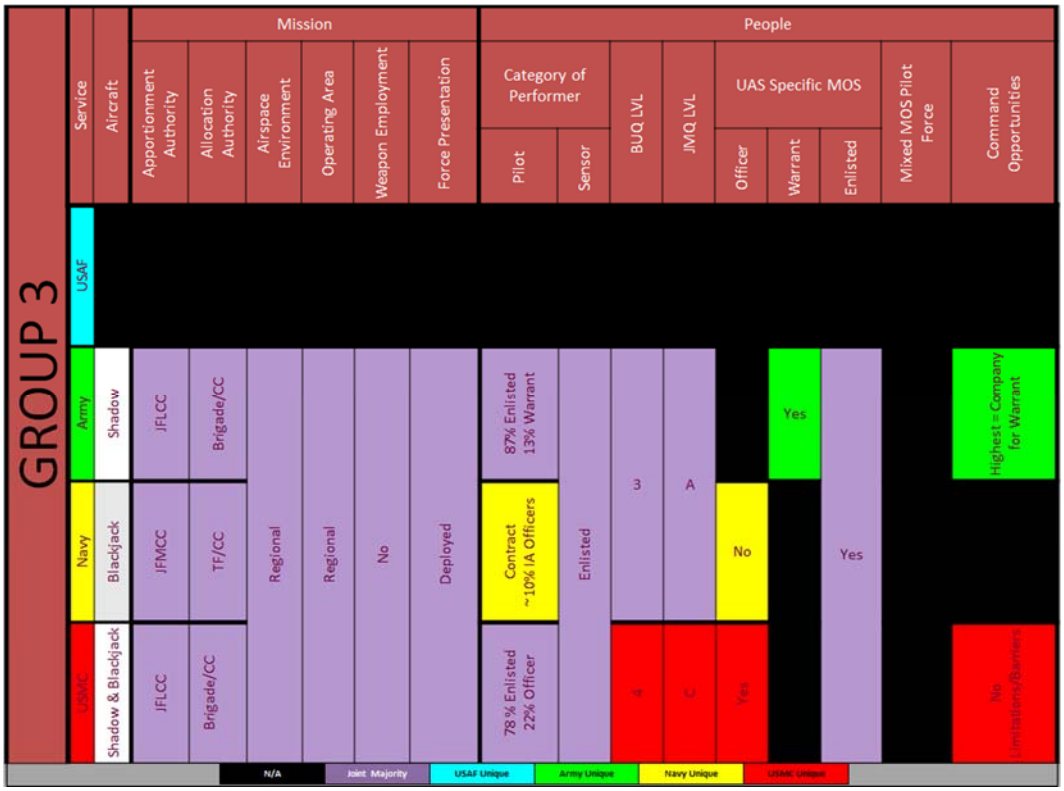
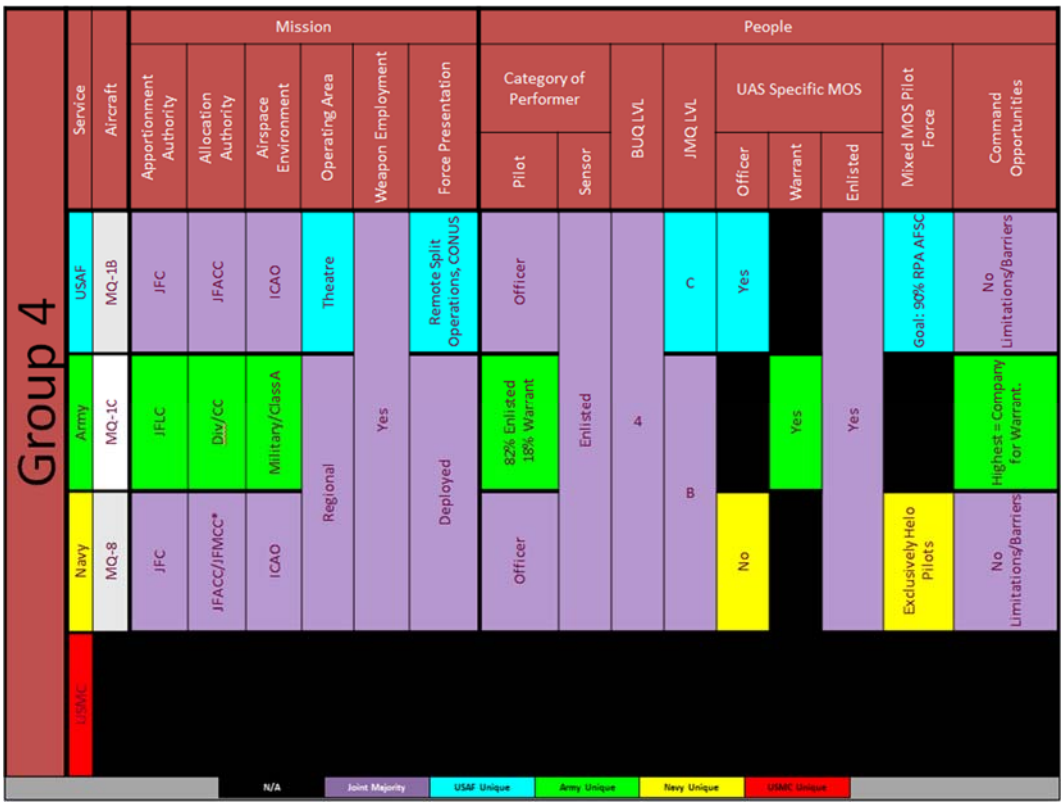
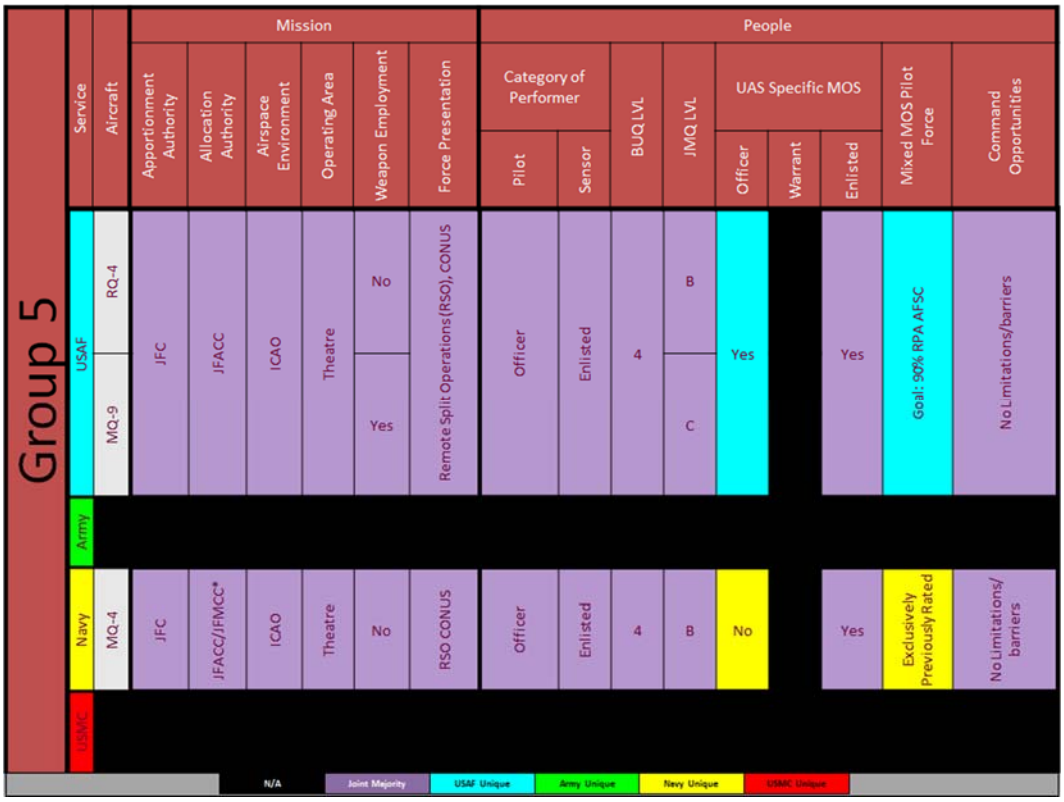


Table 12. Summary of Group 4 UAS



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Table 13. Summary of Group 5 UAS



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5. Service Staffing Business Rules

As seen in the last chapter, each military Service applies a unique "lens" to evaluating its individual requirements. While this approach is anticipated and arguably necessary for a functionally defined military Service, these programs shows some basic commonality that does not necessarily arise from the earlier reviewed statutory guidance. These common practices, referred to from here on as "business rules," are built upon lessons learned, best practices, and, in some cases, the application of commonly accepted cultural perceptions, which shape how and why programs are designed and the manner in which they operate. In other cases, the Services vary vastly between how they present UAS forces. In some cases, the following business rules may seem rudimentary and already addressed in the statutory guidance; however, this analysis aims at capturing commonalities that apply universally to the Services, not Service-unique characteristics described in the previous chapter. This paper does not endorse any of these particular business rules, but rather outlines which business rules are currently in place and provides discussion on any potential implications.

A. Military Incumbency

Statutory guidelines clearly state that the determination of an IG function requires a thorough analysis of the mission and associated risk. If the member is expected to raise arms against an enemy force as part of his/her role, then military incumbency is required.[122] Using this thought process, members assigned to Army maneuver units must be military members since they are expected to move and fire along with the organic force they support. By applying the Marines ethos of "every Marine is a Rifleman," one can also see where the Marines drive military incumbency by the very expeditionary nature of their Service. One can even make a case that the Air Force applies this business rule to the preponderance of their forward-deployed launch and recovery elements (LREs). At a minimum, this concept is applied to the Air Force SOCOM alert-capable launch and recovery force, which requires military personnel to meet the potential instantaneous deployment and subsequent movements required by the nature of their operation.[123]

With this in mind, the first business rule common across all Services is as follows:

[122] This rule does not include self-defense situations.

[123] Input from AFSOC/A5K subject matter experts (SMEs) during RPA Manpower Working Group meeting January 7, 2015.

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UAS operators assigned to a combat maneuver unit must be uniformed military personnel.

While this rule holds true for smaller UAS operators, a counterpoint is possible to this rule because most of today's larger UAS operations occur within the confines of a secure location. This argument contends that because UAS tend to operate from secure forward-operating bases, it is the unit they support that maneuvers throughout the battlespace, not the UAS operators. The larger UAS systems inherently require increased infrastructure, and, therefore, their associated mobility decreases incrementally with the size of the operation. While this situation holds true for current operations, this business rule is still applicable based upon programming for a force that meets the missions tasked to a particular unit, not necessarily the missions or operating environment in which the unit currently finds itself. As discussed later in this chapter, technology maturation may also affect how systems are employed, which would further enable UAS operators to embed with their associated supported units if so desired.

B. Civilians

While research noted several cases in which DoD employed either GOCO or contractor-owned, contractor-operated (COCO) service contracts for UAS operations, at no point did the team come across an incident in which a DoD civilian piloted and/or operated full-motion video sensors for a UAS program leading us to the first observation:

DoD civilians are not used to operate UAS.

While DoD civilians are sometimes heavily involved in support functions (i.e., as full-motion video analysts), they are not involved in physical control of the aircraft. While it appears that the Services have applied the "military incumbency" rule to their own UAS programs, the utilization of contractors across the DoD UAS enterprise implies a comfort level allowing civilians to operate these systems; therefore, this paper will not discount the use of DoD civilians in the analysis of alternatives that follows.

C. International Airspace

Applied primarily to the larger Group 4/5 UAS, each Service uses officers to control operations within international airspace. Although not specifically dictated, the Services appear to have determined that the scope of responsibility associated with the remote integration of an aircraft within the international civilian airspace infrastructure aligns with the additional level of responsibility inherent within the officer corps.

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"Officer equivalents" are required for UAS operations within international airspace.

Although this rule applies across all Services, the focus on the level of resources applied to a specific UAS Officer corps by a Service does reflect its overall mission focus. As outlined in Chapter 4, the Air Force is responsible for responding globally and must have pilots who can operate within all environments, regardless of airspace structure. As such, their entire Group 4/5 pilot force is comprised of officers (greater than or equal to the rank of O-1). The Navy's sea-basing construct and support to the fleet has a similar requirement, thereby similarly shaping its force. While the largest UAS for the Marines is a Group 3, it is expeditionary in nature and must be prepared to operate within locations before a formal military restricted airspace structure has been established. In contrast, while the Army does indeed use WOs for its Group 4 UAS, its UAS program is focused on support to larger general-purpose forces that tend to establish operations after such airspace infrastructures are in place, thereby not requiring the extensive level of officer participation inherent in the other programs.

The term "officer equivalent" is used for this business rule because there are examples of contracted UAS programs that operate within international airspace and have no restrictions on DoD civilians doing the same. In many ways, this situation is similar to those major civil airlines that require pilots to have a bachelor's degree even though this level of education is not an overall FAA/IACAO requirement. The "officer equivalent" term is used to illustrate the level of responsibility with this position.

As a final note, although this business rule appears to apply only to the larger UAS, as technology and capabilities mature, it will also become applicable to smaller UAS.

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D. Sensor/Mission Payload Operator

A commonality across each of the Services is the use of enlisted members as sensor operators. Much like the "officer equivalent" term used previously, enlisted equivalency is phrased to incorporate the level of authority and responsibility applied across both military and contract applications.

UAS sensor/mission payload operator positions are sourced solely with "enlisted equivalents."

E. Precision-Guided Munitions (PGMs)

While military members of all ranks within each of the Services may be called upon to raise arms in support of our nation's defense, the Services have demonstrated that the application of PGMs in warfare brings a responsibility commensurate with the leadership and authority our nation entrusts to our commissioned military officers:

Military officers are required for release authority of PGMs.

As described in 2005 by Professor Michael Schmitt from the George C Marshall European Center for Security Studies, the application of PGMs during Operation Iraqi Freedom demonstrated that the interpretation of international humanitarian law is increasingly complicated for those employing such munitions.[124] Schmitt tells that great care was taken in conducting collateral damage assessments and that if estimates for civilian casualties were projected to increase over a certain threshold, the mission needed Secretary-of-Defense approval.[125] As Schmitt contends, "While there is no legal requirement for higher-level approval as collateral damage or incidental injury grows, the United States recognized that American precision capabilities meant it would be judged harshly for causing harm to civilians and their property."[126] Such an example illustrates the need for the authority which resides within the officer corps.

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124 Michael N. Schmitt, "Precision Attack and International Humanitarian Law," *International Review of the Red Cross* 87, no. 859 (September 2005): 445–466, https://www.icrc.org/eng/assets/files/other/irrc_859_schmitt.pdf.

125 Ibid., 457–458.

126 Ibid., 458.

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While this business rule associated with PGM release authority applies across all Services (and beyond employment of UAS), the Services, as is typical, take independent approaches. For the Army, who views its UAS as an integrated weapon within its maneuver force, PGM release authority is applied through the ground force commander, and that authority is employed under the leadership provided by commissioned WOs within the larger UAS program. Although the Marines' organic UAS do not currently employ a PGM weapons capability, its force structure is designed to accommodate such operations with a dedicated UAS officer corps operating as mission commanders over their operations. For the Air Force, which operates most of the PGM-capable UA, release authority may not always come from a ground force commander. For example, a strike coordination and reconnaissance mission may have a list of nominated targets that will require the aircraft commander to make the final targeting and release authority determination. Senior leaders within the Air Force RPA community contend that for cases in which the pilot is responsible for interpreting the commander's intent, it is necessary to balance the tactical objectives against strategic implications rather than simply follow orders to employ. The Air Force contends for its assigned missions that this decision increases the level of responsibility commensurate with that of an officer.

F. High Cost/Demand, Low Density Assets

Throughout research for this topic, several individuals raised the issue that the cost of larger Group 4/5 UAS drive the requirement for officers as pilots. While this paper found no direct linkage to statutory guidance directing such a requirement, the application of manpower to aircraft does support this conclusion and has thus been included as a current business rule:

Cost of airframes and the high-demand, low-density (HD/LD) nature of large UAS compel the use of officer pilots.

The larger UA, although often thought of—and in some mediums referred to—as disposable are anything but. Pairing the costs of the aircraft and associated systems with the ongoing insatiable demand for their support classify these aircraft as extremely valuable, HD/LD assets. In many cases, in the event of a UA crash, combat rescue teams have been deployed to recover components from the crash site.[127] Such incidents seem counter-intuitive since this deployment if rescue teams places humans at risk within a combat zone to recover parts from an uninhabited system.

[127] Research Team members' personal experiences.

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For an order of magnitude on associated costs, estimate places the RQ-4 Global Hawk around $120 million. Thus, it is easy to understand that the responsibility for operating such a platform should be akin to the authorities and accountabilities associated with a military officer. However, the counterpoint to this business rule seeks the answer to an important question: what exactly is the cut-off value for such a determination? The Air Force's MQ-9 is valued at approximately $12.5 million, and the MQ-1B is valued at approximately $4.5 million. As discussed previously, the Air Force operates both UA with officer pilots, yet the Army's similar MQ-1C program includes enlisted pilots.[128] For a comparison to another weapons system, one estimate places the cost of the Army's Abrams tank at $7.5 million. The Abrams tank is operated by enlisted and junior officers. Another dynamic associated with this discussion comes in light of the HD/LD nature of these assets. While the MQ-1B Predator is not "expensive" (in terms of major military weapons systems), the fact that it is no longer being produced drives a limited supply of resources among a continuing increase in requirements, thereby playing a role in this business rule of high-cost HD/LD assets requiring the level of accountability inherent within a military officer.

G. Summary

In looking at the commonalities between the Services, the six business rules in Table 14 appear universally across the Services and are platform agnostic. Having defined the commonalities and associated business rules currently in place, analysis will now turn toward the discrepancies within the Service's workforce mix strategies.

Table 14. Business Rules for UAS Staffing

1	UAS operators assigned to a combat maneuver unit must be uniformed military personnel.
2	DoD civilians are not used to operate UAS.
3	"Officer equivalents'" are required for UAS operations within international airspace.
4	UAS sensor/mission payload operator positions are sourced solely with "enlisted equivalents."
5	Military officers are required for release authority of PGMs.
6	Cost of airframes and HD/LD nature of large UAS compel the use of officer pilots.

[128] Army enlisted UA pilots are referred to as air vehicle operators.

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6. Additional Observations of Service Staffing Practices

While the business rules define the common practices across UAS programs, Table 9., Table 10., Table 11., Table 12., and Table 13. (see Chapter 4) demonstrated significant differences in terms of category of performer determination. The following analysis provides a view into why these differences exist. Once again, rather than endorsing any of the Service's particular approach, this chapter outlines the differences and provides observations that could affect future workforce staffing decisions.

A. Officer vs. Enlisted Pilot Decision Process

The most commonly debated and discussed staffing decision within DoD's UAS enterprise is the difference between the Army's use of enlisted pilots and the Air Force's use of officer pilots for Group 4 UAS.[129] As seen in Chapter 4, and once again in

Table 15., the majority of the UAS enterprise is staffed similarly, with the Group 4 officer/enlisted paradigm being the major difference. Rather than skirting the obvious, the following subsections analyze elements of this decision process to describe the related rationale and to provide context and/or possible areas for alternate strategies in the future.

1. Cultural Impacts: Air Force

During research, some raised the point that a cultural aspect was behind the Services' category of performer selection, primarily the officer vs. enlisted decision. The Air Force is focused on the command and execution of air combat and is responsible for most of the larger UA within DoD. As described in Chapter 4, the Air Force contends that its global mission and decentralized execution model require a pilot who has the decision-making authority inherent of an officer. This belief is deep-seated within Air Force culture and can be traced back to the Air Corps act of 1926, which legislated that "at least 90 per centum of the officers in each grade below that of brigadier general shall be flying officers."[130]

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129 Although the Navy's Group 4 UAS helicopters play a much smaller role, they are often left out of this discussion even though officers are also used in this role.

130 Air Corps Act of 1926, § 721, 69th Congress, accessed on September 8, 2014, http://legisworks.org/congress/69/publaw-446.pdf. The same legislation also directed that "in a time of peace, not less than 20 per centum of the total number of pilots employed in tactical units of the Air Corps shall be enlisted men." Although the Air Force did indeed have enlisted aviators, in May 1957, the last enlisted aviator, MSgt George Holmes, retired.

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Table 15. Service Category of Performer Summary (Pilots)

Group	Air Force	Army	Navy	Marines
5	70% RPA AFSC	N/A		N/A
4	70% RPA AFSC	18% W.O.		N/A
3	N/A	13% W.O.	~10% IA	22% RPA Officer
2		N/A		
1				

KEY					
Officer (RPA/UAS MOS)	Officer (other)	W.O.	Enlisted	DOD Civilian	Contractor

AFSC: Air Force Specialty Code, IA: Individual Augmentees

Note: This table summarizes the primary focus of those used to control the aircraft. The Air Force and Navy both have approximately one-half of their Group 4/5 UAS force as enlisted sensor operators.

The Air Corps Act was designed to transition the Army Air Service into a more independent branch to strengthen "the conception of military aviation as an offensive, striking arm rather than an auxiliary service."[131] From this ingrained culture of "air mindedness," the Air Force aims to develop senior leaders who are focused on the employment and empowerment of airpower. Ensuring that the leadership pool is focused on aviation, current regulations mimic the days of the Airpower Act by directing "only Line of the Air Force crewmembers occupying active flying positions can command flying organizations."[132] This concept applies directly to the Air Force RPA officers in way that is similar to that of mobility and/or fighter pilots. To develop senior leaders who have

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131 Air Force Historical Support Division Website, "1926 -- The U.S. Army Air Corps Act," accessed September 8, 2014, http://www.afhso.af.mil/topics/factsheets/factsheet.asp?id=15237. It is within this legislation that is was first decried that "Flying units shall in all cases be commanded by flying officers."

132 Department of the Air Force, "Appointment to and Assumption of Command," AFI 51-604 (Washington, DC: Secretary of the Air Force, 4 April 2006), 7, http://static.e-publishing.af.mil/production/1/af_a3_5/publication/afi51-604/afi51-604.pdf. In terms of regulatory guidance, Air Force Instruction (AFI) 11-401, "Aviation Management," and AFI 11-402, "Aviation and Parachutist Service," Aeronautical Ratings and Aviation Badges, make references and list requirements for the rated commissioned officer force. While one paragraph (2.2.1) in AFI 11-402 references a Title 10 authority dictating that "the USAF may award aeronautical ratings to USAF commissioned officers only," this Title 10 reference (Title 10 U.S.C. § 8691 actually states that "Only officers of the Air Force in the following categories may be rated as flying officers." Title 10 U.S.C. § 8691 then lists those who have and/or are receiving some level of flight-related training.

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extensive knowledge and experience employing RPA, those officers must not only execute such operations as a young officer, but also develop throughout their career to appreciate the operational and strategic leadership required to ensure appropriate application of RPA within the nation's application of airpower.

The Air Force also contends that the foundational airpower model of "centralized control, decentralized execution" drives decision-making authority for individual missions into the hands of front-line pilots and therefore is reliant on officers (more on this in subsequent sections). This point was articulated in a 2010 Air Force report on a similar topic, where the author uses the charts in Figure 4a and Figure 4b to depict the difference between Air Force (blue) and Army (green) UAS operating concepts.

Recently, an Air Force RPA working group updated Figure 4 and delineated between the complexity of a system and the responsibility required to operate the system. Through discussions with the working group, this update was an attempt to show that it is possible to spend time and money to train individuals to an appropriate level for execution (pilot vs. operator). However, this particular working group contended that the true determinant in selecting an officer lies in the scope of responsibility required by the pilot (in the working group's case, an officer when talking decentralized execution). Figure 5 depicts the updated chart.

2. Cultural Impacts: Army

The Army's cultural history with enlisted aviators is also traced to the Air Corps Act of 1926, however the Army took a substantially different path than the AF by focusing on enlisted aviators. While the Air Corps Act directed a heavy officer force for the AF, it also directed that "in a time of peace, not less than 20 per centum of the total number of pilots employed in tactical units of the Air Corps shall be enlisted men …."[133] This practice was eventually ended by a War Department order that mandated that all prior enlisted aviators would to be promoted to second lieutenants by 17 November 1942.[134] The introduction of the helicopter into the Army once again drove a dramatic increase in the number of pilots required; however, the congressionally imposed officer force level prevented this expansion.[135]

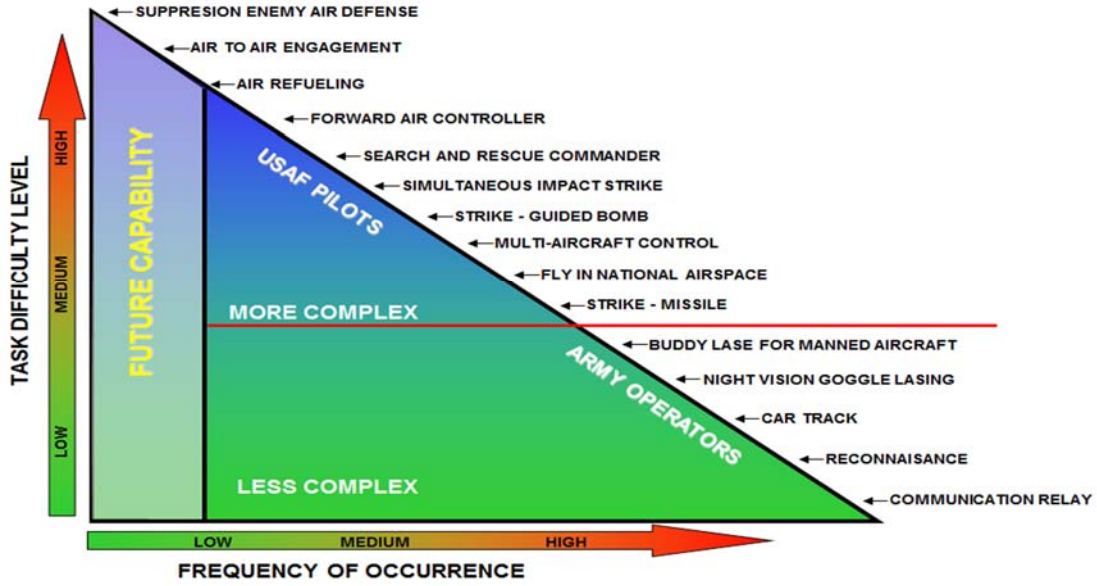
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133 Air Corps Act of 1926, § 721, 69th Congress, accessed on September 8, 2014, http://legisworks.org/congress/69/publaw-446.pdf.

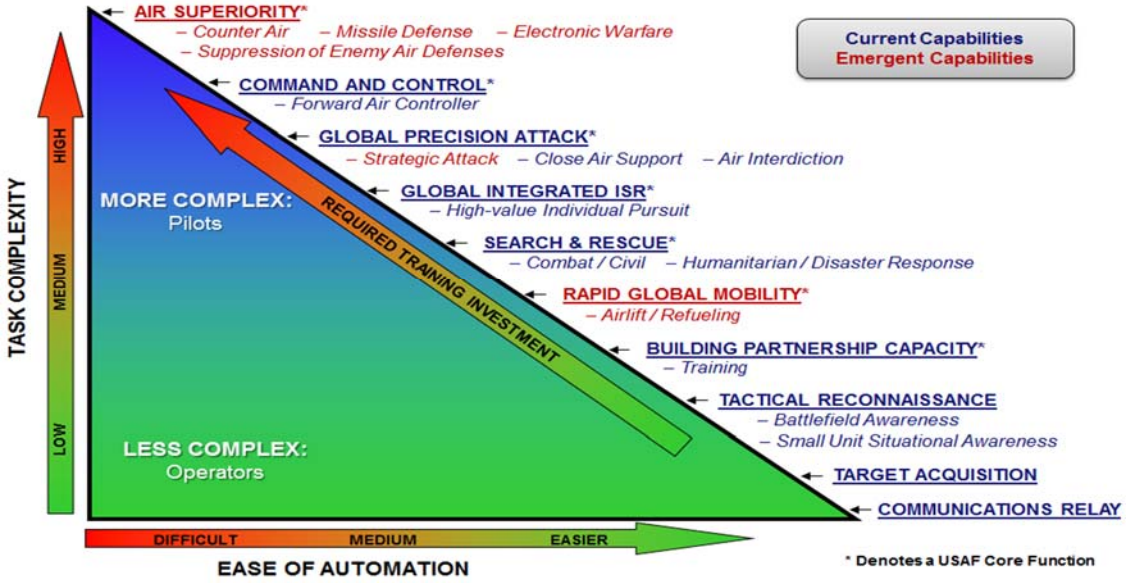
134 National Museum of the Air Force Website, "End of an Era," accessed September 10, 2014, http://www.nationalmuseum.af.mil/factsheets/factsheet.asp?id=1425. Actually took two additional years to fully promote all Army Enlisted Aviators.

135 Warrant Officer Historical Foundation Website, "History of the Army Aviation Warrant Officer," accessed September 10, 2014, https://warrantofficerhistory.org/Hist_Avn_WO.htm.

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(a)



(b)

Source: Major Travis Burdine, USAF, "The Army's 'Organic' Unmanned Aircraft Systems: The Unhealthy Choice for the Joint Operational Environment," *Air and Space Power Journal,* Summer 2009. http://www.au.af.mil/au/afri/aspj/airchronicles/apj/apj09/sum09/burdine.html.

Note: At the time this Air Force report was published, the Army was not using its Group 4 UAS operationally as a strike asset (although it was capable).

Figure 4. UAS Capability Envelope (2010 Air Force Charts)

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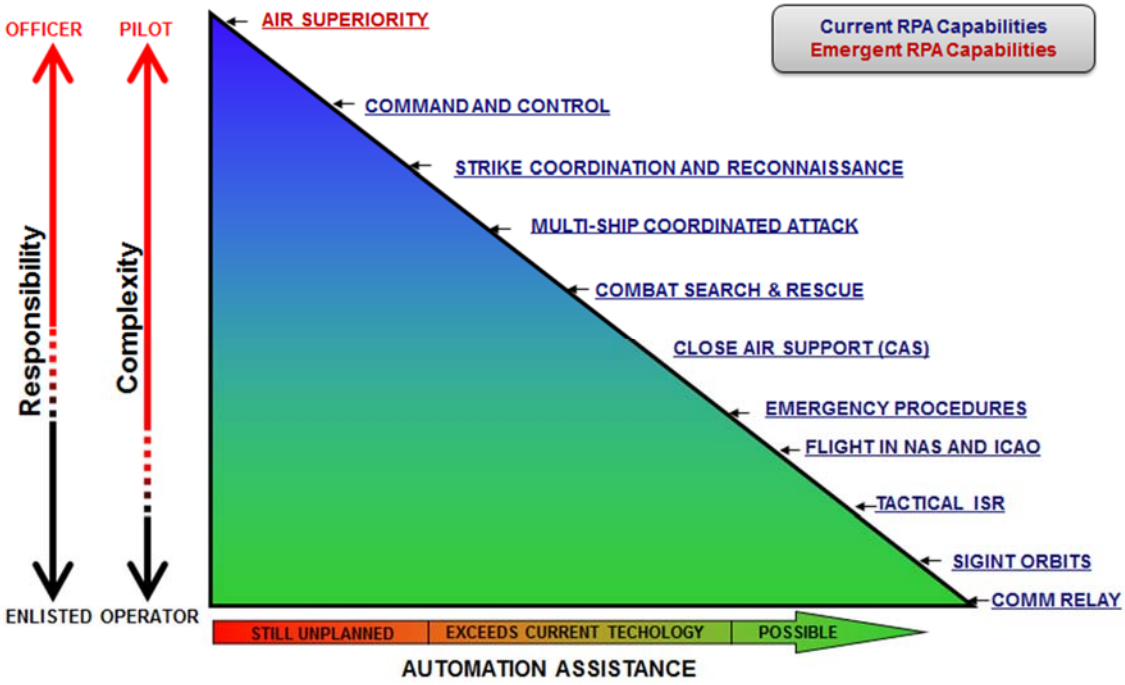


Figure 5. Air Force RPA Working Group Aircraft Capability Envelope (2015)

The solution was WO pilots, whose separate MOS was subsequently approved in 1949. Although the program has evolved in many ways, the Aviation Warrant Officer continues to form the backbone of Army aviation.[136]

An additional cultural perspective is observed in how the Army views the aircraft and crews themselves. As alluded to previously, the tactical nature of the Army's application lends itself to crews being used by Commanders in a similar fashion as their other organic maneuver and fires assets (simply another "tool in the toolbox"). In this role, they are directed where to be and what to do by superiors. This approach is in contrast to the decentralized execution method of the Air Force, where RPA pilots are tasked to support potentially several units during the length of the sortie and are responsible for deciding how to best deliver the desired effects rather than being instructed on what exact steps to take. Thus, where the Air Force extends its pride of pilot's aviation culture/mindset to the RPA community, the Army views the UAS crews as "operators" not pilots (hence, their MOS duty title of Unmanned Aircraft System Operator). Although the Army UAS crews are awarded "wings," this cultural perspective was highlighted at the inaugural ceremony at which aviation badges were awarded to UAS crews by the then-UAS training Battalion

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[136] The Army conducted an Enlisted Aviator Study in 1986. This study determined that creating an enlisted aviator was possible but would not be desirable because the leadership role of the WO would be lost (see Warrant Officer Historical Foundation Website, "History of the Army Aviation Warrant Officer," accessed September 10, 2014, https://warrantofficerhistory.org/Hist_Avn_WO.htm). The 1986 study is available within the Pentagon's library. Location information is provided at http://www.worldcat.org/title/1986-enlisted-aviator-study/oclc/17943829.

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Operations Officer, Captain Kyle Duncan, who stated, "They deserve this recognition. They are not pilots, but they are operating in theater, in aviation, and they're working with rotary aircraft, fixed wing aircraft, with naval, Marine and Army Aviation. They are not getting an aviator's badge; they are getting an aviation badge. We recognize them for their work, as part of aviation."[137]

Based on the analysis of these two individual Service cultures, it is apparent that

Service culture shapes how the roles and responsibilities are viewed for individual category of performers.

3. Visualization Model

In the decision tree introduced in Chapter 2, when determining which category of performer to use, the model depicted stopped simply at "Uniformed Military." Obviously, this decision matrix continues on to include officer and enlisted, along with the previously mentioned officer subsets, as shown in Figure 6.

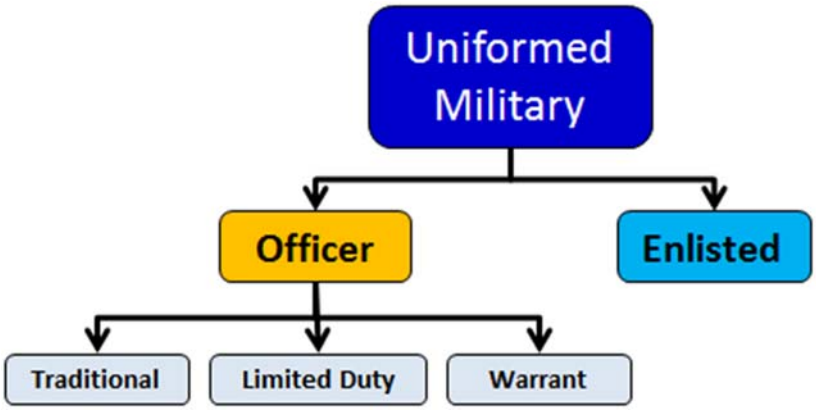


Figure 6. Uniformed Military Category of Performers

[137] Rob Martinez, "Policy Makes UAV Operators Eligible for Aviation Badge," *www.army.mil*, May 7, 2007, accessed October 10, 2014, http://www.army.mil/article/3012/New_Policy_Makes_Soldier_UAV_Operators_Eligible_for_Aviation_Badge/.

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In reviewing the business rules and observations addressed in Chapter 5, it is apparent that the Services' staffing methodologies are driven more by the scope of mission tasked than by the physical characteristics of the aircraft being flown. While this approach is hardly a revelation for those familiar with military history, it is important to highlight this context when looking at staffing methodologies—specifically, when assessing the often emotional discussion over the use of officer vs. enlisted in UAS operations. While the previous Air Force figures attempted to show this complexity, analysis proves that the model is too simplistic. As the updated RPA working group figure (see Figure 5) shows, one can train to any level, but the aspect of "responsibility" plays a significant role in whether an officer is required. When looking at this issue from a non-Air Force perspective, when an officer's authority is required, it is injected appropriately. For the Army, this authority comes in the form of centralized execution and tasking, and, for the Marine Corps, it comes from the Mission Commander. The difference between the three Services in this case is frequency of need, operating environment, and delegation of risk assumption.

As alluded to previously, complexity also plays a role in determining staffing—whether it is the complexity of the system or the complexity of the operations involved. In simple terms, the more complex it is to operate an aircraft, the more likely it is to require an "officer equivalent" to pilot.[138] This same relationship is seen within the civil sector, where international commercial airlines require a bachelor's degree and continuing education for their pilots, while general aviation enthusiasts and some regional carriers do not require a degree to fly simpler aircraft within less congested airspace. When combining these concepts with those discussed in the mission element, business rule, and observation analyses, one can distill the officer vs. enlisted staffing methodology into three major aspects: (1) system complexity, (2) risk assumed, and (3) operational environment.

Figure 7 illustrates the relationship between these events while also showing some of the attributes associated with each axis. This characterization helps to put the analysis of current Service practices and business rules into context and shows how

DoD-assigned missions/responsibilities and the anticipated operating environment shape how the Services view the role of their UAS.

[138] This statement does not imply that enlisted are incapable of working complex systems. It is simply an acknowledgement that the officer corps is more likely to be vetted and trained to include individuals who are capable of the increased complex problem-solving skills associated with analytical thinking.

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To illustrate this point, we will review two examples: (1) the relationship between the Air Force and Army's MQ-1 programs and (2) the Marine Corps' Group 2/3 staffing methodology.

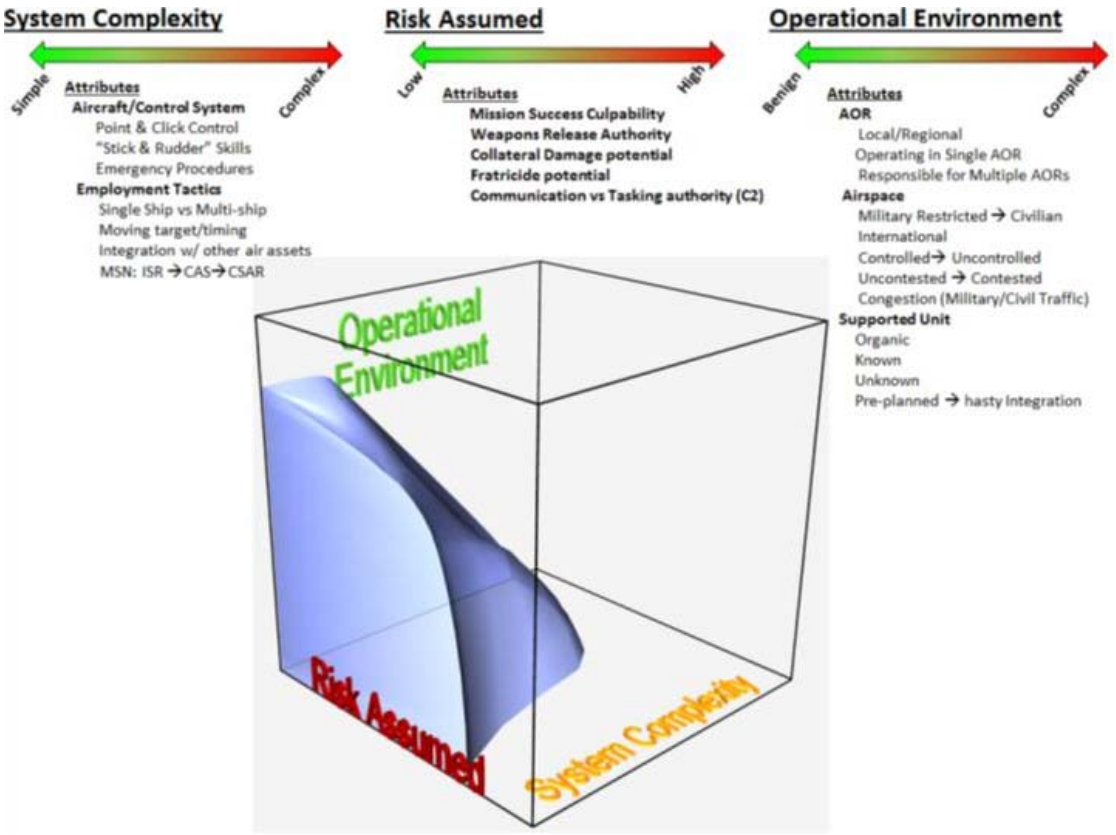


Figure 7. Complexity, Risk, and Environment Relationship

In the first example, the Air Force and Army operate MQ-1 variants yet have different staffing methodologies. The Air Force contends that an officer is required because of the associated mission risk and operational environment, which includes elements such as international/uncontrolled airspace and weapons employment. In addition to these risk factors, although the MQ-1B has basic autopilot features, complexities still exist with this relatively early generation UAS. As shown in Figure 8, this situation places MQ-1 B operations within the region that warrants the use of an officer when aircraft control complexities are combined with the level of risk assumed. In contrast, in the Army's view, its tactically focused, lower risk, regionally isolated operations with centralized control and execution are consistent with the reliance on enlisted operators led primarily by WOs. In addition, the newer MQ-1C variant provides increased autonomy associated with aircraft control (point and click vs. stick and throttle). As seen in Figure 8, this combination of mitigating risk through the combination of technology, operating environment, and operating concept enable an enlisted force structure supporting the Army's MQ-1C operations.

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In the second example, the Marine Corps has used a similar combination of technology, operating environment, and concept of operations (CONOPS) to mitigate risk and reduce its manpower costs. As discussed previously, the Marine UAS program is designed to support the expeditionary nature of the MAGTF.

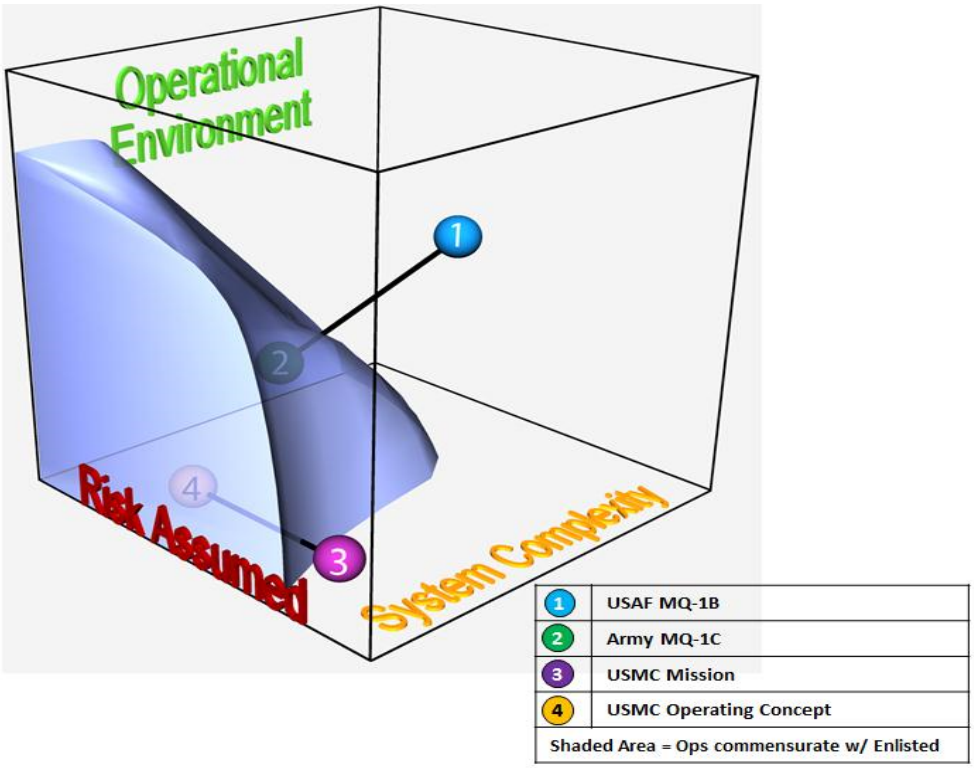


Figure 8. Illustrative Examples: Complexity vs. Risk

Therefore, the program must be able to respond in highly complex operating environments and with little notice, thereby increasing the mission risk to arguably high levels (depicted as "USMC Mission" in Figure 8). The Marine Corps program addressed these issues through a combination of technology and CONOPS. All of the current Marine UAS are relatively simple to operate and do not require an understanding of complex aeronautical concepts to operate or extensive problem solving to address failures. This fact alone makes the operation of the Marine UAS program much like the Army SUAS program, which uses enlisted operators in medium-to-low risk missions. However, as discussed, the anticipated operating environment increases the mission risk of the Marine UAS program. By creating a UAS-specific officer MOS and placing these officers in mission commander roles over the enlisted operators, the Marines feel that they are able to mitigate risk to a level acceptable for enlisted pilots. While the pilots handle the relatively simple task of aircraft control, the officer is responsible for airspace coordination and integration with the overall battle scheme of maneuver. The Marines built their program upon this risk-mitigating operating concept to ensure that the program was unbound by aircraft. While current

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Marine platforms are easy to operate, the Marine force presentation model is designed to support developments similar to those found currently in Group 4 UA, such as long endurance, BLOS control, and weapons employment.[139] As long as the complexity of control remains manageable (i.e., simple), the UAS officer mission commander is responsible for mitigating risk to acceptable levels. In cases where the risk may prove to high (e.g., complex weapons employment in urban scenario), the Marine UAS Officer is qualified and capable of operating the aircraft himself/herself.

4. C2 Operating Concept

As alluded to previously, the rationale behind the Group 4 UAS staffing differences includes not only cultural perspectives, but is also affected by the respective C2 CONOPS applied. The Army contends that the UAS is an organic asset to be tasked and immediately responsive to the ground force commander (centralized control, centralized direction for execution). The Air Force centrally manages tasking aircraft to requirements but requires its crews to determine the best method of support to the commander (centralized control, decentralized execution).[140]

The C2 concept of UAS operations (centralized vs. decentralized) and resultant authority required by aircrew relate directly to officer vs enlisted decision.

B. Designation Practices Regarding Military Personnel

During the maturation of the Service UAS programs, each Service has developed unique organizations and specialty personnel codes to identify those who operate these systems. While UA operations have been ongoing in some form for over 80 years, the development of unique UAS organizations is much more recent. The Army has a long history of operating UAS, and, in terms of "modern" UAS, it started operating with the Pioneer as early as 1985. The Army has had a unique UAS MOS since at least 1993; however, in 2007, the MOS changed from one inside the intelligence branch to one within aviation. Like the Army, the Marine Corps' rich history with UAS led to the establishment of the first UAS Company in 1987 (later developed into a full squadron, VMU-1, in 1996).

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139 Telephone interview with Lt Col (Ret) Kenneth Briggs, HAF/A2CU, recently retired Marine UA officer, September 19, 2014.

140 As articulated in Major Travis Burdine, USAF, "The Army's 'Organic Unmanned Aircraft Systems: The Unhealthy Choice for the Joint Operational Environment," *Air and Space Power Journal*, Summer 2009, http://www.au.af.mil/au/afri/aspj/airchronicles/apj/apj09/sum09/burdine.html.

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While the Marines have always had enlisted operators, the maturation of the career field led to the establishment of an officer UAS MOS in 2013. The Air Force established the first RPA squadron (11 RS) in July 1995 and initially established an AFSC designating an RPA pilot. Then, in 2009, it established the pipeline training and AFSC for those pilots who had not previously flown in other aircraft and were selected and assessed purely for RPA operations. A unique Air Force Sensor-Operator AFSC (previously filled by imagery analysts) was also established in 2009. Finally, the Navy has established unique enlisted classifications to designate those involved in UAS operations; however, unlike the other Services, it relies on accessions from those pilots who have flown other aircraft. Figure 9 shows a summary of the unique personnel identifiers across the Services.

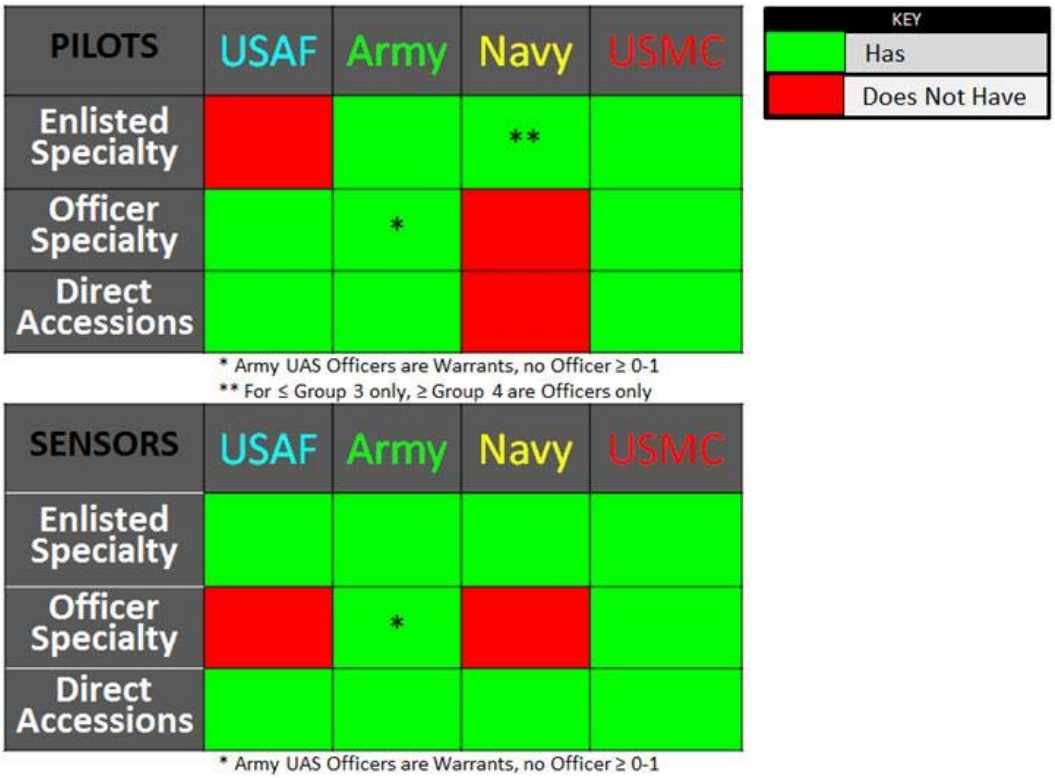


Figure 9. Unique UAS Personnel Identifier Summary

This discussion has highlighted the major similarities across the Services, with a few exceptions. The Navy and Air Force officer pilots are not formally trained to operate the associated UAS payloads, whereas the Army and Marine Corps pilots are qualified on the whole system. For the Marines, this decision is attributable to the simple nature of the platforms used. The Army, for its part, does not have a unique identifier for those officers whose rank is greater than or equal to O-1. The WOs are trained much like their Marine counterparts—to operate as technical experts on the entirety of the weapons system. However, that sentiment may be changing within the Army. The recent Army UAS Roadmap, when outlining the program's mid-term goals (2016–2025), expresses the desire

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to develop an officer UAS corps as a portion of its force. To address the rapid technological advances and increased autonomy associated with UAS, the roadmap stresses that such advances "do not replace thinking leaders capable of dealing with a wide variety of threats spread across the spectrum of operations."[141] To further develop leaders who would be ready to address such challenges, the roadmap decrees that "**the Army should establish a commissioned officer UAS career track** or an additional skill identifier."[142]

The Army stated the need for commissioned officer UAS career track or an additional skill identifier.

While these differences have been noted throughout this paper, the Navy is the only Service to limit the piloting of their Group 4/5 UAS to those pilots who have flown other aircraft (see Table 12 and Table 13).

The Navy is the only Service that does not allow direct accessions to perform Group 4/5 pilot duties.

In discussion with Navy staff, the rationale for not allowing direct accessions has centered on risk and training costs. The contention is that prior training, in aircraft operations and similar mission tasks (e.g., P-8), reduced risk in comparison to training someone who has never flown in a manned platform. It was also stated that this was a less costly model since additional training was not required for a new and unique cadre of personnel. However, this model is true only if the need to fill UAS pilot slots does not create an increase in rated officer requirements across the Navy. The assumption is that the rated officers filling the UAS roles are taken from non-flying-related shore duty assignments. Additional analysis is recommended for the Navy to determine whether (1) these shore duties can now go vacant and/or (2) shore duty assignments previously filled by rated officers can be sustained through the use of other career fields.[143]

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141 U.S. Army, *Unmanned Aircraft Systems Roadmap 2010–2035*, 54.

142 Ibid., (emphasis added).

143 In an era of budget and personnel constraints, a full analysis of shore duty requirements and available manpower is recommended to ensure that the addition of Group 5 UAS operations does not result in an increase in previously rated officer requirements—thereby possibly negating the Navy's "less costly" assumption (similar to what occurred with the Air Force, as demand increased dramatically).

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A point of interest is that the Navy's rationale for using previously rated pilots was the same given by the Air Force when it initially established its RPA fleet in 1995.[144] Although it took 14 years, the Air Force now has a specific pipeline for training direct accessions to conduct Group 4/5 RPA operations at a cost that is 95% less than UPT and training time that is half as long as UPT.[145] This pipeline has reportedly produced qualified aircrew without an increase in safety incidents, as was initially feared.[146] A similar progression is seen in the other Services with the development of UAS specific training pipelines that now focus on direct accessions as the primary source of personnel. If the Navy continues to pursue this staffing methodology in its nascent UAS program, it is safe to assume it will face similar challenges as the AF and face unsupportable manpower requirements as proliferation of UAS within fleet operations becomes more prominent.

C. The Role of Technology

Through the review of current Service practices, the associated UAS roadmaps/ vectors, and developmental opportunities in and out of Defense channels, the research team observed that not only is the demand for UAS reaching an insatiable level, but that the associated technology is also maturing at an exponential rate.

Demand for and development of UAS technology is in a period of exponential growth within the defense and commercial industries.

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144 The Air Force conducted several studies in the infancy of its RPA program to determine if prior aircrew experience was required (and to some extent addressed the Air Force vs. Officer question). A 1998 Air Force Research Laboratory (AFRL) study concluded that prior aviation experience was required and that the skills learned in UPT were critical to flying RPA. In 2002, AFRL executed a more robust evaluation (addressing only MQ-1B operations) and concluded that "stick and rudder" skills were indeed required so that these pilots could be instructed to an appropriate level through various training venues. (The 2002 evaluation compared UPT grads, RPA pilots, Reserve Officers' Training Corps (ROTC) students and civil aviators.)

For more information on these 1998 and 2002 studies, see Ellen M. Hall and William C. Tirre, *USAF Air Vehicle Operator Training Requirements Study*, AFRL-HE-BR-SR-1998-0001 (Brooks AFB, TX: Air Force Research Laboratory, Human Effectiveness Directorate, January 1998), http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA340960; Brian T. Schreiber et al., *Impact of Prior Flight Experience on Learning Predator UAV Operator Skills*, AFRL-HE-AZ-TR-2002-0026 (Mesa, AZ: Air Force Research Laboratory, Human Effectiveness Directorate, Warfighter Training Research Division, February 2002), http://www.dtic.mil/dtic/tr/fulltext/u2/a401588.pdf. The 2002 study was supported by contracted parties from Lockheed Martin and Link Simulation and Training.

145 Cost is a comparison of undergraduate RPA Training and UPT for fighter pilots (T-6, T-38, and Introduction to Fighter Fundamentals). When compared to UPT, for those pilots going to transport or tanker aircraft (T-6 and T-1), URT is 90.6% less costly. Savings are even greater when Major Weapon System (MWS)-specific training is added (i.e., F-16, C-17, MQ-9, and so forth).

146 Multiple discussions with AF/A2CU and A3O Staffers.

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While an in-depth review of technical advancements is beyond the scope of this paper, it is important to note the potential impact that technology development can have on UAS staffing methodologies.

Each of the Services is pursuing its own initiatives to capitalize on the rapid development of UAS technology, to include everything from enhanced sensors to increased autonomy associated with aircraft control. The Air Force's RPA Vector report[147] emphasizes the potential that is available within the SUAS fleet and outlines several innovations underway to evolve these systems so that they can be applied in a much broader scope at the operational and, possibly, strategic levels of engagement. However, the Air Force does not address which category of performer it would use to control such operations. Questions arise (e.g., Will these platforms be capable of executing the missions and roles currently conducted by the Group 4 MQ-1/9? If so, is an Air Force officer pilot still required because of the mission or does the simplicity of the aircraft enable enlisted aviators?).

Although the Group 2/3 UAS currently in service are strictly controlled via LOS operations, technology is currently available to enable BLOS operations. As this technology matures and is fielded (in the short term), there is the possibility to operate these UAS under an RSO construct similar to the larger Air Force and Navy programs. The same could be done with the Army's MQ-1C, thereby eliminating a substantial rotational force requirement. In addition to BLOS technology, the Army, Navy, and Marines have significant interest in unmanned technology within domains other than just the air (i.e., ground and sea). This prevalence of unmanned technology across the domains drives an increased desire—and eventual combat requirement—to simplify and integrate these systems. The Navy has already demonstrated such integration and simplification by using rotary wing UAS designed to deliver supplies to deployed forces with little more than 5 minutes of operator training and a mobile tablet device.[148] In terms of maturing UAS technology, the topic of the day has been the concept of "swarming" UAS (increased autonomous control enabling hundreds of smaller platforms to conduct missions now reserved for the current HD/LD aircraft). As this concept comes to fruition, definite opportunities exist for reducing manpower costs while increasing capacity provided by an increased density of assets. Overall, the observation related to this topic is rather simple:

Maturation of technology will have an impact on the force presentation and staffing methodologies used within DoD's UAS enterprise.

147 United States Air Force, *RPA Vector: Vision and Enabling Concepts 2013–2038.*

148 The Navy flew the first remotely piloted aircraft, an N-9 named *The Wild Goose*, on September 15, 1924. See Callahan, "Reinventing the Drone, Reinventing the Navy (1919–1939)," 105.

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D. Summary

Table 16 lists seven observations of UAS staffing methodologies to bear in mind when considering the Service programs.

Table 16. UAS Staffing Observations

1	Service culture shapes how the roles and responsibilities are viewed for individual category of performers.
2	DoD-assigned missions/responsibilities and the anticipated operating environment shape how the Services view the role of their UAS.
3	The C2 concept of UAS operations (centralized vs. decentralized) and resultant authority required by aircrew relate directly to officer vs enlisted decision.
4	The Army stated the need for commissioned officer UAS career track or an additional skill identifier.
5	The Navy is the only Service that does not allow direct accessions to perform Group 4/5 pilot duties.
6	Demand for and development of UAS technology is in a period of exponential growth within the defense and commercial industries.
7	Maturation of technology will have an impact on the force presentation and staffing methodologies used within DoD's UAS enterprise.

Overall, the analysis of the individual Service staffing models demonstrates significant differences between each. However, in many cases, these differences are justifiable when viewed against the mission requirements of a particular Service's UAS force. While the choice to staff using different categories of performers is justifiable in some cases, it does not mean that current practices are always best. As technology matures, these methodologies should be reassessed as this inevitable increase in both capability and capacity will likely prove current staffing principles unsupportable given the likely continuation of a fiscally constrained operating environment. Analysis of this community highlights not only the ability to gain substantial manpower efficiencies, but also the opportunity for increased cooperation across the Services to capitalize on lessons learned within the enterprise. The next chapter will analyze aspects of UAS missions to identify potential alternative staffing methodologies.

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7. Mission Element Analysis

In comparison to contemporary aircraft systems, UAS offer a unique opportunity in terms of manpower management. The CONOPS combined with the sortie duration (time between takeoff and landing) enable—and in some cases necessitates—multiple individuals to be at the control during the sortie. While this requirement is especially true for the larger Group 4/5 UAS, the rapid development of technology is increasing the capability and flight time associated with the smaller systems, where multiple-crew CONOPs will quickly become the norm.[149] With this in mind, before analyzing staff methodology alternatives, this chapter dissects the basic elements of a UAS sortie to analyze which category of performer is capable of conducting each element. Such analysis raises opportunities for potential force mix efficiencies. For example, as discussed earlier, military incumbency is required for the employment of weapons; however, for Group 4 UAS, the act of employing weapons from a UAS may only take 1 hour (to include the operational prep, communications, and so forth) of a 22-hour sortie. Is there an opportunity to use a different category of performer for the remaining 95% of the sortie?

The review of current Service practices highlights that despite differences in force presentation and operating concepts, the basic mission elements associated with a UAS mission are rather static. The basic mission elements used for this analysis are as follows:

- Launch and recovery operations,
- Transit operations,
- ISR collection,
- Support to deployed forces (combat and non-combat), and
- Weapons employment.

Analysis using these basic mission elements will use the category of performer decision tree described in Chapter 3 and will remain Service and platform agnostic. The elements selected are generic enough that they apply (or can apply) to all UAS operations. For example, a Marine Corps UAS conducting a force reconnaissance mission would include launch and recovery operations, transit operations, and ISR collection and may include support to deployed forces (combat). If Air Force operations within Libya are analyzed (no ground troops), elements would include launch and recovery operations,

[149] Some CONOPS will still include a single crew/operator per mission. This situation is not limited by aircraft size (i.e., only Group 1) but rather by how the system is employed. As Group 1 UAS capability improves to include the potential of swarming, it is quite possible that separate operators would control the launch and transit while another crew(s) is conducting the operation itself.

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transit operations, ISR collection, and weapons employment (under a SCAR mission).[150] In contrast, Army National Guard UAS supporting humanitarian response to a regional flood would include launch and recovery operations, transit operations, and support to deployed forces (non-combat). The key is that each of these elements helps to break down UAS operations into their simplest form and allows us to analyze the manpower requirements regardless of current or future system capabilities.

A. Launch and Recovery Operations

Launch and recovery operations include the physical act of taking off and landing the aircraft, along with operations within and around the terminal location (often an airfield or an afloat forward staging base). These functions are analogous to operations within civil aviation and do not represent an IG task. As Figure 10 depicts, the launch and recovery operation decisions move to the right side of the figure, where the answers are completely dependent on risks that the operational commander is willing/able to accept based upon the operating location. For example, if a UAS team is traveling with a forward-deployed Marine infantry element, operating conditions could include risk that is considered unacceptable for civilians (DoD and/or contracted). On the other hand, if an operating location is rather secure and a civilian organization is able to meet operational demands associated with that location, a contracted force can conduct UAS launch and recovery operations. However, if operational requirements cannot be met, the launch and recovery operation decisions move to the left side of the figure. Through this line of reasoning, the figure shows that military incumbency is not required for basic launch and recovery operations. The question then becomes whether the risk of the operating location is acceptable for a civilian. In either case, a cost-based analysis is required to compare the cost of a contracted operation with that of a civilian and/or military force.[151] Several illustrative examples will show how to analyze operational requirements and determine the appropriate category of performer.

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[150] United States Air Force, *RPA Vector: Vision and Enabling Concepts 2013–2038.* SCAR missions were routinely flown by Air Force UAS crews.

[151] Civilian positions are inherently less costly than their military counterparts, so, in terms of a pure cost analysis, a contractor vs. civilian counterpart is most telling. In the case where no government civilians are available (as is currently the case), this point would be moot. However, for this analysis, the assumption is that government civilian UAS operators are a viable solution.

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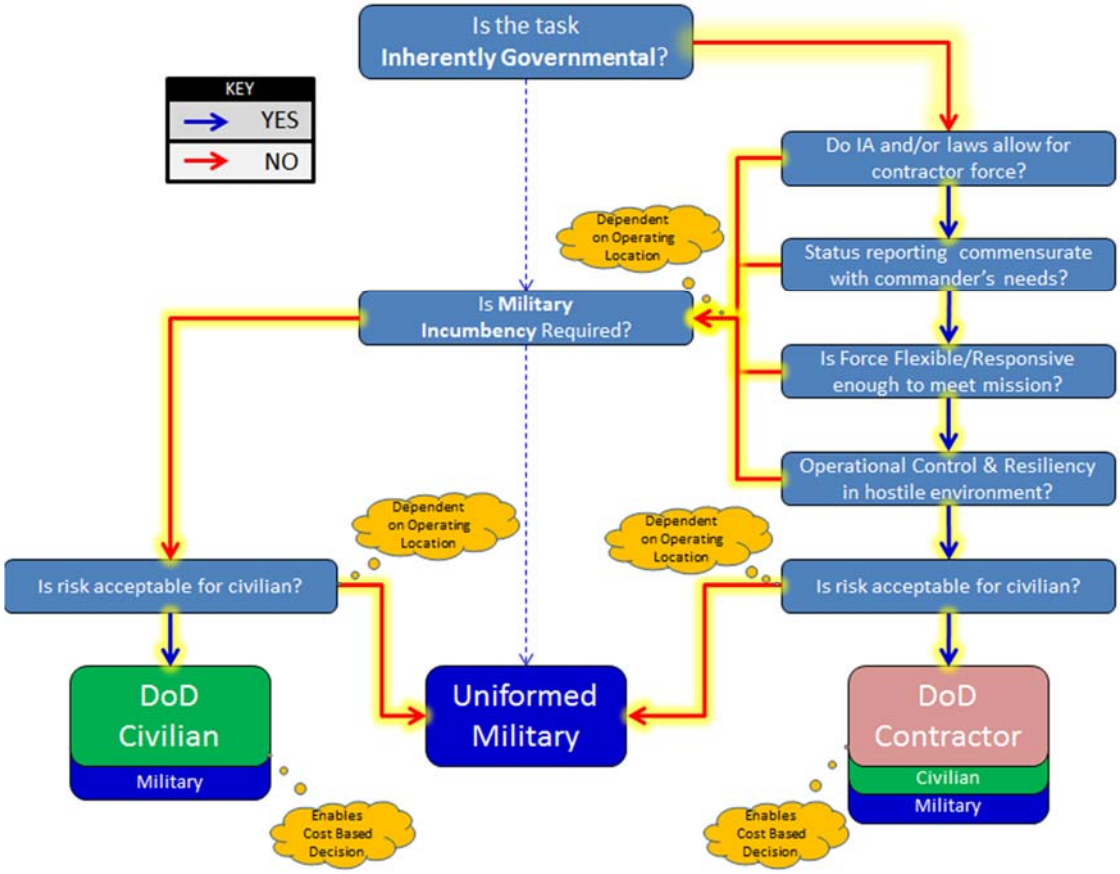


Figure 10. Category of Performer Decision Tree (Launch and Recovery Operations)

The first example is a Group 4 LRE located in southern Europe (providing support to the Mediterranean region). In this case, the location is very secure and has a well-established logistical supply chain. Assuming that a contracted force can meet the desired requirements, the cost for such a contract must be compared with the government civilian and/or military options. In contrast, an operating location out of a Northern Africa nation may not be as secure, and, therefore, risk to force/mission now plays a larger role. In some cases, launch and recovery operations must be prepared to move locations upon short notice to respond to emerging requirements and/or threats. In cases where operational requirements create additional cost requirements, the cost benefit will likely quickly favor the government civilian/military option.

In addition to these examples, new operating concepts/environments and associated technology development have quickly enabled operations from naval vessels. This case is another instance in which the operational risk associated with operating from a combat platform at sea must be included in the overall decision.

The one caveat to these examples would be if operations included base or ship defense for which the crews were required to employ weapons; however, this aspect is addressed

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in the subsequent weapon employment mission element. While these examples illustrate the multiple variables associated with this decision, when analyzing manpower costs, launch and recovery operations lend themselves to a civilian work-force.

B. Transit Operations

Transit operations (see Figure 11) are the part of the mission during which the aircraft travels to/from its terminal location to its operating location. Transit operations can also include travel between various operating locations. Similar to launch and recovery operations, transit operations are not IG nor do they require military incumbency. Therefore, the category of performer decision is primarily based upon an operational risk and cost assessment. Like launch and recovery operations, transit operations open the possibilities of a civilian workforce (i.e., DoD civilian or contracted force).

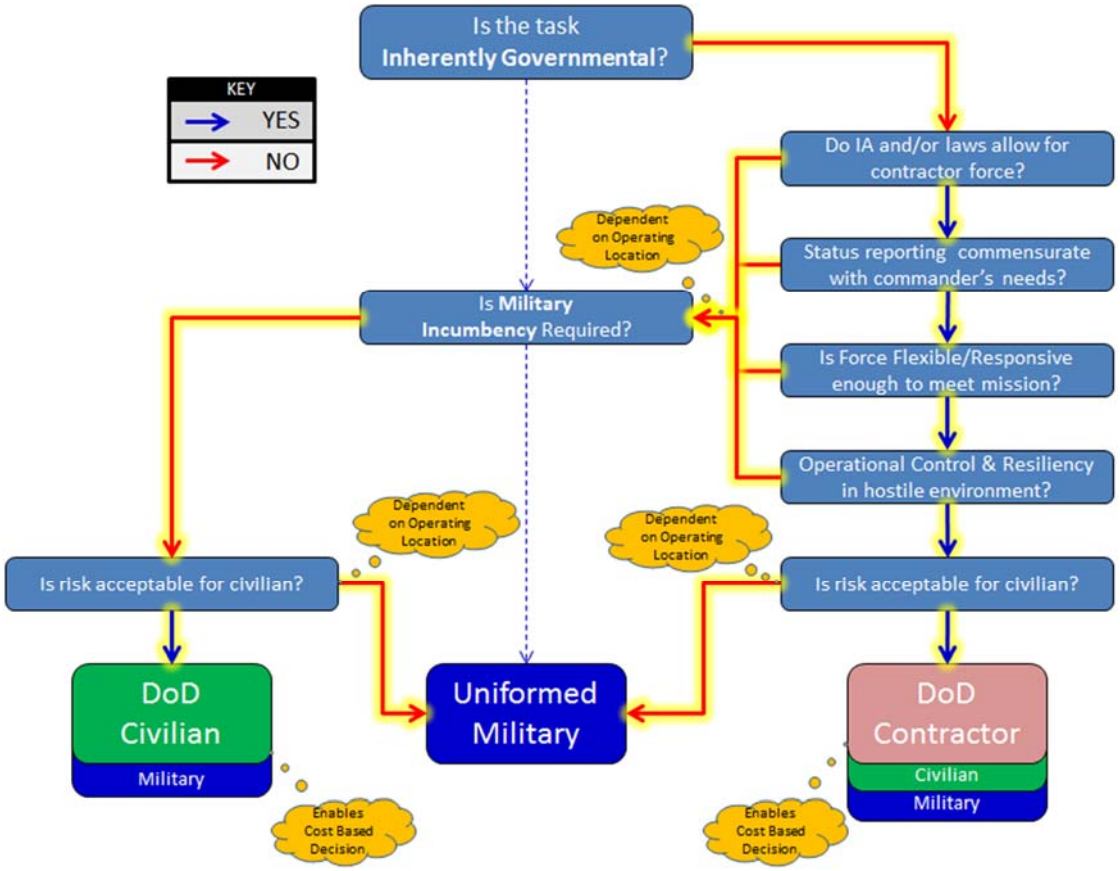


Figure 11. Category of Performer Decision Tree (Transit Operations)

C. ISR Collection

ISR collection includes operating the aircraft during the more "traditional" UAS role of collecting various data that include full-motion video, signals intelligence, synthetic

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aperture radar, and so forth. While there can be significant debate on the IG nature of this activity, ample evidence is available of the willingness of the U.S. Government to contract the services required for this mission set. Therefore, it is inferred that the act of collecting these data is not IG.[152] Therefore, much like the two previous mission elements, Figure 12 depicts the decision tree enabling a risk/cost analysis that identifies this operation as being open to a civilian workforce.

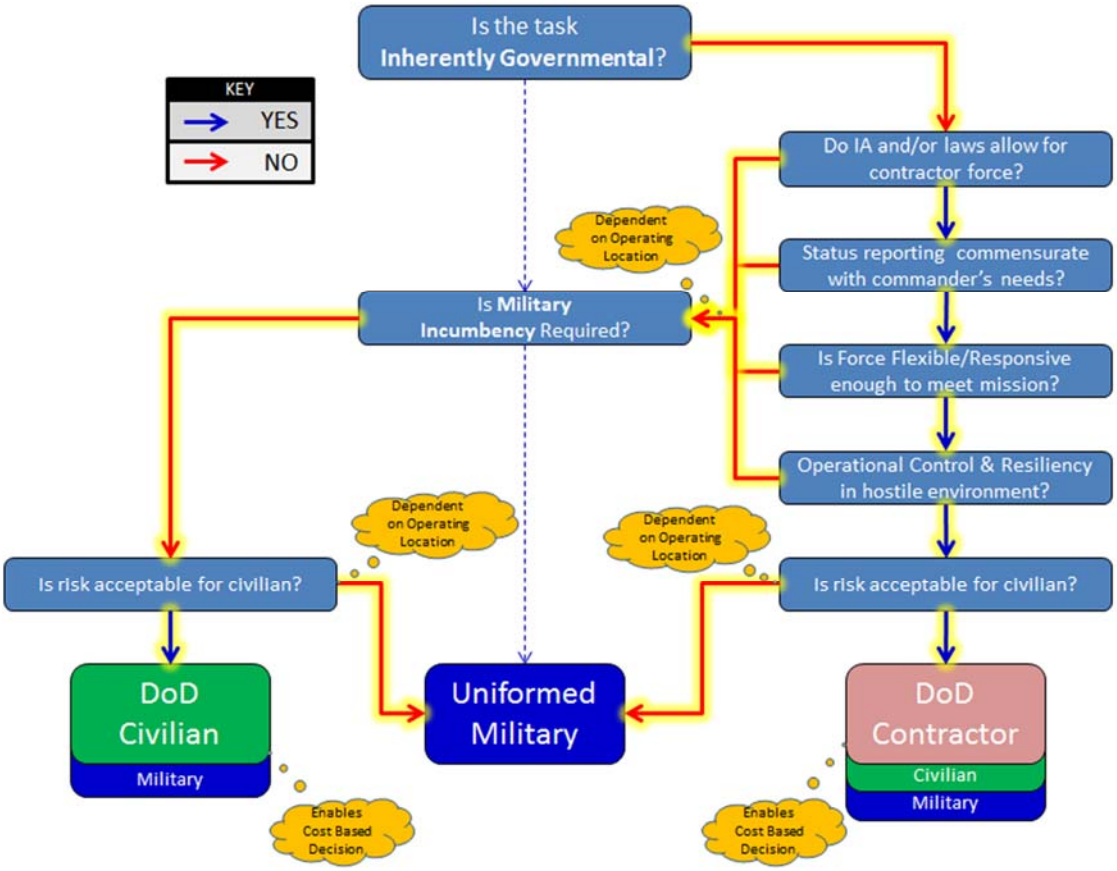


Figure 12. Category of Performer Decision Tree (ISR Collection)

D. Support to Deployed Forces (Combat and Non-combat)

The mission element of support to deployed forces was divided into two separate subcategories: combat and non-combat. In this mission element, the term "deployed" refers to forces that are "outside the wire" or rather beyond the confines of a secured operating location. Those operations within the combat subsection include operations such as direct action (i.e., raids) and convoy escort and operations in support of a naval force since such

[152] Analyzing and exploiting the data to produce intelligence products is also debated but is not within the scope of this research.

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an element must always be prepared to defend the fleet. As depicted in Figure 13 and discussed previously, this type of support should be considered IG. As such, the subsequent decision is based upon operating location and associated risk. Secure and safe locations, such as U.S. operating locations for Air Force RSO, enable a cost-based analysis that shows DoD civilians as a potential cost-saving alternative. On the other hand, if forces are deployed forward in a combat zone, that calculus may require military incumbency based on the threat to force, maneuver requirements, and/or the defensive posture associated with that mission.

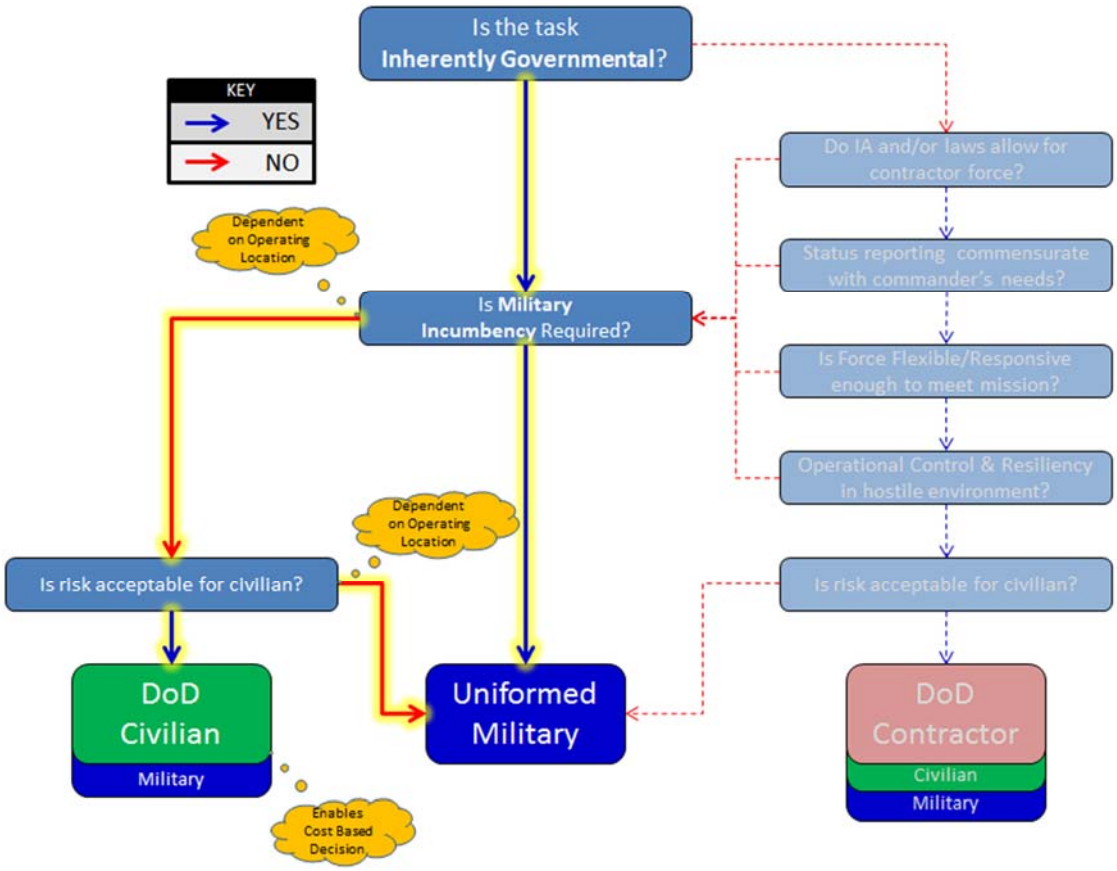


Figure 13. Category of Performer Decision Tree (Support to Deployed Forces (Combat))

In contrast, "non-combat" support operations include overwatch of a force providing humanitarian assistance to an affected region or non-combat personnel recovery operations. Such operations are not IG and therefore, as depicted in Figure 14, the decision is similar to those where DoD civilians and contractors are appropriate in this role. In these situations, risk associated with operating locations will not necessarily come from enemy combatants, but rather from environmental dangers (e.g., a natural disaster) or local criminal elements.

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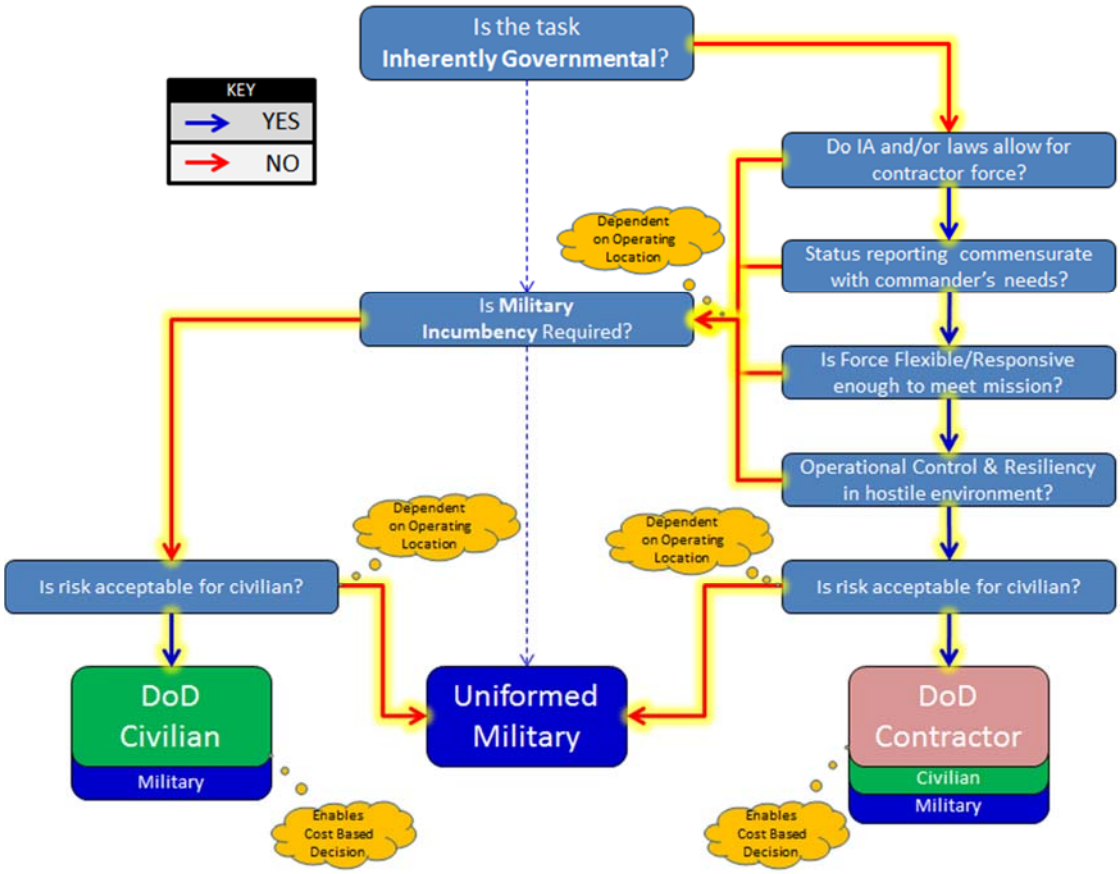


Figure 14. Category of Performer Decision Tree (Support to Deployed Forces (Non-Combat))

E. Weapons Employment

Using the definition provided in Chapter 3, which includes "the employment of, and/or provides terminal guidance to, kinetic weapons," military incumbency is clearly required.[153] As stated in DoDI 1100.22,

[153] As outlined in Appendix A, "kinetic weapons" refer to those weapons that depart an aircraft or are employed from another source (i.e., bombs, missiles, artillery, and so forth). Effects from other sources, such as electronic spectrum or cyber means, are not considered in this analysis.

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> … manpower shall be designated military … if the *planned use of destructive combat capabilities is part of the mission* assigned to this manpower … includes manpower located both *inside and outside a theater of operations* if the personnel operate a weapon system against an enemy or hostile force (e.g., … *unmanned aerial vehicle operators*).[154]

The decision, therefore, is then left to officer vs. enlisted (see Figure 15). Subsequent chapters will address factors associated with authority to the release a precision guided munition but the employer of that munition may indeed be either officer or enlisted.

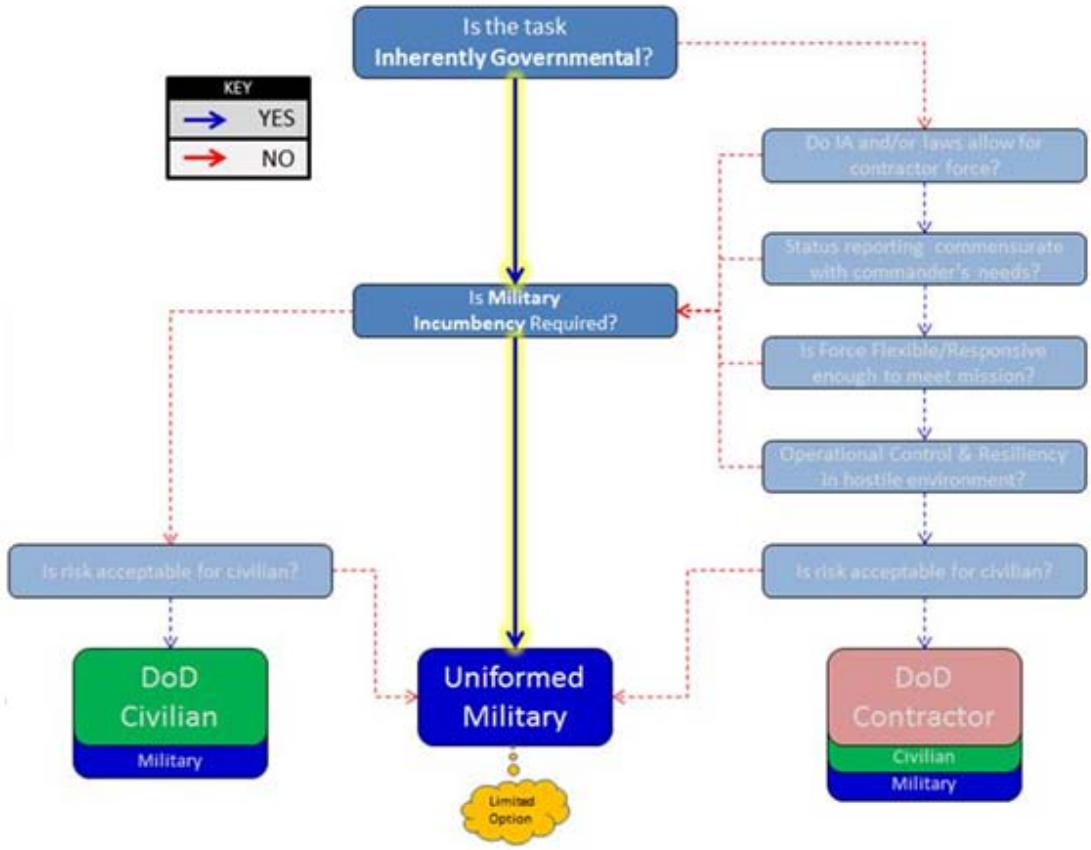


Figure 15. Category of Performer Decision Tree (Weapons Employment)

[154] Department of Defense, "Policy and Procedures for Determining Workforce Mix," DoDI 1100.22, 19 (emphasis added).

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F. Summary

In reviewing each of the mission elements associated with UAS operations, an apparent opportunity is highlighted. Although DoD civilians are not currently used in UAS operations, analysis shows definite opportunities within the enterprise for government civilians. As depicted in Figure 16, the only mission element that is not allowed for the civilian workforce is the employment of weapons. Already a small subset of the DoD UAS enterprise, executed primarily by the USAF and small portion of the Army's fleet, as proliferation of UAS across DoD missions continues, weapons employment will involve only a small fraction of the total force. In this regard, an organization responsible for weapons employment has an opportunity to balance its force to meet mission requirements while also taking advantage of the cost savings associated with civilian billets. Analysis also showed that a contractor-based force can conduct most of the mission elements. With this information, analysis will now focus upon identifying alternative staffing models across the UAS enterprise.

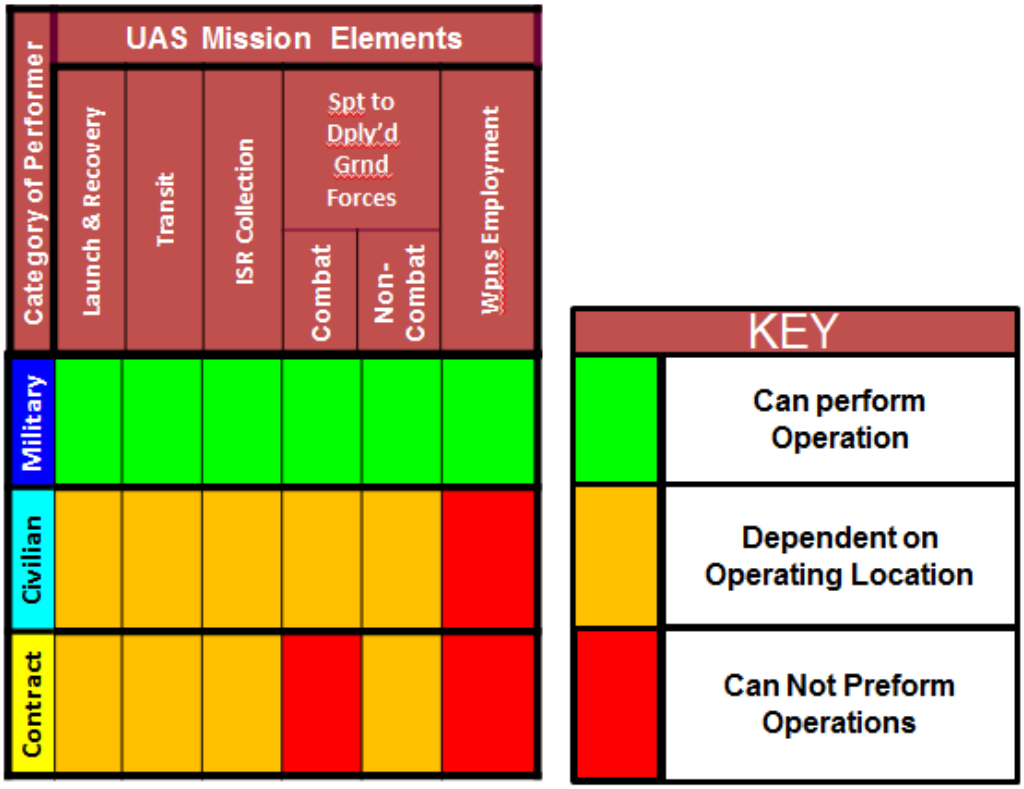


Figure 16. Summary of Mission Element Analysis

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8. Staffing Alternatives

Analysis aimed at identifying alternative cost-saving staffing strategies for the DoD's UAS enterprise identified multiple variables that affect each of the Services' force mix decision-making process. The following force mix alternatives take into account the individual Service roles and missions. Since operational requirements vary widely, some generalities associated with each Service were made. For example, the Marine Corps expeditionary nature requires a capability to operate within hostile and austere environments. This assumption alone drives a necessity for the use of military personnel; however, the following analysis highlights factors that may change that calculus. The following alternatives are organized along category of performer delineations, and, while the alternatives are segregated as such, aggregate variations may indeed be possible.

A. Use of Civilians

> **Manpower shall be designated as civilian except when military incumbency is required ….**[155]

The previous mission element analysis showed that DoD civilians can conduct all aspects of a UAS operation, except when weapons employment is required. Although this exception currently affects only the larger Group 4/5 UAS, the Services must consider when they are planning future capabilities development. Understanding that government civilian billets come with an inherent cost savings over military positions, two alternatives are recommended for further analysis to balance cost-savings with mission requirements: civilian applications to either (1) the LRE and (2) the mission command element (MCE) (i.e., transit and basic ISR collection).

While the following alternatives capitalize on cost savings associated with civilian manpower, several variables beyond the scope of this analysis are associated with the ability to hire civilians into such positions. These factors include operations tempo, shift work, potentially undesirable operating locations, and the strength of the civilian UAS market.[156] In addition, supporting research is required to understand both the availability

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155 Department of Defense, "Guidance for Manpower Management," DoDD 1100.4, 3.

156 See Bureau of Labor Statistics Website, "Occupational Employment Statistics," accessed January 26, 2015, http://www.bls.gov/oes/home.htm. The Bureau of Labor Statistics' Occupational Employment Statistics (OES) program produces such analysis for over 800 various occupations. As of the writing of this paper, the OES had not yet conducted such analyses on the UAS/RPA market. While extensive

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and accessibility of a civilian UAS workforce to feed, and sustain, DoD requirements. If such a pool of individuals do not exist, or won't for several years, this may not be a viable option for the short term. However, if such a workforce is available, their experience and potential longevity in service, without the need to meet military developmental requirements, may provide additional long-term savings. For this paper, to illustrate potential cost savings within the enterprise, the following alternatives assume that these variables are *not* factors.

1. Launch and Recovery

The decision to use government civilians to launch and recover UAS is primarily reliant upon the risk associated with the operating location. The Marines are expected to provide an expeditionary presence that is able to deploy forward and maneuver within hostile and austere environments while employing offensive tactics in defense of their positions (i.e., "pick up a gun and fight"). Therefore, civilian operators do not fit most of the Marine UAS operations.[157] On the other hand, through the use of contractors (e.g., GOCO/COCO UAS), DoD has already demonstrated a willingness to deploy civilians to secure forward operating locations and/or on Navy combat vessels in a variety of positions.

As mentioned, the Marines and the Army are currently focused on smaller UAS systems that are organic to maneuver-type units. These types of operations tend to call for military incumbency; however, as operations become more secure and/or larger systems are used, additional opportunities for civilians will be available. Currently, this situation is the case for the Army, Air Force, and Navy Group 4/5 UAS. As the larger aircraft are typically launched and recovered from secure locations, the associated risk is typically acceptable for government civilians.[158] Since the Air Force has the largest number of Group 4/5 UAS, the following alternative uses Air Force's program numbers even though the concept also applies to Army and Navy programs.[159]

The Air Force MQ-1/9 program of record currently includes 15 LREs.[160] To support this requirement, the Air Force assigns each of its RPA units a portion of LRE billets. As

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market research (e.g., salaries, job requirements, work force demand, and so forth) could address this challenge, it is well outside the scope of this paper.

157 The same can be argued for certain Army infantry units that also operate in this manner.

158 This approach is evident in current operations by the number of civilians on forward operating bases where UAS/RPA operate. In future non-permissive environments, this situation may not be the case; however, these particular UAS are not prone to launch and recover within a non-permissive environment.

159 Due to several variables which are beyond the scope of this study, generalities are used to illustrate a basic analysis.

160 Telephone interview with Maj Michael Lewis, HAF/A3, October 17, 2014.

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shown in Table 17, each LRE consists of 5 pilot and 5 sensor operator billets, for a total of 10 personnel.

Table 17. USAF LRE Manning Requirements (General)

Unit Type Code (UTC) Line Number	Core AFSC	AFSC Title	Grade	Quantity
1	11U3	RPA Pilot	Maj	1
2	11U3	RPA Pilot	Capt	4
3	1U07	RPA Sensor Operator Craftsman		1
4	1U05	RPA Sensor Operator Journeyman		4

Source: Telephone interview with Maj Michael Lewis, HAF/A3, October 17, 2014

Note: Air Force LRE requirements are similar across units. Costing for sensor operators was done using 1N1 AFSC for sensor operators. In addition one E-7, one E-5 and two E-3s were used as a conservative estimation. See Appendix B for the full FCoM data. The numbers used in this table are currently under review by the Air Force since they do not represent enough individuals to meet rotational deployment requirements. The Air Force is looking at increasing the number of billets associated with its LREs to better meet demand. (Note source: Interview with RPA Manpower and Career Development Tiger Team, November 20, 2014).

If one takes all these positions and transitions them to purely civilian equivalent positions, the annual savings equate to $777,696 per LRE. In the case in which all 15 USAF MQ-1/9 LREs were converted to pure civilian operators, an approximate $11.7 million annual savings is realized.[161] However, operationally, it is understood that an all-civilian LRE force would not meet Air Force requirements. For certain LREs, the risk, base defense requirement, and/or host nation agreement will require military personnel. While others LREs are secure enough to allow an all-civilian force, there will be options in between. With this in mind, Table 18. depicts a force mix alternative across the 15 Air Force LREs that could meet an LRE civilian/military force mix.[162] As seen with four all-military LREs, five 60-40, three 20-80, and three all-civilian, the total cost savings is approximately $5.1 million annually ($25.65 million across the Future Years Defense Program (FYDP)).[163]. This savings comes from transitioning approximately half (74 of 150) of the LRE positions from military to civilian.

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161 Annual savings based upon FCoM numbers (see Appendix B). The $776,696 and $11.7 million totals are for full savings to the Federal Government. Savings specific to DoD are $610,776 and $9.16 million, respectively.

162 A full mission analysis of Air Force LRE requirements was not conducted; however, this framework is general enough to meet a majority of Air Force LRE requirements based upon Group 4/5 LRE operations that typically occur in secure locations.

163 Ten Operational Squadrons does not include the MQ-1/9 Training squadron at Holloman AFB or the launch and recovery (LR) squadron at Cannon and Creech AFBs. Savings totals are for full savings to the Federal Government. Savings specific to DoD are $3.9 million annually and $19.48 million over the FYDP.

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Table 18. Annual Costing of Air Force LRE Civilian/Military Force Mix

UTCs	Annual Cost/LRE		# of UTCs	Sub-total		Billets	
	DoD	Fed Gov		DoD	Fed Gov	Mil	Civ
RPA LRE UTC (All Mil)	1,283,861	1,592,561	4	5,135,444	6,370,243	40	0
LRE UTC (2 Civ + 3 Mil)	1,158,832	1,400,764	5	5,794,160	7,003,820	30	20
LRE UTC (4 Civ + 1 Mil)	804,398	979,562	3	2,413,194	2,938,686	6	24
RPA LRE UTC (All Civ)	673,085	814,865	3	2,019,255	2,444,594	0	30
Total for 15 All-Military RPA LRE UTCs				19,257,915	23,888,415		
Total for 15 Force mix RPA UTCs (as presented above)				15,362,053	18,757,343		
Delta (i.e., savings)				3,895,862	5,131,072		

Note: Delta is between mix depicted and all 15 military LREs.

2. Transit Operations

Another mission element in which a civilian force may be useful comes in transit operations. Once again, this section will use Air Force MQ-1/9s since they represent most of the larger UAS force. For this short example, we will use the following basic assumptions: (1) Air Force RPA squadron responsible for 5 CAPs, (2) average flight lasts approximately 22 hours, and (3) the average transit time to/from an objective area takes 2 hours.[164] Using this information, we can calculate the average percentage of scheduled flying time dedicated to transit operations:

$$\%\ \text{Sq Flying Time for Transit} = \frac{(\text{Average Transit Time to Obj} * 2)}{\text{Average Flight Time}}$$

$$\%\ \text{Sq Flying Time for Transit} = \frac{(2\ \text{hrs} * 2)}{22\ \text{hrs}}$$

$$18\% = \frac{4}{22}$$

Based upon our assumptions, this 18% of flying time associated with transit operations can, in theory, be directly applied to a percentage of aircrew required for support. With the program of record for Air Force RPA operations that require 40 pilots to support 4 CAPs, 18% of the crew force equates to 7 pilots. Using math similar to our previous

[164] The 22-hour assumption is standard for MQ-1 operations and has been demonstrated by the recently fielded MQ-9 Extended Range. The basic MQ-9 is airborne closer to 17 hours. Transit time can vary wildly (up to > 8 hours in some operating locations); however, for our analysis, Afghanistan-type transits were assumed, which would place an objective approximately 200–400 miles away (depending on aircraft and wind velocity).

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calculations for the LRE civilian conversions, transitioning 7 pilot positions to DoD civilians would save approximately $560,000 annually:

$$\text{Annual Cost Savings} = (\text{Cost saving per billet}) * (\#\text{ of billets converted})$$

$$\text{Annual Cost Savings} = (\text{O-3 to GS-11}) * 7$$

$$\$559{,}573 = (\$79{,}939) * 7$$

When sensor operators are included in this conversion, the potential annual cost savings increase to around $1 million:

$$\text{Annual Cost Savings} = [\ (\text{O-3 to GS-11}) * 7\ ] + [\ (\text{E-5 to GS-5}) * 7\ ]$$

$$\$1{,}010{,}856 = [\ (\$79{,}939) * 7\ ] + [\ (64{,}469) * 7\ ]$$

Since UAS operations currently run 24/7/365 with transit operations occurring at any time of the day, a force of only 7 crews to perform all transit operations is extremely difficult to schedule operationally.[165] Therefore, we focused on transitioning a full CAP to use civilian billets (10 pilots/10 sensors). This approach allows flexibility in scheduling, as well as an understanding that the same individuals can perform basic mission support up to but not including weapons employment. As Table 19. depicts, approximately $1.37 million annually is saved by converting 1 CAP (20 billets) worth of manpower to DoD civilians.[166] If each of the 10 operational Air Force MQ-1/9 squadrons did this conversion, total program annual savings could total $13.65 million ($68.3 million across the FYDP).[167] Training and test squadrons could further capitalize on civilian manpower since they are not responsible for combat support missions.

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165 Considerations include standard 2-day weekends, sick days, training, time to adapt for shift changes, and so forth. Included is the potential of a limited duty hour during a standard week for civilians (i.e., 40 hours). Although the Air Force is looking at the potential of using pilots only for transit operations, the current construct of also assigning a sensor operator (for help running checklists during emergencies) was used. Removal/decrease in number of sensor operators used would increase savings.

166 Since no model based upon mission analysis is available for the appropriate civil/military mix, best assumptions were made with the available data. Distribution of ranks and grades throughout the squadron was kept as close in line as possible with current Air Force RPA squadron structures.

167 Ten Operational Squadrons does not include the MQ-1/9 Training squadron at Holloman AFB or the LR squadron at Cannon and Creech AFBs. Savings represent savings to the Federal Government. DoD savings are $10.31 million annually or $51.58 million across the FYDP.

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Table 19. Cost Comparison of USAF MQ-1/9 Squadron Using Civilians

USAF RPA Squadron	Annual Cost		Billets	
	DoD	Fed Gov	Mil	Civ
Current	14,223,874	17,557,834	108	0
1 Civilian CAP	13,192,353	16,192,473	88	20
[redacted]				
Delta (i.e., savings)	1,031,521	1,365,361	[redacted]	

Note: Costing considers only the UAS aircrew. Support personnel (e.g., aviation resource management and secretary) are not included.

While these numbers are specific to the Air Force MQ-1/9 program, the Army Gray Eagle companies could also realize savings. If the concept of government civilian operators is established within MQ-1/9, the RQ/MQ-4 missions, which do not include weapons engagement, should be able to accept a greater percentage of DoD civilians, providing another multi-million dollar annual savings across Air Force and Navy programs.

B. Officer vs. Enlisted

As shown in the staffing analysis, while the Services base their staffing methodologies upon their assigned mission roles and responsibilities, there may be some opportunities to transition a portion of the Navy and Air Force Group 4/5 UAS manpower from officer to enlisted. While the Army has had demonstrated success within its MQ-1C program, this decision to use enlisted operators in the Air Force and Navy requires further mission analysis to assess which portion of their respective missions can be met by enlisted pilots. For illustrative purposes, Table 20. depicts the potential cost savings associated with this transfer. The transition of 60% to enlisted pilots can provide up to $1.8 million per squadron ($18.2 million annually, $91 million in FYDP, if accomplished in all 10 operational MQ-1/9 squadrons).

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Table 20. Cost Comparison of Air Force RPA Squadrons Using Enlisted

USAF RPA Squadron	Annual Cost		Delta (i.e., savings)	Pilot Billets	
	DoD	Fed Gov		Officer	Enlisted
All Officer	14,223,874	17,557,834		50	0
20% Enlisted	13,610,200	16,944,160	613,674	40	10
30% Enlisted	13,312910	16,646,870	910,964	35	15
40% Enlisted	13,000,585	16,334,545	1,223,289	30	20
50% Enlisted	12,714,217	16,048,231	1,509,603	35	25
60% Enlisted	12,401,946	15,735,906	1,821,928	20	30

Note: See Appendix B for the breakdown of positions converted. Commander (1), Operation Officer (1), and Squadron Operation Center Billets (5) are not included in enlisted conversion. In addition, the Delta is the same for the Federal Government and DoD.

1. The Marine Model Applied to Air Force and Navy Programs

The Marine Corps model could possibly be applied to the Navy and/or Air Force Group 4/5 UAS squadrons.[168] While initially sound in concept, the Marine Corps model is able to mitigate risk through its operating concept—mitigation that is enabled through technology and the oversight of operations (and associated aircraft control) available to the mission commander. In discussion with various SMEs, the complexities of the MQ-1B and MQ-9 systems associated with the lack of ground control system/operation center oversight available make it unlikely that the Marine Corps model would meet the desired responsiveness required for strategic missions that the Air Force/Navy contend require the more decentralized execution model. Although beyond the scope of this paper, it is recommended that future infrastructure upgrades and/or acquisitions be capable of supporting a manpower model similar to that of the Marine Corps.

2. Warrant Officers (WOs)

The use of WOs is typically addressed in terms of the Air Force program. As stated earlier, lacking such a program, the Air Force would have to develop an entirely new element within its force structure to support this option. To understand the full potential associated with possible manpower savings, a full business case analysis will need to include the cost of establishing a WO program and whether this program would apply to only RPA or include other AFSCs. The Navy, for its part, assessed and terminated its short-lived flight WO program since it conflicted with other force management policies.[169] Rather than disregard this option outright, this study reviewed some basic assumptions on costs associated with manpower savings as if the Air Force had a WO program established.

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[168] UAS-qualified officer mission commander with enlisted UAS pilots controlling aircraft.

[169] Mark D. Faram, "Flying Warrant Program Gets the Ax."

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Table 21 shows approximately $1.3 million potential annual savings associated with converting an Air Force MQ-1/9 squadron to a WO-centric pilot force.[170] In total, the USAF has 1,418 authorized officer billets within RPA, and converting all those to a WO equivalent would save a conservative $110 million annually in manpower costs. Further research comparing the pros and cons and costs associated with establishing a WO force structure is recommended.

Table 21. Cost Comparison of USAF RPA Squadrons Using Warrant Officers

USAF RPA Squadron	Annual Cost		Delta (i.e., savings)
	DoD	Fed Gov	
Current	$14,223,874	$17,557,834	
WO Pilots	$12,917,076	$16,251,036	$1,306,798

Note: Delta is the same for the Federal Government and DoD.

3. Limited Duty Officers (LDOs)

LDOs hold the same rank and benefits as their line officer counterparts. Therefore, while there are no inherent annual cost savings, such a program could be beneficial when considering total life-cycle costs. Since LDOs are focused primarily on their technical competence, they presumably do not require the same "broadening" opportunities as their line counterparts. Previous IDA studies have calculated an average Air Force officer's career at approximately 15 years. Presuming approximately 25% (3.7 years) of an officer's career is spent in a developmental assignment, LDOs present possible savings when considering training costs. However further analysis of the UAS community and such an LDO program is required to assess anticipated retention rates within this fledgling career field. As with the WO program, Services without a preexisting LDO program must analyze the overall cost of establishing this new force structure element and its applicability beyond the UAS community. In addition, restructuring the current policy of selecting LDOs for solely the enlisted ranks and opening such opportunities to the officer corps, may prove to provide additional life-cycle cost benefits.[171]

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[170] Commander and Operations officer were left as Officer (O-5) billets. Transitioning the Major and Captain billets into one W-4, 28 W-3s, and 26 W-2s provided the reported savings. Since the Air Force does not have WOs available in FCoM, Army costing data were substituted.

[171] While further analysis is required, a career path to include "on and off-ramp" opportunities for the current "traditional" officer corps into the LDO might address several force management issues currently under assessment within the DoD.

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C. Total Force Options

Although in-depth research into total force options was beyond the scope of this study, the research team noted a lack of integration. Not only does the Air Force have most of the larger UAS, it is also building a significant Strategic Reserve force using Air Force Reserves and Air National Guard units. However, a majority of these units support only one CAP full time, with a strategic reserve of one to two additional CAPs. Through basic operational scheduling considerations, a single CAP squadron is highly inefficient. Compounding this inefficiency is the fact that of the majority of these Reserve and Guard squadrons are not collocated with their active duty counterparts. Potential efficiencies and cost savings (material and manpower) exist in increasing integration between active duty and strategic reserve forces.

D. Joint Force Options

The apparent duplication of aircraft systems across the Services was raised on multiple occasions. It was understood that the smaller Group 1–3 platforms performed primarily organic support over relatively short time periods, which made the use of a common joint platform across multiple Services understandable. However, while CONOPS differ between the Services, use of almost identical Group 4/5 platforms seems to present several inefficiencies in terms of acquisition, operating, and sustainment costs. Although beyond the scope of this study, further research is recommended. This research should focus on potential efficiencies gained by either consolidating platforms under a single Service or by managing and operating platforms in more integrated manner and may include everything from acquisition parity/interoperability standards to more radical ideas (e.g., creating joint operational squadrons).

E. Use of Contractors

The use of contractors is widespread throughout DoD for UAS, which is understandable based upon the dramatic and rapid development of the associated demand. These systems have proven beneficial, but, since they are not part of a program of record, sustainability and integration across the force has been challenging. Although this study did not have access to the contract costs covering the wide range of GOCO/COCO UAS operations, efficiencies are likely through a more deliberate process. In addition, although contracts were often put in place as a response to an urgent need, these contracts often languished in their transition into a military operated program (e.g., Navy's use of ScanEagle contracts for almost a decade). While this study was focused on finding efficiencies within existing military UAS programs, further research is recommended on contract accountability not only for cost and meeting mission goals, but perhaps more importantly the Services' accountability in transitioning away from contracts in a timely manner when appropriate.

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F. Summary

Based on the initial cost analysis performed, an in-depth costing analysis should be conducted, and this analysis should include full life-cycle costs vs. the annual cost summary estimation provided by FCoM. Analysis should focus on using civilian manpower in both the force mix proposals for launch and recovery operations and for providing each operational Air Force squadron a single "CAPs" worth (20 positions) of civilians for transit and non-kinetic ISR operations. From this initial analysis, the civilian conversion would be the most cost beneficial since previous results show a need to convert 2.5 CAPs worth of manpower to enlisted pilots to gain the same benefits as 1 CAP worth of government civilian pilots. However, detailed life-cycle analysis for the enlisted pilot cases could also provide baseline information to inform the appropriate decision makers.

While transitioning Air Force and Navy pilots to WO positions initially appears to provide annual savings, further cost analysis is required to not only show the full life-cycle costs for the individual positions, but also to include the cost of establishing such a rank structure within each of the Services for UAS operations (and if such a structure would extend beyond UAS into other career fields). Other staffing alternatives mentioned previously are either beyond the scope of this report (Total Force efficiencies) and/or are recommended for further research.

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9. Summary

A. Overview

The purpose of this study was to identify alternative staffing strategies to not only accomplish DoD's current UAS-related missions in a more cost-effective way, but to also help inform and address manpower decisions for the future as current practices become unsupportable based on enterprise growth. By focusing on DoD's mission requirements, along with each individual Service's approach to UAS staffing, several opportunities were identified. While a majority of the Department's UAS missions are conducted similarly across the Services, definite unique approaches are used for the larger (Group 4/5) aircraft. While this paper outlines specific mission areas in which to gain efficiencies, the most notable savings came from considering government civilians as a viable option within the greater UAS enterprise.

This chapter summarizes the overall report and provides recommendations for further research. The preliminary costing results presented in this paper should be followed by an in-depth cost analysis providing full life-cycle costs vs. the FCoM annual cost saving estimations used in support of this analysis.

In terms of defining which individuals, or category of performers, currently conduct and/or are able to execute DoD UAS operations the following was observed.

- Only uniformed military officers can hold positions of command (includes LDOs and WOs).
  LDOs and WOs are subcategories to the officer corps used by some Services to focus on and capture long-term technical expertise.
- The Air Force lacks a WO force structure and, although authorized by Title 10, requires additional overhead to establish such a program. Similarly, the Navy lacks a flight WO program.
- The DoD expeditionary workforce is defined as a DoD civilian subcategory that is organized, trained, and equipped for expeditionary operations

For identifying statutory guidance constraints associated with defining the DoD UAS enterprise, the researchers used guidance primarily from Title 10, DoDD 1100.4 ("Guidance for Manpower Management"), and DoDI 1100.22 ("Policy and Procedures for Determining Workforce Mix"). While Title 10 outlines specific requirements in terms of generic missions (armor, infantry, strategic airlift, and so forth), it does not direct any one

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Service to specifically maintain a UAS capability.[172] Nor does Title 10 direct a specific category of performer to conduct UAS operations.[173]

Title 10

Does NOT direct any singular Service to maintain a UAS program
Does NOT direct a specific category of performer to conduct UAS operations
Does NOT prescribe a percentage of force and/or rank to support UAS

While many intricacies are associated with workforce mix, DoD statutory guidance was distilled into the following three overarching questions in terms of the UAS task in question,

Force mix Analysis Questions

- Is the task inherently governmental?
- Is military incumbency required?
- Is the level of risk to force acceptable for civilians?

These questions built the framework for developing the decision tree in Figure 17 to analyze potential staffing alternatives. While this this generic roadmap is a simplification of the overall requirements, it helped define an appropriate balance across UAS missions and associated force integrated with elements of all categories of performers.

Using the decision tree in Figure 17 to review common mission elements associated with UAS operations highlighted several opportunities—specifically, the potential to use DoD civilians. As depicted in Figure 18, the only mission element that is not allowed for the civilian workforce is the employment of weapons. It was determined, however, that even in an organization responsible for weapons employment, there was an opportunity to balance its force between uniformed military and government civilians to meet mission requirements and take advantage of the associated manpower cost savings. While analysis also depicted that a contractor based force can conduct most of the mission elements,

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172 Example: Title 10, Volume III § 3062 and § 8062 outline Congress' intent for the Army and Air Force, respectively and, in some cases, outline generic structure (e.g., Army branches). However, it does not dictate a UA program. See Armed Forces, 10 U.S.C., Volume III § 3062 and § 8062.

173 For example Title 10 § 8067 dictates that Medical, Judge Advocate, and Chaplain services be performed by officers. There is no such designation for UA programs or even for pilots in general. This IDA paper does not advocate for such direction, but rather highlights the lack of Title 10 restrictions for an unrestricted development of alternative strategies within the constraints of existing generic manpower guidance. See Armed Forces, 10 U.S.C., Volume III § 8067.

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without comparable contract data, the research team was unable to determine an appropriate cost comparison.

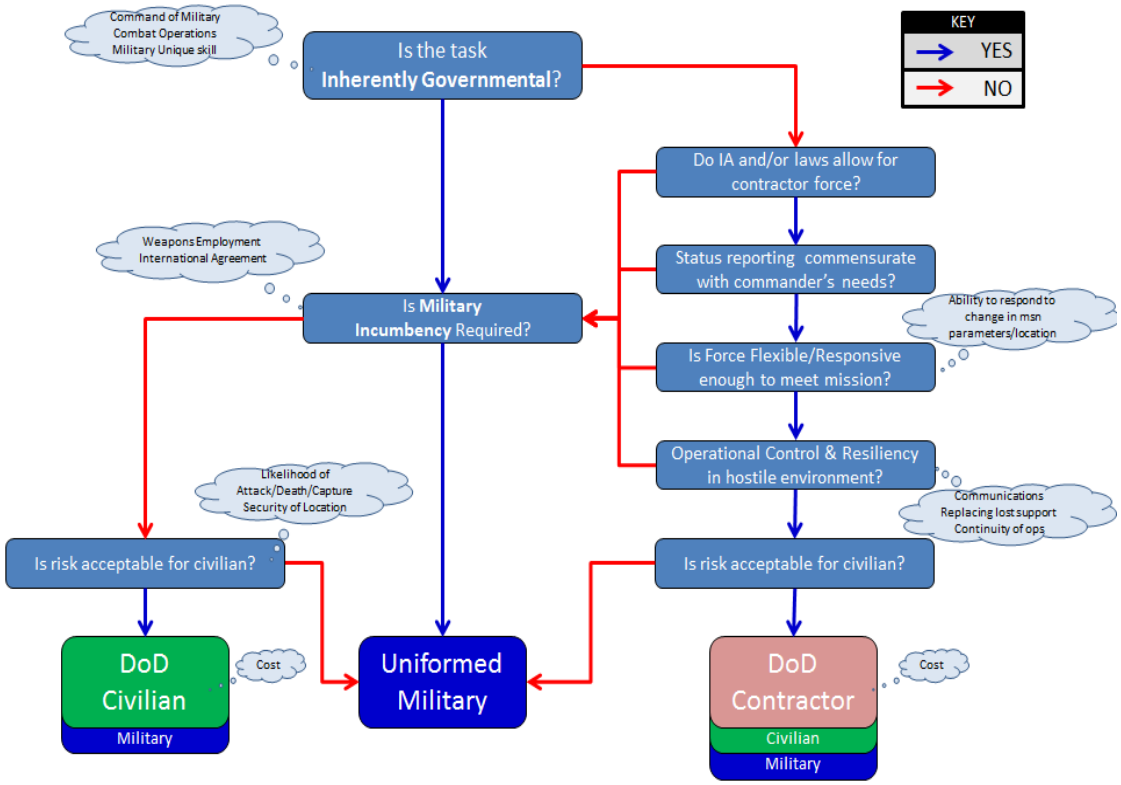


Figure 17. Category of Performer Decision Tree

Note: Subsequent analysis further breakdowns the military component into officer and enlisted subcategories.

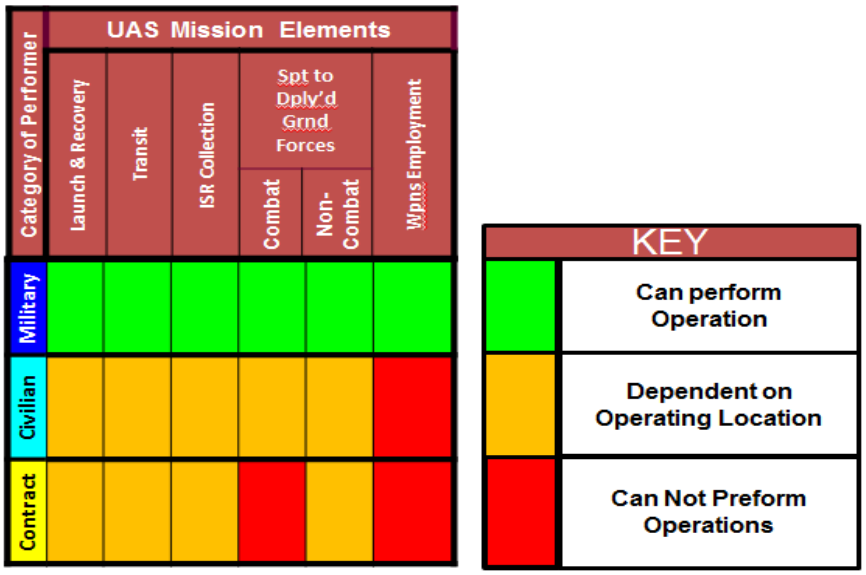
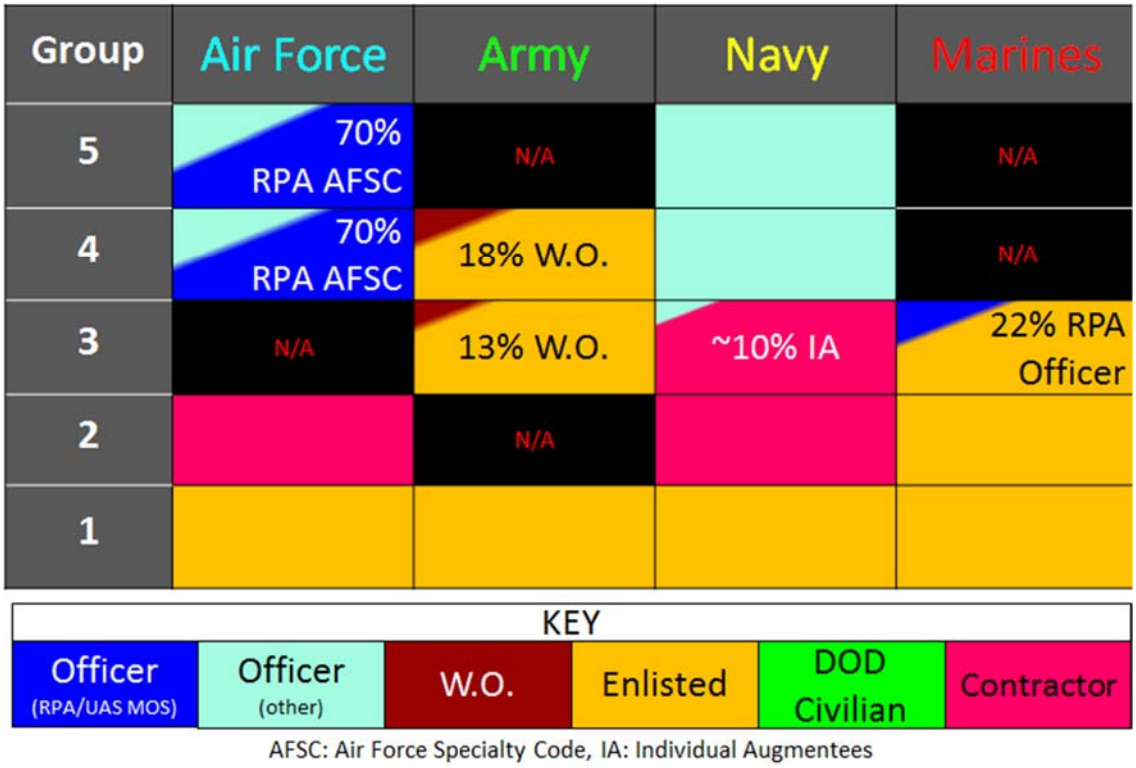


Figure 18. Summary of Mission Element Analysis

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The review of individual Service's practices revealed that many UAS operations were staffed similarly across the Services; however, there are some notable differences. As seen in Table 22., one such difference is the reliance of the Army on WOs to provide leadership within their Group 3/4 UAS units, whereas the other Services rely on officers above the rank of O-1. In addition, while the Air Force and Marines have a dedicated Officer corps for UAS, the Navy and Army do not. The Navy relies on the use of previously qualified pilots from similarly tasked aircraft while the Army relies on its UAS WOs.

Table 22. Service Category of Performer Summary (Pilots)



AFSC: Air Force Specialty Code, IA: Individual Augmentees

Note: This table summarizes the primary focus of those pilots used to control the aircraft. The Air Force and the Navy have approximately one-half their Group 4/5 UAS force as enlisted sensor operators.

In an effort to better understand staffing methodology commonalities across the Services, the business rules in Table 23 appeared as universal across DoD and as platform agnostic.

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Table 23. Business Rules for UAS Staffing

1	UAS operators assigned to a combat maneuver unit must be uniformed military personnel.
2	DoD civilians are not used to operate UAS.
3	"Officer equivalents'" are required for UAS operations within international airspace.
4	UAS sensor/mission payload operator positions are sourced solely with "enlisted equivalents."
5	Military officers are required for release authority of PGMs.
6	Cost of airframes and HD/LD nature of large UAS compel the use of officer pilots.

In addition to these business rules, the observations in Table 24 were identified additional discrepancies across the Services.

Table 24. UAS Staffing Observations

1	Service culture shapes how the roles and responsibilities are viewed for individual category of performers.
2	DoD-assigned missions/responsibilities and the anticipated operating environment shape how the Services view the role of their UAS.
3	The C2 concept of UAS operations (centralized vs. decentralized) and resultant authority required by aircrew relate directly to officer vs enlisted decision.
4	The Army stated the need for commissioned officer UAS career track or an additional skill identifier.
5	The Navy is the only Service that does not allow direct accessions to perform Group 4/5 pilot duties.
6	Demand for and development of UAS technology is in a period of exponential growth within the defense and commercial industries.
7	Maturation of technology will have an impact on the force presentation and staffing methodologies used within DoD's UAS enterprise.

As research continued to encounter the often emotional debate between the use of officers vs. enlisted, several aspects of this debate were considered in analyzing why the Services differed in their methodology. Distilling emotion and cultural biases from the equation, an illustrative model was used to depict the following three major aspects in deciding between officer vs. enlisted: (1) system complexity, (2) risk assumed and (3) operational environment.

Figure 19 illustrates the relationship between these events while also showing some of the attributes associated with each axis. The use of this illustrative relationship model helps to put the analysis of current Service practices and business rules into practice. While the analysis results that were discussed previously indicate that significant differences exist between Service staffing methodologies, the model in Figure 19 shows cases where such decisions are justifiable when viewed against the mission requirements of a particular Service's UAS force. While the choice to present forces using different categories of

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performers is justifiable in some cases, analysis of this community highlights not only the ability to gain manpower efficiencies, but also the opportunity for increased cooperation across the Services to capitalize on lessons learned within the enterprise.

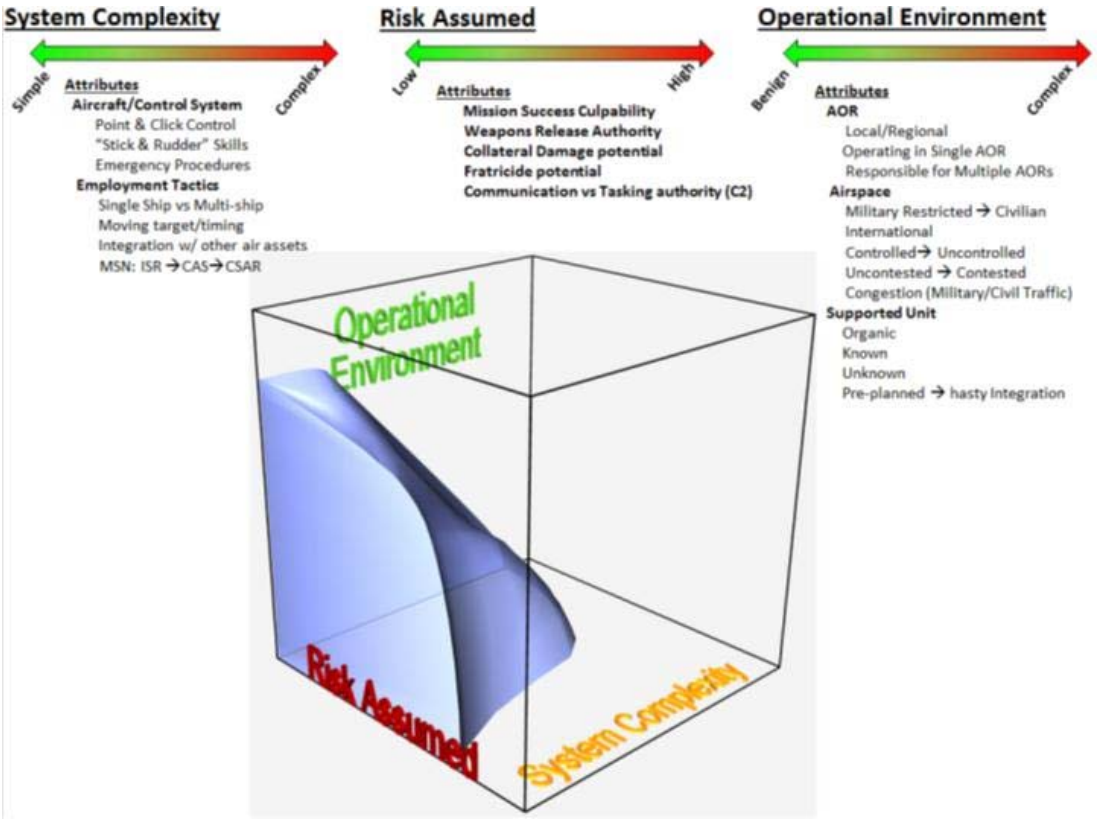


Figure 19. Complexity, Risk, and Environment Relationship

After defining business rules and identifying Service discrepancies and overall opportunities within the UAS enterprise, analysis turned to examining several workforce mix alternatives. As mentioned previously, the concept of considering government civilians as a viable option provided significant savings, especially when dedicating them to specific mission elements, such as conducting launch and recovery operations of Group 4/5 UAS. For the Air Force alone, if all of the launch and recovery assigned billets were transitioned to civilian positions, the annual savings would equate to $777,696 per LRE. Across all 15 assigned Air Force MQ-1/9 launch and recovery elements, this transition could account for an overall annual savings of approximately $11.7 million ($58.5 million over the FYDP).[174] However, it is operationally understood that an all-civilian LRE force would not meet Air Force requirements where risk, base defense requirement, and/or host

[174] Annual savings based upon FCoM numbers. See Appendix B. The $776,696 and $11.7 million totals are for full savings to the Federal Government. Savings specific to DoD are $610,776 and $9.16 million, respectively.

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nation agreements require military personnel. With this in mind, Table 25 depicts a force mix alternative across the 15 USAF LREs which should meet operational requirements.[175] As seen with four all-military LREs, five 60-40, three 20-80, and three all-civilian, the total cost savings is approximately $5.1 million annually ($25.65 million across the FYDP) by transitioning approximately half (74 of 150) of the LRE positions from military to civilian.[176]

Table 25. Costing of USAF LRE Civilian/Military Force Mix

UTCs	Annual Cost/LRE		# of UTCs	Sub-total		Billets	
	DoD	Fed Gov		DoD	Fed Gov	Mil	Civ
RPA LRE UTC (All Mil)	1,283,861	1,592,561	4	5,135,444	6,370,243	40	0
LRE UTC (2 Civ + 3 Mil)	1,158,832	1,400,764	5	5,794,160	7,003,820	30	20
LRE UTC (4 Civ + 1 Mil)	804,398	979,562	3	2,413,194	2,938,686	6	24
RPA LRE UTC (All Civ)	673,085	814,865	3	2,019,255	2,444,594	0	30
Total for 15 All-Military RPA LRE UTCs				19,257,915	23,888,415		
Total for 15 Force mix RPA UTCs (as presented above)				15,362,053	18,757,343		
Delta (i.e., savings)				3,895,862	5,131,072		

Note: Delta is between mix depicted and all 15 military LREs.

In addition to launch and recovery operations, the use of civilians to support transit operations (flying UAS to and from target) was analyzed. For Air Force Group 4 RPA, it was determined that approximately 18% of each sortie was spent flying to and from the target. Allowing for schedule flexibility during 24/7/365 UAS operations, it was recommended that each Air Force operational squadron transition 1 CAPs worth of manpower to civilian positions (20 positions), understanding the same individuals can perform basic mission support up to but not including weapons employment. As Table 26 shows, approximately $1.57 million annually is saved by converting 1 CAP (20 billets) worth of manpower to DoD civilians.[177] If each of the 10 operational Air Force MQ-1/9 squadrons

[175] A full mission analysis of Air Force LRE requirements was not conducted; however, this framework is general enough to meet a majority of Air Force LRE requirements based upon Group 4/5 LRE operations that typically occur in secure locations.

[176] Ten Operational Squadrons does not include the MQ-1/9 Training squadron at Holloman AFB or the LR squadron at Cannon and Creech AFBs. Savings totals are for full savings to the Federal Government. Savings specific to DoD are $3.9 million annually and $19.48 million over the FYDP.

[177] Since no model based upon mission analysis is available for the appropriate civil/military mix, best assumptions were made with the available data. Distribution of ranks and grades throughout the squadron was kept as close in line as possible with current Air Force RPA squadron structures.

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did this conversion, total program annual savings could total $13.65 million ($68.3 million across the FYDP).[178]

Although it is intuitive that manpower costs are less when using enlisted positions vs. officers, analysis explained the rationale behind this decision. However, since this discussion will undoubtedly continue, Table 26 depicts various percentages of officer-to-enlisted conversions considered for the Air Force's MQ-1/9 RPA.[179]

Table 26. Cost Comparison of USAF RPA Squadrons Using Enlisted

USAF RPA Squadron	Annual Cost		Delta (i.e., savings)	Pilot Billets	
	DoD	Fed Gov		Officer	Enlisted
All Officer	14,223,874	17,557,834	[redacted]	50	0
20% Enlisted	13,610,200	16,944,160	613,674	40	10
30% Enlisted	13,312910	16,646,870	910,964	35	15
40% Enlisted	13,000,585	16,334,545	1,223,289	30	20
50% Enlisted	12,714,217	16,048,231	1,509,603	35	25
60% Enlisted	12,401,946	15,735,906	1,821,928	20	30

Note: See Appendix B for the breakdown of positions converted. Commander (1), Operation Officer (1), and Squadron Operation Center Billets (5) are not included in enlisted conversion. In addition, the Delta is the same for the Federal Government and DoD.

While the initial cost analysis used Air Force MQ-1/9 RPA units, based on the information available, savings are also possible when applied to UAS programs in the other Services. Based on the initial cost analysis performed, it is recommended that an in-depth costing analysis be conducted that includes full life-cycle costs vs. the annual cost summary estimation provided by FCoM. Analysis should focus on using civilian manpower within the UAS workforce in support of launch and recovery operations and non-kinetic transit/ISR operations.

B. Recommendations for Further Research

In addition to identifying manpower alternatives, specifically through the use of government civilians within the UAS enterprise, the research team identified the following areas for potential future research:

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[178] Ten Operational Squadrons does not include the MQ-1/9 Training squadron at Holloman AFB or the LR squadron at Cannon and Creech AFBs. Savings represent savings to the Federal Government. DoD savings are $10.31 million annually or $51.58 million across the FYDP.

[179] As mentioned previously, the Air Force's Staff Judge Advocate's (SJA) office has interpreted Title 10, § 8691 to state the Air Force can only use officers as rated pilots. See Armed Forces, 10 U.S.C., Volume III § 8691.

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- Evaluate the accountability process to ensure that the contracts are temporary in nature where appropriate (e.g., Navy's use of contractors in support of UAS operations for over a decade).
- Evaluate staffing alternatives and potential manpower cost savings associated with the UAS maintenance force.
- Evaluate staffing alternatives and potential manpower cost savings associated with the intelligence processing, exploitation and dissemination workforce.
- Establish an Air Force WO program in terms of life-cycle costs and benefit.
- For the evolution of small UAS, determine how can/does the maturation of technology affect Service force presentation and staffing methodologies.
- Determine life-cycle costing for UAS career fields. Infancy of career field equates to a lack of data concerning life-cycle costs. Full study, to include civilian market impacts, is required to accurately estimate future government costs.
- Ensure the rapid development/acquisition of UAS systems. One unique aspect brought to UAS by SOCOM is the inherent ability for Special Operations Forces (SOF) to rapidly develop, acquire, and field emerging technologies. This capability brings dramatic changes to the entire UAS and holds the potential to change the level of support provided by smaller UAS.
- LDO career path: Open the Navy program to include UAS, create an LDO rank structure within the other Services, and/or open LDO accessions to the officer corps.
- Investigate potential efficiencies (manpower, resources, cost, and acquisition timelines) associated with consolidating similar Group 4/5 UAS platforms under a single service (i.e., MQ-1 and/or RQ-4 variants). Research should focus on consolidating platforms under a single Service or managing and operating platforms in more integrated manner. This approach may include everything from acquisition parity/interoperability standards to more radical ideas such as creating joint operational squadrons.

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Appendix A
Statutory Guidance Supporting Data

The following information provides the additional analysis information supporting Chapter 3.

A. Title 10 Foundation

Each Fiscal Year (FY), Congress approves the Department of Defense (DoD) budget, which defines the individual Services' authorized strength. U.S.C. Title 10 (hereafter referred to as Title 10) defines authorized strength as "the largest number of members authorized to be in an armed force."[1] Services are subsequently responsible for the application of that authorized strength across their respective core missions. Although Title 10 outlines specific requirements in terms of generic missions (armor, infantry, strategic airlift, and so forth), it does not direct any one Service to specifically maintain an Unmanned Aircraft System (UAS) capability.[2] Also, Title 10 does not direct a specific category of performer to conduct UAS operations.[3] Since budgetary constraints and mission requirements cause potentially large fluctuations in overall end strength and functional/technical component requirements, the following summary focuses on generic force mix statutory requirements rather than specific numbers or percentages of end strength, neither of which is specifically dictated by congressional and/or DoD statutory guidance.

While the authorized strength is defined by Service FY budgets, in accordance with Title 10, the Secretary of Defense is responsible for annually prescribing the total authorized active duty commissioned officers within each of the armed forces.[4] While Title 10 provides a table outlying the authorized force mix of field grade (O-4 to O-6) officers based upon overall officers allotted, the Service chiefs prescribe the strength of the individual

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1 Armed Forces, 10 U.S.C., Volume I § 101(b)(11) (Washington, DC: U.S. Government Printing Office, July 2011), http://armedservices.house.gov/index.cfm/files/serve?File_id=7C199E0E-1614-497F-A818-B5D5B4BF33B5. The definition also includes "a component, a branch, a grade, or any other category of the armed forces," but the truncated definition suffices for this discussion.

2 Example: Title 10, Volume III § 3062 and § 8062 outline Congress' intent for the Army and Air Force, respectively, and, in some cases, outline generic structure (e.g., Army branches). However, it does not dictate UA program. See Armed Forces, 10 U.S.C., Volume III § 3062 and § 8062 (Washington, DC: U.S. Government Printing Office, July 2011), http://armedservices.house.gov/index.cfm/files/serve?File_id=FC0173D5-F7D3-4D74-8D42-1B9E185B7C6B

3 For example Title 10 § 8067 dictates that Medical, Judge Advocate, and Chaplain services be performed by officers. There is no such designation for UA programs or even for pilots in general. See Armed Forces, 10 U.S.C., Volume III § 8067.

4 Armed Forces, 10 U.S.C., Volume I § 521.

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category of active duty officers within their Service.[5] However, this allocation of personnel is kept at the Service level and is not prescribed across any singular mission set or functional capability (i.e., no percentage of force/rank is directed to support UAS programs).

B. Category of Performer Determination

Department of Defense Directive (DoDD) 1100.4[6] is based upon accomplishing national military objectives with a "minimum manpower that is organized and employed to provide maximum effectiveness ….[7] It further lists flexibility, adaptability and "responsive[ness] to crisis situations and new management strategies"[8] as further guiding principles. Programs must also be supported by long-range strategies that implement Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities (DOTMLPF) policy changes while still maintaining a ready force. In determining the appropriate manpower requirements, the following points summarize DoDD 1100.4 guidance:[9]

Functions that are inherently governmental shall not be contracted.

- Manpower management shall be **flexible, adaptive** to program changes, and **responsive to crisis situations** and new management strategies.
- Enable development of **combat-related skills** or to promote career development in military competencies.
- National military objectives shall be accomplished with a **minimum of manpower** that is organized and employed to provide **maximum effectiveness and combat power**.
- Assigned missions shall be accomplished using the **least costly mix of personnel** (military, civilian, and contract) consistent with military requirements.
- **Consider all available sources** when determining manpower mix to include the **Active and Reserve** military, **civilian** manpower; **intra-governmental, contract,** and host-nation support.

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5 Armed Forces, 10 U.S.C., Volume I § 523

6 Department of Defense, "Guidance for Manpower Management," DoDD 1100.4 (Washington, DC: USD(P&R), February 12, 2005), http://www.dtic.mil/whs/directives/corres/pdf/110004p.pdf.

7 Ibid., 2.

8 Ibid.

9 Ibid. Guiding principles are a synopsis of Section 3.2 and those that are found relevant to this study (emphasis added).

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- **Manpower shall be designated as civilian except when military incumbency is required** for reasons of law, command and control of crisis situations, combat readiness, or esprit de corps; when unusual working conditions are not conducive to civilian employment; or when military-unique knowledge and skills are required for successful performance of the duties.[10]
- Sufficient manpower positions shall be **designated as civilian to develop competencies and skills that may not be taught or recruited directly from the private sector**.
- Manpower authorities shall designate **sufficient manpower to provide a rotation base** for military personnel.

While this relatively generic guidance dictates that force management strategies are appropriately driven by mission requirements and associated manpower costs (both addressed later in the analysis), DoDI 1100.22, "Policy and Procedures for Determining Workforce Mix," builds upon this direction and further outlines the delineation of manpower between uniformed military and civilian:[11]

Manpower shall be designated as civilian except when on or more of the following conditions apply:

- Military-unique knowledge and skills are required for performance of the duties.
- Military incumbency is required by law, E.o. [*sic* E.O.], treaty, or IA [international agreement].
- Military performance is required for command and control, risk mitigation, or esprit de corps.[12]
- Military manpower is needed to provide for overseas and sea-to-shore rotation, career development, or wartime assignments.
- Unusual working conditions or costs are not conducive to civilian employment.

These five principles provide a relatively simple outline for the delineation between uniformed military and DoD civilian, although the associated threshold for each remains

[10] Exemption for "esprit de corps" is further defined in Department of Defense Instruction (DoDI) 1100.2. It provides examples such as military bands, honor guards, Navy Blue Angels, military recruiters, and so forth. See Department of Defense, "Policy and Procedures for Determining Workforce Mix," DoDI 1100.22 (Washington, DC: USD(P&R), April 12, 2010), 37–38, http://www.dtic.mil/whs/directives/corres/pdf/110022p.pdf.

[11] Department of Defense, "Policy and Procedures for Determining Workforce Mix," DoDI 1100.22, 3.

[12] See Footnote 10.

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open to a wide set of interpretations. Analysis within this paper analyzes these thresholds against current Service missions and associated practices.

C. Inherently Governmental (IG)

Within DoDI 1100.22, the following table (Table A-1) is provided as an overview to assist DoD manpower analysts in making the appropriate determination. The term "exemption" is used throughout the table and subsequent discussion as that manpower that is exempted from private sector performance and is therefore IG.

Table A-1. Manpower Mix Criteria

A	Direction and Control of Combat and Crisis Situations		
B	Exemption of Combat Support and Combat Service Support due to Operational Risk		
D	Exemption of Manpower Dual-Tasked For Wartime Assignments		
E	DoD Civilian Authority Direction & Control	F	Military-Unique Knowledge & Skills
G	Exemption for Esprit de Corps		
H	Exemption for Continuity of Infrastructure Operations	I	Military Augmentation of the Infrastructure During War
J	Exemption for Civilian & Military Rotation	K	Exemption for Civilian & Military Career Development
L	Exemption by Law, Executive Order, Treaty or International Agreement		
M	Exempted by DoD Management Decision		
P	Pending Restructuring of Commercial Activities		
R	Subject to Review for Public-Private Competition		
W	Non-Packageable Commercial Activity		
X	Alternative to Public-Private Competition		

Source: Department of Defense, "Policy and Procedures for Determining Workforce Mix," DoDI 1100.22, 12.

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While this paper will not revisit the entire breakdown of the associated criteria, a synopsis of five pertinent criteria is provided to aid in future analysis.[13]

- **Direction and Control of Combat and Crisis Situations**. The following are aspects of these criteria that are all IG.
  - Command of military forces.
  - Operational control of combat, combat support, and combat service support units. Unlike civilians, military personnel must obey all lawful orders at all times and cannot quit or abandon their duties. Although civilians supporting combat operations may find themselves subject to the Uniform Code of Military Justice (UCMJ), only a military commanding officer can exercise that authority.
  - [Conduct of] combat operations. Not only is this criteria IG, but it must also be conducted by designated military forces (i.e., not DoD civilians). "When armed fighting or use of force is deemed necessary for national defense, the Department of Defense may authorize deliberate destructive and/or disruptive action …"[14] with the intent to destroy a hostile force or other military objective by means of employing "firepower and other destructive and disruptive capabilities."[15] Combat is also IG because we must hold military commanders and their forces "*accountable* for the appropriate and controlled use of combat power and adherence to rules of engagement and the law of war."[16] It is also crucial that military commanders execute "*discretionary judgment, leadership, knowledge, and discipline* necessary to perform effectively and responsibly *under fire.*"[17]

[13] Enclosure 4 of DoDI 1100.22 provides an in-depth review of all the criteria listed in Table A-1.

[14] Department of Defense, "Policy and Procedures for Determining Workforce Mix," DoDI 1100.22, 18.

[15] Ibid.

[16] Ibid., (emphasis added).

[17] Ibid., 19 (emphasis added).

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The description of this IG criterion states specifically that

> … manpower shall be designated military … if the *planned use of destructive combat capabilities is part of the mission* assigned to this manpower …. This includes manpower located both *inside and outside a theater of operations* if the personnel operate a weapon system against an enemy or hostile force (e.g., bomber crews, intercontinental ballistic missile crews, and *unmanned aerial vehicle operators*). This does not include technical advice on the operation of weapon systems or other support of non-discretionary nature performed in direct support of combat operations.[18]

– Security in hostile or volatile areas. Some security operations can be considered commercial; however, in general, if the security is provided for operations in "uncontrolled, unpredictable, unstable, high risk, or hostile environments" that function is considered IG.[19] The guidance further states that if there is a "*high likelihood of hostile fire, bombings, biological or chemical attacks*"[20] and the discretionary use of deadly force is expected, private security contractors are not authorized because this is an IG operation.[21] This section also includes operations that entail assisting, reinforcing or rescuing military and/or private security contractors.[22] Also, the security support is IG if "an offensive response to hostile acts or demonstrated hostile intentions would be required to operate in, or move resources through, a hostile area of operation."[23] The instruction further discusses the discretion during operations and when it drives IG operations. Manpower should be IG if "decisions on the appropriate course of action would require substantial discretion, the *outcome of which could significantly affect U.S. objectives* with regard to the life, liberty, or property of private persons, *a military mission*, or *international relations*."[24]

  Finally, this subsection of combat does address the role of contractors within combat support roles and the difference between self-defense and IG offensive operations. It provides the example that support organizations within a

[18] Ibid., (emphasis added).

[19] Ibid.

[20] Ibid., (emphasis added).

[21] Ibid., 20 (emphasis added).

[22] Ibid.

[23] Ibid.

[24] Ibid., (emphasis added).

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fielded military organization—Marines in this case—have an IG function because they must be armed and are expected to conduct offensive operations at any moment when attacked. However, as stated within the instruction, "if a military Service has a *new weapon system* available for use during hostilities, but *sufficient numbers of military maintainers are not yet trained*, the commander might be able to use contract maintenance in a *secure compound* without degrading the operational capability of the system. In such cases, only the IG security forces at the compound are coded [IG]. However, in such cases, contractor personnel may be issued weapons for self-defense."[25]

- **Exemption of CS [Combat Support] and CSS [Combat Service] Support due to Operational Risk.** This criterion expands on some of the combat criteria discussed previously. Support activities are considered IG if, in the judgment of the commander, any of the following are true:
  - Threat level could increase and military personnel would be needed on short notice to provide or augment a military capability.[26]
  - There would be an unsafe number of personnel in hostile area who are not combatants.[27]
  - DoD civilians or private sector contractors will not or cannot continue to perform their work. Includes, but is not limited to, work stoppage due to increased threat level, duration of hostilities, and/or a change in host nation support agreements. Also includes commander's discretion if "there is too great a risk that a contractor would default or not comply with the rules on the use of force."[28]
  - **There is too great a risk that an encounter with an enemy or hostile force would lead to hostilities** and necessitate assistance, reinforcement or rescue.[29]
  - DoD civilians will conduct IG work typically thought of as a commercial activity if their position is "**E-E [emergency-essential]** manpower that provides continuity of operations for essential functions, maintains the availability of combat-essential systems or performs duties critical to combat

[25] Ibid., 21 (emphasis added).

[26] Ibid., 24.

[27] Ibid.

[28] Ibid.

[29] Ibid., (emphasis added).

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operations in overseas locations during a crisis when other civilians are evacuated."[30] These positions are IG when they cannot be vacated or eliminated during a mobilization or other national emergency without seriously impairing the ability of the activity to function effectively. Examples include "supply and maintenance of strategic weapons system … [and] logistical support elements that deploy to hostile areas."[31]

- **Exemption of manpower dual-tasked for wartime assignments.** This criterion is summarized as those functions conducted during peacetime that could easily be accomplished by the commercial sector. However, in the event of a contingency, that function/position is required to mobilize and conduct an IG function (typically those described previously).[32]
- **DoD civilian authority, direction, and control.** This criterion focuses on functions that, although conducted by civilians, are directly and ultimately accountable for accomplishment of missions and/or discretionary exercise of DoD authority.[33] It also includes the IG requirement for those positions where "Defense officials require the incumbent's judgment and insight to make informed decisions and preclude sole reliance on contract advisory assistance."[34]
- **Military-unique knowledge and skills.** This criterion includes manpower that "directs and controls intelligence and counterintelligence operations."[35]

D. Risk Assessment and Determining IG Activities

While the criteria listed in Chapter 3 provide a strong framework for deciding what is and what is not IG, many of these criteria can be contested when discussing UAS operations, especially with today's fiscally constrained environment. As such, the integration of risk analyses is critical to the process. DoDI 1100.22 states that when addressing contractual obligations, risk should be considered "to preclude ceding governmental control and authority of IG functions to the private sector where there is insufficient public **accountability and transparency**."[36] It also discusses analyzing the **operational/ logistical "footprint**" associated with various workforce mix solutions as an overly large

[30] Ibid., 26 (emphasis added).

[31] Ibid.

[32] Ibid.

[33] Ibid., 28.

[34] Ibid., 29.

[35] Ibid., 36.

[36] Ibid., 46 (emphasis added).

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footprint could limit flexibility and introduce an unacceptable level of risk.[37] In addition to these considerations, the following key points summarize the risk factors associated with analyzing risk associated with the command and control of possible workforce mix options:

- **Readiness reporting.** Commanders must have visibility of the readiness of critical support elements to judge the readiness of the military force to conduct and/or sustain military operations. The instruction (DoDI 1100.22) recommends analyzing historical records/studies to indicate whether contractors or DoD emergency-essential employees "perform satisfactorily under environmental conditions, threat levels and for the length of time required.[38]"
- **Replacing lost support.** This loss may be due to combat loss (for this study, an aircraft and/or operator) and/or contractual failure to support. Planners must determine whether alternate sources of support can be obtained in-house or from an alternate private sector provider in the time required for operations.[39]
- **Continuity of operations during hostilities**. Can a contractor sustain operations during hostilities and adjust to situations in which employees are killed or injured, equipment is damaged or destroyed equipment, employees have to be rotated during protracted conflict, and so forth?[40]
- **Operational control in hostile environments**. This factor is closely related to the criteria described under "Exemption of CS and CSS Support due to Operational Risk." In this section, the instruction raises several key points focused on individual/unit performance once attacked and/or involved in hostilities. In first addressing the risk of non-performance, it highlights that although contractors and DoD civilians fall under the UCMJ during war or qualifying contingency operations, the articles dealing with desertion and absence without leave apply specifically to "a member of the armed force"[41] and likely do not apply to civilians. Therefore, the instruction points out that "DoD civilian and DoD contractor employees arguably may quit their jobs or not perform their duties without risk of criminal prosecution under the UCMJ."[42] It also points out that misbehavior before the enemy also only applies to a uniformed military member. This misbehavior includes things such as "running away and cowardly conduct in the

[37] Ibid., 53(emphasis added).

[38] Ibid., 49.

[39] Ibid.

[40] Ibid.

[41] Ibid., 50.

[42] Ibid.

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presence of the enemy and not affording all practicable relief and assistance to other troops when engaged in battle."[43]

This portion of the risk assessment also addresses the need for a military commander to have direct control and unconstrained access/use of all personnel to reconstitute essential support functions after an attack. The need for flexibility and responsiveness is paramount during these situations.

> Commanders often cannot compel DoD civilians or contractor employees to perform work or assume risks that were not agreed upon under the terms of their employment or covered in the terms of the contract. In emergency situations, a military commander may direct DoD civilians to take lawful actions. However, a military commander may only direct contractor employees to take lawful actions so long as those actions do not require them to assume IG responsibilities and the actions are covered by the terms of the contract.[44]

This same consideration is similar when looking at the responsiveness required by military commanders during times of conflict. Since contractor employees do not fall under the direct supervision of the military commander, a contracting officer serves as the liaison between the commander and the contract employee's employer, who is ultimately responsible for that employee's performance. These added layers and separate "contractual lines of authority could hamper or overly complicate the commander's control and constitute an inappropriate risk."[45]

- **Discipline authority.** As mentioned previously, during a declared war or qualifying contingency operation, contractors may fall under UCMJ jurisdiction; however, limits related to the overall guidance associated with the implementation of that jurisdiction "could overly complicate operations in high-risk situations."[46] These limits can also present challenges in the case where a contractor force may not be held to the same level of professionalism one desires by a force conducting operations in a foreign sovereign nation, which could entail everything from lewd contact to disrespect of another's culture.
- **Restrictions due to laws and IAs.** While IAs, such as a Status of Forces Agreement, will often dictate the jurisdiction and interactions concerning military and civilian personnel, there may be situations where these guidelines do not exist or

[43] Ibid.

[44] Ibid., 50–51.

[45] Ibid., 51.

[46] Ibid.

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do not cover all situations applicable. In these cases, civilians may find themselves subject to the host nations laws and jurisdiction. An additional consideration for the use of civilians is the Law of War. Civilians authorized to operate with armed forces may be captured. This capture is not a violation of the Law of War, and they are entitled prisoner of war (POW) status. They may also be armed to provide self-defense; however, they can then also be targeted in the event they are taking a direct part in hostile activities.[47]

E. Kinetic Weapons Employment Notes

Although this paper limits the discussion of UAS weapons employment to those that are offensive in nature, it does not negate the use of offensive firepower under "self-defense" Rules of Engagement (ROE) (i.e., employing weapons from an UAS in support of another force currently under, or impending, attack). However, this paper contends that when employing weapons under such conditions (i.e., Self-Defense (of others) ROE), this situation is an offensive employment and requires military personnel. This paper does not consider self-defense of the UAS itself (i.e., employing weapons on a surface to air threat) justification for a non-military crewmember to employ weapons.[48] In addition, when discussing weapons employment, this paper refers to those weapons that are kinetic in nature (i.e., depart the UA (examples: AGM-114 "Hellfire" missile or GBU-12 laser-guided bomb)). For this paper, the employment of kinetic weapons also includes providing terminal guidance for said weapons. For example, a UA that provides the laser energy to guides a weapon(s) to the intended target would be conducting kinetic weapons operations. As technology and UAS capabilities increase, the use of the UAS itself, typically a smaller UA, as a weapon is also feasible. Such an employment is also included as "kinetic" in this discussion.[49]

Historically, the scope of who is considered "involved" in such kinetic operations has also been debated. This paper limits the scope to the physical act of commanding (i.e., "squeezing the trigger") the following: (1) release of the weapon(s) and/or (2) terminal

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[47] Ibid.

[48] This legal concept is one that can be debated and one on which additional research can be executed. This paper recommends that if an unmanned aircraft (UA) is operating within a threat, or anticipated threat, where Self Defense ROE against a surface to air threat is possible, the appropriate crew manning for such a mission is military, thereby removing the necessity of swapping crews for employment. Such a swap is likely ill-timed and can create additional operational confusion.

[49] This paper does not address any "non-kinetic" weapons employed in various forms of electronic warfare (EW), electronic attack (EA) and/or computer network attack (CNA). ROE for these operations should follow those established for similar operations. For example, if a CNA capability is somehow employed from, and by, an UA crew, the determination for category of performer should mirror that of the Cyber community. In addition, the issue of non-uniformed military/DoD civilian UAS crew/operators passing coordinates, information and/or a target description that would enable a subsequent strike(s) is also not addressed since it is beyond the scope of this paper.

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guidance (e.g., firing laser energy). Also included is the Aircraft Commander during such operations (if/when this individual is different from the person squeezing the trigger). Supporting positions outside of these functions, such as those who provide intelligence for the strike, remain under the policies and practices of those respective functions and career fields.

While the statutory guidance outlined in DoDI 1100.22 is quite clear about military incumbency required to "operate a weapon system against an enemy or hostile force,"[50] the following concept was used by researchers to further amplify and clarify the role of kinetic weapons employment and terminal guidance (as discussed in Chapter 3):[51]

> Uniformed military personnel are required for all UAS operations which include the employment of, and/or provide terminal guidance to, kinetic weapons. Military incumbency is also required for those operations where the UAS crew is in direct support of forces that face the potential of, or are directly engaged in, armed hostilities.

This concept highlights the importance that the Services place on the military incumbency required when UAS crews are directly supporting forces engaged in, or face the near-term potential of, hostilities. It is derived from the belief that the decisions and contributions made by the UAS crew in the act of such support, whether their aircraft is armed or not, have a great influence on the outcome and likely survival of those supported forces (e.g., UAS aircrew informing ground forces which direction suspected enemy fire is coming from). As such, this type of operation not only represents the "exercise of substantial discretion when applying Federal Government authority"[52] as defined by DoDI 1100.22 for IG activities, but is also so inherently a part of combat operations that it drives the requirement further to one of military incumbency

F. UAS Force Mix Principles and Definitions Derived

1. Hierarchy of Performers

Statutory guidance makes it clear that IG functions cannot be contracted and that DoD civilians cannot function in roles where military incumbency is required. Through this same guidance, it is implied that there is a hierarchy of the manpower categories of performers. While DoD civilian employees are the preferred solution when appropriate for

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[50] Department of Defense, "Policy and Procedures for Determining Workforce Mix," DoDI 1100.22, 19.

[51] Ibid.

[52] Ibid., 13.

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non-warfighting Combatant Command requests for forces,[53] if it is appropriate for a DoD civilian, a military member can also fill that role. Conversely, if the function is IG, it cannot be filled by a contracted manpower. Those roles that are appropriate for a contractor can be filled by either a DoD civilian or uniformed military member; however, those functions that require military incumbency can by definition only be fulfilled by uniformed military personnel.

2. Mission-Focused IG Criteria

In determining whether DoD UAS operations are IG, we look specifically at the mission-focused criteria, pertinent to this paper, as listed in Chapter 3:

Key Mission Focused Criteria for IG Determination

- Command of military forces
- Operational control of combat, combat support, and combat service support units
- Conduct of combat operations
- Peacetime commercial function that, in the event of a contingency, is required to mobilize and conduct an IG function
- Ultimately accountable for accomplishment of missions and/or discretionary exercise of DoD authority
- Military-unique knowledge and skills

Focusing specifically on these key mission elements, the first element is rather straightforward: if a position is responsible for the command of military positions, then it also must be military. The next two elements require a definition of the term "combat" in the context of a UAS program. While the employment of weapons from a UA is easily seen as combat, a few specific points require attention. For example, if a UA is armed but there is no possibility of it engaging in weapons employment, does it have to be operated by the military? If a UAS is flown remotely from the Continental United States (CONUS) but is watching ground/naval troops engage in armed conflict on foreign soil/water, does that cross the threshold for "combat ops" in determining whether the mission is IG? Does the determination change if the UAS is simply collecting intelligence and no U.S. or allied ground/naval forces are present? This paper contends that there is a difference, and, while there will always be an element of "it depends," the following definition is provided to clarify the issue in future analysis. In defining combat for associated UAS programs, it was

[53] Department of Defense, "DoD Civilian Expeditionary Workforce," DoDD 1404.10 (Washington, DC: USD(P&R), 29 January 2009), 3, http://www.dtic.mil/whs/directives/corres/pdf/140410p.pdf.

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found this issue was closely tied to the criteria associated with the discretionary exercise of DoD authority. A UAS tasked on a relatively benign mission of collecting video and/or signals intelligence is, in the view of this paper, vastly different from a UAS responsible for the integration with and successful completion of a ground/ naval unit engaged in hostilities. While no specific statutory guidance "spells it out," this paper contends that if U.S. (or allies) forces involved in hostilities are directly supported by UAS, the intent of the statutory guidance is to have that responsibility for mission success in the hands of the U.S. government. Therefore, it is an IG function.

> **UAS Combat.** UAS program activities are considered combat related if there is a possibility that the UAS crew member will be responsible for the employment of kinetic weapons.[54] Also included are operations where the UAS crews are in direct support of forces that face the potential of, or are directly engaged in, armed hostilities.

Therefore, in terms of IG criteria, combat-related operations and/or positions responsible for the operational control of units conducting such operations must be IG.

Turning back to the original questions posed about combat and weapons employment, it was also determined that operating a UA with weapons on board and the actual employment of those weapons are different. Comparing the operation of an armed UA with the transportation of ammunition, the dividing line between IG and non-IG comes in the physical employment of said weapons. As future analysis will show, this delineation is important when looking specifically at the larger UAS launch and recovery operations.

The final two mission-focused criteria are the most subjective. These criteria are easily debated and require full analysis when looking at alternatives. For example, is the launch and recovery of a UAS a "military-unique" skill? Since several civilian companies are now operating UAS, one could easily assess this as "no, it is not IG." However, one could also assess that although operating a UAS is a commercial skill set, it is also one required to mobilize in the event of a contingency.[55] The decision then focuses on whether the mobilized mission constitutes an IG activity. Once again, it depends. In analyzing

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[54] As mentioned previously, this paper limits the scope of employing weapons to the physical act of commanding (i.e., "squeezing the trigger") the following: (1) release of the weapon(s) and/or (2) terminal guidance (e.g., firing laser energy). Also included is the Aircraft Commander during such operations (if/when individual is different from the person "squeezing the trigger"). Supporting positions outside these functions, such as those who provide intelligence for the strike, remain under the policies and practices of those respective functions and career fields.

[55] In the event that the UAS operated at the launch and recovery element requires the crew to employ weapons in an offensive posture, the function would indeed become IG.

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alternatives, this paper has used these two criteria. However, doing so has not provided a clear black and white line, but rather shows that alternatives must be analyzed based on the mission requirements and potential operational environment.

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Appendix B
FCOM Costing Reports

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Organization Comparison Summary				
Organization Name	**Calendar Year**	**Cost to Component**	**Department of Defense**	**Cost to Fed. Govt.**
USAF RPA LRE UTC (2 Civ+3 Mil)	2014	$1,073,677.99	$1,158,831.99	$1,400,763.99
USAF RPA LRE UTC (All Military)	2014	$1,144,650.76	$1,283,860.76	$1,592,560.76
USAF RPA LRE UTC (4 Civ+ 1Mil)	2014	$773,300.05	$804,398.05	$979,562.05
USAF RPA LRE UTC (Civilian)	2014	$669,014.53	$673,084.53	$814,864.53

USAF RPA LRE UTC (2 Civ+3 Mil) (2014)		
Cost to Component(s)	**Department of Defense**	**Cost to Fed. Govt.**
$1,073,677.99	$1,158,831.99	$1,400,763.99

Military Summary - Air Force				
Billets	**PG | YOS | AFSC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
1	E-5 | 6 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
1	E-7 | 15 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$114,941.37	$128,862.37	$159,732.37
2	O-3 | 6 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$282,542.34	$310,384.34	$372,124.34
2	O-4 | 11 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$331,638.10	$359,480.10	$421,220.10

Civilian GS Summary				
Billets	**PG | Step | Series | Location | Occupation | Component**	**Component**	**Department of Defense**	**Fed. Govt.**
2	GS5 | 5 | 2181 | WORLDWIDE: WORLDWIDE | 2181: Aircraft Operation | Air Force	$91,249.64	$92,063.64	$120,419.64
2	GS11 | 5 | 2181 | WORLDWIDE: WORLDWIDE | 2181: Aircraft Operation | Air Force	$165,599.20	$166,413.20	$194,769.20

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Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

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Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	15
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$114,941.37	$128,862.37	$159,732.37	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$49,010.40
Component	BAH	$20,284.00
Component	Retired Pay Accrual (RPA)	$15,879.37
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

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Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-3
YOS	6
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$141,271.17	$155,192.17	$186,062.17	$140,318.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$64,983.60
Component	BAH	$21,575.00
Component	Retired Pay Accrual (RPA)	$21,054.69
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$9,912.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

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Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-4
YOS	11
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$165,819.05	$179,740.05	$210,610.05	$169,078.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$79,117.20
Component	BAH	$25,617.00
Component	Retired Pay Accrual (RPA)	$25,633.97
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$11,705.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

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Position Attributes

Category	Selection
Year	2014
Military Component	Air Force
Pay Grade	GS5
Series	: 2181: Aircraft Operation
Step	5

Civilian Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Programmed Amount
$45,624.82	$46,031.82	$60,209.82	$42,830.96

Civilian Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$31,401.00
Component	OC11 Load Factor	$1,161.84
Component	Fringe Benefit Factor (OC12)	$11,429.96
Component	OC13 Load Factor	$628.02
Component	Training	$1,004.00
Component	Civilian Recruiting	$0.00
Component	Additional Labor Cost	$0.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries (OCONUS only)	$407.00
FED	Additional Labor Cost	$0.00
FED	Unfunded Civilian Retirement (CSRS only)	$8,350.00
FED	Postretirement Health Benefit	$5,805.00
FED	Postretirement Life Insurance	$23.00

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Position Attributes

Category	Selection
Year	2014
Military Component	Air Force
Pay Grade	GS11
Series	: 2181: Aircraft Operation
Step	5

Civilian Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Programmed Amount
$82,799.60	$83,206.60	$97,384.60	$78,514.57

Civilian Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,562.00
Component	OC11 Load Factor	$2,129.79
Component	Fringe Benefit Factor (OC12)	$20,952.57
Component	OC13 Load Factor	$1,151.24
Component	Training	$1,004.00
Component	Civilian Recruiting	$0.00
Component	Additional Labor Cost	$0.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries (OCONUS only)	$407.00
FED	Additional Labor Cost	$0.00
FED	Unfunded Civilian Retirement (CSRS only)	$8,350.00
FED	Postretirement Health Benefit	$5,805.00
FED	Postretirement Life Insurance	$23.00

USAF RPA LRE UTC (All Military) (2014)

Cost to Component(s)	Department of Defense	Cost to Fed. Govt.
$1,144,650.76	$1,283,860.76	$1,592,560.76

Military Summary - Air Force

Billets	PG | YOS | AFSC | Location	Component	Department of Defense	Fed. Govt.
1	E-7 | 15 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$114,941.37	$128,862.37	$159,732.37
2	E-5 | 6 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$175,414.68	$203,256.68	$264,996.68
1	O-4 | 11 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$165,819.05	$179,740.05	$210,610.05
4	O-3 | 6 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$565,084.68	$620,768.68	$744,248.68
2	E-3 | 2 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$123,390.98	$151,232.98	$212,972.98

158 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	15
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$114,941.37	$128,862.37	$159,732.37	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$49,010.40
Component	BAH	$20,284.00
Component	Retired Pay Accrual (RPA)	$15,879.37
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

159 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

160 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-4
YOS	11
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$165,819.05	$179,740.05	$210,610.05	$169,078.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$79,117.20
Component	BAH	$25,617.00
Component	Retired Pay Accrual (RPA)	$25,633.97
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$11,705.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

161 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-3
YOS	6
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$141,271.17	$155,192.17	$186,062.17	$140,318.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$64,983.60
Component	BAH	$21,575.00
Component	Retired Pay Accrual (RPA)	$21,054.69
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$9,912.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

162 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-3
YOS	2
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$61,695.49	$75,616.49	$106,486.49	$51,365.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$23,025.60
Component	BAH	$5,218.00
Component	Retired Pay Accrual (RPA)	$7,460.29
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,186.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

USAF RPA LRE UTC (4 Civ+ 1Mil) (2014)

Cost to Component(s)	Department of Defense	Cost to Fed. Govt.
$773,300.05	$804,398.05	$979,562.05

163 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Military Summary - Air Force				
Billets	**PG | YOS | AFSC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
1	E-7 | 1 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$93,783.32	$107,704.32	$138,574.32
1	O-4 | 11 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$165,819.05	$179,740.05	$210,610.05

Civilian GS Summary				
Billets	**PG | Step | Series | Location | Occupation | Component**	**Component**	**Department of Defense**	**Fed. Govt.**
4	GS5 | 5 | 2181 | WORLDWIDE: WORLDWIDE | 2181: Aircraft Operation | Air Force	$182,499.28	$184,127.28	$240,839.28
4	GS11 | 5 | 2181 | WORLDWIDE: WORLDWIDE | 2181: Aircraft Operation | Air Force	$331,198.40	$332,826.40	$389,538.40

164 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	1
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$93,783.32	$107,704.32	$138,574.32	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$33,030.00
Component	BAH	$20,284.00
Component	Retired Pay Accrual (RPA)	$10,701.72
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

165 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-4
YOS	11
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$165,819.05	$179,740.05	$210,610.05	$169,078.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$79,117.20
Component	BAH	$25,617.00
Component	Retired Pay Accrual (RPA)	$25,633.97
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$11,705.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

166 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Position Attributes

Category	Selection
Year	2014
Military Component	Air Force
Pay Grade	GS5
Series	: 2181: Aircraft Operation
Step	5

Civilian Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Programmed Amount
$45,624.82	$46,031.82	$60,209.82	$42,830.96

Civilian Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$31,401.00
Component	OC11 Load Factor	$1,161.84
Component	Fringe Benefit Factor (OC12)	$11,429.96
Component	OC13 Load Factor	$628.02
Component	Training	$1,004.00
Component	Civilian Recruiting	$0.00
Component	Additional Labor Cost	$0.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries (OCONUS only)	$407.00
FED	Additional Labor Cost	$0.00
FED	Unfunded Civilian Retirement (CSRS only)	$8,350.00
FED	Postretirement Health Benefit	$5,805.00
FED	Postretirement Life Insurance	$23.00

167 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Position Attributes

Category	Selection
Year	2014
Military Component	Air Force
Pay Grade	GS11
Series	: 2181: Aircraft Operation
Step	5

Civilian Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Programmed Amount
$82,799.60	$83,206.60	$97,384.60	$78,514.57

Civilian Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,562.00
Component	OC11 Load Factor	$2,129.79
Component	Fringe Benefit Factor (OC12)	$20,952.57
Component	OC13 Load Factor	$1,151.24
Component	Training	$1,004.00
Component	Civilian Recruiting	$0.00
Component	Additional Labor Cost	$0.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries (OCONUS only)	$407.00
FED	Additional Labor Cost	$0.00
FED	Unfunded Civilian Retirement (CSRS only)	$8,350.00
FED	Postretirement Health Benefit	$5,805.00
FED	Postretirement Life Insurance	$23.00

USAF RPA LRE UTC (Civilian) (2014)

Cost to Component(s)	Department of Defense	Cost to Fed. Govt.
$669,014.53	$673,084.53	$814,864.53

Civilian GS Summary

Billets	PG | Step | Series | Location | Occupation | Component	Component	Department of Defense	Fed. Govt.
4	GS11 | 5 | 2181 | WORLDWIDE: WORLDWIDE | 2181: Aircraft Operation | Air Force	$331,198.40	$332,826.40	$389,538.40
4	GS5 | 5 | 2181 | WORLDWIDE: WORLDWIDE | 2181: Aircraft Operation | Air Force	$182,499.28	$184,127.28	$240,839.28
1	GS7 | 5 | 2181 | WORLDWIDE: WORLDWIDE | 2181: Aircraft Operation | Air Force	$56,273.80	$56,680.80	$70,858.80
1	GS12 | 5 | 2181 | WORLDWIDE: WORLDWIDE | 2181: Aircraft Operation | Air Force	$99,043.05	$99,450.05	$113,628.05

168 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Position Attributes

Category	Selection
Year	2014
Military Component	Air Force
Pay Grade	GS11
Series	: 2181: Aircraft Operation
Step	5

Civilian Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Programmed Amount
$82,799.60	$83,206.60	$97,384.60	$78,514.57

Civilian Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,562.00
Component	OC11 Load Factor	$2,129.79
Component	Fringe Benefit Factor (OC12)	$20,952.57
Component	OC13 Load Factor	$1,151.24
Component	Training	$1,004.00
Component	Civilian Recruiting	$0.00
Component	Additional Labor Cost	$0.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries (OCONUS only)	$407.00
FED	Additional Labor Cost	$0.00
FED	Unfunded Civilian Retirement (CSRS only)	$8,350.00
FED	Postretirement Health Benefit	$5,805.00
FED	Postretirement Life Insurance	$23.00

169 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Position Attributes

Category	Selection
Year	2014
Military Component	Air Force
Pay Grade	GS5
Series	: 2181: Aircraft Operation
Step	5

Civilian Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Programmed Amount
$45,624.82	$46,031.82	$60,209.82	$42,830.96

Civilian Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$31,401.00
Component	OC11 Load Factor	$1,161.84
Component	Fringe Benefit Factor (OC12)	$11,429.96
Component	OC13 Load Factor	$628.02
Component	Training	$1,004.00
Component	Civilian Recruiting	$0.00
Component	Additional Labor Cost	$0.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries (OCONUS only)	$407.00
FED	Additional Labor Cost	$0.00
FED	Unfunded Civilian Retirement (CSRS only)	$8,350.00
FED	Postretirement Health Benefit	$5,805.00
FED	Postretirement Life Insurance	$23.00

170 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Position Attributes

Category	Selection
Year	2014
Military Component	Air Force
Pay Grade	GS7
Series	: 2181: Aircraft Operation
Step	5

Civilian Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Programmed Amount
$56,273.80	$56,680.80	$70,858.80	$53,052.78

Civilian Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$38,895.00
Component	OC11 Load Factor	$1,439.12
Component	Fringe Benefit Factor (OC12)	$14,157.78
Component	OC13 Load Factor	$777.90
Component	Training	$1,004.00
Component	Civilian Recruiting	$0.00
Component	Additional Labor Cost	$0.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries (OCONUS only)	$407.00
FED	Additional Labor Cost	$0.00
FED	Unfunded Civilian Retirement (CSRS only)	$8,350.00
FED	Postretirement Health Benefit	$5,805.00
FED	Postretirement Life Insurance	$23.00

171 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Position Attributes

Category	Selection
Year	2014
Military Component	Air Force
Pay Grade	GS12
Series	: 2181: Aircraft Operation
Step	5

Civilian Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Programmed Amount
$99,043.05	$99,450.05	$113,628.05	$94,106.45

Civilian Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$68,993.00
Component	OC11 Load Factor	$2,552.74
Component	Fringe Benefit Factor (OC12)	$25,113.45
Component	OC13 Load Factor	$1,379.86
Component	Training	$1,004.00
Component	Civilian Recruiting	$0.00
Component	Additional Labor Cost	$0.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries (OCONUS only)	$407.00
FED	Additional Labor Cost	$0.00
FED	Unfunded Civilian Retirement (CSRS only)	$8,350.00
FED	Postretirement Health Benefit	$5,805.00
FED	Postretirement Life Insurance	$23.00

172 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

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Organization Comparison Summary				
Organization Name	**Calendar Year**	**Cost to Component**	**Department of Defense**	**Cost to Fed. Govt.**
USAF RPA MCE (All Military)	2014	$12,720,405.89	$14,223,873.89	$17,557,833.89
USAF RPA MCE (1 Civ CAP)	2014	$11,967,304.92	$13,192,352.92	$16,192,472.92

USAF RPA MCE (All Military) (2014)		
Cost to Component(s)	**Department of Defense**	**Cost to Fed. Govt.**
$12,720,405.89	$14,223,873.89	$17,557,833.89

Military Summary - Air Force				
Billets	**PG | YOS | AFSC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
49	O-3 | 6 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$6,922,287.33	$7,604,416.33	$9,117,046.33
6	O-4 | 11 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$994,914.30	$1,078,440.30	$1,263,660.30
5	E-7 | 15 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$574,706.85	$644,311.85	$798,661.85
1	O-5 | 16 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$191,064.79	$204,985.79	$235,855.79
1	E-9 | 20 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$144,742.76	$158,663.76	$189,533.76
1	E-5 | 6 | 8T0x0 : Professional Military Education Instructor | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
10	E-3 | 2 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$616,954.90	$756,164.90	$1,064,864.90
1	E-5 | 6 | 3S2x1 : Education And Training | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
1	E-8 | 18 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$128,312.23	$142,233.23	$173,103.23
8	E-4 | 4 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$608,326.88	$719,694.88	$966,654.88
1	O-5 | 14 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$183,529.11	$197,450.11	$228,320.11
10	E-6 | 7 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$952,249.30	$1,091,459.30	$1,400,159.30
14	E-5 | 6 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,227,902.76	$1,422,796.76	$1,854,976.76

174 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-3
YOS	6
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$141,271.17	$155,192.17	$186,062.17	$140,318.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$64,983.60
Component	BAH	$21,575.00
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$9,912.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$21,054.69
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

175 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-4
YOS	11
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$165,819.05	$179,740.05	$210,610.05	$169,078.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$79,117.20
Component	BAH	$25,617.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$25,633.97
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$11,705.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00

176 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	15
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$114,941.37	$128,862.37	$159,732.37	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$49,010.40
Component	BAH	$20,284.00
Component	Retired Pay Accrual (RPA)	$15,879.37
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

177 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	16
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$191,064.79	$204,985.79	$235,855.79	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$95,688.00
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$31,002.91
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

178 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-9
YOS	20
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$144,742.76	$158,663.76	$189,533.76	$145,299.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$68,083.20
Component	BAH	$22,659.00
Component	Retired Pay Accrual (RPA)	$22,058.96
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$10,136.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

179 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	8T0x0 : Professional Military Education Instructor

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00

180 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-3
YOS	2
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$61,695.49	$75,616.49	$106,486.49	$51,365.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$23,025.60
Component	BAH	$5,218.00
Component	Retired Pay Accrual (RPA)	$7,460.29
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,186.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

181 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	3S2x1 : Education And Training

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

182 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-8
YOS	18
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$128,312.23	$142,233.23	$173,103.23	$123,131.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,211.20
Component	BAH	$21,669.00
Component	Retired Pay Accrual (RPA)	$18,536.43
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$9,090.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

183 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-4
YOS	4
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$76,040.86	$89,961.86	$120,831.86	$65,541.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$27,936.00
Component	BAH	$12,350.00
Component	Retired Pay Accrual (RPA)	$9,051.26
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,898.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00

184 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	14
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$183,529.11	$197,450.11	$228,320.11	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$89,996.40
Component	BAH	$27,471.00
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$29,158.83
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

185 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-6
YOS	7
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$95,224.93	$109,145.93	$140,015.93	$94,747.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$35,578.80
Component	BAH	$19,271.00
Component	Retired Pay Accrual (RPA)	$11,527.53
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,042.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

186 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

USAF RPA MCE (1 Civ CAP) (2014)

Cost to Component(s)	Department of Defense	Cost to Fed. Govt.
$11,967,304.92	$13,192,352.92	$16,192,472.92

187 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Military Summary - Air Force				
Billets	**PG | YOS | AFSC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
1	O-5 | 14 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$183,529.11	$197,450.11	$228,320.11
5	O-4 | 11 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$829,095.25	$898,700.25	$1,053,050.25
8	E-5 | 6 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$701,658.72	$813,026.72	$1,059,986.72
1	E-5 | 6 | 8T0x0 : Professional Military Education Instructor | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
1	E-8 | 18 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$128,312.23	$142,233.23	$173,103.23
10	E-6 | 7 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$952,249.30	$1,091,459.30	$1,400,159.30
40	O-3 | 6 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$5,650,846.80	$6,207,686.80	$7,442,486.80
1	E-9 | 20 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$144,742.76	$158,663.76	$189,533.76
1	E-5 | 6 | 3S2x1 : Education And Training | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
7	E-3 | 2 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$431,868.43	$529,315.43	$745,405.43
8	E-4 | 4 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$608,326.88	$719,694.88	$966,654.88
1	O-5 | 16 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$191,064.79	$204,985.79	$235,855.79
4	E-7 | 15 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$459,765.48	$515,449.48	$638,929.48

Civilian GS Summary				
Billets	**PG | Step | Series | Location | Occupation | Component**	**Component**	**Department of Defense**	**Fed. Govt.**
6	GS6 | 5 | 0006 | NATIONWIDE | 0006: Correctional Institution Administration | Air Force	$346,680.36	$346,680.36	$431,748.36
1	GS7 | 5 | 0006 | NATIONWIDE | 0006: Correctional Institution Administration | Air Force	$64,100.66	$64,100.66	$78,278.66
10	GS11 | 5 | 0006 | NATIONWIDE | 0006: Correctional Institution Administration | Air Force	$943,821.70	$943,821.70	$1,085,601.70
3	GS5 | 5 | 0006 | NATIONWIDE | 0006: Correctional Institution Administration | Air Force	$155,827.77	$155,827.77	$198,361.77

188 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	14
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$183,529.11	$197,450.11	$228,320.11	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$89,996.40
Component	BAH	$27,471.00
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$29,158.83
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

189 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-4
YOS	11
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$165,819.05	$179,740.05	$210,610.05	$169,078.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$79,117.20
Component	BAH	$25,617.00
Component	Retired Pay Accrual (RPA)	$25,633.97
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$11,705.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

190 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

191 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	8T0x0 : Professional Military Education Instructor

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

192 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-8
YOS	18
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$128,312.23	$142,233.23	$173,103.23	$123,131.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,211.20
Component	BAH	$21,669.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$18,536.43
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$9,090.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00

193 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-6
YOS	7
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$95,224.93	$109,145.93	$140,015.93	$94,747.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$35,578.80
Component	BAH	$19,271.00
Component	Retired Pay Accrual (RPA)	$11,527.53
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,042.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

194 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-3
YOS	6
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$141,271.17	$155,192.17	$186,062.17	$140,318.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$64,983.60
Component	BAH	$21,575.00
Component	Retired Pay Accrual (RPA)	$21,054.69
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$9,912.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

195 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-9
YOS	20
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$144,742.76	$158,663.76	$189,533.76	$145,299.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$68,083.20
Component	BAH	$22,659.00
Component	Retired Pay Accrual (RPA)	$22,058.96
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$10,136.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

196 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	3S2x1 : Education And Training

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

197 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-3
YOS	2
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$61,695.49	$75,616.49	$106,486.49	$51,365.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$23,025.60
Component	BAH	$5,218.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,186.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$7,460.29
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00

198 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-4
YOS	4
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$76,040.86	$89,961.86	$120,831.86	$65,541.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$27,936.00
Component	BAH	$12,350.00
Component	Retired Pay Accrual (RPA)	$9,051.26
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,898.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

199 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	16
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$191,064.79	$204,985.79	$235,855.79	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$95,688.00
Component	BAH	$27,471.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$31,002.91
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00

200 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	15
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$114,941.37	$128,862.37	$159,732.37	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$49,010.40
Component	BAH	$20,284.00
Component	Retired Pay Accrual (RPA)	$15,879.37
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

201 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Position Attributes

Category	Selection
Year	2014
Military Component	Air Force
Pay Grade	GS6
Series	: 0006: Correctional Institution Administration
Step	5

Civilian Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Programmed Amount
$57,780.06	$57,780.06	$71,958.06	$54,498.62

Civilian Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$39,955.00
Component	OC11 Load Factor	$1,478.34
Component	Fringe Benefit Factor (OC12)	$14,543.62
Component	OC13 Load Factor	$799.10
Component	Training	$1,004.00
Component	Civilian Recruiting	$0.00
Component	Additional Labor Cost	$0.00
Department of Defense	Additional Labor Cost	$0.00
FED	Additional Labor Cost	$0.00
FED	Unfunded Civilian Retirement (CSRS only)	$8,350.00
FED	Postretirement Health Benefit	$5,805.00
FED	Postretirement Life Insurance	$23.00

202 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Position Attributes

Category	Selection
Year	2014
Military Component	Air Force
Pay Grade	GS7
Series	: 0006: Correctional Institution Administration
Step	5

Civilian Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Programmed Amount
$64,100.66	$64,100.66	$78,278.66	$60,565.69

Civilian Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$44,403.00
Component	OC11 Load Factor	$1,642.91
Component	Fringe Benefit Factor (OC12)	$16,162.69
Component	OC13 Load Factor	$888.06
Component	Training	$1,004.00
Component	Civilian Recruiting	$0.00
Component	Additional Labor Cost	$0.00
Department of Defense	Additional Labor Cost	$0.00
FED	Additional Labor Cost	$0.00
FED	Unfunded Civilian Retirement (CSRS only)	$8,350.00
FED	Postretirement Health Benefit	$5,805.00
FED	Postretirement Life Insurance	$23.00

203 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Position Attributes

Category	Selection
Year	2014
Military Component	Air Force
Pay Grade	GS11
Series	: 0006: Correctional Institution Administration
Step	5

Civilian Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Programmed Amount
$94,382.17	$94,382.17	$108,560.17	$89,632.53

Civilian Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$65,713.00
Component	OC11 Load Factor	$2,431.38
Component	Fringe Benefit Factor (OC12)	$23,919.53
Component	OC13 Load Factor	$1,314.26
Component	Training	$1,004.00
Component	Civilian Recruiting	$0.00
Component	Additional Labor Cost	$0.00
Department of Defense	Additional Labor Cost	$0.00
FED	Additional Labor Cost	$0.00
FED	Unfunded Civilian Retirement (CSRS only)	$8,350.00
FED	Postretirement Health Benefit	$5,805.00
FED	Postretirement Life Insurance	$23.00

204 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Position Attributes

Category	Selection
Year	2014
Military Component	Air Force
Pay Grade	GS5
Series	: 0006: Correctional Institution Administration
Step	5

Civilian Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Programmed Amount
$51,942.59	$51,942.59	$66,120.59	$48,895.31

Civilian Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$35,847.00
Component	OC11 Load Factor	$1,326.34
Component	Fringe Benefit Factor (OC12)	$13,048.31
Component	OC13 Load Factor	$716.94
Component	Training	$1,004.00
Component	Civilian Recruiting	$0.00
Component	Additional Labor Cost	$0.00
Department of Defense	Additional Labor Cost	$0.00
FED	Additional Labor Cost	$0.00
FED	Unfunded Civilian Retirement (CSRS only)	$8,350.00
FED	Postretirement Health Benefit	$5,805.00
FED	Postretirement Life Insurance	$23.00

205 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Organization Comparison Summary				
Organization Name	**Calendar Year**	**Cost to Component**	**Department of Defense**	**Cost to Fed. Govt.**
USAF RPA MCE (All Military)	2014	$12,720,405.89	$14,223,873.89	$17,557,833.89
USAF RPA MCE (60% Enlisted Pilot)	2014	$10,898,478.03	$12,401,946.03	$15,735,906.03
USAF RPA MCE (50% Enlisted Pilot)	2014	$11,210,803.29	$12,714,271.29	$16,048,231.29
USAF RPA MCE (40% Enlisted Pilot)	2014	$11,497,116.70	$13,000,584.70	$16,334,544.70
USAF RPA MCE (30% Enlisted Pilot)	2014	$11,809,441.96	$13,312,909.96	$16,646,869.96
USAF RPA MCE (20% Enlisted Pilot)	2014	$12,106,732.04	$13,610,200.04	$16,944,160.04

USAF RPA MCE (All Military) (2014)		
Cost to Component(s)	**Department of Defense**	**Cost to Fed. Govt.**
$12,720,405.89	$14,223,873.89	$17,557,833.89

Military Summary - Air Force				
Billets	**PG | YOS | AFSC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
49	O-3 | 6 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$6,922,287.33	$7,604,416.33	$9,117,046.33
6	O-4 | 11 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$994,914.30	$1,078,440.30	$1,263,660.30
5	E-7 | 15 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$574,706.85	$644,311.85	$798,661.85
1	O-5 | 16 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$191,064.79	$204,985.79	$235,855.79
1	E-9 | 20 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$144,742.76	$158,663.76	$189,533.76
1	E-5 | 6 | 8T0x0 : Professional Military Education Instructor | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
10	E-3 | 2 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$616,954.90	$756,164.90	$1,064,864.90
1	E-5 | 6 | 3S2x1 : Education And Training | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
1	E-8 | 18 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$128,312.23	$142,233.23	$173,103.23
8	E-4 | 4 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$608,326.88	$719,694.88	$966,654.88
1	O-5 | 14 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$183,529.11	$197,450.11	$228,320.11
10	E-6 | 7 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$952,249.30	$1,091,459.30	$1,400,159.30
14	E-5 | 6 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,227,902.76	$1,422,796.76	$1,854,976.76

206 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-3
YOS	6
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$141,271.17	$155,192.17	$186,062.17	$140,318.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$64,983.60
Component	BAH	$21,575.00
Component	Retired Pay Accrual (RPA)	$21,054.69
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$9,912.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

207 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-4
YOS	11
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$165,819.05	$179,740.05	$210,610.05	$169,078.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$79,117.20
Component	BAH	$25,617.00
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$11,705.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$25,633.97
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

208 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	15
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$114,941.37	$128,862.37	$159,732.37	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$49,010.40
Component	BAH	$20,284.00
Component	Retired Pay Accrual (RPA)	$15,879.37
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

209 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	16
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$191,064.79	$204,985.79	$235,855.79	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$95,688.00
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$31,002.91
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

210 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-9
YOS	20
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$144,742.76	$158,663.76	$189,533.76	$145,299.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$68,083.20
Component	BAH	$22,659.00
Component	Retired Pay Accrual (RPA)	$22,058.96
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$10,136.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

211 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	8T0x0 : Professional Military Education Instructor

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00

212 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-3
YOS	2
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$61,695.49	$75,616.49	$106,486.49	$51,365.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$23,025.60
Component	BAH	$5,218.00
Component	Retired Pay Accrual (RPA)	$7,460.29
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,186.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

213 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	3S2x1 : Education And Training

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

214 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-8
YOS	18
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$128,312.23	$142,233.23	$173,103.23	$123,131.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,211.20
Component	BAH	$21,669.00
Component	Retired Pay Accrual (RPA)	$18,536.43
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$9,090.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

215 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-4
YOS	4
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$76,040.86	$89,961.86	$120,831.86	$65,541.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$27,936.00
Component	BAH	$12,350.00
Component	Retired Pay Accrual (RPA)	$9,051.26
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,898.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Additional Labor Cost	$0.00
FED	Miscellaneous Expenses	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00

216 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	14
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$183,529.11	$197,450.11	$228,320.11	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$89,996.40
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$29,158.83
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

217 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-6
YOS	7
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$95,224.93	$109,145.93	$140,015.93	$94,747.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$35,578.80
Component	BAH	$19,271.00
Component	Retired Pay Accrual (RPA)	$11,527.53
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,042.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

218 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

USAF RPA MCE (60% Enlisted Pilot) (2014)

Cost to Component(s)	Department of Defense	Cost to Fed. Govt.
$10,898,478.03	$12,401,946.03	$15,735,906.03

219 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Military Summary - Air Force				
Billets	**PG | YOS | AFSC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
1	E-5 | 6 | 3S2x1 : Education And Training | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
5	E-7 | 15 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$574,706.85	$644,311.85	$798,661.85
6	O-4 | 11 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$994,914.30	$1,078,440.30	$1,263,660.30
8	E-4 | 4 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$608,326.88	$719,694.88	$966,654.88
1	E-9 | 20 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$144,742.76	$158,663.76	$189,533.76
1	O-5 | 16 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$191,064.79	$204,985.79	$235,855.79
20	E-3 | 2 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,233,909.80	$1,512,329.80	$2,129,729.80
28	E-5 | 6 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$2,455,805.52	$2,845,593.52	$3,709,953.52
1	O-5 | 14 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$183,529.11	$197,450.11	$228,320.11
1	E-5 | 6 | 8T0x0 : Professional Military Education Instructor | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
16	E-6 | 7 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,523,598.88	$1,746,334.88	$2,240,254.88
1	E-8 | 18 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$128,312.23	$142,233.23	$173,103.23
19	O-3 | 6 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$2,684,152.23	$2,948,651.23	$3,535,181.23

220 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	3S2x1 : Education And Training

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

221 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	15
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$114,941.37	$128,862.37	$159,732.37	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$49,010.40
Component	BAH	$20,284.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$15,879.37
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

222 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-4
YOS	11
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$165,819.05	$179,740.05	$210,610.05	$169,078.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$79,117.20
Component	BAH	$25,617.00
Component	Retired Pay Accrual (RPA)	$25,633.97
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$11,705.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

223 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-4
YOS	4
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$76,040.86	$89,961.86	$120,831.86	$65,541.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$27,936.00
Component	BAH	$12,350.00
Component	Retired Pay Accrual (RPA)	$9,051.26
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,898.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

224 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-9
YOS	20
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$144,742.76	$158,663.76	$189,533.76	$145,299.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$68,083.20
Component	BAH	$22,659.00
Component	Retired Pay Accrual (RPA)	$22,058.96
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$10,136.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

225 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	16
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$191,064.79	$204,985.79	$235,855.79	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$95,688.00
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$31,002.91
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

226 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-3
YOS	2
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$61,695.49	$75,616.49	$106,486.49	$51,365.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$23,025.60
Component	BAH	$5,218.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$7,460.29
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,186.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00

227 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

228 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	14
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$183,529.11	$197,450.11	$228,320.11	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$89,996.40
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$29,158.83
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

229 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	8T0x0 : Professional Military Education Instructor

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

230 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-6
YOS	7
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$95,224.93	$109,145.93	$140,015.93	$94,747.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$35,578.80
Component	BAH	$19,271.00
Component	Retired Pay Accrual (RPA)	$11,527.53
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,042.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

231 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-8
YOS	18
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$128,312.23	$142,233.23	$173,103.23	$123,131.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,211.20
Component	BAH	$21,669.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	Retired Pay Accrual (RPA)	$18,536.43
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$9,090.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

232 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-3
YOS	6
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$141,271.17	$155,192.17	$186,062.17	$140,318.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$64,983.60
Component	BAH	$21,575.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$21,054.69
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$9,912.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00

USAF RPA MCE (50% Enlisted Pilot) (2014)

Cost to Component(s)	Department of Defense	Cost to Fed. Govt.
$11,210,803.29	$12,714,271.29	$16,048,231.29

233 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Military Summary - Air Force				
Billets	**PG | YOS | AFSC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
26	E-5 | 6 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$2,280,390.84	$2,642,336.84	$3,444,956.84
15	E-6 | 7 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,428,373.95	$1,637,188.95	$2,100,238.95
1	E-5 | 6 | 3S2x1 : Education And Training | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
1	E-5 | 6 | 8T0x0 : Professional Military Education Instructor | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
18	E-3 | 2 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,110,518.82	$1,361,096.82	$1,916,756.82
5	E-7 | 15 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$574,706.85	$644,311.85	$798,661.85
8	E-4 | 4 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$608,326.88	$719,694.88	$966,654.88
1	E-9 | 20 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$144,742.76	$158,663.76	$189,533.76
24	O-3 | 6 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$3,390,508.08	$3,724,612.08	$4,465,492.08
1	E-8 | 18 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$128,312.23	$142,233.23	$173,103.23
1	O-5 | 14 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$183,529.11	$197,450.11	$228,320.11
1	O-5 | 16 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$191,064.79	$204,985.79	$235,855.79
6	O-4 | 11 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$994,914.30	$1,078,440.30	$1,263,660.30

234 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00

235 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-6
YOS	7
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$95,224.93	$109,145.93	$140,015.93	$94,747.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$35,578.80
Component	BAH	$19,271.00
Component	Retired Pay Accrual (RPA)	$11,527.53
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,042.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

236 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	3S2x1 : Education And Training

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

237 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	8T0x0 : Professional Military Education Instructor

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

238 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-3
YOS	2
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$61,695.49	$75,616.49	$106,486.49	$51,365.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$23,025.60
Component	BAH	$5,218.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$7,460.29
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,186.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00

239 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	15
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$114,941.37	$128,862.37	$159,732.37	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$49,010.40
Component	BAH	$20,284.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Retired Pay Accrual (RPA)	$15,879.37
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

240 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-4
YOS	4
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$76,040.86	$89,961.86	$120,831.86	$65,541.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$27,936.00
Component	BAH	$12,350.00
Component	Retired Pay Accrual (RPA)	$9,051.26
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,898.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

241 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-9
YOS	20
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$144,742.76	$158,663.76	$189,533.76	$145,299.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$68,083.20
Component	BAH	$22,659.00
Component	Retired Pay Accrual (RPA)	$22,058.96
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$10,136.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

242 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-3
YOS	6
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$141,271.17	$155,192.17	$186,062.17	$140,318.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$64,983.60
Component	BAH	$21,575.00
Component	Retired Pay Accrual (RPA)	$21,054.69
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$9,912.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

243 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-8
YOS	18
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$128,312.23	$142,233.23	$173,103.23	$123,131.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,211.20
Component	BAH	$21,669.00
Component	Retired Pay Accrual (RPA)	$18,536.43
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$9,090.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

244 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	14
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$183,529.11	$197,450.11	$228,320.11	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$89,996.40
Component	BAH	$27,471.00
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$29,158.83
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

245 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	16
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$191,064.79	$204,985.79	$235,855.79	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$95,688.00
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$31,002.91
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

246 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-4
YOS	11
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$165,819.05	$179,740.05	$210,610.05	$169,078.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$79,117.20
Component	BAH	$25,617.00
Component	Retired Pay Accrual (RPA)	$25,633.97
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$11,705.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

USAF RPA MCE (40% Enlisted Pilot) (2014)

Cost to Component(s)	Department of Defense	Cost to Fed. Govt.
$11,497,116.70	$13,000,584.70	$16,334,544.70

247 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Military Summary - Air Force				
Billets	**PG | YOS | AFSC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
14	E-6 | 7 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,333,149.02	$1,528,043.02	$1,960,223.02
1	E-9 | 20 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$144,742.76	$158,663.76	$189,533.76
1	E-5 | 6 | 8T0x0 : Professional Military Education Instructor | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
1	E-5 | 6 | 3S2x1 : Education And Training | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
1	E-8 | 18 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$128,312.23	$142,233.23	$173,103.23
8	E-4 | 4 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$608,326.88	$719,694.88	$966,654.88
1	O-5 | 16 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$191,064.79	$204,985.79	$235,855.79
5	E-7 | 15 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$574,706.85	$644,311.85	$798,661.85
23	E-5 | 6 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$2,017,268.82	$2,337,451.82	$3,047,461.82
6	O-4 | 11 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$994,914.30	$1,078,440.30	$1,263,660.30
1	O-5 | 14 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$183,529.11	$197,450.11	$228,320.11
17	E-3 | 2 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,048,823.33	$1,285,480.33	$1,810,270.33
29	O-3 | 6 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$4,096,863.93	$4,500,572.93	$5,395,802.93

248 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-6
YOS	7
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$95,224.93	$109,145.93	$140,015.93	$94,747.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$35,578.80
Component	BAH	$19,271.00
Component	Retired Pay Accrual (RPA)	$11,527.53
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,042.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

249 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-9
YOS	20
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$144,742.76	$158,663.76	$189,533.76	$145,299.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$68,083.20
Component	BAH	$22,659.00
Component	Retired Pay Accrual (RPA)	$22,058.96
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$10,136.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

250 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	8T0x0 : Professional Military Education Instructor

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00

251 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	3S2x1 : Education And Training

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00

252 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-8
YOS	18
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$128,312.23	$142,233.23	$173,103.23	$123,131.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,211.20
Component	BAH	$21,669.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$9,090.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$18,536.43
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00

253 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-4
YOS	4
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$76,040.86	$89,961.86	$120,831.86	$65,541.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$27,936.00
Component	BAH	$12,350.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,898.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Retired Pay Accrual (RPA)	$9,051.26
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

254 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	16
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$191,064.79	$204,985.79	$235,855.79	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$95,688.00
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$31,002.91
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

255 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	15
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$114,941.37	$128,862.37	$159,732.37	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$49,010.40
Component	BAH	$20,284.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	Retired Pay Accrual (RPA)	$15,879.37
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00

256 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00

257 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-4
YOS	11
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$165,819.05	$179,740.05	$210,610.05	$169,078.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$79,117.20
Component	BAH	$25,617.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$11,705.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$25,633.97
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

258 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	14
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$183,529.11	$197,450.11	$228,320.11	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$89,996.40
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$29,158.83
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

259 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-3
YOS	2
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$61,695.49	$75,616.49	$106,486.49	$51,365.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$23,025.60
Component	BAH	$5,218.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$7,460.29
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,186.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00

260 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-3
YOS	6
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$141,271.17	$155,192.17	$186,062.17	$140,318.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$64,983.60
Component	BAH	$21,575.00
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$9,912.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$21,054.69
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

USAF RPA MCE (30% Enlisted Pilot) (2014)

Cost to Component(s)	Department of Defense	Cost to Fed. Govt.
$11,809,441.96	$13,312,909.96	$16,646,869.96

261 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Military Summary - Air Force				
Billets	**PG | YOS | AFSC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
1	O-5 | 14 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$183,529.11	$197,450.11	$228,320.11
13	E-6 | 7 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,237,924.09	$1,418,897.09	$1,820,207.09
1	O-5 | 16 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$191,064.79	$204,985.79	$235,855.79
5	E-7 | 15 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$574,706.85	$644,311.85	$798,661.85
1	E-5 | 6 | 8T0x0 : Professional Military Education Instructor | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
6	O-4 | 11 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$994,914.30	$1,078,440.30	$1,263,660.30
1	E-8 | 18 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$128,312.23	$142,233.23	$173,103.23
34	O-3 | 6 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$4,803,219.78	$5,276,533.78	$6,326,113.78
1	E-9 | 20 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$144,742.76	$158,663.76	$189,533.76
1	E-5 | 6 | 3S2x1 : Education And Training | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
15	E-3 | 2 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$925,432.35	$1,134,247.35	$1,597,297.35
8	E-4 | 4 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$608,326.88	$719,694.88	$966,654.88
21	E-5 | 6 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,841,854.14	$2,134,195.14	$2,782,465.14

262 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	14
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$183,529.11	$197,450.11	$228,320.11	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$89,996.40
Component	BAH	$27,471.00
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$29,158.83
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

263 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-6
YOS	7
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$95,224.93	$109,145.93	$140,015.93	$94,747.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$35,578.80
Component	BAH	$19,271.00
Component	Retired Pay Accrual (RPA)	$11,527.53
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,042.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

264 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	16
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$191,064.79	$204,985.79	$235,855.79	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$95,688.00
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$31,002.91
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

265 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	15
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$114,941.37	$128,862.37	$159,732.37	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$49,010.40
Component	BAH	$20,284.00
Component	Retired Pay Accrual (RPA)	$15,879.37
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00

266 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	8T0x0 : Professional Military Education Instructor

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00

267 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-4
YOS	11
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$165,819.05	$179,740.05	$210,610.05	$169,078.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$79,117.20
Component	BAH	$25,617.00
Component	Retired Pay Accrual (RPA)	$25,633.97
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$11,705.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

268 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-8
YOS	18
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$128,312.23	$142,233.23	$173,103.23	$123,131.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,211.20
Component	BAH	$21,669.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$9,090.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$18,536.43
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00

269 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-3
YOS	6
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$141,271.17	$155,192.17	$186,062.17	$140,318.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$64,983.60
Component	BAH	$21,575.00
Component	Retired Pay Accrual (RPA)	$21,054.69
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$9,912.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

270 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-9
YOS	20
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$144,742.76	$158,663.76	$189,533.76	$145,299.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$68,083.20
Component	BAH	$22,659.00
Component	Retired Pay Accrual (RPA)	$22,058.96
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$10,136.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

271 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	3S2x1 : Education And Training

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

272 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-3
YOS	2
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$61,695.49	$75,616.49	$106,486.49	$51,365.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$23,025.60
Component	BAH	$5,218.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,186.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$7,460.29
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

273 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-4
YOS	4
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$76,040.86	$89,961.86	$120,831.86	$65,541.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$27,936.00
Component	BAH	$12,350.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,898.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$9,051.26
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

274 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

USAF RPA MCE (20% Enlisted Pilot) (2014)

Cost to Component(s)	Department of Defense	Cost to Fed. Govt.
$12,106,732.04	$13,610,200.04	$16,944,160.04

275 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Military Summary - Air Force				
Billets	**PG | YOS | AFSC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
10	E-6 | 7 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$952,249.30	$1,091,459.30	$1,400,159.30
1	E-5 | 6 | 8T0x0 : Professional Military Education Instructor | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
1	E-9 | 20 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$144,742.76	$158,663.76	$189,533.76
21	E-5 | 6 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,841,854.14	$2,134,195.14	$2,782,465.14
13	E-3 | 2 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$802,041.37	$983,014.37	$1,384,324.37
1	E-8 | 18 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$128,312.23	$142,233.23	$173,103.23
1	O-5 | 16 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$191,064.79	$204,985.79	$235,855.79
8	E-4 | 4 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$608,326.88	$719,694.88	$966,654.88
39	O-3 | 6 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$5,509,575.63	$6,052,494.63	$7,256,424.63
1	O-5 | 14 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$183,529.11	$197,450.11	$228,320.11
1	E-5 | 6 | 3S2x1 : Education And Training | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
6	O-4 | 11 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$994,914.30	$1,078,440.30	$1,263,660.30
5	E-7 | 15 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$574,706.85	$644,311.85	$798,661.85

276 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-6
YOS	7
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$95,224.93	$109,145.93	$140,015.93	$94,747.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$35,578.80
Component	BAH	$19,271.00
Component	Retired Pay Accrual (RPA)	$11,527.53
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,042.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

277 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	8T0x0 : Professional Military Education Instructor

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

278 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-9
YOS	20
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$144,742.76	$158,663.76	$189,533.76	$145,299.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$68,083.20
Component	BAH	$22,659.00
Component	Retired Pay Accrual (RPA)	$22,058.96
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$10,136.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

279 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Education Assistance	$419.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

280 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-3
YOS	2
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$61,695.49	$75,616.49	$106,486.49	$51,365.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$23,025.60
Component	BAH	$5,218.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,186.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$7,460.29
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

281 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-8
YOS	18
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$128,312.23	$142,233.23	$173,103.23	$123,131.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,211.20
Component	BAH	$21,669.00
Component	Retired Pay Accrual (RPA)	$18,536.43
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$9,090.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

282 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	16
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$191,064.79	$204,985.79	$235,855.79	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$95,688.00
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$31,002.91
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

283 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-4
YOS	4
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$76,040.86	$89,961.86	$120,831.86	$65,541.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$27,936.00
Component	BAH	$12,350.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,898.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$9,051.26
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

284 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-3
YOS	6
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$141,271.17	$155,192.17	$186,062.17	$140,318.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$64,983.60
Component	BAH	$21,575.00
Component	Retired Pay Accrual (RPA)	$21,054.69
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$9,912.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

285 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	14
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$183,529.11	$197,450.11	$228,320.11	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$89,996.40
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$29,158.83
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

286 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	3S2x1 : Education And Training

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

287 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-4
YOS	11
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$165,819.05	$179,740.05	$210,610.05	$169,078.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$79,117.20
Component	BAH	$25,617.00
Component	Miscellaneous Expenses	$11,705.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$25,633.97
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00

288 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	15
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$114,941.37	$128,862.37	$159,732.37	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$49,010.40
Component	BAH	$20,284.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	Retired Pay Accrual (RPA)	$15,879.37
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00

289 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Organization Comparison Summary				
Organization Name	**Calendar Year**	**Cost to Component**	**Department of Defense**	**Cost to Fed. Govt.**
USAF RPA MCE (All Military)	2014	$12,720,405.89	$14,223,873.89	$17,557,833.89
USAF RPA Warrant Officer	2014	$11,413,607.62	$12,917,075.62	$16,251,035.62

USAF RPA MCE (All Military) (2014)		
Cost to Component(s)	**Department of Defense**	**Cost to Fed. Govt.**
$12,720,405.89	$14,223,873.89	$17,557,833.89

Military Summary - Air Force				
Billets	**PG | YOS | AFSC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
49	O-3 | 6 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$6,922,287.33	$7,604,416.33	$9,117,046.33
6	O-4 | 11 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$994,914.30	$1,078,440.30	$1,263,660.30
5	E-7 | 15 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$574,706.85	$644,311.85	$798,661.85
1	O-5 | 16 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$191,064.79	$204,985.79	$235,855.79
1	E-9 | 20 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$144,742.76	$158,663.76	$189,533.76
1	E-5 | 6 | 8T0x0 : Professional Military Education Instructor | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
10	E-3 | 2 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$616,954.90	$756,164.90	$1,064,864.90
1	E-5 | 6 | 3S2x1 : Education And Training | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
1	E-8 | 18 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$128,312.23	$142,233.23	$173,103.23
8	E-4 | 4 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$608,326.88	$719,694.88	$966,654.88
1	O-5 | 14 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$183,529.11	$197,450.11	$228,320.11
10	E-6 | 7 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$952,249.30	$1,091,459.30	$1,400,159.30
14	E-5 | 6 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,227,902.76	$1,422,796.76	$1,854,976.76

290 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-3
YOS	6
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$141,271.17	$155,192.17	$186,062.17	$140,318.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$64,983.60
Component	BAH	$21,575.00
Component	Retired Pay Accrual (RPA)	$21,054.69
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$9,912.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

291 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-4
YOS	11
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$165,819.05	$179,740.05	$210,610.05	$169,078.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$79,117.20
Component	BAH	$25,617.00
Component	Retired Pay Accrual (RPA)	$25,633.97
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$11,705.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

292 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	15
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$114,941.37	$128,862.37	$159,732.37	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$49,010.40
Component	BAH	$20,284.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$15,879.37
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00

293 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	16
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$191,064.79	$204,985.79	$235,855.79	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$95,688.00
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$31,002.91
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

294 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-9
YOS	20
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$144,742.76	$158,663.76	$189,533.76	$145,299.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$68,083.20
Component	BAH	$22,659.00
Component	Retired Pay Accrual (RPA)	$22,058.96
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$10,136.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

295 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	8T0x0 : Professional Military Education Instructor

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

296 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-3
YOS	2
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$61,695.49	$75,616.49	$106,486.49	$51,365.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$23,025.60
Component	BAH	$5,218.00
Component	Retired Pay Accrual (RPA)	$7,460.29
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,186.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

297 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	3S2x1 : Education And Training

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00

298 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-8
YOS	18
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$128,312.23	$142,233.23	$173,103.23	$123,131.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,211.20
Component	BAH	$21,669.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$9,090.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Retired Pay Accrual (RPA)	$18,536.43
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Additional Labor Cost	$0.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00

299 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-4
YOS	4
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$76,040.86	$89,961.86	$120,831.86	$65,541.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$27,936.00
Component	BAH	$12,350.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$9,051.26
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,898.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00

300 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	14
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$183,529.11	$197,450.11	$228,320.11	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$89,996.40
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$29,158.83
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

301 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-6
YOS	7
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$95,224.93	$109,145.93	$140,015.93	$94,747.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$35,578.80
Component	BAH	$19,271.00
Component	Retired Pay Accrual (RPA)	$11,527.53
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,042.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

302 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

USAF RPA Warrant Officer (2014)

Cost to Component(s)	Department of Defense	Cost to Fed. Govt.
$11,413,607.62	$12,917,075.62	$16,251,035.62

303 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Military Summary - Air Force				
Billets	**PG | YOS | AFSC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
1	E-9 | 20 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$144,742.76	$158,663.76	$189,533.76
14	E-5 | 6 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$1,227,902.76	$1,422,796.76	$1,854,976.76
10	E-3 | 2 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$616,954.90	$756,164.90	$1,064,864.90
1	O-5 | 16 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$191,064.79	$204,985.79	$235,855.79
1	O-5 | 14 | 18SxZ : SPEC OPS RPA PILOT | CONUS (Standard)	$183,529.11	$197,450.11	$228,320.11
1	E-5 | 6 | 3S2x1 : Education And Training | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
5	E-7 | 15 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$574,706.85	$644,311.85	$798,661.85
1	E-5 | 6 | 8T0x0 : Professional Military Education Instructor | CONUS (Standard)	$87,707.34	$101,628.34	$132,498.34
10	E-6 | 7 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$952,249.30	$1,091,459.30	$1,400,159.30
8	E-4 | 4 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$608,326.88	$719,694.88	$966,654.88
1	E-8 | 18 | 1N1x1 : Imagery Analysis | CONUS (Standard)	$128,312.23	$142,233.23	$173,103.23

Military Summary - Army				
Billets	**PG | YOS | MOS/AOC | Location**	**Component**	**Department of Defense**	**Fed. Govt.**
1	W-4 | 16 | -- | CONUS (Standard)	$154,259.26	$168,180.26	$199,050.26
26	W-2 | 5 | -- | CONUS (Standard)	$2,909,242.70	$3,271,188.70	$4,073,808.70
28	W-3 | 9 | -- | CONUS (Standard)	$3,546,901.40	$3,936,689.40	$4,801,049.40

304 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-9
YOS	20
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$144,742.76	$158,663.76	$189,533.76	$145,299.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$68,083.20
Component	BAH	$22,659.00
Component	Retired Pay Accrual (RPA)	$22,058.96
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$10,136.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

305 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00

306 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-3
YOS	2
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$61,695.49	$75,616.49	$106,486.49	$51,365.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$23,025.60
Component	BAH	$5,218.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$7,460.29
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,186.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00

307 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	16
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$191,064.79	$204,985.79	$235,855.79	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$95,688.00
Component	BAH	$27,471.00
Component	Retired Pay Accrual (RPA)	$31,002.91
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

308 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	O-5
YOS	14
MHA	CONUS (Standard)
AFSC	18SxZ : SPEC OPS RPA PILOT

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$183,529.11	$197,450.11	$228,320.11	$191,940.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$89,996.40
Component	BAH	$27,471.00
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$9,565.00
Component	PCS / Relocation	$6,461.00
Component	Miscellaneous Expenses	$13,157.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$29,158.83
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

309 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	3S2x1 : Education And Training

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

310 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-7
YOS	15
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$114,941.37	$128,862.37	$159,732.37	$108,811.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$49,010.40
Component	BAH	$20,284.00
Component	Retired Pay Accrual (RPA)	$15,879.37
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,962.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

311 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-5
YOS	6
MHA	CONUS (Standard)
AFSC	8T0x0 : Professional Military Education Instructor

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$87,707.34	$101,628.34	$132,498.34	$79,953.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$32,814.00
Component	BAH	$16,415.00
Component	Retired Pay Accrual (RPA)	$10,631.74
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$6,041.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

312 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-6
YOS	7
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$95,224.93	$109,145.93	$140,015.93	$94,747.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$35,578.80
Component	BAH	$19,271.00
Component	Retired Pay Accrual (RPA)	$11,527.53
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$7,042.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

313 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-4
YOS	4
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$76,040.86	$89,961.86	$120,831.86	$65,541.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$27,936.00
Component	BAH	$12,350.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$9,051.26
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$4,898.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00

314 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Air Force
Year	2014
Pay Grade	E-8
YOS	18
MHA	CONUS (Standard)
AFSC	1N1x1 : Imagery Analysis

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$128,312.23	$142,233.23	$173,103.23	$123,131.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$57,211.20
Component	BAH	$21,669.00
Component	PCS / Relocation	$3,185.00
Component	Miscellaneous Expenses	$9,090.00
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$419.00
Component	Recruitment & Advertising	$590.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$18,536.43
Component	Basic Allowances for Subsistence (BAS)	$4,290.60
Component	Training	$9,565.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00

315 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Army
Year	2014
Pay Grade	W-4
YOS	16
MHA	CONUS (Standard)

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$154,259.26	$168,180.26	$199,050.26	$165,050.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$72,406.80
Component	BAH	$23,741.67
Component	PCS / Relocation	$6,265.00
Component	Miscellaneous Expenses	$12,964.11
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$484.00
Component	Recruitment & Advertising	$1,611.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$23,459.80
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$6,616.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00

316 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Billet Attributes

Category	Selection
Military Component	Army
Year	2014
Pay Grade	W-2
YOS	5
MHA	CONUS (Standard)

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$111,893.95	$125,814.95	$156,684.95	$122,848.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$44,398.80
Component	BAH	$20,298.53
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$6,616.00
Component	PCS / Relocation	$6,265.00
Component	Miscellaneous Expenses	$11,124.53
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$484.00
Component	Recruitment & Advertising	$1,611.00
Component	Additional Labor Cost	$0.00
Component	Retired Pay Accrual (RPA)	$14,385.21
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

317 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Billet Attributes

Category	Selection
Military Component	Army
Year	2014
Pay Grade	W-3
YOS	9
MHA	CONUS (Standard)

Billet Costing Summary (Annual)

Cost to Component	Department of Defense	Federal Government	Rate
$126,675.05	$140,596.05	$171,466.05	$140,791.00

Billet Costing Details (Annual)

	Cost Type	Annual Cost
Component	Base Pay	$54,021.60
Component	BAH	$22,454.75
Component	Retired Pay Accrual (RPA)	$17,503.00
Component	Basic Allowances for Subsistence (BAS)	$2,954.88
Component	Training	$6,616.00
Component	PCS / Relocation	$6,265.00
Component	Miscellaneous Expenses	$11,008.82
Component	Medicare-Eligible Retiree Health Care (MERHC)	$3,756.00
Component	Education Assistance	$484.00
Component	Recruitment & Advertising	$1,611.00
Component	Additional Labor Cost	$0.00
Department of Defense	Discount Groceries	$407.00
Department of Defense	Child Development (Day Care Facilities)	$601.00
Department of Defense	DoDEA and Family Assistance	$1,865.00
Department of Defense	Miscellaneous Expenses	$0.00
Department of Defense	Health Care (AD and AD FM)	$11,048.00
Department of Defense	Additional Labor Cost	$0.00
FED	Child Education (Impact Aid)	$337.00
FED	Treasury Contribution to Retirement	$19,951.00
FED	Treasury Contribution for Concurrent Receipts	$1,979.00
FED	Treasury Contribution to MERHCF	$1,541.00
FED	Veterans Benefits (Cash and In-Kind)	$7,062.00
FED	Miscellaneous Expenses	$0.00
FED	Additional Labor Cost	$0.00

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Appendix D
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Appendix E
Abbreviations

A2CU	Air Force RPA Capabilities Division
ADP	Army Doctrine Publication
AETC	Air Education and Training Command
AFB	Air Force Base
AFQT	Armed Forces Qualification Test
AFRL	Air Force Research Laboratory
AFSC	Air Force Specialty Code
AFSOC	Air Force Special Operations Command
AGL	altitude above ground level
AGM	air-to-ground tactical missile
AGR	active guard and reserve
ASUW	anti-surface warfare
ASW	anti-submarine warfare
AVO	air vehicle operator
BAMS	broad area maritime surveillance
BDA	battle damage assessment
BLOS	beyond-line-of-sight
BUQ	basic UAS qualification
C2	command and control
C3	command, control, and communication
CAAF	contractors authorized to accompany the force
CAN	computer network attack
CAP	Combat Air Patrol
CAPE	Cost Assessment and Program Evaluation
CAS	close air support
CJCS	Chairman of the Joint Chiefs of Staff
CJCSI	Chairman of the Joint Chiefs of Staff Instruction
COCO	contractor-owned, contractor-operated
CONOPS	concept of operations
CONUS	Continental United States
CS	combat support
CSAR	combat search and rescue
CSS	combat service support
CWO	Chief Warrant Officer
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities
DS	direct support
E.O.	Executive Order

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EA	electronic attack
EOD	explosive ordnance disposal
EW	eelctronic warfare
FAA	Federal Aviation Administration
FCoM	Full Cost of Manpower
FL	flight level
FP	force protection
FY	Fiscal Year
FYDP	Future Years Defense Program
GBU	Guided Bomb Unit
GCS	ground control station
GOCO	government-owned, contractor-operated
GS	general support Government Service
HD/LD	high-demand, low-density
HHQ	Higher Headquarters
IA	international agreement
IAA	Incident Awareness and Assessment
IBCT	Infantry Brigade Combat Team
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IG	Inherently Governmental
ISR	Intelligence, Surveillance, and Reconnaissance
JFC	Joint Force Commander
JMQ	joint mission qualification
JMTL	Joint Mission Task List
JSTARS	Joint Surveillance Target Attack Radar System
LDO	limited duty officer
LOS	line-of-sight
LR	launch and recovery
LRE	launch and recovery element
MAGTF	Marine Air Ground Task Force
MCE	mission command element
MDA	maritime domain awareness
MEF	Marine Expeditionary Force
MGySgt	Master Gunnery Sergeant
MIW	mine warfare
MOS	military occupational specialty
MPO	mission payload operator
MWS	Major Weapon System
NAS	National Airspace System
NAVSPECWARCOM	Naval Special Warfare Command
NCO	non-commissioned officer
OES	Occupational Employment Statistics
OMCM	organic mine counter measures
OSD	Office of the Secretary of Defense

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OUSD(P&R)	Office of the Under Secretary of Defense for Personnel and Readiness
PCS	Private Security Contractor
PED	processing, exploitation, and dissemination
PGM	precision guided munition
PIC	pilots in command
POW	prisoner of war
PR	personal recovery
ROE	Rules of Engagement
ROTC	Reserve Officers' Training Corps
RPA	remotely piloted aircraft
RS	reconnaissance squadron (Air Force)
RSO	remote split operations
RSTA	reconnaissance, surveillance, and target acquisition
SAUS-O	SUAS operators
SCAR	strike coordination and reconnaissance
SEAL	Sea, Air, Land Teams
SJA	Staff Judge Advocate
SME	subject matter expert
SOCOM	Special Operations Command
SOF	Special Operations Forces
SOFA	Status of Forces Agreement
SUAS	small unmanned aircraft systems
TR	traditional reservist
TUAS	Tactical Unmanned Aerial Systems
U.S.C.	U.S. Code
UA	unmanned aircraft
UAS	Unmanned Aircraft System
UAV	unmanned aerial vehicle
UCAS	Unmanned Combat Air System
UCMJ	Uniform Code of Military Justice
UPT	undergraduate pilot training
URT	undergraduate RPA training
USAF	United States Air Force
USMC	United States Marine Corps
USSOCOM	United States Special Operations Command
UTC	Unit Type Code
VFR	Visual Flight Rules
VMU	unmanned aircraft squadron (Marine Corps)
VP	patrol squadron (Navy)
VUP	unmanned patrol squadron (Navy)
WO	warrant officer

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The purpose of this study is to identify alternative staffing strategies to accomplish the Department of Defense's (DoD) Unmanned Aircraft System (UAS)-related missions in a more cost-effective fashion. Research aimed at analyzing DoD's mission requirements along with the individual Service's approach to UAS staffing. Mission analysis identified various "business rules" applied across the DoD along with opportunities for cost savings. One of the most notable of these savings came from the use of a balanced workforce comprise of both uniformed military and government civilian. Specific opportunities rest within the larger unmanned aircraft systems where the AF alone could save a potential of approximately $94M across the FYDP by simply utilizing government civilians to appropriate mission elements. Analysis also reviewed the often emotional debate between the use of officers vs enlisted pilots and developed a model to depict three major elements for decision makers, 1) System Complexity, 2) Risk Assumed and 3) Operational Environment. While the Services' staffing choices are in some cases justifiable, analysis highlighted trade space to gain manpower efficiencies and increased Service cooperation. While this report offers an initial cost analysis, a full scale costing analysis for this burgeoning career field is recommended.

15. SUBJECT TERMS

Unmanned, Unmanned Aerial Vehicle, Unmanned Aircraft System, Remotely Piloted Aircraft, Drone, Staffing, Manning, UAV, UAS, RPA, Force Mix

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Selected Acquisition Report (SAR)

RCS: DD-A&T(Q&A)823-421

Airborne & Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS)

As of FY 2017 President's Budget

Defense Acquisition Management
Information Retrieval
(DAMIR)

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Common Acronyms and Abbreviations for MDAP Programs

Acq O&M - Acquisition-Related Operations and Maintenance
ACAT - Acquisition Category
ADM - Acquisition Decision Memorandum
APB - Acquisition Program Baseline
APPN - Appropriation
APUC - Average Procurement Unit Cost
$B - Billions of Dollars
BA - Budget Authority/Budget Activity
Blk - Block
BY - Base Year
CAPE - Cost Assessment and Program Evaluation
CARD - Cost Analysis Requirements Description
CDD - Capability Development Document
CLIN - Contract Line Item Number
CPD - Capability Production Document
CY - Calendar Year
DAB - Defense Acquisition Board
DAE - Defense Acquisition Executive
DAMIR - Defense Acquisition Management Information Retrieval
DoD - Department of Defense
DSN - Defense Switched Network
EMD - Engineering and Manufacturing Development
EVM - Earned Value Management
FOC - Full Operational Capability
FMS - Foreign Military Sales
FRP - Full Rate Production
FY - Fiscal Year
FYDP - Future Years Defense Program
ICE - Independent Cost Estimate
IOC - Initial Operational Capability
Inc - Increment
JROC - Joint Requirements Oversight Council
$K - Thousands of Dollars
KPP - Key Performance Parameter
LRIP - Low Rate Initial Production
$M - Millions of Dollars
MDA - Milestone Decision Authority
MDAP - Major Defense Acquisition Program
MILCON - Military Construction
N/A - Not Applicable
O&M - Operations and Maintenance
ORD - Operational Requirements Document
OSD - Office of the Secretary of Defense
O&S - Operating and Support
PAUC - Program Acquisition Unit Cost

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PB - President's Budget
PE - Program Element
PEO - Program Executive Officer
PM - Program Manager
POE - Program Office Estimate
RDT&E - Research, Development, Test, and Evaluation
SAR - Selected Acquisition Report
SCP - Service Cost Position
TBD - To Be Determined
TY - Then Year
UCR - Unit Cost Reporting
U.S. - United States
USD(AT&L) - Under Secretary of Defense (Acquisition, Technology and Logistics)

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Program Information

Program Name

Airborne & Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS)

DoD Component

Army

Responsible Office

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6007 Combat Drive
Aberdeen Proving Ground, MD 21005

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Phone: 443-395-2669
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Date Assigned: August 19, 2014

References

SAR Baseline (Development Estimate)

Defense Acquisition Executive (DAE) Approved Acquisition Program Baseline (APB) dated October 17, 2008

Approved APB

Defense Acquisition Executive (DAE) Approved Acquisition Program Baseline (APB) dated May 1, 2014

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Mission and Description

Airborne & Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS) products are software programmable, multi-band, multi-mode, mobile ad hoc networking radios, providing simultaneous voice and data communications for Army aviation platforms. The radios will operate in networks supporting the Common Operational Picture, situational awareness, and interoperability of Mission Command systems throughout the battlefield. AMF must ensure the soldier's ability to communicate both horizontally and vertically via voice and data within all mission areas and Combat Operational Environments. AMF helps close capability gaps by extending data networking to company echelons and below, enabling network services to the platform, and connecting Army aviation platforms to Army ground and Joint air network domains.

AMF will procure the Small Airborne Networking Radio (SANR) as a Non-Developmental Item. The SANR is a two-channel, software-defined, National Security Agency Type 1 certified networking radio providing seamless real-time information for operation in mobile and dynamic combat environments that will meet tactical communications requirements as validated by the Army aviation community. SANR will provide increased data throughput to Army aviation platforms via the Soldier Radio Waveform (SRW) and Wideband Networking Waveform (WNW) capabilities, and maintain Single Channel Ground and Airborne Radio System (SINCGARS) capability. SANR will replace the current SINCGARS radios on Army aviation platforms. SANR is planned for implementation on the following platforms: Apache (AH-64E), Black Hawk (UH-60V, UH-60M, HH-60M, and MH-60M), Chinook (CH-47F and MH-47G), Gray Eagle Unmanned Aircraft System (MQ-1C), and Little Bird (MH-6) aircraft. SANR will enhance and further enable the ability of the maneuver commander to integrate and synchronize aviation forces with land based operational forces. SANR, employed on Army aviation platforms, will enable aviation combat elements (Combat Aviation Brigades, Theater Aviation Brigades, and Special Operations Aviation Regiment) to better utilize the inherent versatility of airborne communications as a complement to the unique capabilities of the other combat arms. SANR will give commanders enhanced situational awareness and mission command in a package that provides a more responsive means of directing aircraft to match changing maneuver forces situations and missions.

The fielding of SANR will follow the deployment of ground network capabilities. The SANR radio will provide SRW, SINCGARS and the WNW capability to all Army tactical aircraft (reconnaissance, attack, cargo, and utility).

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Executive Summary

General:

The objective of the AMF JTRS program is to purchase Non-Developmental Item production-ready radios capable of operating network and legacy waveforms for Army aviation platforms. The acquisition approach will leverage prior industry and Government investment in software-defined radios to meet stated user requirements.

The Small Airborne Networking Radio (SANR) will be a two-channel radio that will run the Single Channel Ground and Airborne Radio System waveform, Soldier Radio Waveform, and Wideband Networking Waveform to interoperate with ground forces and maintain connectivity for combat operations. The SANR subprogram is designated an ACAT ID.

SANR:

As reported in the September 2015 Exception SAR, the addition of sunk RDT&E costs to the SANR subprogram, as a result of the August 2015 ADM that directed close out of the Small Airborne Link 16 Terminal subprogram, triggered a threshold breach of the APB SANR RDT&E objective. A Program Deviation Report was submitted in January 2016 as formal notification that a threshold breach to the APB occurred.

SANR acquisition activities resumed in FY 2016. These activities include market research, development and release of the request for proposal, along with preparation for, and start of, source selection activities in support of contract award.

An update to the AMF JTRS APB is under review. The APB will be finalized upon approval of the SANR CPD.

There are no significant software-related issues with this program at this time.

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Threshold Breaches

APB Breaches		
Schedule		☐
Performance		☐
Cost	RDT&E	☑
	Procurement	☐
	MILCON	☐
	Acq O&M	☐
O&S Cost		☐
Unit Cost	PAUC	☐
	APUC	☐

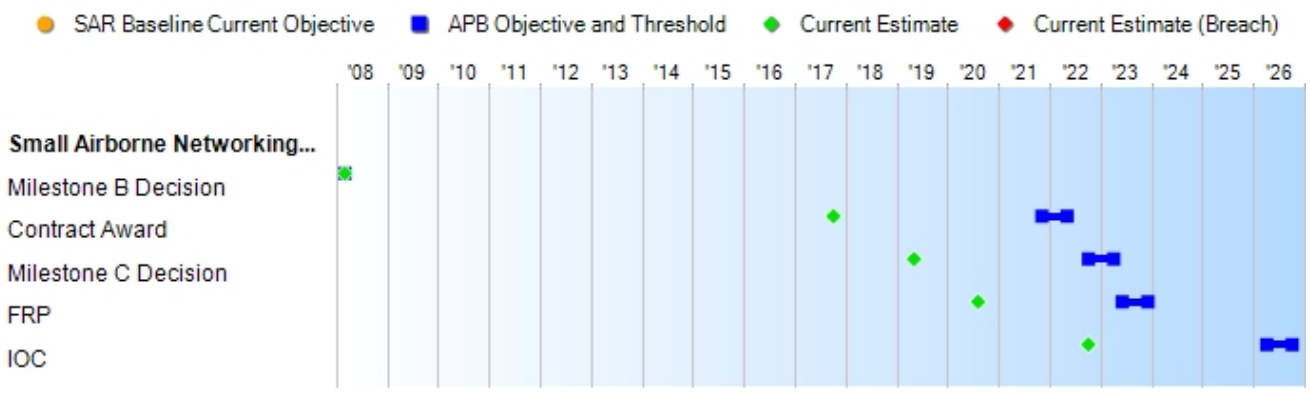
Nunn-McCurdy Breaches		
Current UCR Baseline		
	PAUC	None
	APUC	None
Original UCR Baseline		
	PAUC	None
	APUC	None

Explanation of Breach

The RDT&E APB breach was previously reported in the September 2015 SAR. A Program Deviation Report was submitted in January 2016.

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Schedule



Schedule Events				
Events	**SAR Baseline Development Estimate**	**Current APB Development Objective/Threshold**		**Current Estimate**
Milestone B Decision	Dec 2007	Mar 2008	Mar 2008	Mar 2008
Contract Award	Feb 2008	Nov 2021	May 2022	Oct 2017
Milestone C Decision	Nov 2011	Oct 2022	Apr 2023	May 2019
FRP	Jul 2014	Jun 2023	Dec 2023	Aug 2020
IOC	Aug 2014	Apr 2026	Oct 2026	Oct 2022

Change Explanations

None

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Performance

Performance Characteristics				
SAR Baseline Development Estimate	**Current APB Development Objective/Threshold**		**Demonstrated Performance**	**Current Estimate**
Have an internal growth capability				
Open system architecture IAW DISR; Modular, Scaleable, Flexible Form Factors	Open system architecture IAW DISR; Modular, Scaleable, Flexible Form Factors	Open system architecture IAW DISR; Modular, Scaleable, Flexible Form Factors	TBD	N/A
JTR set modes / capabilities configuration and reconfiguration via software				
By operators in their operational environment	By operators in their operational environment	By operators in their operational environment	TBD	N/A
Multi-channel routing and retransmission				
Objective waveforms that are same in mode (voice, data, or video) and use like data rates and operate at permissible security classification levels	Objective waveforms that are same in mode (voice, data, or video) and use like data rates and operate at permissible security classification levels	KPP waveforms that are same in mode (voice, data, or video) and use like data rates and operate at permissible security classification levels	TBD	N/A
Support waveforms.				
Maritime / Fixed: Same as Threshold. Small Airborne: Threshold plus UHF SATCOM, SINCGARS, Havequick II, EPLRS	Maritime / Fixed: Same as Threshold. Small Airborne: Threshold plus UHF SATCOM, SINCGARS, Havequick II, EPLRS	Maritime / Fixed: UHF SATCOM, MUOS. Small Airborne: MUOS, SRW, WNW, Link 16	TBD	N/A
To operate on designated number of channels at the same time.				
Small Airborne: 10 channels. Maritime / Fixed (full duplex): 10 channels	Small Airborne: 10 channels. Maritime / Fixed (full duplex): 10 channels	Small Airborne: 2 channels. Maritime / Fixed (full duplex): 4 channels	TBD	N/A
Scaleable networking services				
All domains	All domains	All domains	TBD	N/A
Network extension / coverage				
Across organizational boundaries	Across organizational boundaries	Across organizational boundaries	TBD	N/A
JTR system network interoperability				
Interoperate with Allied / Coalition and commercial networks; satisfy 100% of top -level IER	Interoperate with Allied / Coalition and commercial networks; satisfy 100% of top-level IER	Interoperate with Service and Joint networks; satisfy 100% of critical top-level IERs	TBD	N/A
Sustainment - Operational Availability (Ao)				
0.99 (channel)	0.99 (channel)	0.96 (channel)	TBD	N/A

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Requirements Reference

JTRS ORD Increment 1 Version 3.2 dated April 9, 2003 / v.3.2.1 errata dated August 28, 2006 and as modified by JROC Memorandum 063-11 dated April 29, 2011

Change Explanations

None

Notes

The current APB represents the Milestone B Acquisition Strategy. A revised CPD is currently in staffing with the Army Capabilities Integration Center of the Training & Doctrine Command. The program office anticipates a subset of the approved KPPs will apply to the approved CPD.

Acronyms and Abbreviations

DISR - Defense Information Standards Registry
EPLRS - Enhanced Position Location Reporting System
IAW - In Accordance With
IER - Information Exchange Requirement
JTR - Joint Tactical Radio
MUOS - Mobile User Objective System
SATCOM - Satellite Communications
SINCGARS - Single Channel Ground and Airborne Radio System
SRW - Soldier Radio Waveform
UHF - Ultra High Frequency
WNW - Wideband Networking Waveform

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Track to Budget

RDT&E

Appn		BA	PE	
Navy	1319	05	0604280N	
	Project		**Name**	
	3073		AMF JTRS	(Sunk)
Army	2040	05	0604280A	
	Project		**Name**	
	162		Joint Tactical Radio / Network Enterprise Domain	(Sunk)
Army	2040	05	0605380A	
	Project		**Name**	
	EA9		Airborne Maritime Fixed Small Airborne (AMF-SA)	(Sunk)
	EG6		Small Airborne Networking Radio (SANR)	
Air Force	3600	05	0604280F	
	Project		**Name**	
	655068		Joint Tactical Radio System (JTRS)	(Sunk)

Procurement

Appn		BA	PE	
Army	2035	02	0204380A	
	Line Item		**Name**	
	B90902		AMF JTRS	(Sunk)
	B90904		AMF JTRS	

Notes

B90900 is the parent Line Item number to B90902 and B90904.

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Cost and Funding

Cost Summary

Total Acquisition Cost							
Appropriation	BY 2008 $M			BY 2008 $M	TY $M		
	SAR Baseline Development Estimate	Current APB Development Objective/Threshold		Current Estimate	SAR Baseline Development Estimate	Current APB Development Objective	Current Estimate
RDT&E	1681.6	1256.2	1381.8	**1463.3**[1]	1764.2	1279.1	1502.8
Procurement	5459.7	1387.1	1525.8	1443.8	6569.8	2092.1	1990.6
Flyaway	--	--	--	1201.0	--	--	1655.2
Recurring	--	--	--	1201.0	--	--	1655.2
Non Recurring	--	--	--	0.0	--	--	0.0
Support	--	--	--	242.8	--	--	335.4
Other Support	--	--	--	129.6	--	--	179.5
Initial Spares	--	--	--	113.2	--	--	155.9
MILCON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acq O&M	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	7141.3	2643.3	N/A	2907.1	8334.0	3371.2	3493.4

[1] *APB Breach*

Current APB Cost Estimate Reference

Program Office Estimate aligned with FY 2015 President's Budget dated March 04, 2014

Confidence Level

Confidence Level of cost estimate for current APB: 50%

Original APB cost estimate was established by OSD decision at 50% confidence level.

Cost Notes

Costs do not reflect funding for platform integration and installation. Army requirements by platform and year, including integration and installation of Small Airborne Networking Radios (SANR) on host platforms, are documented separately.

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Total Quantity			
Quantity	**SAR Baseline Development Estimate**	**Current APB Development**	**Current Estimate**
RDT&E	204	192	162
Procurement	24920	14060	14060
Total	25124	14252	14222

Quantity Notes

The fielding plan and procurement funding are based on current Army requirements of 7,030 SANR (14,060 channels).

RDT&E quantity of 81 units (162 channels) reflect planned deliveries to the Army for integration onto platforms. This quantity does not include 19 units (38 channels) required for testing.

AMF PAUC and APUC units of measure are per channel. Quantities are channels with the assumption of two channels per radio.

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Cost and Funding

Funding Summary

Appropriation Summary									
FY 2017 President's Budget / December 2015 SAR (TY$ M)									
Appropriation	Prior	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	To Complete	Total
RDT&E	1419.8	6.2	5.0	35.9	6.8	10.8	9.4	8.9	1502.8
Procurement	0.0	0.0	0.0	0.0	41.0	64.2	82.9	1802.5	1990.6
MILCON	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acq O&M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PB 2017 Total	1419.8	6.2	5.0	35.9	47.8	75.0	92.3	1811.4	3493.4
PB 2016 Total	1293.6	6.2	10.4	35.4	48.5	86.9	163.2	1735.3	3379.5
Delta	126.2	0.0	-5.4	0.5	-0.7	-11.9	-70.9	76.1	113.9

Funding Notes

Starting in FY 2014, all AMF RDT&E funding resides in Army PE 0605380A.

The Prior delta of +$126.2M between PB 2016 Total and the PB 2017 Total is comprised of +$129.9M and -$3.7M where $129.9M is due to the movement of sunk cost associated with AMF acquisition program from SALT to SANR. This amount is offset by a prior year adjustment -$3.7M in the Navy account.

Quantity Summary										
FY 2017 President's Budget / December 2015 SAR (TY$ M)										
Quantity	Undistributed	Prior	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	To Complete	Total
Development	162	0	0	0	0	0	0	0	0	162
Production	0	0	0	0	0	296	340	524	12900	14060
PB 2017 Total	162	0	0	0	0	296	340	524	12900	14222
PB 2016 Total	162	0	0	0	0	296	340	1188	12236	14222
Delta	0	0	0	0	0	0	0	-664	664	0

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Cost and Funding

Annual Funding By Appropriation

Annual Funding 1319 | RDT&E | Research, Development, Test, and Evaluation, Navy							
Fiscal Year	Quantity	TY $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2003	--	--	--	--	--	--	8.4
2004	--	--	--	--	--	--	43.0
2005	--	--	--	--	--	--	54.3
2006	--	--	--	--	--	--	55.9
2007	--	--	--	--	--	--	53.5
2008	--	--	--	--	--	--	99.3
2009	--	--	--	--	--	--	212.3
2010	--	--	--	--	--	--	306.9
2011	--	--	--	--	--	--	303.5
2012	--	--	--	--	--	--	119.5
2013	--	--	--	--	--	--	9.1
Subtotal	--	--	--	--	--	--	1265.7

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Annual Funding 1319 | RDT&E | Research, Development, Test, and Evaluation, Navy							
Fiscal Year	Quantity	BY 2008 $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2003	--	--	--	--	--	--	9.4
2004	--	--	--	--	--	--	47.0
2005	--	--	--	--	--	--	57.8
2006	--	--	--	--	--	--	57.7
2007	--	--	--	--	--	--	53.9
2008	--	--	--	--	--	--	98.3
2009	--	--	--	--	--	--	207.4
2010	--	--	--	--	--	--	295.4
2011	--	--	--	--	--	--	285.3
2012	--	--	--	--	--	--	110.5
2013	--	--	--	--	--	--	8.3
Subtotal	--	--	--	--	--	--	1231.0

DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding 2040 | RDT&E | Research, Development, Test, and Evaluation, Army							
Fiscal Year	Quantity	TY $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2016	--	--	--	--	--	--	6.2
2017	--	--	--	--	--	--	5.0
2018	--	--	--	--	--	--	35.9
2019	--	--	--	--	--	--	6.8
2020	--	--	--	--	--	--	10.8
2021	--	--	--	--	--	--	9.4
2022	--	--	--	--	--	--	8.9
Subtotal	162	--	--	--	--	--	83.0

349 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding 2040 | RDT&E | Research, Development, Test, and Evaluation, Army							
Fiscal Year	Quantity	BY 2008 $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2016	--	--	--	--	--	--	5.4
2017	--	--	--	--	--	--	4.3
2018	--	--	--	--	--	--	30.1
2019	--	--	--	--	--	--	5.6
2020	--	--	--	--	--	--	8.7
2021	--	--	--	--	--	--	7.4
2022	--	--	--	--	--	--	6.9
Subtotal	162	--	--	--	--	--	68.4

350 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding 3600 | RDT&E | Research, Development, Test, and Evaluation, Air Force							
Fiscal Year	Quantity	TY $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2003	--	--	--	--	--	--	12.8
2004	--	--	--	--	--	--	28.1
2005	--	--	--	--	--	--	36.1
2006	--	--	--	--	--	--	77.1
Subtotal	--	--	--	--	--	--	154.1

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Annual Funding 3600 | RDT&E | Research, Development, Test, and Evaluation, Air Force							
Fiscal Year	Quantity	BY 2008 $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2003	--	--	--	--	--	--	14.4
2004	--	--	--	--	--	--	30.8
2005	--	--	--	--	--	--	38.6
2006	--	--	--	--	--	--	80.1
Subtotal	--	--	--	--	--	--	163.9

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Annual Funding 2035 | Procurement | Other Procurement, Army							
Fiscal Year	Quantity	TY $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2019	296	34.0	--	--	34.0	7.0	41.0
2020	340	39.1	--	--	39.1	25.1	64.2
2021	524	60.3	--	--	60.3	22.6	82.9
2022	2264	249.0	--	--	249.0	47.3	296.3
2023	1844	201.6	--	--	201.6	29.7	231.3
2024	1800	201.0	--	--	201.0	30.1	231.1
2025	1444	166.2	--	--	166.2	26.8	193.0
2026	1368	161.1	--	--	161.1	25.6	186.7
2027	1304	157.1	--	--	157.1	25.4	182.5
2028	920	115.9	--	--	115.9	21.4	137.3
2029	832	106.9	--	--	106.9	19.8	126.7
2030	692	92.3	--	--	92.3	18.5	110.8
2031	296	44.9	--	--	44.9	13.9	58.8
2032	136	25.8	--	--	25.8	11.1	36.9
2033	--	--	--	--	--	11.1	11.1
Subtotal	14060	1655.2	--	--	1655.2	335.4	1990.6

DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding 2035 | Procurement | Other Procurement, Army							
Fiscal Year	Quantity	BY 2008 $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2019	296	27.8	--	--	27.8	5.7	33.5
2020	340	31.3	--	--	31.3	20.1	51.4
2021	524	47.4	--	--	47.4	17.7	65.1
2022	2264	191.8	--	--	191.8	36.4	228.2
2023	1844	152.2	--	--	152.2	22.4	174.6
2024	1800	148.8	--	--	148.8	22.3	171.1
2025	1444	120.6	--	--	120.6	19.5	140.1
2026	1368	114.6	--	--	114.6	18.2	132.8
2027	1304	109.6	--	--	109.6	17.7	127.3
2028	920	79.3	--	--	79.3	14.6	93.9
2029	832	71.7	--	--	71.7	13.2	84.9
2030	692	60.7	--	--	60.7	12.1	72.8
2031	296	28.9	--	--	28.9	9.0	37.9
2032	136	16.3	--	--	16.3	7.0	23.3
2033	--	--	--	--	--	6.9	6.9
Subtotal	14060	1201.0	--	--	1201.0	242.8	1443.8

Low Rate Initial Production

An LRIP request is anticipated at Milestone C.

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Foreign Military Sales

None

Nuclear Costs

None

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Unit Cost

Unit Cost Report

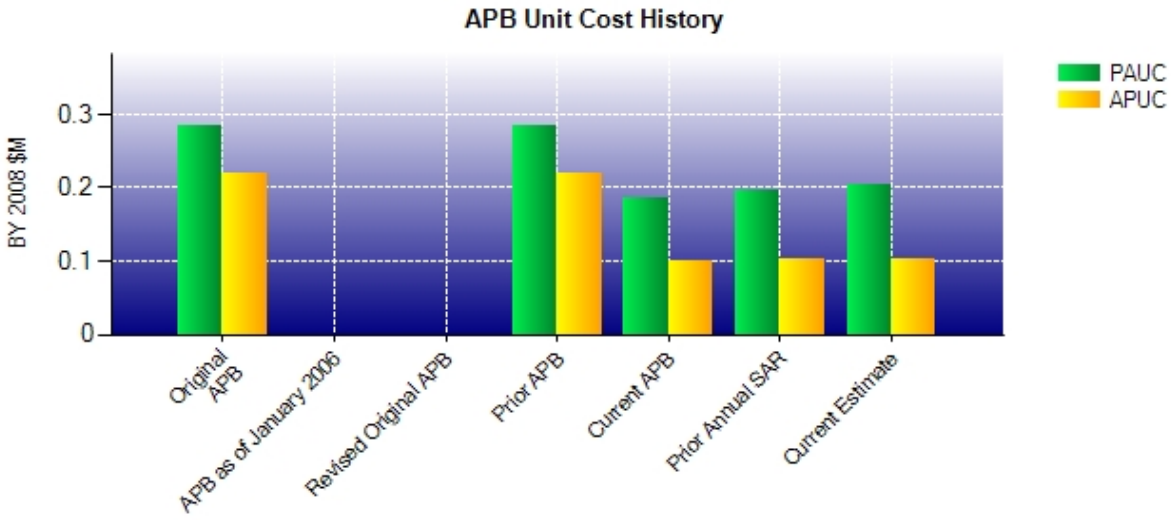
Item	BY 2008 $M Current UCR Baseline (May 2014 APB)	BY 2008 $M Current Estimate (Dec 2015 SAR)	% Change
Program Acquisition Unit Cost			
Cost	2643.3	2907.1	
Quantity	14252	14222	
Unit Cost	0.185	0.204	+10.27
Average Procurement Unit Cost			
Cost	1387.1	1443.8	
Quantity	14060	14060	
Unit Cost	0.099	0.103	+4.04

Item	BY 2008 $M Original UCR Baseline (Oct 2008 APB)	BY 2008 $M Current Estimate (Dec 2015 SAR)	% Change
Program Acquisition Unit Cost			
Cost	7141.3	2907.1	
Quantity	25124	14222	
Unit Cost	0.284	0.204	-28.17
Average Procurement Unit Cost			
Cost	5459.7	1443.8	
Quantity	24920	14060	
Unit Cost	0.219	0.103	-52.97

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Unit Cost History



Item	Date	BY 2008 $M		TY $M	
		PAUC	APUC	PAUC	APUC
Original APB	Oct 2008	0.284	0.219	0.332	0.264
APB as of January 2006	N/A	N/A	N/A	N/A	N/A
Revised Original APB	N/A	N/A	N/A	N/A	N/A
Prior APB	Oct 2008	0.284	0.219	0.332	0.264
Current APB	May 2014	0.185	0.099	0.237	0.149
Prior Annual SAR	Dec 2014	0.196	0.103	0.238	0.142
Current Estimate	Dec 2015	0.204	0.103	0.246	0.142

SAR Unit Cost History

Current SAR Baseline to Current Estimate (TY $M)									
Initial PAUC Development Estimate	Changes								PAUC Current Estimate
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
0.332	-0.005	0.066	0.013	0.001	-0.185	0.000	0.024	-0.086	0.246

Current SAR Baseline to Current Estimate (TY $M)									
Initial APUC Development Estimate	Changes								APUC Current Estimate
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
0.264	-0.004	0.016	0.023	0.000	-0.182	0.000	0.025	-0.122	0.142

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SAR Baseline History				
Item	SAR Planning Estimate	SAR Development Estimate	SAR Production Estimate	Current Estimate
Milestone A	N/A	N/A	N/A	N/A
Milestone B	N/A	Dec 2007	N/A	Mar 2008
Milestone C	N/A	Nov 2011	N/A	May 2019
IOC	N/A	Aug 2014	N/A	Oct 2022
Total Cost (TY $M)	N/A	8334.0	N/A	3493.4
Total Quantity	N/A	25124	N/A	14222
PAUC	N/A	0.332	N/A	0.246

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Cost Variance

Summary TY $M				
Item	**RDT&E**	**Procurement**	**MILCON**	**Total**
SAR Baseline (Development Estimate)	1764.2	6569.8	--	8334.0
Previous Changes				
Economic	-23.5	-36.4	--	-59.9
Quantity	-29.9	-2646.8	--	-2676.7
Schedule	-139.9	+326.1	--	+186.2
Engineering	+12.3	--	--	+12.3
Estimating	-80.4	-2549.8	--	-2630.2
Other	--	--	--	--
Support	--	+340.0	--	+340.0
Subtotal	-261.4	-4566.9	--	-4828.3
Current Changes				
Economic	-1.0	-15.8	--	-16.8
Quantity	--	--	--	--
Schedule	--	+1.4	--	+1.4
Engineering	--	--	--	--
Estimating	+1.0	-5.4	--	-4.4
Other	--	--	--	--
Support	--	+7.5	--	+7.5
Subtotal	--	-12.3	--	-12.3
Total Changes	-261.4	-4579.2	--	-4840.6
CE - Cost Variance	1502.8	1990.6	--	3493.4
CE - Cost & Funding	1502.8	1990.6	--	3493.4

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Summary BY 2008 $M				
Item	**RDT&E**	**Procurement**	**MILCON**	**Total**
SAR Baseline (Development Estimate)	1681.6	5459.7	--	7141.3
Previous Changes				
Economic	--	--	--	--
Quantity	-27.4	-2250.6	--	-2278.0
Schedule	-140.4	+23.5	--	-116.9
Engineering	+11.0	--	--	+11.0
Estimating	-61.4	-2027.3	--	-2088.7
Other	--	--	--	--
Support	--	+236.2	--	+236.2
Subtotal	-218.2	-4018.2	--	-4236.4
Current Changes				
Economic	--	--	--	--
Quantity	--	--	--	--
Schedule	--	--	--	--
Engineering	--	--	--	--
Estimating	-0.1	-4.3	--	-4.4
Other	--	--	--	--
Support	--	+6.6	--	+6.6
Subtotal	-0.1	+2.3	--	+2.2
Total Changes	-218.3	-4015.9	--	-4234.2
CE - Cost Variance	1463.3	1443.8	--	2907.1
CE - Cost & Funding	1463.3	1443.8	--	2907.1

Previous Estimate: September 2015

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RDT&E	$M	
Current Change Explanations	Base Year	Then Year
Revised escalation indices. (Economic)	N/A	-1.0
Adjustment to FY 2022 to account for previously funded requirements within the FYDP. (Estimating)	+6.9	+8.9
Revised estimate to align with adjustments in FY 2017 PB. (Estimating)	-7.3	-8.2
Adjustment for current and prior escalation. (Estimating)	+0.3	+0.3
RDT&E Subtotal	-0.1	0.0

Procurement	$M	
Current Change Explanations	Base Year	Then Year
Revised escalation indices. (Economic)	N/A	-15.8
Additional schedule variance due to procurement buy profile shifting quantity from FY 2021 to FY2022 to align with FY 2017 PB. (Schedule)	0.0	+1.4
Revised estimate to align with FY 2017 PB which resulted in program fielding schedule adjustment. (Estimating)	-4.3	-5.4
Increase in Other Support as a result of fact-of-life changes related to manpower and overhead. (Support)	+5.0	+5.4
Increase in Initial Spares due to adjustments in buy profile and fielding schedule. (Support)	+1.6	+2.1
Procurement Subtotal	+2.3	-12.3

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Contracts

There are no Contracts data to display.

363 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Deliveries and Expenditures

Deliveries				
Delivered to Date	Planned to Date	Actual to Date	Total Quantity	Percent Delivered
Development	0	0	162	0.00%
Production	0	0	14060	0.00%
Total Program Quantity Delivered	0	0	14222	0.00%

Expended and Appropriated (TY $M)			
Total Acquisition Cost	3493.4	Years Appropriated	14
Expended to Date	1422.1	Percent Years Appropriated	45.16%
Percent Expended	40.71%	Appropriated to Date	1426.0
Total Funding Years	31	Percent Appropriated	40.82%

The above data is current as of February 09, 2016.

The decrease of $0.3M from $1,422.4M to $1,422.1M since the September 2015 SAR is associated with the Navy Account (RDT&E Account 1319); the adjustment is for returned funds no longer needed by the activity.

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Operating and Support Cost

Cost Estimate Details

Date of Estimate: December 30, 2015
Source of Estimate: POE
Quantity to Sustain: 14060
Unit of Measure: Channels
Service Life per Unit: 20.00 Years
Fiscal Years in Service: FY 2020 - FY 2052

O&S costs are based on the procurement of 7,030 two-channel radios (7,030 x 2 = 14,060), each with a 20-year estimated service life. RDT&E quantities are not sustained.

Sustainment Strategy

The project is currently in the pre-solicitation stage. The program office will conduct an in-depth assessment of risks to logistics and training as information on the product becomes available. The program office will execute a step approach to contracting for a Performance Based Logistics (PBL) solution to be initiated after the FRP decision. Initial procurement of test/integration units is planned to come with a one-year warranty and Interim Contractor Logistics Support at contract award. The program office plans to conduct a business case analysis using actual cost, usage, and turn-around times before FRP. This approach will facilitate transition to full PBL implementation with greater understanding of requirements, more effective metrics, and greater cost fidelity. Depot Source of Repair Analysis will also be conducted prior to Milestone C. The training concept is being jointly developed by the PEO for Command, Control, and Communications - Tactical, PM Tactical Radios, PM AMF, the Army Training and Doctrine Command Training Directorate and the U.S. Army Aviation Center of Excellence, and will include a System Training Plan to accompany the validated requirements document.

Antecedent Information

No Antecedent. AMF radios are software programmable, multi-band, multi-mode, mobile ad hoc networking radios, providing simultaneous voice, data, and video communications, and which may be employed in new and innovative ways as compared to any currently fielded legacy radio.

Annual O&S Costs BY2008 $K

Cost Element	Small Airborne Networking Radio (SANR) Average Annual Cost Per Channels	No Antecedent (Antecedent)
Unit-Level Manpower	0.305	--
Unit Operations	0.000	--
Maintenance	3.561	--
Sustaining Support	1.773	--
Continuing System Improvements	0.209	--
Indirect Support	0.000	--
Other	--	--
Total	5.848	--

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Item	Total O&S Cost $M			
	Small Airborne Networking Radio (SANR)			No Antecedent (Antecedent)
	Current Development APB Objective/Threshold		Current Estimate	
Base Year	2887.4	3176.1	1644.5	0.0
Then Year	5311.8	N/A	2837.3	N/A

Equation to Translate Annual Cost to Total Cost

14,060 channels * 20 years * $5.848K = $1,644,457.60K = $1,644.5M (BY 2008 $M)

O&S Cost Variance		
Category	**BY 2008 $M**	**Change Explanations**
Prior SAR Total O&S Estimates - Sep 2015 SAR	1651.2	
Programmatic/Planning Factors	30.1	Revised estimate due to shift in buy profile to align with FY 2017 PB.
Cost Estimating Methodology	-36.8	Removal of unit operations costs. Army requirements for fuel, oil and lubricants for SANR will be incurred by the host platform.
Cost Data Update	0.0	
Labor Rate	0.0	
Energy Rate	0.0	
Technical Input	0.0	
Other	0.0	
Total Changes	-6.7	
Current Estimate	1644.5	

Disposal Estimate Details

Date of Estimate: December 30, 2015

Source of Estimate: POE

Disposal/Demilitarization Total Cost (BY 2008 $M): Total costs for disposal of all Channels are 1.6

Selected Acquisition Report (SAR)

RCS: DD-A&T(Q&A)823-420



MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle)

As of FY 2017 President's Budget

Defense Acquisition Management
Information Retrieval
(DAMIR)

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Common Acronyms and Abbreviations for MDAP Programs

Acq O&M - Acquisition-Related Operations and Maintenance
ACAT - Acquisition Category
ADM - Acquisition Decision Memorandum
APB - Acquisition Program Baseline
APPN - Appropriation
APUC - Average Procurement Unit Cost
$B - Billions of Dollars
BA - Budget Authority/Budget Activity
Blk - Block
BY - Base Year
CAPE - Cost Assessment and Program Evaluation
CARD - Cost Analysis Requirements Description
CDD - Capability Development Document
CLIN - Contract Line Item Number
CPD - Capability Production Document
CY - Calendar Year
DAB - Defense Acquisition Board
DAE - Defense Acquisition Executive
DAMIR - Defense Acquisition Management Information Retrieval
DoD - Department of Defense
DSN - Defense Switched Network
EMD - Engineering and Manufacturing Development
EVM - Earned Value Management
FOC - Full Operational Capability
FMS - Foreign Military Sales
FRP - Full Rate Production
FY - Fiscal Year
FYDP - Future Years Defense Program
ICE - Independent Cost Estimate
IOC - Initial Operational Capability
Inc - Increment
JROC - Joint Requirements Oversight Council
$K - Thousands of Dollars
KPP - Key Performance Parameter
LRIP - Low Rate Initial Production
$M - Millions of Dollars
MDA - Milestone Decision Authority
MDAP - Major Defense Acquisition Program
MILCON - Military Construction
N/A - Not Applicable
O&M - Operations and Maintenance
ORD - Operational Requirements Document
OSD - Office of the Secretary of Defense
O&S - Operating and Support
PAUC - Program Acquisition Unit Cost

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PB - President's Budget
PE - Program Element
PEO - Program Executive Officer
PM - Program Manager
POE - Program Office Estimate
RDT&E - Research, Development, Test, and Evaluation
SAR - Selected Acquisition Report
SCP - Service Cost Position
TBD - To Be Determined
TY - Then Year
UCR - Unit Cost Reporting
U.S. - United States
USD(AT&L) - Under Secretary of Defense (Acquisition, Technology and Logistics)

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Program Information

Program Name

MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle)

DoD Component

Army

Responsible Office

COL Courtney P. Cote
Unmanned Aircraft Systems (UAS) Project Office
Building 5300
Redstone Arsenal, AL 35898

courtney.p.cote.mil@mail.mil

Phone: 256-313-5327
Fax: 256-313-5445
DSN Phone: 897-5327
DSN Fax: 897-5445
Date Assigned: July 11, 2014

References

SAR Baseline (Production Estimate)

Defense Acquisition Executive (DAE) Approved Acquisition Program Baseline (APB) dated March 25, 2011

Approved APB

Defense Acquisition Executive (DAE) Approved Acquisition Program Baseline (APB) dated September 12, 2013

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Mission and Description

The MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle) provides the Division Commander a dedicated, assured, multi-mission unmanned aircraft system for the tactical fight assigned to the Combat Aviation Brigade (CAB) in each Division and supports the Division Fires, Battlefield Surveillance Brigades, and Brigade Combat Teams based upon the Division Commander's priorities. Additionally, MQ-1C Gray Eagle provides reconnaissance, surveillance, and target acquisition; command and control; communications relay; signals intelligence; electronic warfare; attack; detection of weapons of mass destruction; battle damage assessment; and manned-unmanned teaming capabilities. Fifteen Gray Eagle Warfighting companies are assigned as follows: ten companies assigned to Army divisions, one company to the National Training Center (NTC), one company to the U.S. Army Special Operations Command (USASOC), and three companies to the Intelligence and Security Command (INSCOM).

Version 8.7, Revision 3 of the CPD for MQ-1C Gray Eagle defines an operational requirement for Improved Gray Eagle (IGE). IGE provides for increased range, endurance, and payload carrying capability for Echelons Above Division. IGE provides the Army with an extended range, multi-purpose unmanned aircraft system capable of executing reconnaissance, security, attack, and intelligence collection missions in the range of military operations. Sensors/payloads include an Electro -Optical/Infrared/Laser Designator, Synthetic Aperture Radar/Moving Target Indicator, Signals Intelligence, and Hellfire missiles; providing a near all-weather mission capability. When integrated with manned systems, manned-unmanned teaming, IGE enhances the capability to provide more accurate and timely information and intelligence, and significantly reduces the time to conduct tactical engagements. A total of 36 of the 167 MQ-1C UAS aircraft will be delivered in the IGE configuration.

A Gray Eagle Company is configured into three equal platoons. The Gray Eagle System consists of 12 MQ-1C aircraft, each with the following payloads: Electro-Optical/Infrared, Laser Range Finder/Laser Designator, Synthetic Aperture Radar/Ground Moving Target Indicator, communications relay, and Hellfire Missiles. Ground equipment includes: six Ground Control Stations (GCS), seven Ground Data Terminals, three satellite communication Ground Data Terminals, one Mobile GCS, the Automated Takeoff and Landing System which consists of six Tactical Automatic Landing System-Tracking Subsystems, two per runway, and Ground-Based Sense and Avoid. USASOC and INSCOM companies will contain the full complement of system equipment. However, the Divisional and NTC companies will have fewer assets while at Continental United States (CONUS) locations. These units will have nine aircraft and five GCS with corresponding support equipment. When deployed outside CONUS, the Army will reallocate equipment from other units which will bring these companies to full Gray Eagle System equipment strength. Each Gray Eagle company will consist of 125 soldiers within the Divisional CAB and the NTC. Each unit will have three identical platoons; each platoon is capable of operating independently when fully equipped.

MQ-1C Gray Eagle is fielded across tactical and operational elements: the CAB in support of Army divisions, the 116th Military Intelligence Brigade (also known as the Aerial Intelligence Brigade) in support of the Army INSCOM, and the 160th Special Operations Aviation Regiment (Airborne) in support of USASOC. All three organizations utilize the balanced platoon configuration, providing for three identical flight platoons within the company. This configuration provides increased employment flexibility to the commander (consolidated, split-based, or remote split-based operations) and increased operational tempo over previous configurations with minimal additions of equipment while keeping soldier numbers constant. INSCOM and SOCOM units are composed of eight IGE aircraft and four acquisition baseline aircraft; the eight IGE's will be deployed in split based operations at two separate locations. The four baseline aircraft will remain in CONUS for training purposes.

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Executive Summary

A MQ-1C Gray Eagle Follow-on Test & Evaluation (FOT&E) was successfully completed on June 12, 2015. Performance and reliability data were collected on 1,160 flight hours and 1,500 Universal Ground Control Station (UGCS) hours during the 42 sorties flown between May 14, 2015 and June 12, 2015. The FOT&E primary purpose was to evaluate UGCS equipment and the new split-based operations concept. Additional goals accomplished during FOT&E included continuous operation of a Link-16 network (Net Ready KPP) throughout the test event, and successful execution of an Adversarial Assessment Cyber Test. While the Gray Eagle hardware performed exceptionally well throughout the test, preliminary observations and feedback from evaluators emphasized deficiencies directly attributable to training. The PM and U.S. Army Training and Doctrine Command are addressing these concerns.

A MQ-1C Gray Eagle Configuration Steering Board (CSB) was held on July 14, 2015. The CSB was a result of a FY 2016 Resource Management Decision that funded the MQ-1C Gray Eagle program to procure one additional Echelon Above Division (EAD) company and support equipment. Additionally, the CSB considered Courses of Action (COA) for the Army to pursue an extended range capable Improved Gray Eagle and considered the revised Gray Eagle CPD requirement for validation. The CSB, Army Systems Acquisition Review Council and Army Requirements Oversight Council concurred with the COA to validate the revised requirement for the EAD MQ-1C Gray Eagle and granted authority to pursue the extended range capable MQ-1C Gray Eagle configuration for FY 2015 and FY 2016 procurement. The CSB approved procurement of 36 Improved Gray Eagle aircraft. An ADM dated August 13, 2015, approved procurement of 15 additional MQ-1C Gray Eagle Unmanned Aircraft and associated ground support equipment for a total of 167 MQ-1C Gray Eagle aircraft. Additionally, the ADM approved and authorized an acquisition and contracting strategy for Gray Eagle extended range modifications. An updated APB is in staffing and planned for approval in 3rd Quarter FY 2016.

Overall, the MQ-1C Gray Eagle acquisition program costs are stable. There are no anticipated program requirements or issues that would negatively affect program cost. MQ-1C Gray Eagle production continues with Firm Fixed Price FRP I, II and III contracts. FRP IV is planned for contract award in FY 2016. As of December 31, 2015 a total of 131 of 167 MQ-1C Gray Eagle aircraft have been delivered. To date, there are nine companies fielded with approximately 175,000+ flight hours with greater than 90 percent operational availability.

There are no significant software-related issues with this program at this time.

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Threshold Breaches

APB Breaches		
Schedule		☐
Performance		☐
Cost	RDT&E	☐
	Procurement	☐
	MILCON	☐
	Acq O&M	☐
O&S Cost		☐
Unit Cost	PAUC	☐
	APUC	☐

Nunn-McCurdy Breaches		
Current UCR Baseline		
	PAUC	None
	APUC	None
Original UCR Baseline		
	PAUC	None
	APUC	None

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Schedule



Schedule Events				
Events	**SAR Baseline Production Estimate**	**Current APB Production Objective/Threshold**		**Current Estimate**
Milestone B	Apr 2005	Apr 2005	Apr 2005	Apr 2005
SDD (EMD) Contract Award	Apr 2005	Apr 2005	Apr 2005	Apr 2005
Critical Design Review	Feb 2006	Feb 2006	Feb 2006	Feb 2006
Milestone C	Mar 2011	Mar 2011	Mar 2011	Mar 2011
IOT&E				
IOT&E Start	Sep 2011	Jul 2012	Jul 2012	Jul 2012
IOT&E Complete	Oct 2011	Aug 2012	Aug 2012	Aug 2012
IOC	Jun 2012	Dec 2012	Dec 2012	Dec 2012
FRP Decision	Apr 2012	Jul 2013	Jul 2013	Jun 2013
FOT&E I	Aug 2012	May 2015	Nov 2015	Jun 2015
FOT&E II	May 2013	N/A	N/A	N/A

Change Explanations

None

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Acronyms and Abbreviations

FOT&E - Follow-On Test and Evaluation
IOT&E - Initial Operational Test and Evaluation
SDD - System Development and Demonstration

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Performance

Performance Characteristics				
SAR Baseline Production Estimate	**Current APB Production Objective/Threshold**		**Demonstrated Performance**	**Current Estimate**
Net Ready				
The system must fully support execution of all operational activities identified in the applicable joint and system integrated architectures and the system must satisfy the technical requirements for Net-Centric military operations to include 1) DISR mandated GIG IT standards and profiles identified in the TV-1, 2) DISR mandated GIG KIPs identified in the KIP declaration table, 3) NCOW RM Enterprise Services 4) IA requirements including availability, integrity, authentica-tion, confident-iality, and non-repudiation, and issuance of an ATO by the DAA, and 5) Operationally effective information exchanges; and mission critical performance and IA attributes, data correctness, data availability, and consistent data processing specified in the applicable joint and system integrated architecture views. The system must be able to enter and be managed in the network, and exchange data in a secure manner.	The system must fully support execution of all operational activities identified in the applicable joint and system integrated architectures and the system must satisfy the technical requirements for Net-Centric military operations to include 1) DISR mandated GIG IT standards and profiles identified in the TV-1, 2) DISR mandated GIG KIPs identified in the KIP declaration table, 3) NCOW RM Enterprise Services 4) IA requirements including availability, integrity, authentica-tion, confident-iality, and non-repudiation, and issuance of an ATO by the DAA, 5) Operationally effective information exchanges; and mission critical performance and IA attributes, data correctness, data availability, and consistent data processing specified in the applicable joint and system integrated architecture views.	The system must fully support execution of joint critical operational activities identified in the applicable joint and system integrated architectures and the system must satisfy the technical requirements for transition to Net-Centric military operations to include 1) DISR mandated GIG IT standards and profiles identified in the TV-1, 2) DISR mandated GIG KIPs identified in the KIP declaration table, 3) NCOW RM Enterprise Services 4) IA requirements including availability, integrity, authentica-tion, confident-iality, and non-repudiation, and issuance of an IATO by the DAA, 5) Operationally effective information exchanges; and mission critical performance and IA attributes, data correctness, data availability, and consistent data processing specified in the applicable joint and system integrated architecture views.	Met threshold at IOT&E, LINK16 demonstrated at FOT&E I	The system must fully support execution of all operational activities identified in the applicable joint and system integrated architectures and the system must satisfy the technical requirements for Net-Centric military operations to include 1) DISR mandated GIG IT standards and profiles identified in the TV-1, 2) DISR mandated GIG KIPs identified in the KIP declaration table, 3) NCOW RM Enterprise Services 4) IA requirements including availability, integrity, authentica-tion, confident-iality, and non-repudiation, and issuance of an ATO by the DAA, 5) Operationally effective information exchanges; and mission critical performance and IA attributes, data correctness, data availability, and consistent data processing specified in the applicable joint and system integrated architecture views.

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Multi Payload/Weight Capability				
The aircraft is capable of simultan-eously carrying two payloads with a combined minimum weight of 300 lbs.	UA will be capable of simultan-eously carrying three or more payloads with a combined minimum weight of 300 lbs.	UA will be capable of simultan-eously carrying two payloads with a combined minimum weight of 200 lbs.	Met threshold at IOT&E	UA will be capable of simultaneously carrying three or more payloads with a combined minimum weight of 300 lbs.
Airframe Sensors Payload Capability				
The aircraft will be capable of accepting payloads that are: EO/IR/LD capable of providing a 90% PD of a military target from the aircraft's operational altitude out to a minimum of 30km slant range. EO/IR/LD capable of providing a 90% PR of a military target, from the aircraft's operational altitude, out to a minimum of 10km slant range. SAR/GMTI Sensor capable of providing 85% PD of a military target, from the aircraft's operational altitude, out to a minimum 10km slant range in clear weather	MQ-1C UA will be capable of accepting payloads that are: EO/IR/LD capable of providing: 90% PD of a military target, from the UA's operational altitude out to a minimum of 30 km slant range; 90% PR of a military target, from the UA's operational altitude, out to a minimum of 10 km slant range; SAR/GMTI sensor capable of providing 85% PD of a military target, from the UA's operational altitude, out to a minimum of 10 km slant range in clear weather.	EO/IR/LD capable of providing: 90% PD of a military target, from the UA's operational altitude out to a minimum of 25 km slant range; 90% PR of a military target, from the UA's operational altitude out to a minimum of 9 km slant range.	Met objective, verified CSP during Production Prove-Out Test	MQ-1C UA will be capable of accepting payloads that are: EO/IR/LD capable of providing: 90% PD of a military target, from the UA's operational altitude out to a minimum of 30 km slant range; 90% PR of a military target, from the UA's operational altitude, out to a minimum of 10 km slant range; SAR/GMTI sensor capable of providing 85% PD of a military target, from the UA's operational altitude, out to a minimum of 10 km slant range in clear weather.
Sustainment				
The aircraft system must maintain a combat Ao of 90%.	MQ-1C must maintain a combat Ao of 90%.	MQ-1C must maintain a combat Ao of 80%.	Met updated threshold KPP at IOT&E	MQ-1C must maintain a combat Ao of 90%.
Aircraft Propulsion				
The aircraft engine will be powered by DoD/NATO standard heavy fuel (JP8 Fuel).	UA engine will be powered by DoD/NATO standard heavy fuel (JP8 Fuel).	UA engine will be powered by DoD/NATO standard heavy fuel (JP8 Fuel).	Met objective	UA engine will be powered by DoD/NATO standard heavy fuel (JP8 Fuel).
Weapons Capable				
The aircraft shall be capable of engaging traditional and non-traditional ground moving, stationary, and water borne moving targets with the AGM-114P-4A and AGM-	MQ-1C must be capable of engaging traditional and non-traditional ground moving and stationary and water borne moving and stationary targets with the AGM-	MQ-1C must be capable of engaging traditional and non-traditional ground moving and stationary targets with the AGM-114P-4A and AGM-114N-4.	Met threshold; (35) Hellfire shots DT/OT; (100+) Hellfire shots in OIF/OEF	MQ-1C must be capable of engaging traditional and non-traditional ground moving and stationary and water borne moving and stationary targets with the AGM-114P-4A and

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114N-4 and other AGM-114 variants or similar future AGMs and small light weight precision munitions.	114P-4A and AGM-114N-4 and other AGM -114 variants or similar future AGMs and small light weight precision munitions.			AGM-114N-4 and other AGM-114 variants or similar future AGMs and small light weight precision munitions.
Survivability and Force Protection				
The GCS-V3 will be mounted onto an Army standard tactical vehicle with the ability to be up armored.	The GCS will be mounted onto an Army standard tactical vehicle with the ability to be up armored.	The GCS will be mounted onto an Army standard tactical vehicle with the ability to be up armored.	Met objective	The GCS will be mounted onto an Army standard tactical vehicle with the ability to be up armored.

Requirements Reference

CPD dated March 24, 2009

Change Explanations

None

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Acronyms and Abbreviations

% - Percent
AGMs - Air-to-Ground Missiles
Ao - Operational Availability
ATO - Approval to Operate
CSP - Common Sensor Payload
DAA - Designated Approval Authority
DISR - Department of Defense Information Technology Standards Registry
DT - Developmental Test
EO/IR/LD - Electro-Optical/Infrared/Laser Designator
FOT&E - Follow-On Test and Evaluation
GCS-V3 - Ground Control Station Version Three
GIG - Global Information Grid
IA - Information Assurance
IATO - Interim Approval to Operate
IOT&E - Initial Operational Test and Evaluation
IT - Information Technology
KIP - Key Interface Profile
km - Kilometers
lbs - Pounds
NATO - North Atlantic Treaty Organization
NCOW RM - Net Centric Operations Warfare Reference Model
OEF - Operation Enduring Freedom
OIF - Operation Iraqi Freedom
OT - Operational Test
PD - Probability of Detection
PR - Probability of Recognition
SAR/GMTI - Synthetic Aperature Radar/Ground Moving Target Indicator
TV - Technical View
UA - Unmanned Aircraft

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Track to Budget

RDT&E

Appn	BA	PE
Army	2040 07	0305204A

Project	Name	
D09	Research, Development, Test and Evaluation, Army	(Sunk)
Notes:	FY 2005 - FY 2010	

Appn	BA	PE
Army	2040 07	0305219A

Project	Name
MQ1	Research, Development, Test and Evaluation, Army
Notes:	Beginning FY 2011

Procurement

Appn	BA	PE
Army	2031 02	0305219A

Line Item	Name		
A00020	MQ-1 Payload	(Shared)	(Sunk)

Appn	BA	PE
Army	2031 01	0305219A

Line Item	Name
A0005	MQ-1 UAV
Notes:	FY 2010 - FY 2036

Appn	BA	PE
Army	2031 02	0313400A

Line Item	Name	
A01001	MQ-1 Payload	(Shared)
Notes:	Beginning in FY 2015	

Appn	BA	PE
Army	2031 02	0305219A

Line Item	Name	
A01005	CSP FMV	(Shared)

Appn	BA	PE
Army	2035 02	0030500A

Line Item	Name	
00305000	Other Procurement, Army	(Sunk)
Notes:	FY 2007 - FY 2009	

Notes

The MQ-1C Gray Eagle program baseline includes the Common Sensor Payload (CSP) procurement, which is part of the MQ-1 Payloads Aircraft Procurement, Army budget line. The funding line is shared with the CSP, Synthetic Aperture Radar, Ground Moving Target Indicator, and the Tactical Signals Intelligence Payload.

MILCON

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Appn		BA	PE
Army	2050	02	0202096A

Project	Name
VARIOUS	VARIOUS

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Cost and Funding

Cost Summary

Total Acquisition Cost							
Appropriation	BY 2010 $M			BY 2010 $M	TY $M		
	SAR Baseline Production Estimate	Current APB Production Objective/Threshold		Current Estimate	SAR Baseline Production Estimate	Current APB Production Objective	Current Estimate
RDT&E	895.3	931.7	1024.9	940.4	896.3	945.3	951.8
Procurement	3364.7	2988.0	3286.8	3276.3	3572.0	3217.3	3502.4
Flyaway	--	--	--	2472.2	--	--	2641.3
Recurring	--	--	--	2215.2	--	--	2370.3
Non Recurring	--	--	--	257.0	--	--	271.0
Support	--	--	--	804.1	--	--	861.1
Other Support	--	--	--	502.2	--	--	541.0
Initial Spares	--	--	--	301.9	--	--	320.1
MILCON	992.0	578.5	636.4	608.9	1080.7	640.2	667.2
Acq O&M	0.0	0.0	--	0.0	0.0	0.0	0.0
Total	5252.0	4498.2	N/A	4825.6	5549.0	4802.8	5121.4

Confidence Level

Confidence Level of cost estimate for current APB: 50%

The ICE to support the MQ-1C Gray Eagle program Milestone C decision, like all life cycle cost estimates previously performed by the CAPE office, is built upon a product-oriented work breakdown structure, based on historical actual cost information to the maximum extent possible, and, most importantly, based on conservative assumptions that are consistent with actual demonstrated contractor and government performance for a series of acquisition programs in which the Department has been successful.

The confidence level for the Full Rate Production-aproved Acquisition Program Baseline (APB) is 50% and is based on the May 9, 2013, approved Army Cost Position and are in accordance with Army cost guidance, Army Regulations (AR) 11-18. It is difficult to calculate mathematically the precise confidence levels associated with life cycle cost estimates prepared for MDAPs. Based on the rigor in methods used in building estimates, the strong adherence to the collection and use of historical cost information, and the review of applied assumptions, we project that it is about equally likely that the estimate will prove too low or too high for execution of the program described.

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Total Quantity			
Quantity	SAR Baseline Production Estimate	Current APB Production	Current Estimate
RDT&E	2	2	2
Procurement	29	29	32
Total	31	31	34

Quantity Notes

A Gray Eagle Company is configured into three equal platoons. The Gray Eagle System consists of 12 MQ-1C aircraft, each with payloads. Ground equipment includes: six Ground Control Stations, seven Ground Data Terminals, three satellite communication Ground Data Terminals, one Mobile Ground Control Station, the Automated Takeoff and Landing System which consists of six Tactical Automatic Landing System-Tracking Subsystems (two per runway), and Ground Based Sense and Avoid. U.S. Army's Special Operations Command and Intelligence Support Command companies will contain the full complement of system equipment however, the Divisional and National Training Center (NTC) companies will have fewer assets while at Continental United States (CONUS) locations. These units will have nine aircraft and five GCS with corresponding support equipment. When deployed outside CONUS, the Army will reallocate equipment from other units which will bring these companies to full Gray Eagle System equipment strength. Each Gray Eagle company will consist of 125 soldiers within the divisional Combat Aviation Brigade and the NTC. Each unit will have three identical platoons; each platoon is capable of operating independently when fully equipped.

A Resource Management Decision in FY 2015 increased the FY 2016 PB budget for the procurement of an additional 15 aircraft. An ADM directed the Army Acquisition Objective increase from 152 to 167 aircraft and increased the total platoons by three from 31 to 34. Although the fielding strategy evolved, the Army continues to use the number of platoons as the metric to determine program APUC and PAUC.

384 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Cost and Funding

Funding Summary

Appropriation Summary									
FY 2017 President's Budget / December 2015 SAR (TY$ M)									
Appropriation	Prior	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	To Complete	Total
RDT&E	938.3	0.0	13.5	0.0	0.0	0.0	0.0	0.0	951.8
Procurement	3104.8	322.2	60.2	15.2	0.0	0.0	0.0	0.0	3502.4
MILCON	597.2	0.0	47.0	23.0	0.0	0.0	0.0	0.0	667.2
Acq O&M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PB 2017 Total	4640.3	322.2	120.7	38.2	0.0	0.0	0.0	0.0	5121.4
PB 2016 Total	4640.5	286.9	122.7	15.3	0.0	0.0	0.0	0.0	5065.4
Delta	-0.2	35.3	-2.0	22.9	0.0	0.0	0.0	0.0	56.0

Quantity Summary										
FY 2017 President's Budget / December 2015 SAR (TY$ M)										
Quantity	Undistributed	Prior	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	To Complete	Total
Development	2	0	0	0	0	0	0	0	0	2
Production	0	29	3	0	0	0	0	0	0	32
PB 2017 Total	2	29	3	0	0	0	0	0	0	34
PB 2016 Total	2	29	3	0	0	0	0	0	0	34
Delta	0	0	0	0	0	0	0	0	0	0

385 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Cost and Funding

Annual Funding By Appropriation

Annual Funding 2040 | RDT&E | Research, Development, Test, and Evaluation, Army							
Fiscal Year	Quantity	TY $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2005	--	--	--	--	--	--	54.3
2006	--	--	--	--	--	--	90.6
2007	--	--	--	--	--	--	123.7
2008	--	--	--	--	--	--	103.4
2009	--	--	--	--	--	--	61.8
2010	--	--	--	--	--	--	135.1
2011	--	--	--	--	--	--	119.2
2012	--	--	--	--	--	--	121.9
2013	--	--	--	--	--	--	68.7
2014	--	--	--	--	--	--	13.1
2015	--	--	--	--	--	--	46.5
2016	--	--	--	--	--	--	--
2017	--	--	--	--	--	--	13.5
Subtotal	2	--	--	--	--	--	951.8

386 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding 2040 | RDT&E | Research, Development, Test, and Evaluation, Army							
Fiscal Year	Quantity	BY 2010 $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2005	--	--	--	--	--	--	58.8
2006	--	--	--	--	--	--	95.5
2007	--	--	--	--	--	--	127.3
2008	--	--	--	--	--	--	104.4
2009	--	--	--	--	--	--	61.6
2010	--	--	--	--	--	--	132.7
2011	--	--	--	--	--	--	114.8
2012	--	--	--	--	--	--	115.6
2013	--	--	--	--	--	--	64.1
2014	--	--	--	--	--	--	12.0
2015	--	--	--	--	--	--	41.8
2016	--	--	--	--	--	--	--
2017	--	--	--	--	--	--	11.8
Subtotal	2	--	--	--	--	--	940.4

387 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding 2031 | Procurement | Aircraft Procurement, Army							
Fiscal Year	Quantity	TY $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2010	6	249.9	67.7	73.0	390.6	100.1	490.7
2011	6	242.7	57.7	92.9	393.3	110.3	503.6
2012	6	301.3	85.6	25.5	412.4	196.0	608.4
2013	4	192.8	116.5	54.1	363.4	87.1	450.5
2014	4	277.8	144.6	19.7	442.1	87.8	529.9
2015	2	122.9	58.2	--	181.1	65.3	246.4
2016	3	185.7	54.8	5.8	246.3	75.9	322.2
2017	--	--	9.8	--	9.8	50.4	60.2
2018	--	--	4.4	--	4.4	10.8	15.2
Subtotal	31	1573.1	599.3	271.0	2443.4	783.7	3227.1

388 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding 2031 | Procurement | Aircraft Procurement, Army							
Fiscal Year	Quantity	BY 2010 $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2010	6	243.4	65.9	71.1	380.4	97.5	477.9
2011	6	232.1	55.2	88.9	376.2	105.5	481.7
2012	6	283.4	80.5	24.0	387.9	184.4	572.3
2013	4	178.2	107.6	50.0	335.8	80.5	416.3
2014	4	252.8	131.7	17.9	402.4	79.9	482.3
2015	2	110.2	52.2	--	162.4	58.5	220.9
2016	3	164.3	48.5	5.1	217.9	67.2	285.1
2017	--	--	8.5	--	8.5	43.8	52.3
2018	--	--	3.7	--	3.7	9.2	12.9
Subtotal	31	1464.4	553.8	257.0	2275.2	726.5	3001.7

389 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Common Sensor Payload (TY$M):
FY 2010 ($48.5M)
FY 2011 ($48.2M)
FY 2012 ($61.5M)
FY 2013 ($73.6M)
FY 2014 ($29.2M)
FY 2015 ($8.4M)
FY 2016 ($35.2M)
FY 2017 ($4.8M)
FY 2018 ($4.4M)

390 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding 2035 | Procurement | Other Procurement, Army							
Fiscal Year	Quantity	TY $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2007	--	--	--	--	--	9.7	9.7
2008	--	--	31.4	--	31.4	24.3	55.7
2009	1	151.2	15.3	--	166.5	43.4	209.9
Subtotal	1	151.2	46.7	--	197.9	77.4	275.3

391 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding 2035 | Procurement | Other Procurement, Army							
Fiscal Year	Quantity	BY 2010 $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2007	--	--	--	--	--	9.9	9.9
2008	--	--	31.6	--	31.6	24.5	56.1
2009	1	150.2	15.2	--	165.4	43.2	208.6
Subtotal	1	150.2	46.8	--	197.0	77.6	274.6

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Annual Funding 2050 | MILCON | Military Construction, Army	
Fiscal Year	TY $M Total Program
2011	102.0
2012	228.0
2013	107.2
2014	36.0
2015	124.0
2016	--
2017	47.0
2018	23.0
Subtotal	667.2

DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding 2050 | MILCON | Military Construction, Army	
Fiscal Year	BY 2010 $M
	Total Program
2011	96.6
2012	213.1
2013	98.8
2014	32.2
2015	109.2
2016	--
2017	39.9
2018	19.1
Subtotal	608.9

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Low Rate Initial Production

Item	Initial LRIP Decision	Current Total LRIP
Approval Date	3/29/2010	7/3/2012
Approved Quantity	2	6
Reference	Milestone C ADM	LRIP III ADM
Start Year	2010	2012
End Year	2011	2016

The Current Total LRIP Quantity is more than 10% of the total production quantity due to MDA directed quantities to facilitate the MQ-1C Gray Eagle capability entrance into theater as quickly as possible.

Initial LRIP Decision
The original LRIP quantity was two MQ-1C Gray Eagle systems which equates to six platoon sets (24 aircraft).

Current Total LRIP
The Current Total LRIP quantity is six MQ-1C Gray Eagle systems which equates to 18 platoon sets and includes LRIP I (24 aircraft and two attrition aircraft), LRIP II (24 aircraft and five attrition aircraft) and LRIP III (29 aircraft).

395 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Foreign Military Sales

None

Nuclear Costs

None

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Unit Cost

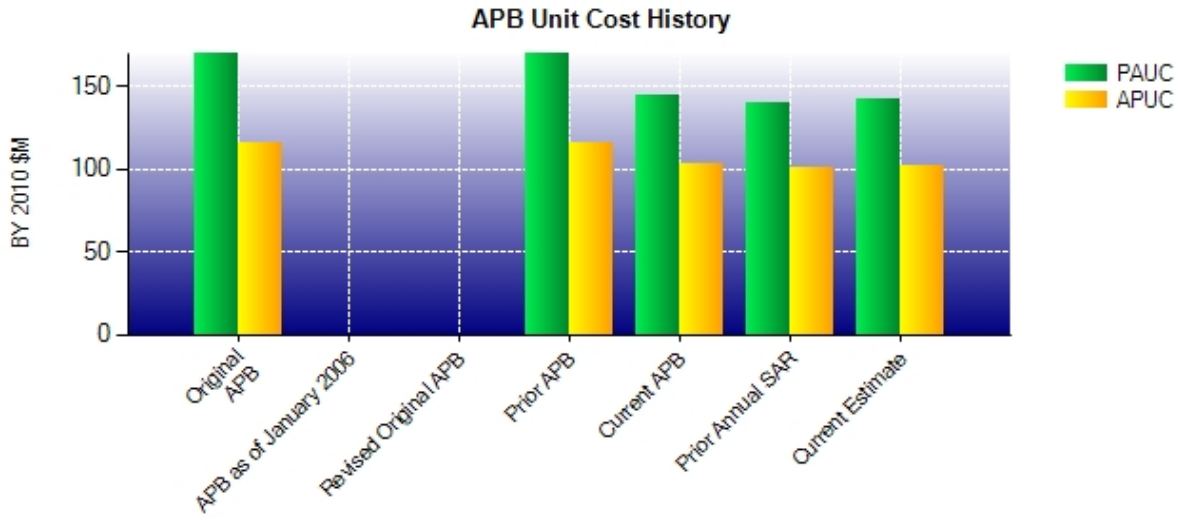
Unit Cost Report

Item	BY 2010 $M Current UCR Baseline (Sep 2013 APB)	BY 2010 $M Current Estimate (Dec 2015 SAR)	% Change
Program Acquisition Unit Cost			
Cost	4498.2	4825.6	
Quantity	31	34	
Unit Cost	145.103	141.929	-2.19
Average Procurement Unit Cost			
Cost	2988.0	3276.3	
Quantity	29	32	
Unit Cost	103.034	102.384	-0.63

Item	BY 2010 $M Original UCR Baseline (Mar 2011 APB)	BY 2010 $M Current Estimate (Dec 2015 SAR)	% Change
Program Acquisition Unit Cost			
Cost	5252.0	4825.6	
Quantity	31	34	
Unit Cost	169.419	141.929	-16.23
Average Procurement Unit Cost			
Cost	3364.7	3276.3	
Quantity	29	32	
Unit Cost	116.024	102.384	-11.76

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Unit Cost History



Item	Date	BY 2010 $M		TY $M	
		PAUC	APUC	PAUC	APUC
Original APB	Mar 2011	169.419	116.024	179.000	123.172
APB as of January 2006	N/A	N/A	N/A	N/A	N/A
Revised Original APB	N/A	N/A	N/A	N/A	N/A
Prior APB	Feb 2012	169.419	116.024	179.000	123.172
Current APB	Sep 2013	145.103	103.034	154.929	110.941
Prior Annual SAR	Dec 2014	140.182	101.178	148.982	108.372
Current Estimate	Dec 2015	141.929	102.384	150.629	109.450

SAR Unit Cost History

Initial SAR Baseline to Current SAR Baseline (TY $M)									
Initial PAUC Development Estimate	Changes								PAUC Production Estimate
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
401.600	0.094	-242.537	-7.813	13.968	13.152	0.000	0.536	-222.600	179.000

Current SAR Baseline to Current Estimate (TY $M)									
PAUC Production Estimate	Changes								PAUC Current Estimate
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
179.000	0.976	-11.079	0.129	2.562	-18.068	0.000	-2.891	-28.371	150.629

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Initial SAR Baseline to Current SAR Baseline (TY $M)									
Initial APUC Development Estimate	Changes								APUC Production Estimate
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
285.100	0.141	-177.121	0.000	14.931	-0.452	0.000	0.573	-161.928	123.172

Current SAR Baseline to Current Estimate (TY $M)									
APUC Production Estimate	Changes								APUC Current Estimate
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
123.172	0.716	-6.539	0.138	1.088	-6.053	0.000	-3.072	-13.722	109.450

SAR Baseline History				
Item	SAR Planning Estimate	SAR Development Estimate	SAR Production Estimate	Current Estimate
Milestone A	N/A	N/A	N/A	N/A
Milestone B	N/A	Apr 2005	Apr 2005	Apr 2005
Milestone C	N/A	Feb 2010	Mar 2011	Mar 2011
IOC	N/A	Feb 2012	Jun 2012	Dec 2012
Total Cost (TY $M)	N/A	5322.6	5549.0	5121.4
Total Quantity	N/A	13	31	34
PAUC	N/A	409.431	179.000	150.629

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Cost Variance

Summary TY $M				
Item	**RDT&E**	**Procurement**	**MILCON**	**Total**
SAR Baseline (Production Estimate)	896.3	3572.0	1080.7	5549.0
Previous Changes				
Economic	+4.8	+31.8	+8.3	+44.9
Quantity	--	+160.3	--	+160.3
Schedule	--	+4.4	--	+4.4
Engineering	+38.8	+34.8	--	+73.6
Estimating	-1.6	-226.4	-429.8	-657.8
Other	--	--	--	--
Support	--	-109.0	--	-109.0
Subtotal	+42.0	-104.1	-421.5	-483.6
Current Changes				
Economic	-0.5	-8.9	-2.3	-11.7
Quantity	--	--	--	--
Schedule	--	--	--	--
Engineering	+13.5	--	--	+13.5
Estimating	+0.5	+32.7	+10.3	+43.5
Other	--	--	--	--
Support	--	+10.7	--	+10.7
Subtotal	+13.5	+34.5	+8.0	+56.0
Total Changes	+55.5	-69.6	-413.5	-427.6
CE - Cost Variance	951.8	3502.4	667.2	5121.4
CE - Cost & Funding	951.8	3502.4	667.2	5121.4

400 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Summary BY 2010 $M				
Item	RDT&E	Procurement	MILCON	Total
SAR Baseline (Production Estimate)	895.3	3364.7	992.0	5252.0
Previous Changes				
Economic	--	--	--	--
Quantity	--	+140.8	--	+140.8
Schedule	--	+0.1	--	+0.1
Engineering	+32.1	+25.8	--	+57.9
Estimating	+0.7	-178.6	-391.6	-569.5
Other	--	--	--	--
Support	--	-115.1	--	-115.1
Subtotal	+32.8	-127.0	-391.6	-485.8
Current Changes				
Economic	--	--	--	--
Quantity	--	--	--	--
Schedule	--	--	--	--
Engineering	+11.8	--	--	+11.8
Estimating	+0.5	+28.6	+8.5	+37.6
Other	--	--	--	--
Support	--	+10.0	--	+10.0
Subtotal	+12.3	+38.6	+8.5	+59.4
Total Changes	+45.1	-88.4	-383.1	-426.4
CE - Cost Variance	940.4	3276.3	608.9	4825.6
CE - Cost & Funding	940.4	3276.3	608.9	4825.6

Previous Estimate: December 2014

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RDT&E	$M	
Current Change Explanations	Base Year	Then Year
Revised escalation indices. (Economic)	N/A	-0.5
Adjustment for current and prior escalation. (Estimating)	+0.5	+0.5
Additional funding for Follow-On Test and Evaluation II associated with Improved Gray Eagle extended range modifications. (Engineering)	+11.8	+13.5
RDT&E Subtotal	+12.3	+13.5

Procurement	$M	
Current Change Explanations	Base Year	Then Year
Revised escalation indices. (Economic)	N/A	-8.9
Adjustment for current and prior escalation. (Estimating)	+5.8	+6.4
Revised estimate to align with FY 2017 PB which resulted in increased funding for Common Systems Payloads. (Estimating)	+7.8	+8.8
Revised estimate to reflect actuals. (Estimating)	+15.0	+17.5
Adjustment for current and prior escalation. (Support)	+1.8	+1.9
Decrease in Other Support for Contractor Logistics Support. (Support)	-4.4	-5.4
Increase in Initial Spares based on split based operations and FY 2017 PB impacts. (Support)	+12.6	+14.2
Procurement Subtotal	+38.6	+34.5

MILCON	$M	
Current Change Explanations	Base Year	Then Year
Revised escalation indices. (Economic)	N/A	-2.3
Adjustment for current and prior escalation. (Estimating)	+1.7	+1.8
Revised estimate for changes in Army baseline strategy for stationing and fielding MQ-1C Gray Eagle. (Estimating)	+6.8	+8.5
MILCON Subtotal	+8.5	+8.0

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Contracts

General Notes

Contract W58RGZ-12-C-0075, Performance Based Logistics (PBL), is not included in the December 2014 and December 2015 SAR. The MQ-1C Gray Eagle program does not have an Acquisition Operations and Maintenance (O&M) contract. Contract W58RGZ-12-C -0075 is for PBL to support fielded systems and funded with O&M, Army - Overseas Contingency Operations accounts.

Contract Identification

Appropriation: Procurement
Contract Name: LRIP 3
Contractor: General Atomics - Aeronautical Systems, Inc.
Contractor Location: 14200 Kirkham Way
Poway, CA 92064
Contract Number: W58RGZ-12-C-0057
Contract Type: Fixed Price Incentive(Firm Target) (FPIF)
Award Date: July 06, 2012
Definitization Date: July 06, 2012

Contract Price							
Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price At Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
411.0	424.6	29	541.6	559.5	29	545.8	544.1

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to contract modifications P00001 through P00039 adding a platoon set of ground equipment, updated spares, changing from Portable Ground Control Station to Mobile Ground Control Station, and the definitization of an Engineering Change for Universal Ground Control Stations and spares.

Contract Variance		
Item	Cost Variance	Schedule Variance
Cumulative Variances To Date (12/31/2015)	-5.8	-0.7
Previous Cumulative Variances	+2.8	-11.2
Net Change	-8.6	+10.5

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Cost and Schedule Variance Explanations

The unfavorable net change in the cost variance is due to additional subcontractor support on UGCS effort and additional hours incurred in Program Management as a result of several programmatic UGCS and Mobile Ground Control Station changes.

The favorable net change in the schedule variance is due to the June 2015 replan of the Integrated Master Schedule and Performance Measurement Baseline incorporation of Engineering Changes. In addition, deliveries of UGCS hardware during FY 2015 reduced the cumulative schedule variance.

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Contract Identification

Appropriation: Procurement

Contract Name: Full Rate Production (FRP)

Contractor: General Atomics - Aeronautical Systems, Inc.

Contractor Location: 14200 Kirkham Way
Poway, CA 92064

Contract Number: W58RGZ-13-C-0109

Contract Type: Firm Fixed Price (FFP)

Award Date: September 13, 2013

Definitization Date: September 13, 2013

Contract Price							
Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price At Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
199.7	N/A	15	580.5	N/A	57	580.5	580.5

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to exercising contract options established under the initial contract award, container modifications, and Engineering Changes for Universal Ground Control Stations, Spares, and production quantities for Improved Gray Eagle.

Cost and Schedule Variance Explanations

Cost and Schedule Variance reporting is not required on this (FFP) contract.

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Contract Identification

Appropriation: RDT&E

Contract Name: 4.3.2 Software

Contractor: General Atomics - Aeronautical Systems, Inc

Contractor Location: 14200 Kirkham Way
Poway, CA 92064-7103

Contract Number: W58RGZ-13-C-0136

Contract Type: Cost Plus Incentive Fee (CPIF)

Award Date: September 25, 2013

Definitization Date: September 25, 2013

Contract Price							
Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price At Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
70.2	N/A	N/A	70.2	N/A	N/A	70.9	71.7

Contract Variance		
Item	Cost Variance	Schedule Variance
Cumulative Variances To Date (12/31/2015)	-1.2	0.0
Previous Cumulative Variances	-0.3	-1.4
Net Change	-0.9	+1.4

Cost and Schedule Variance Explanations

The unfavorable net change in the cost variance is due to additional efforts incurred on the subcontractor’s Information Assurance on software builds, and Systems Engineering to address quality concerns.

The favorable net change in the schedule variance is due to completion of contractual effort for repair of damaged test components.

Notes

This contract is more than 90% complete; therefore, this is the final report for this contract.

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Contract Identification

Appropriation: Procurement

Contract Name: Engineering Services II

Contractor: General Atomics - Aeronautical Systems, Inc.

Contractor Location: 14200 Kirkham Way
Poway, CA 92064-7103

Contract Number: W58RGZ-13-C-0110

Contract Type: Cost Plus Fixed Fee (CPFF)

Award Date: September 30, 2013

Definitization Date: September 30, 2013

Contract Price							
Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price At Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
38.5	N/A	N/A	76.2	N/A	N/A	71.4	69.6

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to exercising contract options established under initial contract award for Solid Core, Airworthiness and Universal Ground Control Stations and contract modifications through P00042.

Contract Variance		
Item	Cost Variance	Schedule Variance
Cumulative Variances To Date (12/31/2015)	+6.7	-2.9
Previous Cumulative Variances	+10.6	-3.2
Net Change	-3.9	+0.3

Cost and Schedule Variance Explanations

The unfavorable net change in the cost variance is due to completion of Program Management effort and Tactical Signals Intelligence Payload Hardware/Software Development Sub-Engineering Services Memorandums (SESM).

The favorable net change in the schedule variance is due to ongoing efforts on Special Operations Command Vortex Integration SESM.

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Deliveries and Expenditures

Deliveries				
Delivered to Date	**Planned to Date**	**Actual to Date**	**Total Quantity**	**Percent Delivered**
Development	2	2	2	100.00%
Production	25	25	32	78.13%
Total Program Quantity Delivered	27	27	34	79.41%

Expended and Appropriated (TY $M)			
Total Acquisition Cost	5121.4	Years Appropriated	12
Expended to Date	3192.3	Percent Years Appropriated	85.71%
Percent Expended	62.33%	Appropriated to Date	4962.5
Total Funding Years	14	Percent Appropriated	96.90%

The above data is current as of February 29, 2016.

131 MQ-1C Gray Eagle aircraft of 167 planned (152 planned in Current APB) completed the Material Inspection and Receiving Reporting process as of December 31, 2015. Inspected and received MQ-1C Gray Eagle aircraft is the metric used for deliveries and is converted to systems.

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Operating and Support Cost

Cost Estimate Details

Date of Estimate:	June 14, 2013
Source of Estimate:	SCP
Quantity to Sustain:	31
Unit of Measure:	System
Service Life per Unit:	20.00 Years
Fiscal Years in Service:	FY 2011 - FY 2037

The O&S estimate is based on the June 14, 2013 DAB approved FRP Service Cost Position. The MQ-1C Gray Eagle O&S cost estimate includes 152 MQ-1C Gray Eagle acquisition program aircraft, 31 platoons with associated ground equipment, and results in 327 operational system years over a 20 year service life. O&M cost was based on actual Unmanned Aircraft System (UAS) consumption data, analogy to Predator, and O&S Management Information System (OSMIS) Blackhawk data. The cost is applied as steady state across the MQ-1C Gray Eagle program in accordance with the program schedule.

An updated APB is currently being staffed with PM UAS and the Deputy Assistant Secretary of the Army for Cost Estimating and should be completed 3rd Quarter FY 2016.

O&S changes listed in earlier sections of the SAR, namely the Executive Summary and Cost and Funding sections, that relate to the FY 2015 Congressional Plus-up, FY 2016 PB with increased procurement from 152 to 167 aircraft, and an increase of three platoons from 31 to 34 are not included in this O&S section. These changes will be reflected in the next SAR.

A basic MQ-1C Gray Eagle system includes balanced platoons, each with four aircraft and associated support equipment and payloads to include: Electro-Optical/Infrared/Laser Designator, communications relay, and up to four Hellfire Missiles. The Common Sensor Payload and Synthetic Aperture Radar/Ground Moving Target Indicator are one per aircraft. Ground equipment at a platoon level includes: two Universal Ground Control Stations, three Universal Ground Data Terminals, one satellite communication Ground Data Terminal, one Mobile Ground Control Station per Gray Eagle Company, an Automated Take Off and Landing System which includes two Tactical Automatic Landing Systems and ground support equipment to include Ground-Based Sense and Avoid. A MQ-1C Gray Eagle Company is configured into three equal platoons and includes nine MQ-1C Gray Eagle aircraft for conventional companies (non-deployed) and when deployed the Army will adjust a company to full MQ-1C Gray Eagle System strength (12 aircraft and associated ground support equipment).

Sustainment Strategy

The sustainment strategy includes a Performance Based Logistics (PBL) contract. Soldiers operate systems and perform 85 percent of the basic field maintenance. Field Service Representatives support the remaining 15 percent of basic field maintenance through PBL efforts. Some of the Depot Level Reparables will be accomplished by organic depots through a Public Private Partnership (PPP) arrangement. The PPP with organic depot efforts will be determined through cost-benefit analysis and application of section 2466, title 10, U.S.C. and the 50-50 rule.

Antecedent Information

No Antecedent

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Annual O&S Costs BY2010 $M		
Cost Element	**MQ-1C Gray Eagle Average Annual Cost Per System**	**No Antecedent (Antecedent) N/A**
Unit-Level Manpower	10.300	0.000
Unit Operations	1.300	0.000
Maintenance	3.460	0.000
Sustaining Support	3.750	0.000
Continuing System Improvements	0.360	0.000
Indirect Support	0.870	0.000
Other	2.460	0.000
Total	22.500	--

The $2.460M Other cost is O&M related, Military Pay and Allowances (Medical & Morale, Welfare, Recreation) and includes other costs from U.S. Army Special Operations Command (USASOC) and Aerial Exploitation Battalions (AEB).

Item	Total O&S Cost $M			
	MQ-1C Gray Eagle			No Antecedent (Antecedent)
	Current Production APB Objective/Threshold		Current Estimate	
Base Year	7357.3	8093.0	7357.3	0.0
Then Year	9950.8	N/A	9950.8	N/A

On February 5, 2013, the Chief of Staff of the Army approved an Execution Order (EXORD) changing the MQ-1C Gray Eagle fielding configuration to provide greater capability across the Army. The EXORD directed fielding MQ-1C Gray Eagle companies to ten Army divisions, one to the National Training Center (NTC), two to USASOC units, and two to the AEB for a total of 15 companies. The two USASOC companies will be configured with 12 aircraft each (24 total) and the 13 companies assigned to Army divisions, NTC and the AEBs will be fielded with nine aircraft each (117 total) while based in the Continental United States (CONUS). Seven aircraft are assigned to the institutional training base at Fort Huachuca, Arizona. The four remaining aircraft are for attrition. When a company or AEB assigned to a division deploys outside CONUS, the Army will reassign equipment, as required, to bring the company to full MQ-1C Gray Eagle system equipment strength (12 aircraft and associated ground support equipment).

Equation to Translate Annual Cost to Total Cost

Total O&S Costs $7357.3 (BY 2010 $M) / 327 Operational System years = $22.5 (BY 2010 $M) per system.

O&S Cost Variance		
Category	**BY 2010 $M**	**Change Explanations**
Prior SAR Total O&S Estimates - Dec 2014 SAR	7357.3	
Programmatic/Planning Factors	0.0	
Cost Estimating Methodology	0.0	
Cost Data Update	0.0	
Labor Rate	0.0	

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Energy Rate	0.0
Technical Input	0.0
Other	0.0
Total Changes	0.0
Current Estimate	7357.3

Disposal Estimate Details

Date of Estimate: June 14, 2013

Source of Estimate: SCP

Disposal/Demilitarization Total Cost (BY 2010 $M): Total costs for disposal of all System are 35.2

The Demilitarization costs per the FRP SCP in June 2013 is $35.2 (BY 2010 $M).

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PERFORMANCE OF THE DEFENSE ACQUISITION SYSTEM

2016 ANNUAL REPORT

OCTOBER 24, 2016

Approved for public release; distribution unlimited.

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FOREWORD

Eliminate all other factors, and the one which remains must be the truth.

—Sir Arthur Conan Doyle
in "The Sign of the Four"

As this report is being published, I am concluding 5 years of serving as the Under Secretary of Defense for Acquisition, Logistics, and Technology. This fourth report in the series continues my long-term effort to bring data-driven decision making to acquisition policy. This report demonstrates that the Department of Defense (DoD) is making continuing progress in improving acquisition. The overall series presents strong evidence that the DoD has moved—and is moving—in the right direction with regard to the cost, schedule, and quality of the products we deliver. There is, of course, much more that can be done to improve defense acquisition, but with the 5-year moving average of cost growth on our largest and highest-risk programs at a 30-year low, it is hard to argue that we are not moving in the right direction.

Each year we add cumulative data and new analysis to the report. This year is no exception. While that data can show us ways and places to improve, I believe there is no secret to what it takes to achieve good results in defense acquisition. The short form of this is to: (1) set reasonable requirements, (2) put professionals in charge, (3) give them the resources that they need, and (4) provide strong incentives for success. Unfortunately, there is a world of complexity and difficulty in each of these four items.

Creating new—and sometimes well beyond the current state of the art—weapons systems that will give our warfighters a decisive operational advantage far into the future will never be a low-risk endeavor. That risk can be managed, however, and while we should not expect perfection, we should be able to keep the inevitable problems that will arise within reasonable bounds. We should also be able to continuously improve our performance as we learn from our experience and work to improve our ability to make sound acquisition decisions. This volume and its predecessors are dedicated to these propositions.

We open this volume with some accrued insights and an attempt to refute some popular myths about defense acquisition. Too much of our decision making on acquisition policy has been based on cyclical and intuitive conventional wisdom and on anecdote—or just the desire, spurred by frustration, to affect change. As I've worked in this field for more than four decades, it has become clear to me that there is no "acquisition magic"—no easy solution or set of solutions that will miraculously change

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our results. Most attempts to direct or legislate acquisition "magic" in some form have been counterproductive and often only increased the system's bureaucracy and rigidity or led to excessive risk taking—neither of which is helpful. What we need, and always will need, is professionalism, hard work, attention to detail, and flexible policies and incentives that the data show align with the results we desire. Improving each of these is a continuous endeavor of which this volume is a part.

The Honorable Frank Kendall,
Under Secretary of Defense for
Acquisition, Technology, and Logistics



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PRINCIPLES FOR IMPROVING DEFENSE ACQUISITION

People matter most; we can never be too professional or too competent.

Continuous improvement will be more effective than radical change.

Data should drive policy.

Critical thinking is necessary for success; fixed rules are too constraining.

Controlling life-cycle cost is one of our jobs; staying on budget isn't enough.

Incentives work—we get what we reward.

Competition and the threat of competition are the most effective incentives.

Defense acquisition is a team sport.

Our technological superiority is at risk and we must respond.

We should have the courage to challenge bad policy.

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ORGANIZATION OF THE REPORT

Highlights. The following section briefly discusses recent actions and key findings from the report, providing page references to detailed discussions in the main body. It also provides some insights to illustrate how this kind of analysis is informing actions within the DoD. Though not comprehensive, it provides perspectives and insights gleaned from the entire report.

Chapter 1 provides background material on acquisition, spending levels and trends, and general perspectives on measuring institutional performance to set the stage for the analysis presented in subsequent chapters.

Chapter 2 analyzes the performance outcomes of our acquisition institutions from a variety of perspectives: DoD-wide, by commodity type, contract- and program-level, military department, and contractors. This chapter builds on the results from prior annual reports, updating some analysis and providing new results using different datasets. To a large extent, this chapter presents an ongoing view of performance and trends.

Chapter 3 discusses new analysis on broader factors that influence acquisition outcomes. We start with how broad acquisition reforms and the funding climate affect program cost growth. We follow with analysis that identifies the major correlates of cost growth in Operating and Support (O&S) cost estimates while programs are in acquisition. We then provide a short progress report on the implementation of our affordability process, followed by preliminary analysis of the stability of program requirements. Following this, we provide analyses on how many units we procure relative to original plans, an update of program cancellation and sunk costs, and the frequency of new major program starts. Finally, the chapter closes with summary analysis and highlights of issues, successes, and suggestions from our program managers and program executive officers.

Chapter 4 provides selected measures of the inputs to the defense system and its internal processes, including acquisition workforce improvements and incentives, contractor bid-protest rates and outputs, our performance relative to competition and small-business goals, and trends in improving the efficiency and backlog of contractor audits.

Appendix A provides a concise overview of DoD's Better Buying Power strategic effort to improve defense acquisition efficiency and effectiveness.

Appendices B–E provide details on the statistical analyses and methods employed in selected studies.

Appendix F–G defines program and general acronyms used in the report.

Appendices H–I lists the figures, tables, and references in the report.

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PERFORMANCE HIGHLIGHTS

A key part of improving a system is objectively measuring its performance and the effects of policies, processes, and inputs on the outcomes of the system. Without this, we cannot tell where we have problems, what is working (or not), and whether management changes are making things better (or worse). In the case of defense acquisition, the primary outcome is the value of operational capabilities delivered in time for our warfighters to address threats. Unfortunately, it is very difficult to measure the final operational performance and value of our systems across systems and commodities. Our reports can objectively measure and thus focus on the cost, schedule, and technical performance of our acquisitions—aggregated to look for statistically significant trends together with correlates, institutional differences, and theory to inform ways to improve future outcomes. Each performance measure has its strengths and weaknesses, so we use multiple measures (e.g., at both the program and contract level) and subsequent analysis to see if the answers point in the same direction. We add experience and theoretical insights to guide our conclusions.

This is the fourth annual report on the Performance of the Defense Acquisition System, using quantitative analysis of broad data to measure institutional performance. This annual report series is a central part of Better Buying Power (BBP). It continues to reflect results in defense acquisition performance from ongoing DoD compliance with the Improve Acquisition Act of 2010 and the earlier Weapon Systems Acquisition Reform Act of 2009. Although similarly motivated, our efforts go beyond the specifics of those laws to seek additional insights for improving the defense acquisition system's performance. This study also fulfills ongoing Office of Management and Budget (OMB) requests for evidence-based analytic studies on acquisition performance. It is encouraging to see evidence of performance improvement over the last few years. However, these results are not a reason to pause in our efforts. They should motivate us to press ahead even more vigorously.

PRIOR ANNUAL REPORTS IN THE SERIES

The first report by the Under Secretary of Defense (USD) for Acquisition, Technology, and Logistics (USD(AT&L), 2013b)[1] analyzed recent and historical data to establish performance references and to begin looking for evidence of what factors affect cost, schedule, and technical performance. For example, we found that undefinitized contract actions (UCAs) usually can be employed in early procurement without incurring cost growth, but UCAs correlate historically with cost and schedule growth on development contracts. That first report also established measures of cost growth at both the program and contract levels that avoid confounding issues

[1] Throughout this report we follow APA and Chicago style guidelines wherein multiple documents in the same year by the same author are differentiated by adding sequential letters (a, b, c, etc.) after the year in order of publication.

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such as quantity effects, reporting these measures across our major programs and their contracts. We realized that years will be needed to see the full results of our improvement initiatives (our major programs last many years and new policies tend to affect programs incrementally). The journey toward data-driven policies started with our original report and continues here.

The second report (USD(AT&L), 2014a) built on the first, adding another year of data to the series of cost, schedule, and technical performance measures while reporting insights from new policy analysis. Some signs of improvements were seen—but not everywhere. Outliers required further analysis given their distorting effects on the portfolio in certain metrics and on the overall perceptions about the defense acquisition system when viewed as exemplars. Expanded analysis of the correlation of contract type on cost and schedule outcomes found that the prevalent debate on whether "cost-reimbursement" or "fixed-price" contracts are best at controlling prices is a red herring. The *real* issue is how effective the incentives are for each contract type based on the situation at hand. Also, firm-fixed-price contracting alone may not result in fixed prices in the end because some fixed-price contract deliverables are structured as narrow requirements or increments so that the Government still has all the true risks and must pay for changes. We found that incentive contracts (cost-plus-incentive-fee and fixed-price-incentive) control cost, price, and schedule as well as, or better than, other types—and with generally lower, yet fair, margins. Each situation depends on risk, cost knowledge, uncertainty, and a number of other factors—so we should avoid dictating a single approach.

Last year's annual report built on and extended the series of data from the first two reports. We saw more statistically significant trends and differences, so we have greater confidence in the positive changes we are seeing. Cost growth on our major programs generally is at, or better than, historical levels, but outliers remain a problem. Median biennial change in total needed program funding has been near zero since 2009 (although past growth over baselines remains). Contractors on Major Defense Acquisition Program (MDAP) contracts are doing a better job of meeting cost targets. The number of MDAP contracts started since 2009 with price reductions has increased significantly compared to earlier contracts. Also, preliminary analysis showed that the percentages of government execution costs (direct and overhead) are at or below defense industry overhead levels, and they are not unreasonable in absolute percentages. Additionally, work from the Institute for Defense Analyses (and confirmed by the related analysis below) provided an important cautionary tale that high acquisition cost growth for programs and tight budgetary environments (like the one at present) during program baselining are very strongly correlated.

Below are highlights of this fourth report along with page references to more detailed discussion later in the report. As with the prior annual reports, many analyses are beginnings and indicate areas that need further work, but in others we now see similar indicators in multiple measures, increasing our confidence in the results.

While we use somewhat different metrics, our program-level results reflect what the Government Accountability Office (GAO) has been reporting recently (see GAO, 2014, 2015a)—that we are seeing significant, measurable improvements in cost control for recent years.

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ACTIONABLE INSIGHTS

The highlights below and detailed data in this report provide useful insights for stakeholders and practitioners.

Myth Busters

Myth: All defense acquisition programs have large cost growth.
Reality: **Cost control has improved significantly.** Not only is cost growth significantly lower than historical levels, but recent efforts have dramatically lowered cost growth further. Multiple measures summarized below show statistically lower cost growth on major programs: number of Nunn-McCurdy breaches; Section 828 "overruns" on programs since 2009; proportion of programs needing less funding than originally planned; biennial cost growth in development and production; total production cost growth; and annual growth of contracted costs. Historical analyses also show that cost controls are better than in the decades before Goldwater-Nichols (USD(AT&L), 2014a, pp. 47–49). We do still have legacy problems on older programs. Total research, development, test and evaluation (RDT&E) cost growth is still rising due to older programs. We need to do better through continued evolutionary improvements, but recent improvements focused on acquisition fundamentals and an empowered government workforce have been more successful than laissez-faire acquisition reforms of the mid-1990s or prior to the passage of Goldwater-Nichols and the Packard Commission reforms of the late 1980s.

Myth: Defense programs usually cut quantity (e.g., to pay for cost growth).
Reality: **Most major programs deliver the original baseline quantity or more.** We don't as a rule cut program quantity. As discussed below and on p. *104*, most MDAPs actually produce the quantities we originally planned at Milestone (MS) B. This runs counter to the impression given from just focusing on certain high-visibility programs such as the F-22 program or the DDG 1000 Zumwalt-class destroyer that incurred major cuts in quantity.

Myth: Swings in O&S cost estimates indicate poor program management.
Reality: **The dynamics of cost estimates indicate that O&S costs appear to be heavily driven by external inflation factors.** Analysis shows that the recent dynamics of program O&S costs estimated during acquisition correlate with the dynamics of labor, health-care, fuel, and maintenance costs. While this aligns with intuition, it also indicates that O&S cost increases involve both factors that the acquisition system cannot control (e.g., wages, health-care costs, and fuel costs) as well as some that can, in part be controlled (e.g., system reliability, fuel efficiency, and ease of maintenance). Operational tempo also affects O&S costs through many of these factors (e.g., the amount of fuel consumed and maintenance costs), and changes in forecasted tempo will affect O&S costs independent of both inflation and weapon system performance. Thus, while the acquisition system needs continued attention to the levers it can control (with full knowledge that their effects often will not be seen for decades), stakeholders need to recognize the strong influence of other factors on O&S costs. (*See discussion starting on p. 95.*)

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Myth: Program requirements are unstable.
***Reality:* High-level requirements seldom change on major programs, and very few programs have many changes.** About 85 percent of MDAPs showed no changes that we could trace from the original MS B baseline to the latest Selected Acquisition Report (SAR) report for the program. Moreover, of the few programs with any traced changes, most had only one. This is commensurate with experts' experience and GAO's findings (2015b), which also indicate that changes are largely made at the engineering level as development seeks ways to meet high-level requirements. Changes, however, are not always bad. Some changes reflect prudent requirement reductions to unforeseen high costs of options uncovered in development or new affordability pressures. Other changes address new threats that otherwise would render an unmodified system obsolete upon delivery. Thus, flexibility, prudence, and continued tradeoffs, together with ruthless management attention to cost implications, are more important in the end than simple edicts at the extremes of change control. (*See discussion starting on p. 100.*)

Myth: The DoD cannot acquire systems quickly.
***Reality:* DoD acquisition can be timely and responsive.** Despite criticism that defense acquisition is too slow, the highlights below show that schedule growth is lower than cost growth in development, and cycle times for major programs have increased only from about 5 years to 7 years since the 1980s with dramatic increases in weapon system complexity.[2] This is not to say that internal processes cannot be improved, so efforts continue to institutionalize streamlining and tailoring.

Myth: Increased bid protests reflect a deteriorating ability to conduct source selections.
***Reality:* Contracting processes are generally fair, rigorous, and objective—and protests are rarely sustained**. Despite concerns arising from increased numbers of protested solicitations and contract awards, GAO data indicate that protests and sustainments remain very low both in number and as a percentage of solicitations and awards. Protests to GAO have averaged about 2.5 percent of solicitations and about 0.25 percent of contracts. The sustainment rate remains very low—about 30 per year, or 2 percent of the approximately 1,300 annual protests. *(See discussion starting on p. 125.)*

Myth: The DoD is pursuing cost savings at the expense of contractor profits.
Reality: **Major defense companies remain profitable despite the DoD's increased success at tying profits to performance**. Further data build on prior reports to show that the DoD's efforts to improve cost performance are not a war on profits but a reasonable alignment of industry and government goals. *(See Figure H-21 on p. xlviii below.)*

Myth: Defense acquisition is broken.
Reality: **The acquisition system for decades has given the United States the most capable military in the world and has been improving both in the past and more recently.** While there is no absolute definition for sufficiency, the data in these annual performance reports indicate

[2] Also, unpublished analysis indicates that the DoD has successful approaches for rapidly acquiring urgently needed capabilities that leverage mature technology. These approaches generally are limited by available technology restrictions on reprogramming appropriated funds.

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that the system functions reasonably well compared to the past and continues improving. We cannot look at a single metric to measure the performance of the defense acquisition system, and many metrics work at odds with each other. For example, the so-called "iron triangle" of cost, schedule, and technical performance has long shown that emphasizing one or two dimensions often is done at the expense of the others. While cost (followed by schedule) metrics are the easiest to quantify, data for all three dimensions indicate stability and, in many cases, significant improvement.

Insights for Current and Future Leadership

First, let us discuss insights that primarily affect both DoD-wide and DoD Component[3] leadership.

The lack of programs in our "new product pipeline" may be putting technological superiority at risk. Both RDT&E budget levels—particularly Engineering and Manufacturing Development budgets—and program new-start data indicate a slowdown since the mid-2000s. Total budget reductions limit what we can do, but it is important to step back and watch these macro trends in the context of increasing threats (technologically, pace, and diversity). The DoD's recent response has been to add a number of early stage experimental prototyping efforts. This is an important and necessary step but does not deliver capability or designs that are ready for production and fielding in any substantial quantity.

Be particularly careful to ensure realistic program baselines—especially when budgets are tight. Further analysis published in this report reinforces prior concerns that excessive optimism or risk tolerance may be particularly acute when programs are initiated during tight budget periods (such as at present), leading to the higher cost growth seen on these programs. We should explicitly recognize this and avoid setting up our successors for large overruns.[4] For example, acquisition and DoD Component leadership should ensure adequate risk reduction before MS B and apply healthy skepticism about novel approaches that are marketed as offering substantial cost reductions (i.e., if it sounds too good to be true, it probably is. In a tight-budget climate, industry is motivated to be optimistic and take greater risk in order to win new business. DoD programmers also are motivated to put pressure on acquisition professionals to lower cost estimates and funding requirements. Because of these tendencies, the Defense Acquisition Executive (DAE) is focusing particularly on cost and schedule realism for Acquisition Category (ACAT) I and Major Automated Information Systems (MAIS) programs at milestone decision reviews. (*See detailed analysis and discussion starting on p. 92.*)

[3] For purposes of this report, *DoD Components* include the Office of the Secretary of Defense (OSD), military departments, and all defense agencies, DoD field activities, and other entities within the DoD that are authorized to award or administer contracts, grants, cooperative agreements, and other transactions.

[4] See, for example, the bidding and acceptance on the Space-Based Infrared Systems-High (SBIRS-High) program (Thompson, 2012), and the problem of overly optimistic cost estimates at MS B for the F-35 (DPARCA, 2010f).

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Be prepared to incur statutory overrun penalties. As shown in Table H-2 (p. xxxiv below), the Army and Navy are a few billion dollars away from incurring a Section 828 penalty for Program Acquisition Unit Cost (PAUC) cost growth on MDAPs that started since 2009. Growth on individual programs may be warranted in order to address threat or critical engineering issues, and the prospect of penalties should not deter sound decisions on program content or requirements. The penalties were created to encourage better program planning, but the impact, which will come years after program initiation, is more likely to affect decisions made after cost growth is realized. Penalty avoidance, like Nunn McCurdy avoidance, should not be the primary decision criterion once cost growth has been realized; the priority should be getting critically needed capability to the warfighter at the best cost possible.

We need a metric for the portion of O&S costs related solely to weapon system design and performance. Analysis shows that many of the factors that correlate with growth of O&S cost estimates reported during acquisition are outside the control of the acquisition system (i.e., wages, health-care costs, and fuel prices). Current O&S metrics do not separate acquisition program effects from these external effects. However, a new metric could be developed to measure these internal program effects by holding the external variables constant from MS B forward (solely for purposes of comparison) so that the effects solely from the acquisition system are revealed.

Listen to feedback from the DoD's professional acquisition leadership. The annual program manager (PM) assessments sent to the DAE provide useful perspective on the realities of conditions where acquisition actually takes place—in program offices. Our PMs tended to be positive about strategy, system performance, program cost, and contracting (although the latter was raised often as both a success and issue). Conversely, funding difficulties, risks, and cyber issues top the list of concerns. Some topics have high levels of both success and problems—especially schedule performance, contractor performance, and the implications of changing technology. (See p. 110.)

Just as important, our program executive officers (PEOs) raised a number of system issues across their portfolios while making insightful suggestions on how we can improve the defense acquisition system (see p. 114). For example, the PEOs note that system improvements (e.g., savings) come at a cost—namely, we need sufficient workforce to think through and execute more efficient acquisition approaches. Blind "headquarter" or other cuts in government and contractor workforce can be extremely counterproductive.

Program-Level Insights

Focusing on acquisition fundamentals and cost control makes a difference. Proactive management and creative thinking contribute significantly and measurably to cost control. Multiple measures and analyses in this and prior annual reports (e.g., see Figure H-4 on p. xxviii) show that fundamentals work in controlling costs. We need to keep up the good work. These savings are dependent on workforce expertise, sufficiency, empowerment, and the degree to which we can illustrate and prove these linkages will go a long way toward ensuring continued success. The institution of "should cost" management and its consistent emphasis over the last

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6 years by the acquisition chain-of-command been a success and should be a permanent feature of the DoD's acquisition culture. Staying within budget is not the definition of success.

Don't neglect suitability (reliability, maintainability, etc.) in pursuing system performance. Operational tests show that major programs are often effective when they tested as operationally suitable, but the converse is not true (see p. 20). This correlation by itself does not prove causality, but it reinforces the logic that the so-called "-illities" (e.g., interoperability, availability, maintainability, reliability) are important to achieving the mission. For example, well-engineered systems that address suitability factors are probably also better positioned to be effective. Also, no matter its features, a weapon system may not serve its function if it is unreliable and unavailable to the warfighter.

Don't neglect O&S cost implications in early system requirements and design. Analysis shows that many of the factors that correlate with growth of SAR O&S cost estimates (i.e., wages, health-care costs, and fuel prices) are outside of program management control. While PMs cannot control these external factors, they can affect fuel efficiency and maintenance costs (e.g., system reliability, ease of maintenance, and repair automation). Usually, these aspects must be addressed very early in the system's design, so don't neglect them in early program planning and management. That is why the new affordability process sets goals and caps on life-cycle costs early in the program's life (e.g., at the point of the Materiel Development Decision (MDD) and MS A, when bigger design changes can be made). Don't neglect them just because you cannot control the external factors and uncertainties remain.

Don't let up on ensuring rigorous source selections that align government value structures, source-selection rules, and industry's goal of winning. While GAO data on source selections provide encouraging news that our practices generally are fair and rigorous, we should not let up on efforts to improve source selections. The basic integrity and fairness of our processes are fundamental to maintaining public confidence in how taxpayer resources are spent.

Use fixed-price contracting judiciously in development. In our updated guidance on contract incentives (Director of Defense Procurement and Acquisition Policy [DDPAP], 2016b), data from prior annual reports (USD(AT&L), 2014a), and experience (Kendall, 2013) indicate using fixed-price contracts in development can be very risky and counterproductive, while incentive contracts can yield good cost control at lower risk and lower prices. All of the following five criteria should generally be met before using fixed-price contracts in development:

1) Requirements are stable
2) Technologies are mature
3) The contractor is experienced
4) The contractor can absorb overruns
5) The contractor has a business case for absorbing any overruns that occur

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ACTIONS SINCE THE LAST REPORT

This annual report measures institutional performance trends using a variety of metrics. This year we also provide a summary of major actions and events that have occurred since the last report.

Major Program Actions by the DAE

- **Delegation**. Milestone Decision Authority was delegated from the DAE to the respective DoD Component (usually a military department) on 28 ACAT I programs since July 2015.[5]
- **CH-53K.** Advanced procurement to support the first CH-53K heavy-lift helicopter's low-rate initial production (LRIP) lot was approved in April 2016 to position the program for MS C without further impacting projected Initial Operational Capability (IOC) date. Should MS C ultimately not be approved, these parts and material would be used for other rotary wing aircraft within the current Navy inventory.
- **DEAMS.** Limited Deployment was granted to enable the Air Force to improve over initial operational test results prior to returning for a Full-Deployment Decision of this accounting and management system. The Air Force will also conduct a critical change review to ensure that: the new cost and schedule estimates for the program include plans to reduce defects consistent with a program of this maturity; the Oracle R12 upgrade is completed effectively; and future deployments are tied to performance gains verified through demonstrated software stability and logically sequenced test events.
- **EPAWSS.** The high reliance on off-the-shelf components allowed the F-15 Eagle Passive/Active Warning and Survivability System (EPAWSS) acquisition to be highly tailored, have a very short Technology Maturation and Risk Reduction (TMRR) phase, and have Milestone Decision Authority (MDA) delegation to the Air Force.
- **F-35.** We continue to negotiate better prices aligned with actual costs and employ strong contract performance incentives on LRIP lots to drive costs down, improve performance, and minimize concurrency problems. The Air Force declared IOC in August 2016 for the conventional F-35A variant fighter jet.
- **FAB-T.** The Family of Advanced Beyond Line of Sight Terminals (FAB-T) Command Post Terminal (CPT) subprogram passed MS C in October 2015 to support Presidential and National Voice Conferencing operational transition from existing aging assets and maintain the earliest possible FAB-T CPT IOC schedule.

[5] Delegations from July 2015 through September 2016:

Army:	DCGS-A Inc 1, GCSS-A, H-47 Block II, IFPC Inc 2-I, JLTV, LMP Inc 2, PAC-3 MSE, PIM, IPPS-A, and WIN-T Inc 2
Navy:	AAG, CANES, LHA-6JPALS, P-8A, MQ-8, MUOS, SSN 774, and T-AO 205
Air Force:	WAS, AEHF, F-15 EPAWSS, ICBM Fuze Modernization, MOP GBU-57A/B, MPS Inc 5, Space Fence Inc 1, and CRH
Defense Health Agency:	TMIP-J

(program abbreviations are defined in Appendix F starting on p. 169).

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- **GBSD.** The Ground Based Strategic Deterrent (GBSD) program was approved in August 2016 to enter TMRR, but significant cost and industrial-base uncertainties remain given limited historical data and the long period since the last Intercontinental Ballistic Missile (ICBM) development program. TMRR will produce more current and directly applicable information to support higher confidence cost estimates and inform baselines.
- **GPS OCX.** The DAE, Secretary of the Air Force, acquisition chain of command, and prime contractor's chief executive officer together are conducting quarterly "deep dive" reviews as a result of continued cost increases and schedule slips. The Global Positioning System (GPS) next-generation Operational Control System (OCX) program also breached its critical Nunn-McCurdy threshold in June 2016 *(see p. 26)*.
- **JAGM.** Given the strong potential for future international sales, the Joint Air-to-Ground Missile (JAGM) program is implementing Defense Exportability Features in Engineering, Manufacturing and Development (EMD), and the Army plans to obtain the appropriate Technology Security/Foreign Disclosure approval authorities prior to MS C.
- **KC-46A.** MS C and approval for LRIP were authorized in August 2016 at a higher quantity to permit an orderly increase in the production rate of this military aerial refueling and transport aircraft upon completion of operational testing, which was delayed to correct design and manufacturing issues and to complete performance verification and hardware certification. The contractor, Boeing, has now recorded reach-forward losses totaling about $1.7 billion on the EMD phase contract (Boeing, 2016).
- **RMS.** The Remote Minehunting System (RMS) was canceled in March 2016 due to unsatisfactory progress on system reliability and availability *(see p. 26)*.

Institutional and Policy Changes

- **Acquisition Workforce Development.** The DoD continues to increase the capabilities of our workforce, leveraging legislated authorities and funding such as the Defense Acquisition Workforce Development Fund (DAWDF) as well as the Force of the Future initiatives *(see p. 119).*
- **M&As.** The Department of Justice clarified DoD authorities on mergers and acquisitions (M&As), resolving concerns that we had insufficient authorities to address our wider concerns regarding about the ongoing consolidation trend in the defense industry.
- **Innovation and Technical Excellence.** The DoD essentially has completed the initial implementation of the BBP 3.0 set of acquisition policy initiatives and continues monthly follow-up through the Business Senior Integration Group.
- **Commercial Outreach.** The DoD renewed outreach to the commercial sector through the Defense Innovation Unit, Experimental (DIUx).
- **Independent Research and Development (IR&D).** In February 2016, the DoD proposed a Defense Federal Acquisition Regulation Supplement requirement that an appropriate DoD official be notified of new IR&D efforts in order to ensure that these investments are of potential interest to the DoD. Then results would have to be reported to facilitate utilization. We also issued in February an advanced notice of proposed rulemaking that would preclude misusing future IR&D expenditures to reduce evaluated bid prices in competitive source selections.

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- **Intelligence Support to Acquisition.** To better address emerging threats, we are improving the latency, dissemination, and relevance of intelligence to inform acquisition planning and system updates.
- **Contracted Services.** A new DoD Instruction (DoDI) 5000.74 was issued in January 2016 to establish a management structure for the acquisition of contracted services while authorizing DoD Component decision authorities to tailor the procedures to best achieve cost, schedule, and performance objectives (USD(AT&L), 2016).
- **Affordability.** We continue to apply and enforce affordability constraints on MDAPs and smaller programs, driving requirements tradeoff and management decisions during execution *(see p. 99).*
- **Independent Technical Risk Assessments.** We released a new *Risk, Issue, and Opportunity Management Guide* in June 2015 to help programs better identify risks, quantify their potential effects, and develop strategies to address and mitigate those risks.
- **Cybersecurity.** We are ensuring that new cybersecurity regulations are applied to DoD contracts to better secure unclassified controlled technical information resident in the defense industry.
- **Source-Selection Procedures.** A common set of principles and procedures for effectively conducting competitively negotiated source selections was updated in March 2016, including new guidance on Value-Adjusted Total Evaluated Price (VATEP) tradeoffs and appropriate uses of Lowest-Price Technically Acceptable (LPTA).
- **Incentive and Other Contract Types.** A major guidebook update (DDPAP, 2016b) provides advice on the selection and negotiation of the most appropriate and effective contract type and incentives for a given acquisition situation, emphasizing how to apply judgment and tailor our contracting to improve outcomes and contractor performance.
- **O&S Cost Management.** Published in February 2016, a new guidebook for PMs and product-support managers provides tools and best practices for O&S cost analyses to inform early life-cycle decisions, effect reliability trades, and identify Should-Cost initiatives having the greatest effect on future O&S costs.
- **Performance-Based Logistics.** A March 2016 update of our *Performance-Based Logistics (PBL) Guidebook* reviews common myths about PBLs, adds new guidance regarding intellectual property issues, and continues to provide best practices, selection criteria for when PBLs are appropriate, and practical examples to maximize successful outcomes (Assistant Secretary of Defense for Logistics and Materiel Readiness, 2016).
- **PM/PEO Assessments.** To better understand performance issues and successes in the acquisition system, we expanded the annual PM assessments to include PEO assessments sent directly to the DAE and Service Acquisition Executives (SAEs) *(see pp. 110 and 114).*

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FUNDING GROWTH AND DAES

Policy, sound planning, and execution decisions by DoD executives should bear on the effectiveness of the overall acquisition system. This is particularly true for the program structure and associated baselines set at MS B against which future cost performance is measured. Therefore, in our annual reports we track the performance of programs started under different acquisition executives to help reinforce accountability and provide an initial look for possible trends for further analysis.

Figure H-1 and Figure H-2 show growth in MDAP[6] Planned Total Funding in development and procurement (respectively) for active[7] and completed MDAPs against original baselines as reported to Congress in the SARs. Note that SAR funding data reflect current PM estimates of total needs by the end of the program for the current program configuration, including past actual funding, the current budget request, planned funding in the Future Years Defense Program (FYDP), and planned funding beyond the FYDP to the end of the program. Growth is measured against the baseline set at the original MS B and can be positive or negative.

These figures also show who served as the DAE at the time of the MDAP's MS B approval. Later in the report we show similar charts for the programs started under different SAEs in the three military departments. (*See sections starting on pp. 12 and 69*).

These charts neither reflect the effectiveness of subsequent oversight or major program changes by later DAEs during execution oversight, nor do they reflect statistical analysis to control for other internal and external variables that could have led to a program's success or problems. Defense acquisition is complex, and each measure has its strengths and weaknesses, so attributing performance to a single measure is subject to the limitations of that measure. For example, some programs may appear to be performing well in terms of total planned RDT&E funding but may be having problems that are reflected in other measures (e.g., total needed procurement funding; estimated operational costs; or cost growth on one of the program's major contracts). Thus, a combined examination of available data is important before reaching conclusions. Nevertheless, they are a crude indicator of the effectiveness of the decisions made by these officials. *(See detailed discussion starting on p. 12.)*

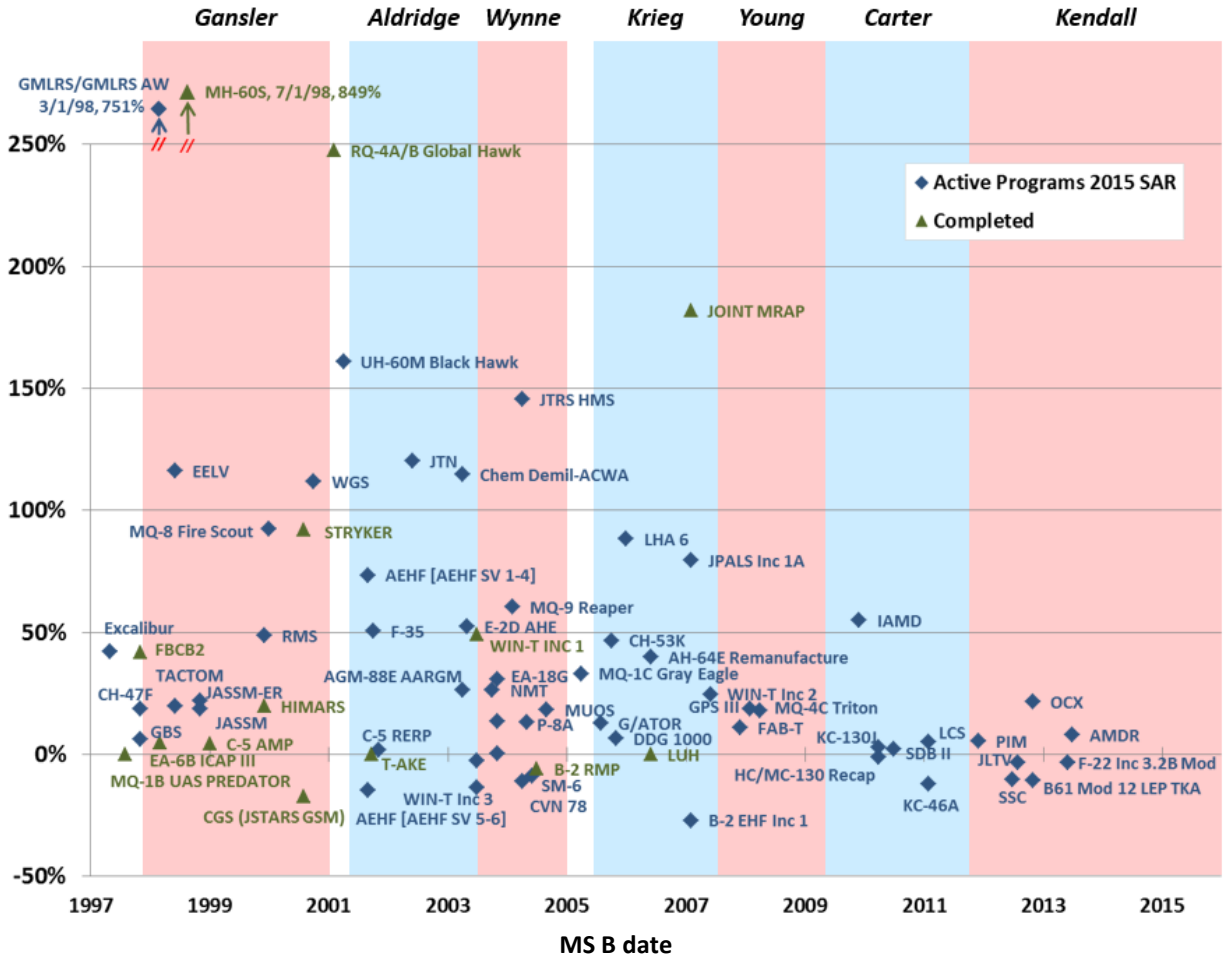
[6] MDAPs are DoD acquisition programs that are not highly sensitive (classified) and are either: (a) designated as such by the Secretary of Defense, or (b) estimated to require an eventual total expenditure for RDT&E of more than $480 million (in Fiscal Year [FY] 2014 constant dollars) or an eventual total expenditure for procurement (including all planned increments or spirals) of more than $2.79 billion (in FY 2014 constant dollars)—see 10 U.S.C., Section 2430(a), and USD(AT&L) (2015a, p. 44).

[7] In this report, *active* MDAPs are those that provide SARs and have passed MS B. MDAPs cease providing SARs and are deemed *completed* after they deliver 90 percent of total U.S. quantity or spend 90 percent of planned expenditures. See 10 U.S.C., Section 2432(g).

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Figure H-1. Program Cost-Related Development Performance Baselined in DAE Periods

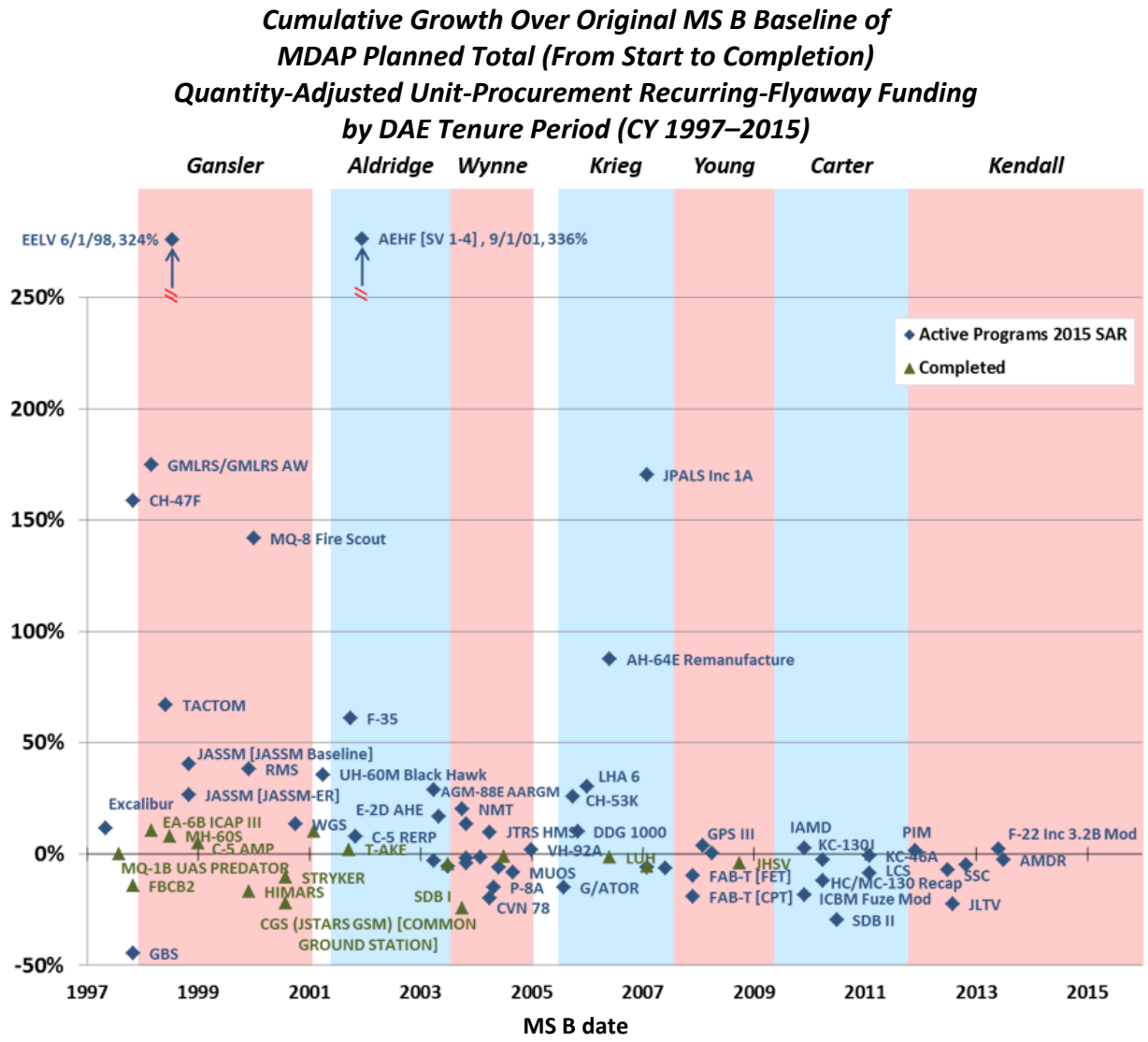
Cumulative Growth Over Original MS B Baseline of MDAP Planned Total (From Start to Completion) RDT&E Funding by DAE Tenure Period (CY 1997–2015)



NOTE: This shows total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. These are percentage changes after adjusting for inflation from original MS B baseline of actual past and estimated future funding as reported in each program's latest SAR. Total RDT&E is an insightful measure because it is necessary, regardless of quantity. White bars between DAE shaded regions represent periods with no confirmed executive. Not shown are relatively new programs that have not spent at least 30 percent of their original EMD schedule. Program abbreviations are defined in Appendix F starting on p. 159.

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Figure H-2. Program Cost-Related Procurement Performance Baselined in DAE Periods



NOTE: This shows growth in total unit recurring flyaway needed funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. White bars between DAE shaded regions represent periods with no confirmed executive. Not shown are relatively new programs that have not spent at least 30 percent of their original EMD schedule. Program abbreviations are defined in Appendix F starting on p. 159.

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COST-RELATED IMPROVEMENTS

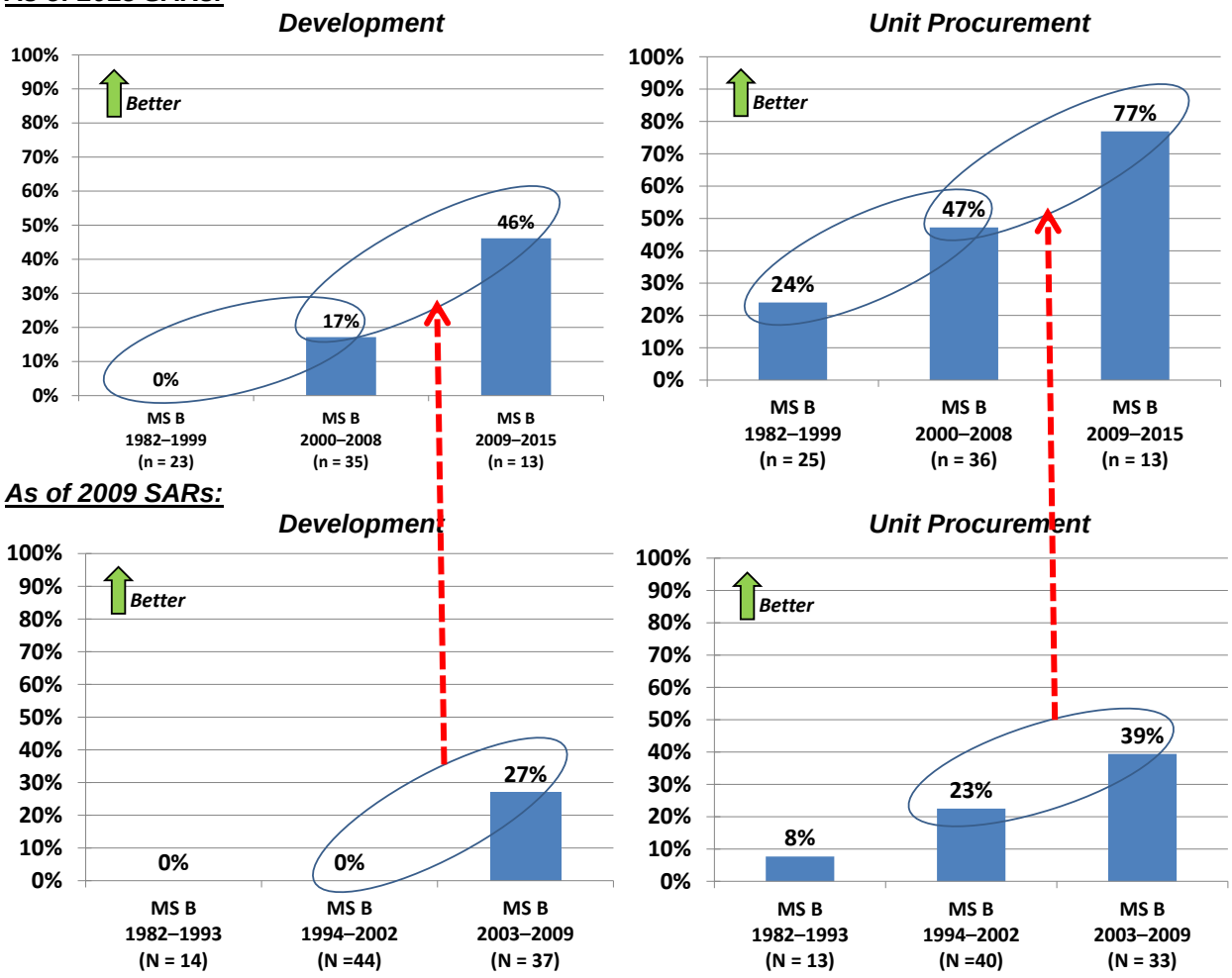
Recent data on MDAPs at the program- and contract-level have shown some statistically significant improvement trends in funding, price, and cost control, although complicating factors raise caveats and potential concerns.

More MDAPs are showing program funding reductions in both development and production. Relative to their original MS B baselines, more active MDAPs by proportion are estimated to have total RDT&E and unit-procurement funding reductions (sometimes referred to as "underruns") as of 2015 than as of 2009—even after we remove relatively new programs that would be unlikely to currently show growth (see Figure H-3). *(See detailed discussion starting on pp. 43 and 58).* The 2015 numbers are slightly lower than we saw last year in the 2014 data, but they remain significant. These data reflect similar results discussed below where biennial cost growth at the program level and the annual growth of contracted costs for MDAPs both have dropped significantly in recent years.

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Figure H-3. Planned Reductions in Program Funding

Proportions of Active MDAPs With Reductions Since Original MS B Baseline in Cumulative Planned Total (From Start to Completion) Funding (2009 and 2015 SARs)

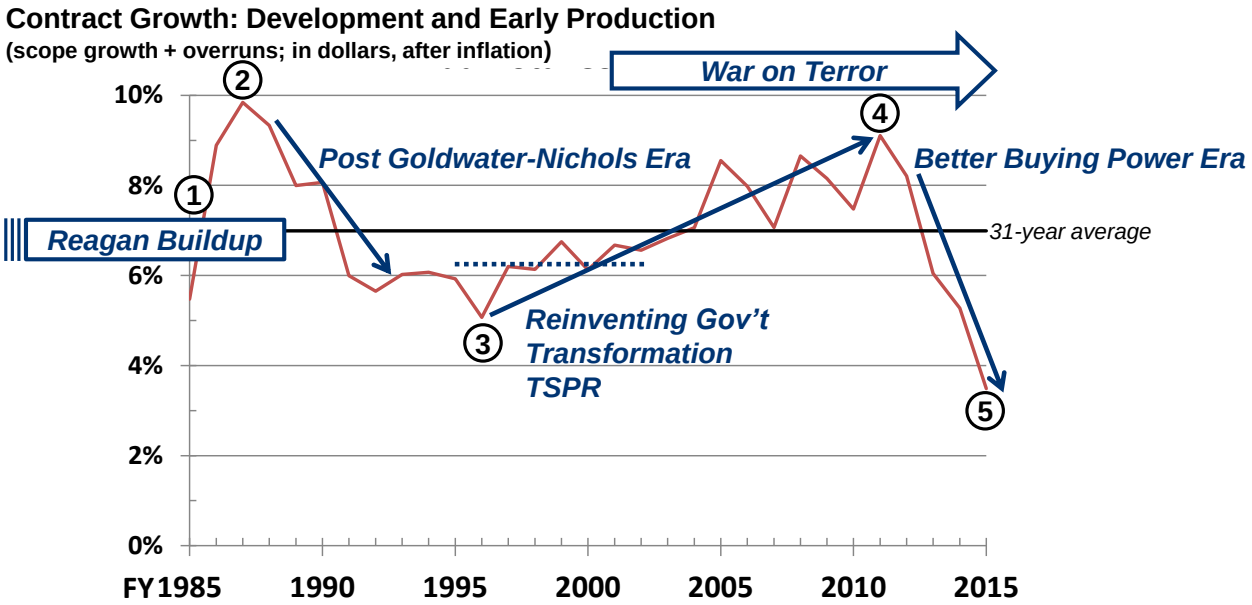


NOTE: Development funding is total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes and cost growth relative to targets. Procurement funding is growth in unit recurring-flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes and cost growth relative to targets. Statistically significant differences between adjacent periods are marked with an oval. A program shows a reduction if current total is below the original MS B baseline. To reduce bias from newer programs, relatively new programs that have not been through at least 30 percent of their original EMD schedule are not included. MS B dates are calendar years.

Improved contract cost control beyond budgetary effects. The growth of contracted costs for major programs has dropped during Better Buying Power from 9 percent in fiscal year (FY) 2011 to a new 30-year low of 3.5 percent in 2015 (see Figure H-4). After accounting for budgetary effects, statistical analysis found an almost 2 percentage-point drop since 2012 and 1 percentage-point drop after Goldwater-Nichols and the Packard Commission recommendations were implemented. Analysis also found that the defense acquisition system adjusts in the future for unforeseen cost "shocks," dampening their effects. *(See detailed discussion starting on p. 83)*

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Figure H-4. Actual Growth of Contract Costs (FY 1985–2015)



NOTE: Five-year moving average of annual growth in contracted total costs is shown relative to negotiated cost targets on major contracts of Major Defense Acquisition Programs (MDAPs), as well as MAIS that are MDAPs, in EMD and early production that reported earned-value (EV) data (i.e., almost no firm-fixed price or full-production contracts). This contract cost measure is *different* than statutory measures of program cost growth relative to baselines. Such changes reflect added work and overruns after adjusting for inflation. This measure should not be mistaken for the total costs of these programs because it excludes non-contracted costs and the majority of production contracts, which tend to be firm-fixed-price and do not report the data used for this analysis. These data summarize 18,470 EV reports on 1,123 major contracts for 239 MDAPs.

Program-level improvements. Table H-1 summarizes program-level results for MDAPs in development and procurement. Most (but not all) show improvement. For total RDT&E funding growth from original baseline, medians are still flat on a program basis but increasing on a dollar basis. In terms of quantity-adjusted unit procurement costs from original baseline, medians dropped 5 percentage points from SAR year[8] 2014 (on a dollar basis) and 2 percentage points (on a program basis). Biennially, medians are still flat since 2009 at about 0 percent. Note, however, that one measure (cumulative RDT&E growth from original baseline on a dollar basis) has a backlog of cost growth that will likely remain until those older programs exit the portfolio. We will discuss that later in this section.

[8] A *SAR year* includes information up until the SAR's submission date, which may reflect events and budgeting decisions from the beginning of the following calendar year (especially from January, when the budget request is being finalized). In other words, SAR years are similar to calendar years but may include data past December 31.

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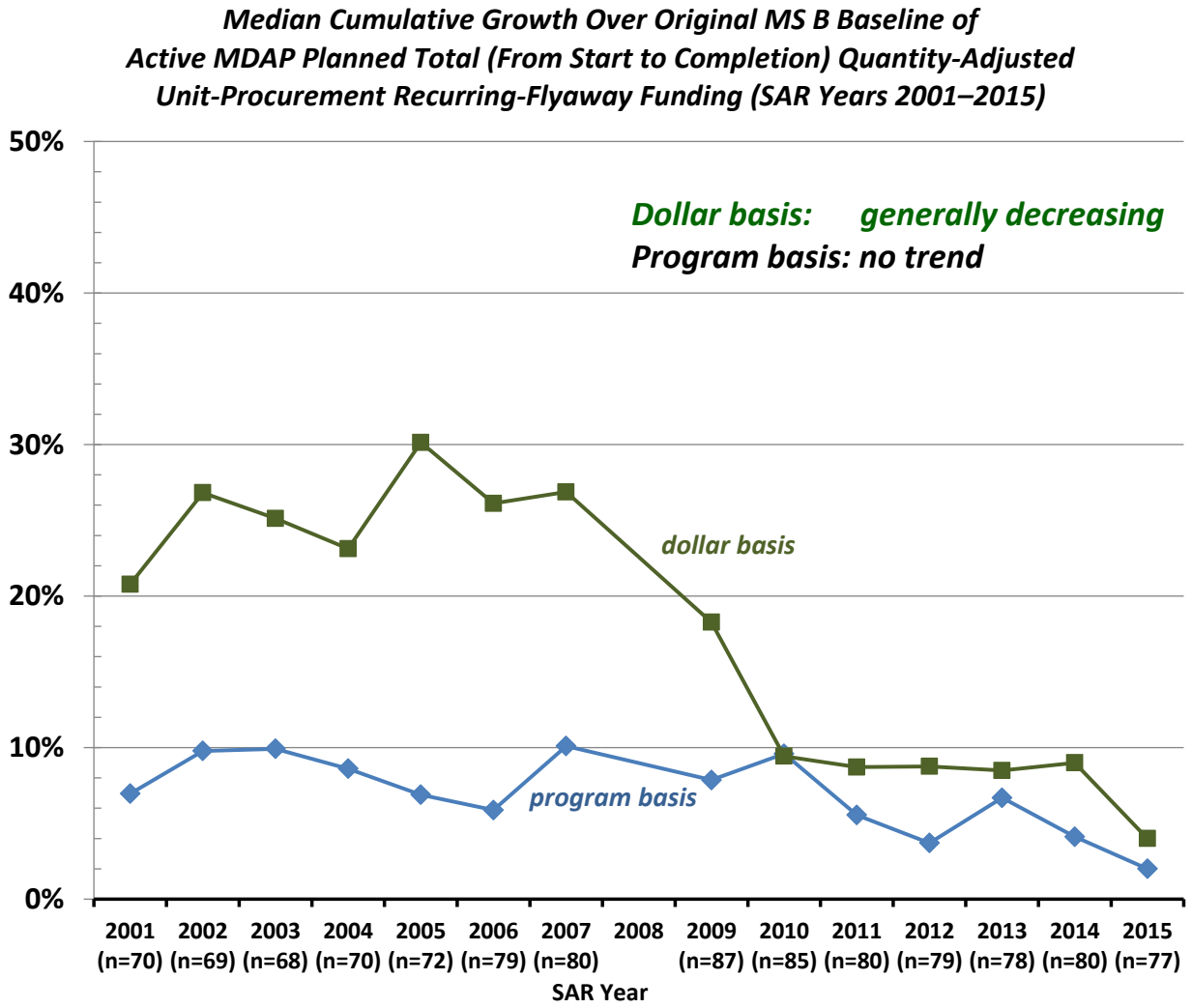
Table H-1. Changes in MDAP Cost Growth from 2014 to 2015 SARs

		Basis	(Change from 2014 to 2015 SARs)	
RDT&E		**Basis**	**Medians**	**Description**
Cumulative *(from original baseline)*		***Program***	19% → 19%	*flat*
		Dollar	45% → 49%	*still high*
Biennial		***Program***	1% → 1%	*flat*
		Dollar	0% → 1%	*slightly higher, but still very modest*
Procurement *(quantity-adjusted)*				
Cumulative *(from original baseline)*		***Program***	4% → 2%	*lower (apparent)*
		Dollar	9% → 4%	*lower (apparent)*
Biennial		***Program***	0% → 0%	*flat*
		Dollar	0% → 0%	*flat*

Lower total MDAP funding growth since original baselines in production. Adjusting for quantity changes and the dollar size of programs, the median quantity-adjusted unit funding growth since original MS B baseline has been statistically lower after 2009 and dropped further in 2015 (see the dollar-basis line in Figure H-5). On a program basis, the recent total unit funding appears somewhat lower at the median, but the population differences are not statistically significant (see the more detailed Figure 2-22). In other words, larger active MDAPs (by dollar) generally have brought their growth in total unit procurement funding needs to levels close to the median for all MDAPs regardless of size. Note that this is not the case in development, where increases are seen by program and dollar in recent years—see Figure H-16 below. *(See detailed discussion starting on p. 50.)*

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Figure H-5. Program Cost-Related Performance: Procurement



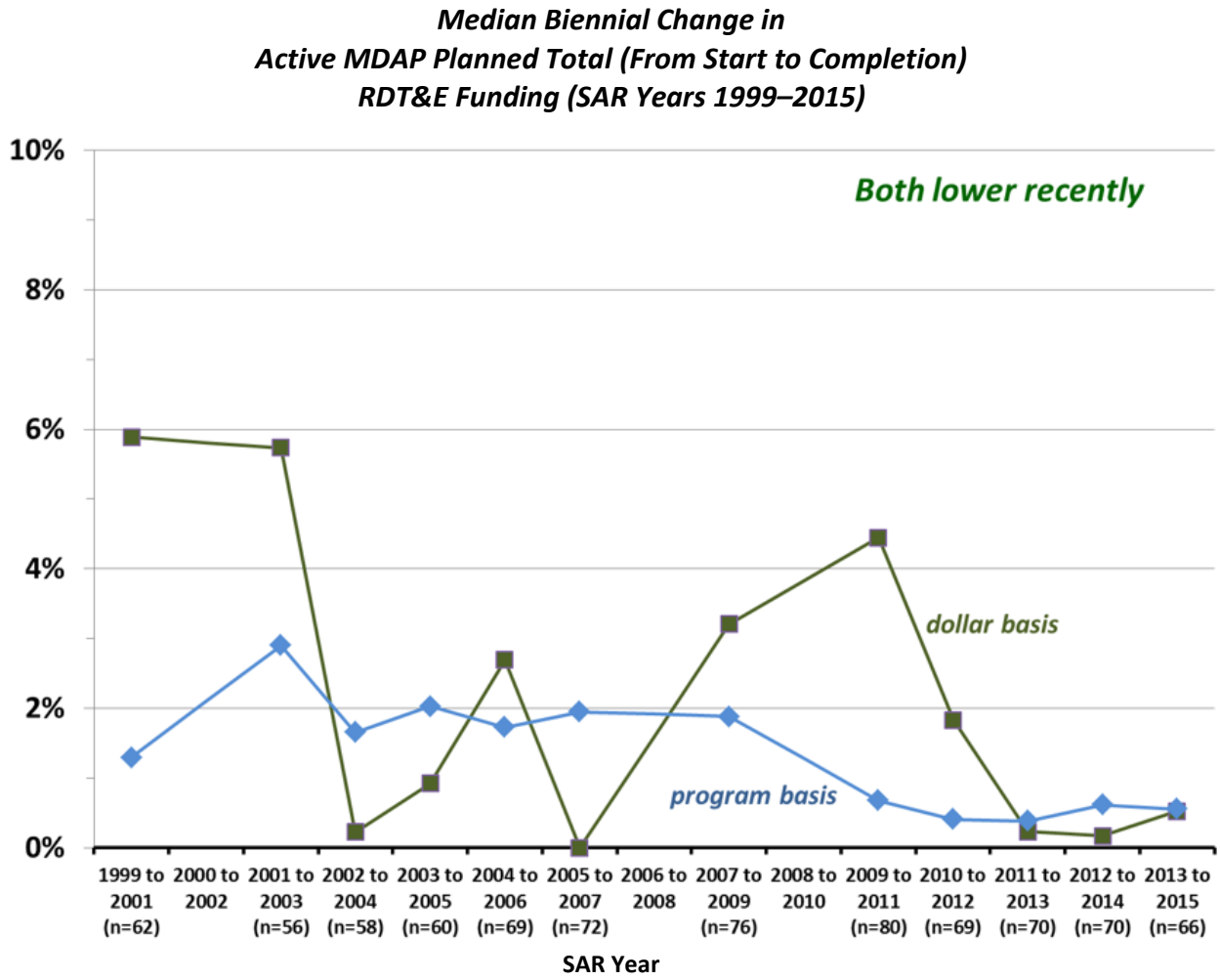
NOTE: This shows growth in unit recurring flyaway funding (i.e., for the production of a single usable end-item) after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. The trend on a dollar basis (weighting by program size) is statistically significant, but the lower results on a program basis (unweighted by dollar size) do not yet represent a statistically significant trend (see Figure 2-22 for details). These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. Not included are relatively new programs that have not spent at least 30 percent of their original EMD.

Lower biennial change in MDAP program funding for both development and production. In addition to measuring total growth against original baselines, we also measure biennial growth to monitor incremental (marginal) growth. Median biennial change in funding growth continues to be lower in recent years both on a program basis and when adjusting for the size of programs (i.e., on a dollar basis)—see Figure H-6 and Figure H-7. In both program and dollar bases, biennial changes have been below 1 percent since 2011 for development and essentially zero or below since 2009 for procurement. These are measured using total program RDT&E funding and quantity-adjusted unit procurement (recurring unit flyaway funding), including past and needed future funding. *(See detailed discussion starting on pp. 40 and 54.)*

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Figure H-6. Program Cost-Related Biennial Performance: Development

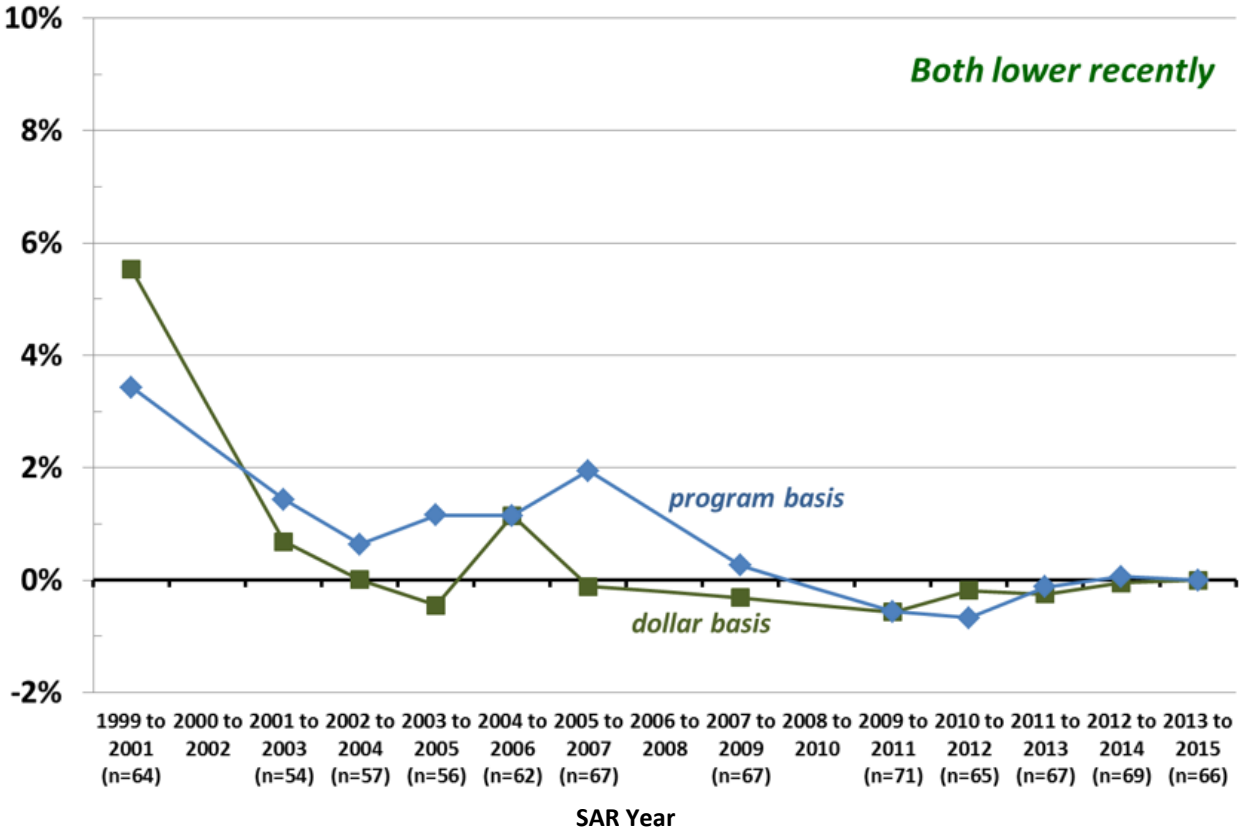


NOTE: This measures biennial changes in total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. Both trends are statistically significant. Total RDT&E is an insightful measure because it is necessary, regardless of quantity. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not included. The dollar-basis value for 2010–2012 is higher than last year's report due to an error from not including 2011 F-35 fighter jet engine RDT&E dollars in 2010. Other slight adjustments in 2002–2004 and 2003–2005 reflect the addition of the Chemical Demilitarization (Chem Demil) programs to the dataset on program and dollar bases.

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Figure H-7. Program Cost-Related Biennial Performance: Procurement

Median Biennial Change in
Active MDAP Planned Total (From Start to Completion)
Quantity-Adjusted Unit-Procurement Recurring-Flyaway Funding (SAR Years 1999–2015)



NOTE: This measures biennial changes in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. Indicated trends are statistically significant. Not included are relatively new programs that have not spent at least 30 percent of their original EMD schedule.

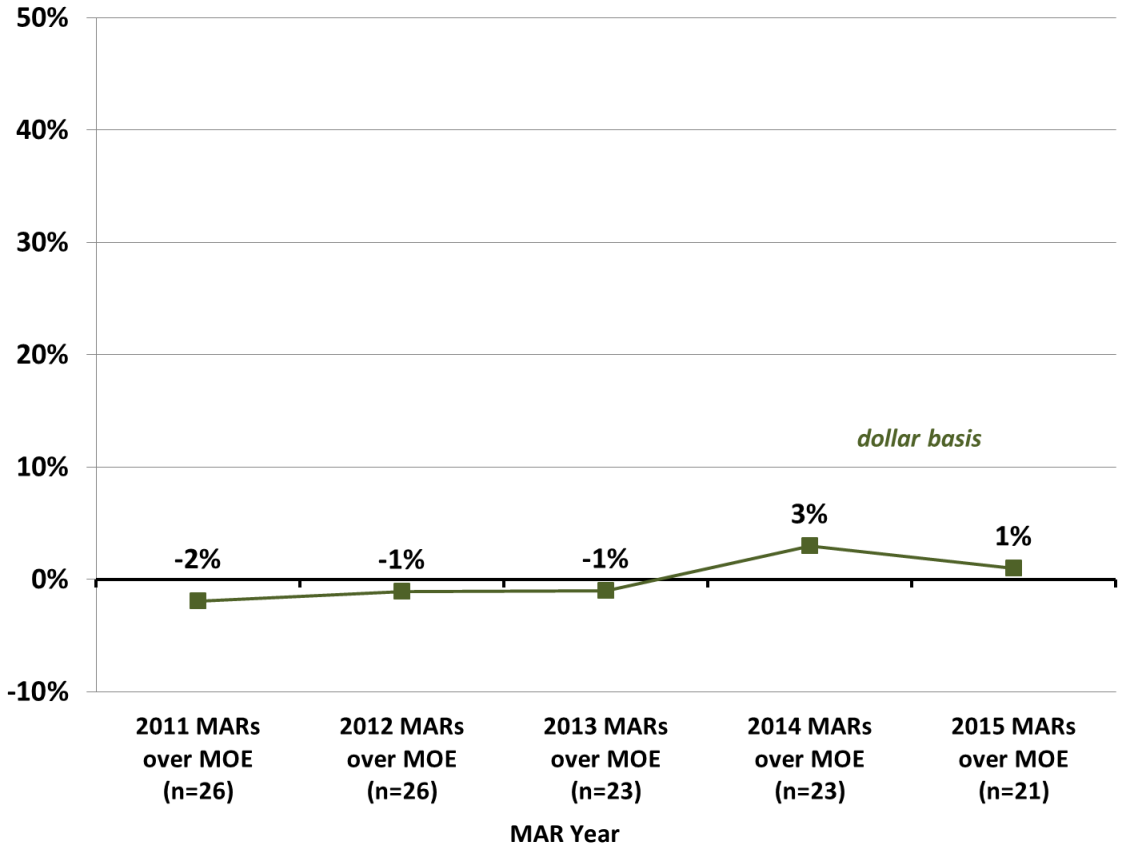
Lower median MAIS funding growth. As shown in Figure H-8, the median funding growth in the MAIS Annual Reports (MARs) compared to the MAR Original Estimate (MOE) dropped in MAR Year[9] 2015 after a small rise in 2014. Note that the magnitude of cumulative funding growth for MAIS programs is much smaller than those for MDAPs in development (Figure H-16) and production (Figure H-5). *(See detailed Figure 2-8 on p. 32 and associated discussion.)*

[9] MAR Years are analogous to SAR Years.

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Figure H-8. Program Cost-Related Performance: Information Systems

Median Cumulative Growth Over Original Baseline of Planned Total (From Start to Completion) Funding for Active MAIS (MAR Year 2011–2015)



NOTE: Trends is statistically significant. Growth may reflect content changes. Immature programs that have not completed at least 30 percent of their original EMD schedule time were excluded to help control for maturity.

No penalties from new statutory overrun calculations on recent MDAPs. Section 828 of the FY 2016 National Defense Authorization Act (NDAA) (Public Law 114–92) enacted a new cost-growth calculation and associated penalty by military department across their MDAPs that started since 2009. Table H-2 summarizes the results for the 2014 and 2015 SARs. None of the military departments has net positive overruns and thus none of them incurred penalties for either of these years. We also note that each military department improved from its 2014 to 2015 SARs. *(See detailed discussion and data starting on p. 66.)*

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Table H-2. Military Department MDAP "Overrun" Calculations and Penalties (SAR Years 2014–2015)

Department	2014 SAR Net Portfolio Overrun *(BY17$, B)*	2014 SAR Penalty	2015 SAR Net Portfolio Overrun *(BY17$, B)*	2015 SAR Penalty
Army	−0.5	$0	−3.9	$0
Navy	−2.9	$0	−4.0	$0
Air Force	−25.3	$0	−30.0	$0

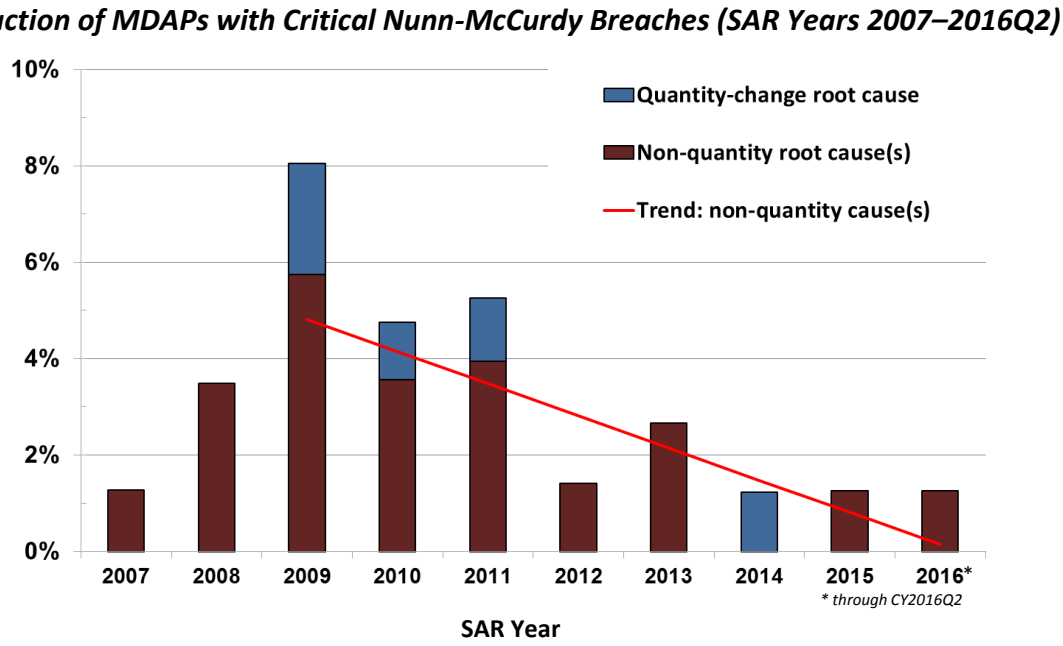
NOTE: "Overruns" in this case are defined (by Section 828 of the FY 2016 NDAA relative to original PAUC baselines at current total quantities. To aid comparison between the two years, all dollars are converted to a common FY 2017 base year (BY) and rounded to the nearest $100 million.

Lower recent rates of Nunn-McCurdy breaches. As shown in Figure H-9, there have been statistically significant downward trends since 2009 of both nonquantity-related critical breaches (shown) and all critical Nunn-McCurdy cost-growth breaches.[10] *(See detailed discussion and data starting on p. 22.)*

[10] Nunn-McCurdy "cost" growth thresholds are established by law and trigger reporting to Congress and other specific actions by the DoD (see discussion starting on p. 19). As discussed earlier with respect to PAUC, these "cost" measures reflect funding and include the underlying contractor and government execution costs plus contractor margins (profits and fees).

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Figure H-9. Program Cost-Related Performance: Nunn-McCurdy Breaches



NOTE: This chart includes data through CY 2016Q2, which is the second quarter of CY 2016, inclusive. Breaches due to quantity changes are based on Performance Assessments and Root Cause Analyses (PARCA) root-cause analysis or review of information from the program's DoD Component. JSOW has been recategorized as quantity related (a change from last year's report). Since PARCA was not established until the Weapon System Acquisition Reform Act (WSARA) of 2009, it is unknown whether quantity changes were a root cause of breaches before 2009. There is a statistically significant downward trend in both total critical breaches and non-quantity-related critical breaches since 2009. Cost breaches are after adjusting for inflation. Since it usually takes a few years before a program might breach again, we removed programs from the portfolio count that have breached recently to avoid the potential bias toward an artificially low breach rate (i.e., this adjustment makes the metric more conservative). Also, relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. For the trend analysis, we used the breach rates instead of counts to control for changes in portfolio size between years, although the patterns are very similar because the size of the MDAP portfolio is relatively stable.

SCHEDULE-RELATED PERFORMANCE

While cost growth eventually affects warfighter capabilities through opportunity cost effects on quantity and other programs, schedule growth directly delays the delivery of capabilities that address operational needs and threats. Thus, we are expanding our analysis of schedule-related performance to look for trends in cycle time and schedule growth. As with cost, schedule-related metrics vary depending on what is included (e.g., whether active or incomplete programs are included, raising questions of remaining maturity bias) and how they are calculated (e.g., whether in years relative to baselines or in percentages of growth, the latter of which are not symmetrical around 0 percent).

The following schedule-related metrics show mixed performance; some show increases while others show zero or negative growth. Generally, the magnitudes of any changes are lower in percentage than cost growth relative to baselines.

Historical MDAP schedule growth shows no trend in time. When measuring schedule growth from MS B or C to IOC by start date, we saw no significant trend across all MDAPs. In other

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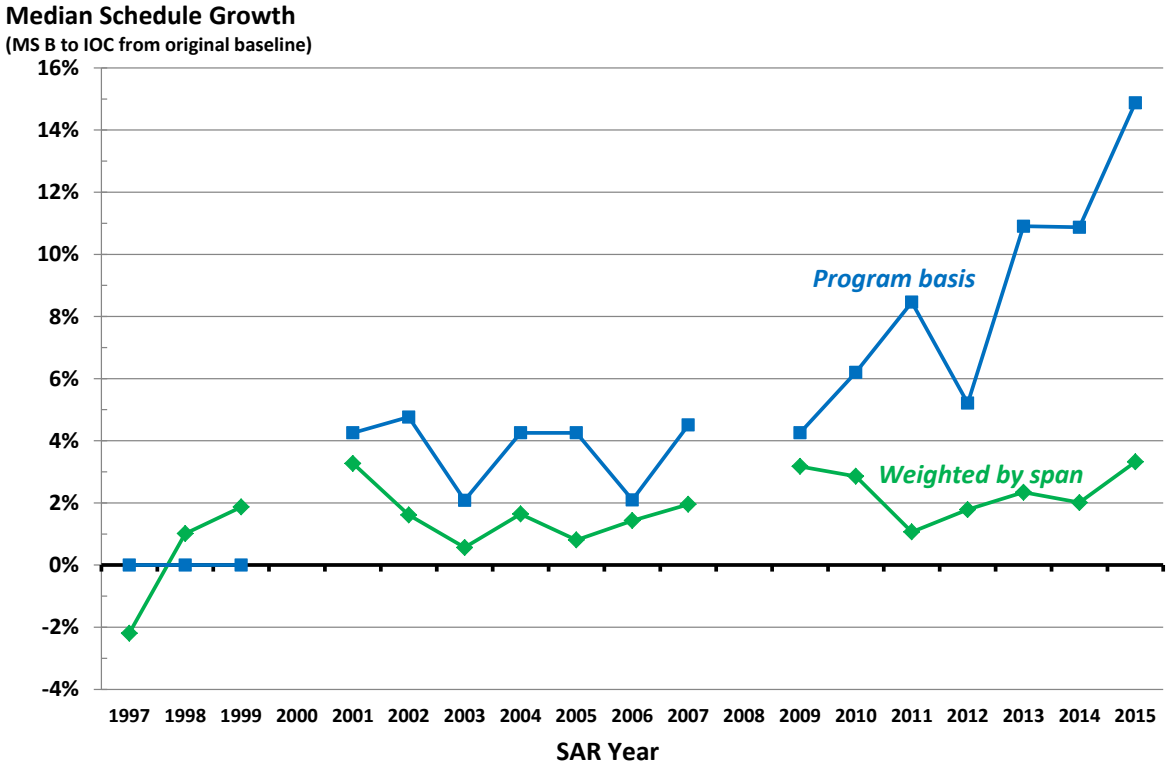
words, essentially no part of the variation is explained generally by a trend in time. The median overall growth since 1981 is 1 percent (up from 0 percent last year). We do see a downward trend in the subset of programs that have not yet achieved IOC, but it is too early to tell whether the trend is real or are merely due to the fact that the programs are not yet complete. *(See discussions starting on p. 46.)*

MDAPs have averaged about 7 years to reach IOC, showing about 3 percent growth overall. The average MDAP that reported between calendar year (CY) 1997–2015 took about 7 years to reach IOC from initiation at MS B or C. This is about 3 percent above the average planned length. The actual portfolio variation (standard deviation) grows by about 5 months. In other words, the portfolio of programs that have achieved IOC showed modest schedule growth, measured in months, not years. *(See discussion starting on p. 45.)*

Recent median schedule growth on active, shorter MDAPs is increasing. In a different measure examining all then-active MS-B-start programs (regardless of whether they have reached IOC or not), we have seen a marked increase in schedule growth from program start (MS B) to IOC from about 4 percent to about 15 percent at the median on programs since 2009 on a program basis (see Figure H-10). Schedule growth across the distribution in CY 2015 was statistically higher than it was in 1997–1999 and 2004–2005. However, when weighting by program span (so that longer programs weigh more than shorter programs), the trend remains relatively flat at about 2 percent. Thus, recent schedule growth (in percent) on active programs generally appears to be concentrated on shorter programs. We also found (in separate analysis) that shorter programs tended to have higher schedule-growth percentage variation than longer programs. *(See discussion starting on p. 46.)*

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Figure H-10. Median MDAP Schedule Growth for Active Programs (SAR Years 1997–2015)



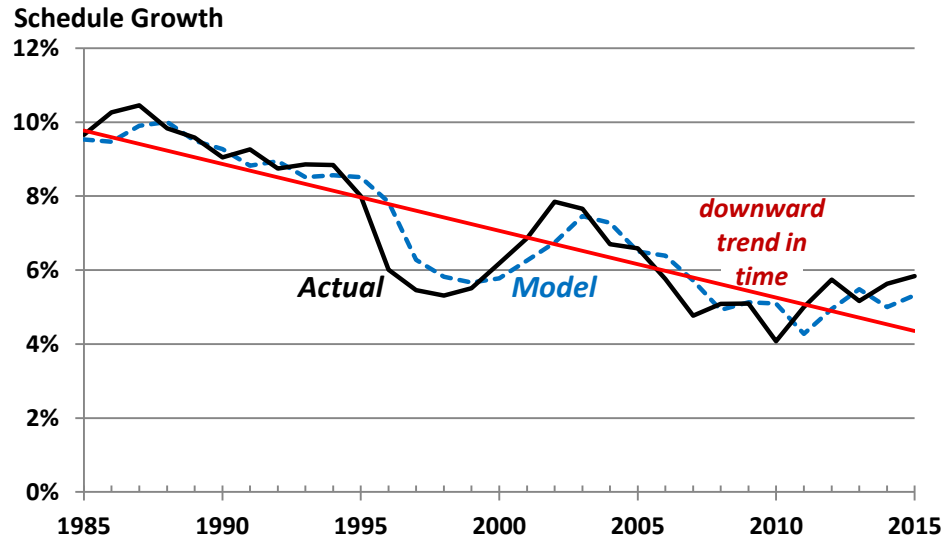
NOTE: Program basis weighted each program equally. Schedule growth on a program basis across the distribution in CY 2015 was statistically higher (at the 5-percent level of significance) than it was in 1997–1999 and 2004–2005. Weighting by span increases the contribution of longer programs relative to shorter programs (analogously to weighting cost growth by the dollar size of a program). There were no complete SARs in 2000 and 2008 due to changes in presidential administrations. No programs that started at MS C are included.

MDAP development contract length has grown slowly with system complexity. In comparison to program schedules, when examining development contracts for MDAPs we also see a cycle time of about 7 years. Historically, contract cycle time has grown since 1980 (when it was about 4 years and we had many large overruns on programs in the 1970s) through the 1990s (when it was about 5 years) to the present level of about 6.5 years since about FY 2002. These increases are commensurate with data from our prior reports and probably reflect increases in system complexity and capabilities over the last 35 years. *(See discussions starting on p. 60.)*

Schedule growth is declining on major MDAP contracts. In contrast to program-level data, major development contracts for MDAPs are showing a statistically significant decline since 1985. Our model also shows that any random deviations from this trend are corrected in later years, preserving the trend. Figure H-11 shows that this analytic model closely fits the actual data. *(See discussion starting on p. 61.)*

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Figure H-11. Contract Schedule Growth (FY 1985–2015)

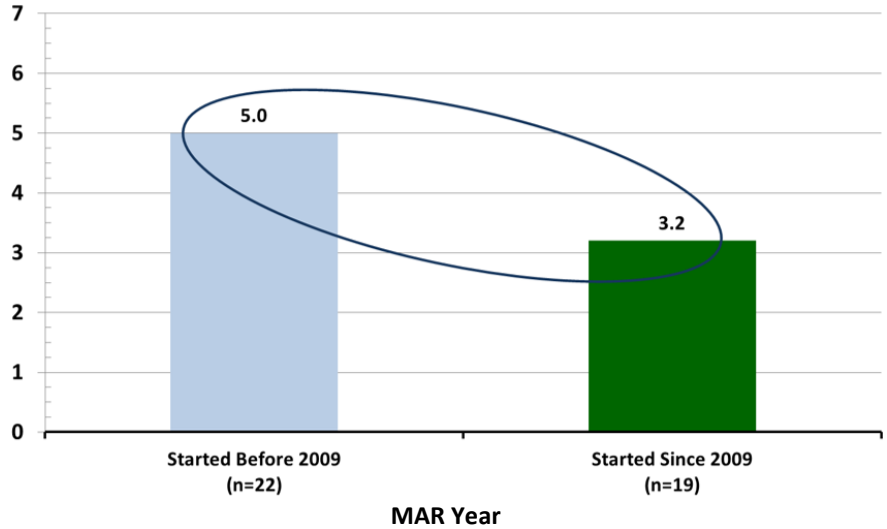


NOTE: 18,470 earned-value reports on 1,123 major contracts for 239 MDAPs.

Median MAIS cycle time is lower. MAIS cycle time is particularly important given the fast pace of information technology advancement. Here cycle time is measured from either MS B or Funds-First-Obligated (FFO) to the Full-Deployment Decision (FDD). As shown in Figure H-12, the median cycle time as reported in the MARs dropped from 5 years before 2009 to 3.2 years since 2009; this result is unchanged from last year's report. Further data and analysis are needed to determine whether we are faster at acquiring MAIS or are planning MAIS in smaller increments. *(See detailed Figure 2-21 on p. 49 and associated discussion.)*

Figure H-12. Program Length: Information Systems

Median Originally Estimated Cycle Time for Active MAIS (2011–2015 MARs)

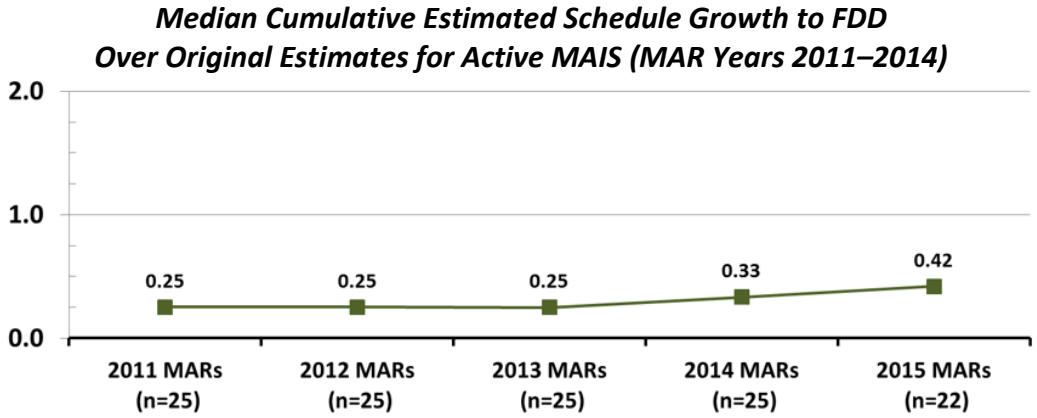


NOTE: These changes may reflect systemic reductions in how much work is included in an MAIS. Original estimates are those in the MAIS' first MAR. Included are the latest data on programs that appeared in at least one MAR from 2011 through 2014. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not included.

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MAIS program schedule growth. We also track MAIS schedule growth to understand actual execution. As shown in Figure H-13, the median schedule growth across then-active MAIS programs has increased slightly from 3 months in 2011 to 5 months in 2015. Again, further data and analysis are needed to determine whether MAIS programs are executing well relative to plans or if requirements and work content are being adjusted to keep programs close to original schedules. *(See detailed discussion on p. 30.)*

Figure H-13. Program Schedule Growth: Information Systems



NOTE: These measures do not control for any changes in work content or specifications. Original estimates are those reported in the first MAR for each MAIS. Schedule period is from MS B or FFO to FDD. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not included

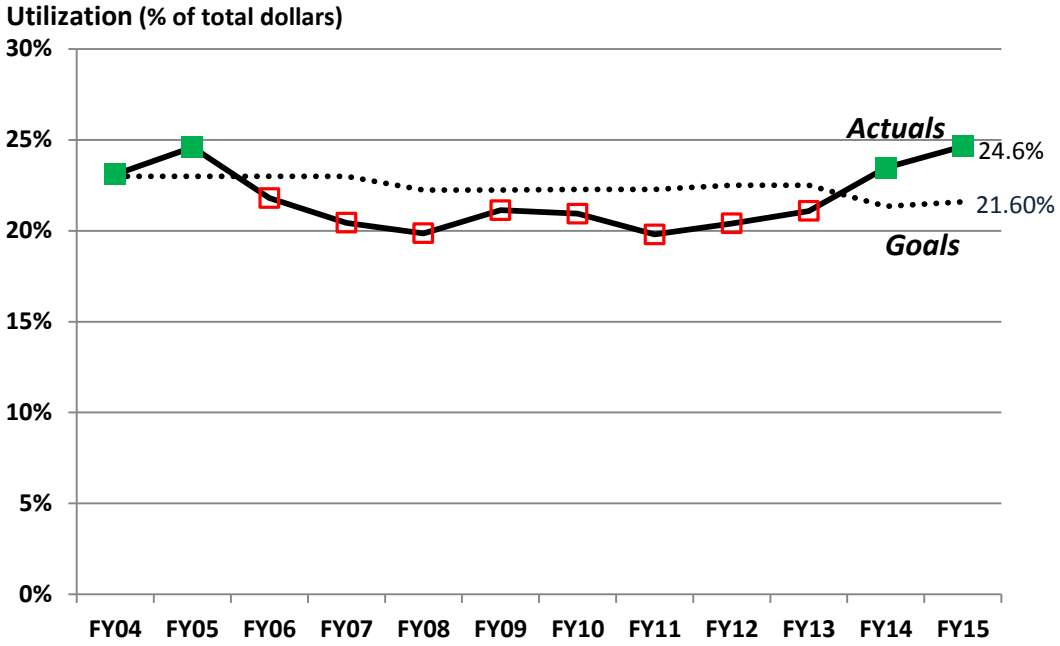
Improvements in Institutional Inputs

Acquisition workforce capability and quality improvements. Workforce professionalism is central to the performance of the defense acquisition system. With strong support from Congress, we have made strides in improving the capabilities, qualifications, demographics, and leadership of the workforce through various strategic initiatives. The workforce grew by about a quarter after FY 2008 when it was recognized that the DoD had serious deficiencies in this area. This growth was stopped as budgets declined after 2011, but since then the size of the workforce has remained roughly constant. Quantity (the number of people) alone is insufficient. We now focus on improving the quality, experience and professionalism of the workforce. The percent of the workforce lacking certifications has dropped from 14 percent in FY 2008 to 3 percent in the first quarter of FY 2016. We have reduced a significant shortfall in late mid-career staff through strategic hiring. Finally, board-certification has articulated and applied advanced quality standards for many categories of key acquisition leaders. *(See further discussion starting on p.* 119*.)*

Increased small-business utilization on prime contracts. Figure H-14 shows actual DoD-wide small-business utilization (measured as a percentage of dollars obligated) relative to yearly goals. At the prime contract level, recent trends since FY 2011 have been steadily improving; we exceeded our FY 2014 and FY 2015 goals by 2.1 and 3.0 percentage points, respectively, surpassing all prior years except FY 2005. *(See further discussion starting on p. 135.)*

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Figure H-14. Small-Business Prime Contracting Utilization Trends: Goals and Actuals (FY 2001–FY 2015)



NOTE: Closed green squares indicate that the goal for that fiscal year was achieved; open red squares indicate that the goal was not achieved.

WHERE IMPROVEMENT IS NEEDED

While progress has been made in a number of performance measures, improvement is flat or could be improved in others.

Initial operational test ratings remain about the same. The whole reason we have defense acquisition is to provide operational capabilities to our warfighters against current and evolving threats. Cost and schedule control are important, but more important is the relative value of operational benefits given costs. Operational performance goes beyond merely meeting technical requirements established before program inception. Threats can change and those initial requirements may lag operational aspects important to performance in the field. One measure of performance is the operational test results reported by the DoD Director of Operational Test and Evaluation (DOT&E) at the end of LRIP. These initial operating tests, often referred to as Beyond-LRIP (BLRIP) tests, provide independent data on the operational effectiveness and suitability of the system at this point.

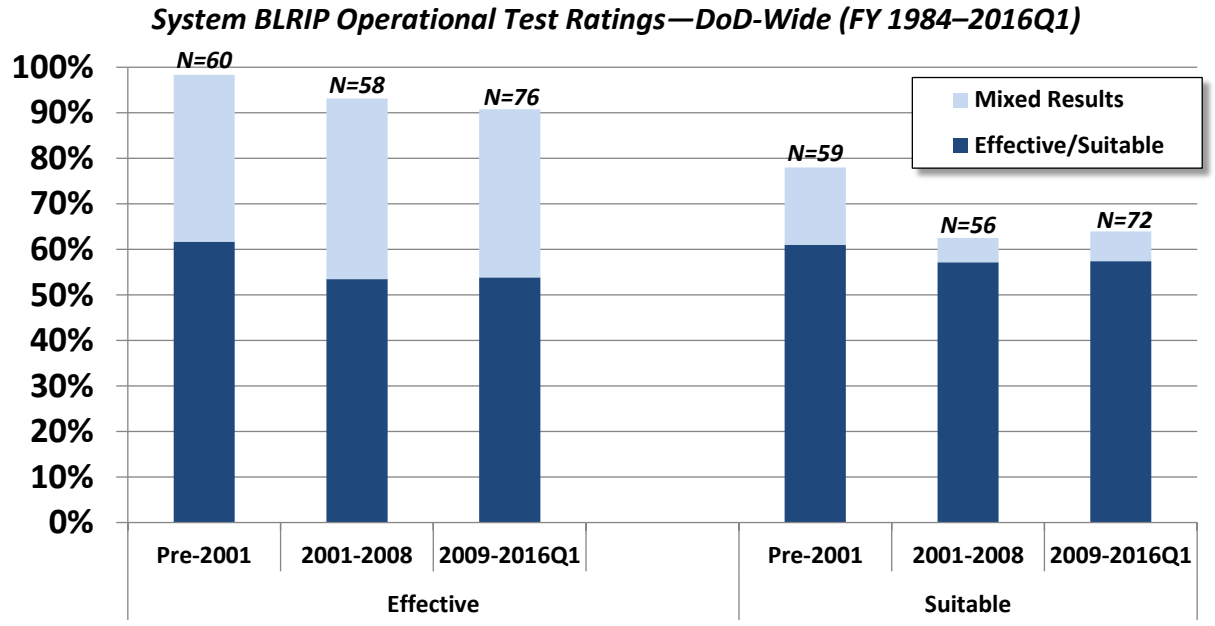
Figure H-15 summarizes the results of these BLRIP operational tests. While the absolute percentages are slightly lower, the differences between the time periods are not statistically significant, and we are not able to distinguish statistically significant differences based on the incumbent DOT&E. Further analysis discussed in the report found that a program is fairly likely to test out as effective if it tested as suitable, but the converse is not true. In other words, we have a number of effective programs that revealed issues with safety, interoperability,

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availability, maintainability, and reliability. However, systems that demonstrated suitability also tended to be effective against threats. *(See detailed discussion starting on p. 16 and 62.)*

These data do not reflect subsequent remediation of the issues found during operational testing. Structured data on subsequent operational tests have a much lower sample size and showed no obvious trends. Note, however, that any remaining limitations are subject to tradeoff decisions that weigh remediation cost and performance factors against the benefits of early introduction of advanced capabilities.

Figure H-15. System Operational Test Performance



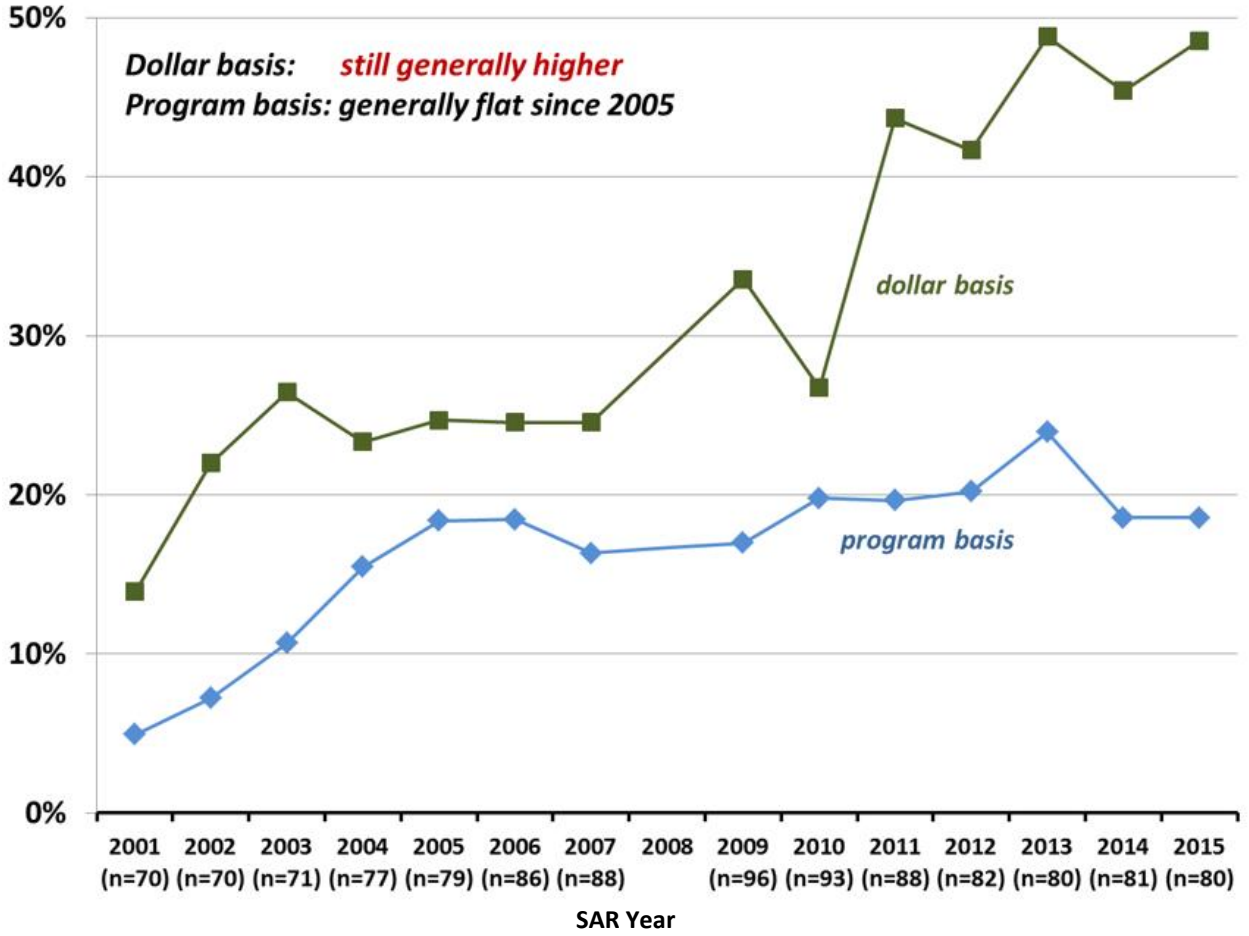
Source: DOT&E BLRIP reports.
NOTE: Differences are not statistically significant. Sample sizes differ between Effective and Suitable for some DoD Components because effectiveness and suitability could not be determined in all cases.

Higher total MDAP RDT&E funding growth since original baselines. While biennial changes in total planned and actual RDT&E funding growth has been decreasing recently (see p. xxx), cumulative RDT&E funding over original MS B baselines continued its increase since 2001 on a dollar basis but has been statistically flat since 2004 on a program basis (see Figure H-16). Since recent biennial changes in planned and actual total funding have been near zero at the median, this metric is unlikely to reverse (even if no more RDT&E growth occurs) until programs with earlier RDT&E growth (e.g., the F-35, which had significant historical development cost growth but has been stable since the Nunn McCurdy breach in 2010) exit the MDAP portfolio. Negative growth would be required to reduce this metric, absent programs dropping out of the dataset. *(See detailed discussion starting on p. 35.)*

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Figure H-16. Program Cost-Related Performance: Development

Median Cumulative Growth Over Original MS B Baseline of Active MDAP Planned Total (From Start to Completion) RDT&E Funding (SAR Years 2001–2015)



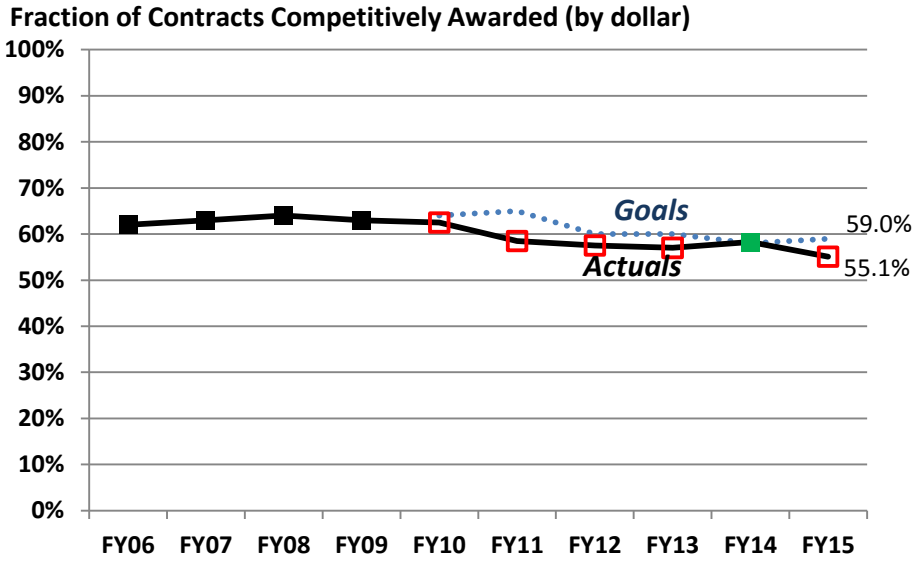
NOTE: This shows total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. Both trends are statistically significant. These are percentage changes from original MS B baseline after adjusting for inflation of actual past and estimated future funding as reported in each program's latest SAR. Total RDT&E is an insightful measure because it is necessary regardless of quantity. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not included. The dollar-basis value for 2010 is lower than last year's report due to an error in double counting the F-35 engine RDT&E dollars in that year. There are also slight corrections in 2002–2003 on a program basis adding the Chem Demil program and in 2014 to include three subprograms to the dataset.

Competition rates are falling. Figure H-17 plots the percentage of all DoD contract dollars that were competitively awarded from FY 2006 to FY 2015. Since goals were established in FY 2010, we had declining actuals until we made progress in FY 2014 at reversing the trend. However, competition rates declined again in FY 2015 despite an increased goal and strong management emphasis by the DAE through the Business Senior Integration Group for that year. Major drivers of this trend are high-value sole-source Foreign Military Sales, fewer new program starts, and higher percentages of the MDAP portfolio (e.g., shipbuilding and aviation programs) in

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production and thus sole or dual sourced. Increased bid-protesting also forces us to award sole-source contracts to bridge until we can let the new contract awards. We anticipate continued challenges from fiscal uncertainties, but this will remain an area of management focus. *(See detailed discussion starting on p. 135.)*

Figure H-17. Competition Trends: Goals and Actuals (FY 2006–2015)



NOTE: Fraction of contracts competitively awarded is measured on a dollar basis. We did not establish goals until FY 2010. Open symbols indicate that the subcategory goal for that fiscal year was not achieved. Closed green symbols indicate that the subcategory goal was achieved for that year.

Subcontracting utilization of small businesses. As shown in Figure H-14 on p. xl above, small-business utilization on subcontracts to our prime contractors has been declining since FY 2010. We have missed the goals for the past 4 years. To address this trend, the DoD continues to apply statutory procedures wherein contractors who fail to comply in good faith with the requirements of their small-business subcontracting plans are in material breach of their contracts and are subject to liquidated damages (see the Federal Acquisition Regulation [FAR], Section 19.7). We also emphasize the importance of small-business subcontracting with senior management at our major primes when reviewing their institutional performance. In addition, we are modifying our acquisition strategies to further open up competitions on components for our large weapons systems.

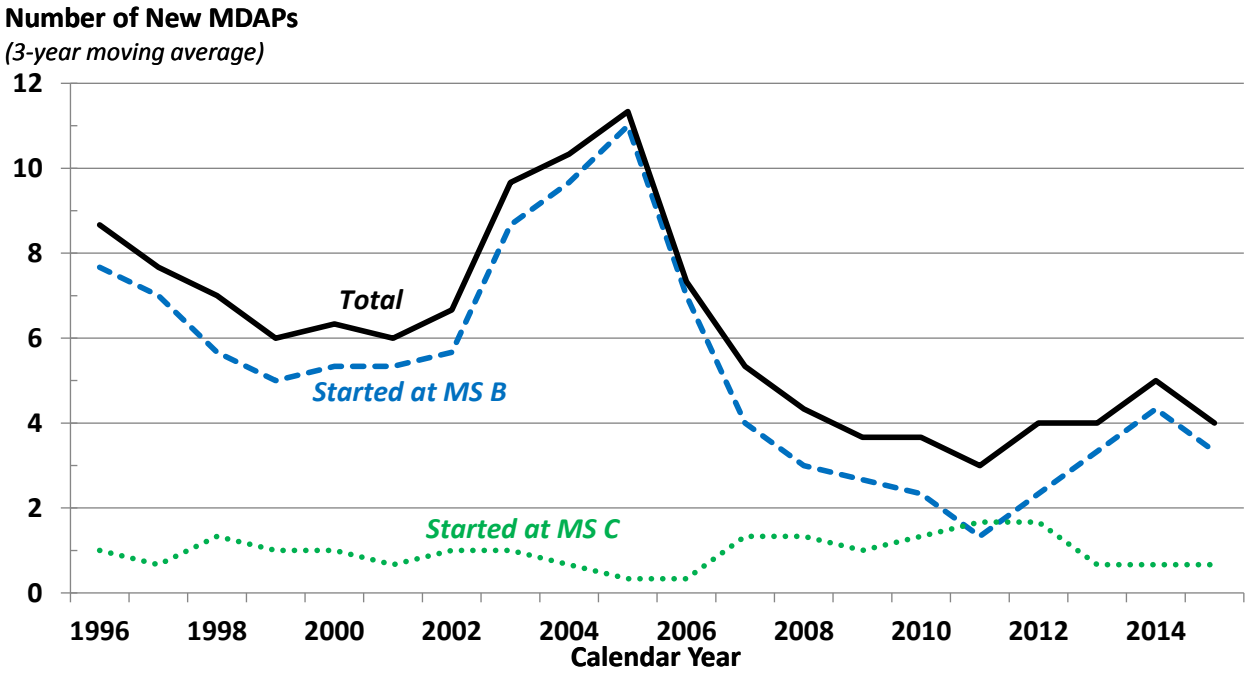
Other Observations

Technical superiority concerns continue. Declining investments in both RDT&E and production (see Figure 1-4 on p. 4) at a time of accelerating threats is delaying and limiting development and production of superior capabilities in quantities that are operationally relevant. Also, trend analysis of RDT&E budget activities (BAs) supports our concern that budget reductions are affecting new system development, which constitutes the programs in the DoD's new product pipeline. BA 6.5 (System Development and Demonstration, which supports programs after MS

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B) drops below BA 6.4 (Advanced Component Development and Prototypes) after FY 2014 (see Figure 1-5 on p. 5) instead of being higher. As part of the Third Offset Strategy and consistent with BBP 3.0, the DoD is increasing its investments in BA 6.4 by funding a number of risk-reduction prototype programs. Without funds to continue these efforts into the more expensive BA 6.5 phase to further develop the systems for production, these demonstrations will not result in fielded capabilities. Figure H-18 also shows that the number of new MDAPs has dropped in recent years to about half of what we saw in the mid-1990s and two-thirds of the peak in the mid-2000s.

Figure H-18. Frequency of New MDAP Starts: 3-Year Moving Average (CY 1996–2015)



NOTE: Dates were extracted from CY 1997–2015 SARs, with MS start dates in 1994–1996 extracted from the 1997 SARs. The data points for 1996 reflect the average for calendar years 1994–1996.

MDAP requirements are relatively stable. Preliminary analysis of performance requirements in unclassified baselines and SARs indicate that about 15 percent of 121 MDAPs showed requirements changes that we could trace from the original MS B baseline to the latest SAR for the program. Most of the programs with any traced changes had only one such change. For cases in which we could judge a change as more or less stringent,[11] about half of more stringent requirement changes were in a single program (FMTV, a ground vehicle), and half of the less-stringent changes were in the (subsequently canceled) NPOESS satellite program. Further

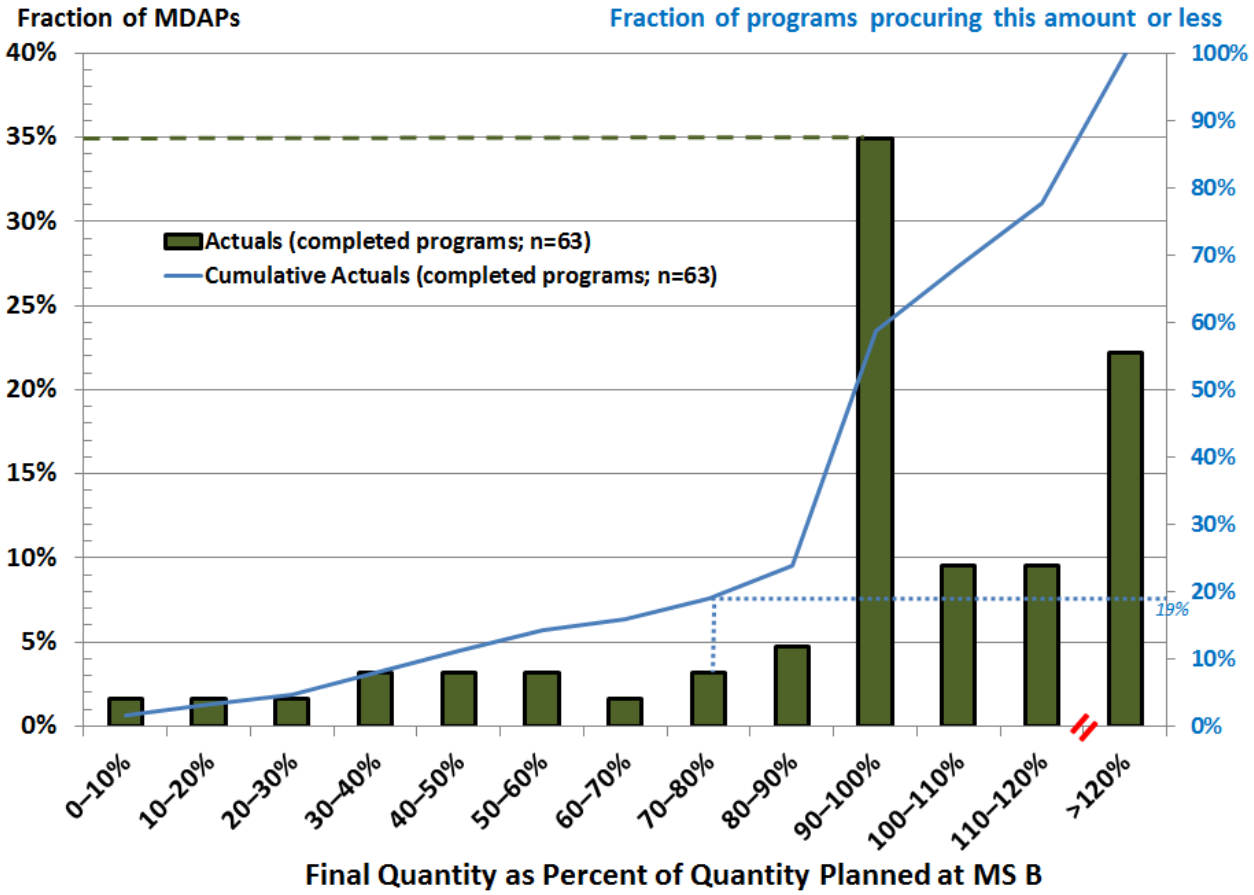
[11] As opposed to additions, deletions, or cases where it is not readily clear whether the change is harder or easier to implement.

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analysis is needed, but for the most part system requirements appear to be stable. (*See detailed analysis and discussion starting on p. 100.*)

Most MDAPs deliver the original baseline quantity or more. Figure H-19 shows the actual number of units procured by completed MDAPs over the last 19 years. More than 80 percent of programs delivered at least 80 percent of their originally planned units, and just over 40 percent of programs delivered more than originally planned. This general pattern also appears to be holding for currently active programs. (*See detailed analysis and discussion starting on p. 104.*)

Figure H-19. Actual Quantity Procured Compared to Original MS B Plans for Completed Programs (1997–2015 SARs)



NOTE: Completed programs are those that stop reporting after approximately 90 percent of units are delivered or 90 percent of funds are expended. There were n=63 completed programs in our dataset. The bars show the fraction of the 63 programs that procured the indicated range of original quantity percentages (e.g., 35 percent of the 63 programs procured 90–100 percent of their originally planned quantity). The blue line measures cumulative fraction of programs and is read off the y-axis on the right side of the plot (e.g., 19 percent of the programs procured less than 80 percent of their originally baselined quantity.

Tight budgets may motivate overly optimistic program baselines. Changes in DoD budgets at the start of a program (MS B) correlate in the opposite direction of the overall economic cycle (i.e., countercyclically) with changes in total contracted costs aligned to MS B for the contract's

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parent MDAP. Thus, as budgets go down, total contracted costs (including both work-content growth and cost-over-target overruns) generally increase, and the opposite occurs when budgets go up. Analysis also found three stabilizing correction factors that adjust growth in total contracted costs when actuals vary from what was expected from the model. (*See detailed analysis and discussion starting on p. 92.*)

The countercyclical nature of total growth of MDAP contracted costs by MS B start date seems to imply that in tight budgetary environments resource planners were willing to take risks to maintain program start rates and used unrealistic and optimistic initial cost estimates to fit more content into military department budgets. With optimistic initial estimates on what typically are higher-risk development efforts, we would expect the higher cost growth that the data reflect.

Conversely, in accommodating budgetary environments, there may have been less pressure to assume risk to maintain number of program starts, so DoD Components may have had more realistic program start rates and cost estimates. With realistic initial estimates and low risks, we would expect lower cost growth.

These data (along with prior results from McNicol and Wu, 2014) further support caution about starting programs with overly optimistic program cost baselines and contract cost targets during periods when budgets are contracting or low, as in the current environment.

Schedule growth is lower than cost growth in development. Overall median schedule growth (B/C to IOC) since 1981 for active and completed programs is running at 1 percent while schedule growth on only active programs has ranged from 0 percent in 1997 to about 15 percent in 2015. In contrast, MDAP program- and contract-level cost growth in development tends to run in the 20–45 percent range, depending on what measures, data, and adjustments are included. Thus, there are indications that the DoD generally may prioritize schedule over cost, which makes sense given that our primary mission is equipping the warfighter against existing threats, but the data and results on schedule growth are mixed.

Operationally suitable programs are fairly likely to be operationally effective, too. An examination of the coincidence between DOT&E test results shows that major programs often tested as operationally effective when they tested as operationally suitable, but the converse was not true. In other words, we have a number of effective systems that have suitability issues (e.g., safety, interoperability, availability, maintainability, and reliability), but systems that address these suitability issues tended to also be effective against threats. (*See detailed analysis and discussion starting on p. 20.*)

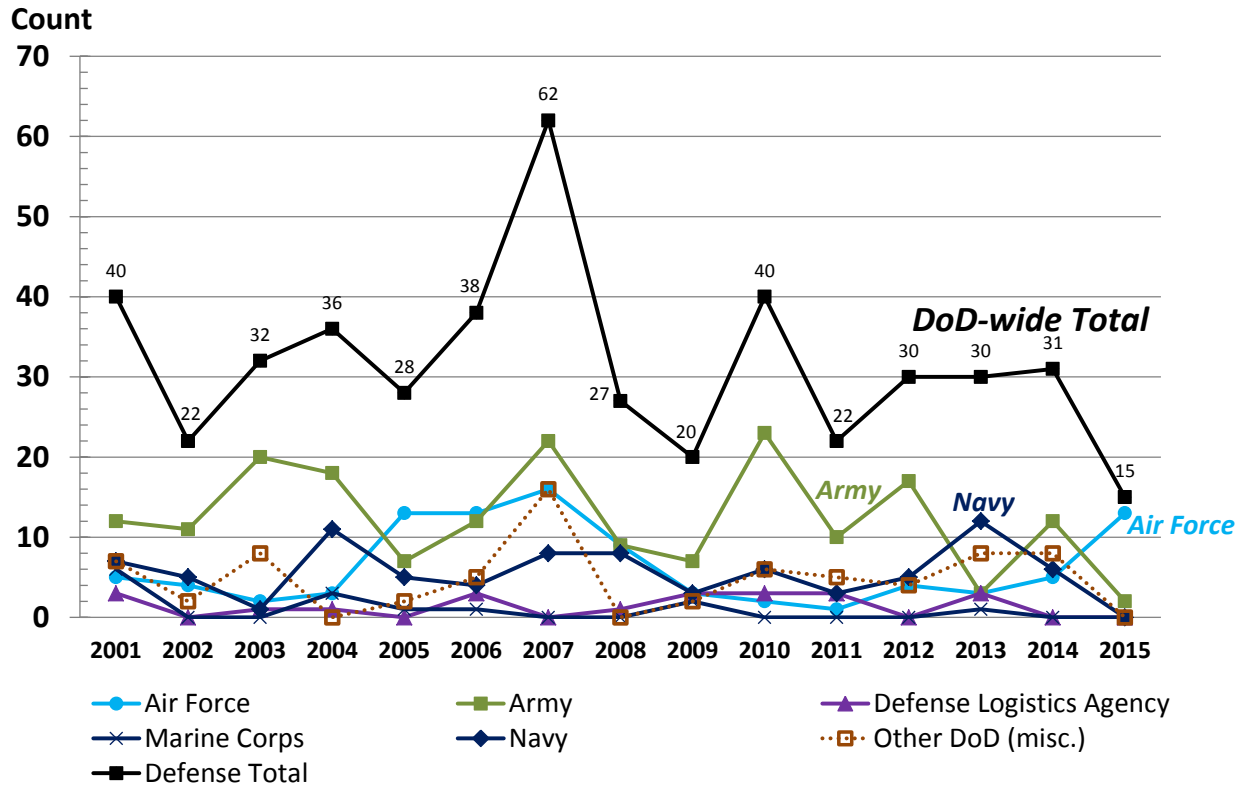
Labor, health-care, fuel, and maintenance costs appear to drive O&S cost estimates. DoD-wide, these factors correlate closely with O&S cost estimate changes reported in 2001–2014 SARs after adjusting for inflation. With some differences, these are also the dominant correlate types of factors for growth in O&S estimates by DoD Component and commodity. In nearly all cases, growth in system service life or quantity did not correlate with growth in O&S cost estimates. Thus, dynamics in these factors appear to be important for controlling O&S costs, and we found these dynamics can cause estimates to vary significantly from year to year (i.e.,

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actual annual growths varied widely from about +/−15 percent since 2001). (*See detailed analysis and discussion starting on p. 95.*)

Bid-protest sustainments remain low despite increased filings. Despite corporate bid protests to GAO nearly doubling to about 1,300 per year, competitive source selections have increased by half and protests average only about 2.5 percent of solicitations (and about 0.25 percent of contract awards). As for outcomes, the number of sustainments by GAO has remained statistically flat at about 30 per year (see Figure H-20)—about 2 percent of filings. Thus, the increased number of protests appears to reflect, in part, external industry strategies or competitive pressures from the declining DoD budgets rather than poor DoD source-selection performance. These results are commensurate with the Congressional Research Service's recent analysis of bid-protest rates (Schwartz and Manual, 2015). *(See further discussion starting on p. 125.)*

Figure H-20. Number of Protests Sustained by GAO (FY 2001–2015)



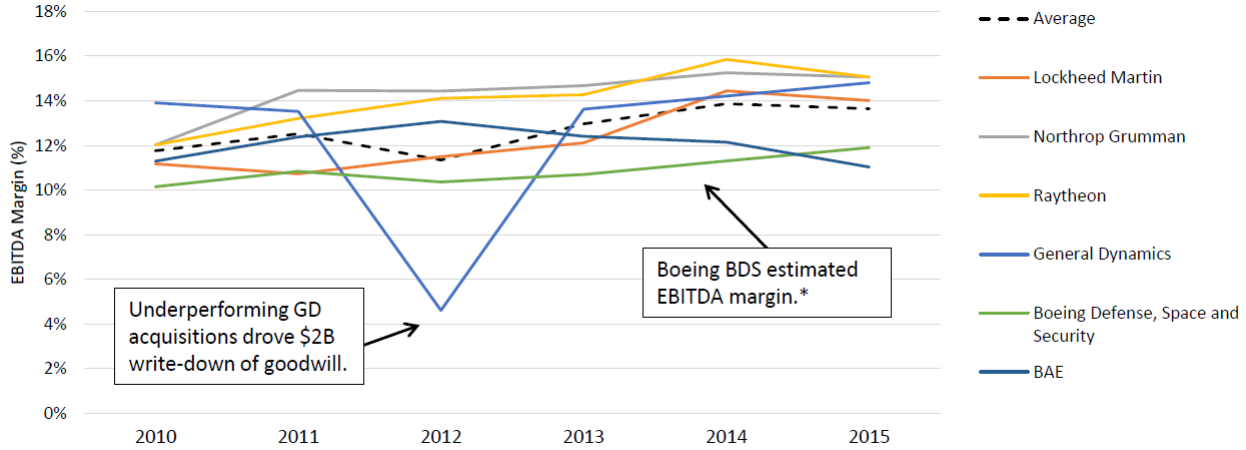
Source: GAO

Prime defense contractors remain profitable. We monitor operating margins of our prime contractors to ensure that the net effect of our cost-control efforts—combined with other issues such as sequestration—are not negatively affecting the health of our industrial base. In addition to the operating margin data published in our 2014 annual report (USD(AT&L), 2014a, pp. 77–79), Figure H-21 plots the trends in earnings before interest, taxes, depreciation and amortization (EBITDA) since 2010 for the six largest DoD prime contractors. Generally, these

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primes have performed consistently or slightly better against this measure since before BBP 1.0 was initiated in 2010. We will examine lower tiers on the industrial base in subsequent reports.

Figure H-21. Historical EBITDA Margin of the Six Largest DoD Primes (CY 2010–2015)



SOURCE: Company 10-K reports (Bloomberg).
NOTES: EBITDA are earnings before interest, taxes, depreciation and amortization. Years refer to corporate fiscal years (coinciding with calendar years).

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ACKNOWLEDGMENTS

The analysis in this report could not have been performed without authoritative structured data archives in the DoD and GAO. The analysis was primarily conducted by Dan Davis, Ken Munson, Douglas J. Buettner, and Philip S. Anton, with much-appreciated assistance and contributions from Joseph Beauregard, Gary R. Bliss, Caroline Chien, Ellen Chou, Karen Cook, Margaret Cregan, Brian Davidson, Terence Emmert, Adrienne Evertson, Randall Fisher, Alan Fu, Susan Gates (RAND), Lynne Giordano, Larry Klapper, Matthias Maier, Andrew Monje, Philip D. Rodgers, Lisa Romney, Garry Shafovaloff, Thomas Sheehan, Nancy Spruill, René Thomas-Rizzo; E. Andrew Long and Catherine Warner (DOT&E); and Edward Goldstein, Jeanette S. McKinney, and Ralph O. White (GAO). Philip S. Anton, Dan Davis, Ken Munson, and Douglas J. Buettner were the primary writers, with very helpful reviews and comments provided by Philip D. Rodgers, Gary R. Bliss, Michael Glennon, Claire Grady, Susan Raps, and Kenyata Wesley. Benjamin Tyree and Michael Shoemaker cheerfully provided excellent editing on a very compressed schedule.

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1. The Acquisition Landscape and Performance Measures

Our acquisition system—its institutions, offices, laboratories, workforce, managers, executives, and industrial partners—conducts research, provides a wide range of services, develops and produces new goods and weapon systems, and sustains these capabilities for warfighters and other operators. The performance of that system is measured relative to its outputs and outcomes of interest. Identifying internal policies, processes, workforce, and management capabilities that bear positively or negatively on those measures requires data and analysis to avoid speculative or cyclical policy choices based on current conventional wisdom and untested hypotheses.

The Defense Acquisition System

Institutional performance is all about acquiring value as efficiently (cheaply) as possible. Value to the DoD stems from the immediate benefits (i.e., technical performance) of the goods and services acquired in a responsive time (schedule) compared to the costs to the taxpayer. Hence, measures of cost, schedule, and performance serve as the basis for measuring the effectiveness and efficiency of the acquisition system in converting inputs to outputs (see Figure 1-1). The subsequent operational benefits of the acquired capabilities to address threats and fill capability gaps is more difficult to measure objectively with available data, and we will continue to explore ways to efficiently obtain such data on outcomes.

How Internal Functions and Processes Affect Performance

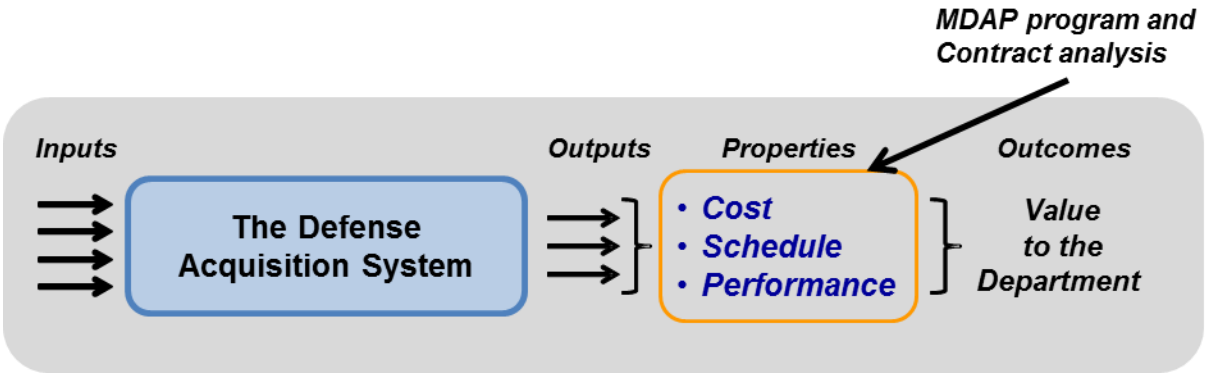
The acquisition system can be measured at two fundamental levels: (1) the major outputs and outcomes of the system, and (2) the key functions, responsible entities, and institutions responsible within the system to achieve those outputs and outcomes. The most readily available and measurable outcomes assessed throughout the report are cost and schedule performance, but some readily available information on technical performance is analyzed also.

Decomposing the acquisition system into major functional responsibilities enables analysis of how elements of the system affect ultimate outcomes. Intermediate outputs and outcomes of key institutional functions may correlate with cost, schedule, and performance outcomes, but others may be too small or difficult to discern from available data. Nevertheless, a functional decomposition facilitates an understanding of how well the defense acquisition system performs, based on management principles and intermediary outputs and outcomes. As this work moves forward, our greatest challenge remains identifying the relationships between and among factors the DoD can affect (policies, contract terms, incentives, workforce capacity and skills, etc.) and the outcomes sought. This report is a continuing step in that process.

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Much of our analysis is statistical, focusing on institutional outcomes and their trends, rather than on single acquisitions and outliers (see Appendix A for a detailed discussion of the statistical methodologies). The objective is to see how well we are doing, learn from these generalities, and change our policies and tradecraft as we seek to improve outcomes. Many of the results continue leveraging readily available data on collections of programs and contracts and examining them from different groupings and perspectives. We continue looking for statistically significant differences on samples large enough to avoid an overgeneralization from case studies.

Figure 1-1. Output Measures for the Defense Acquisition System



PHASES OF ACQUISITION

This report assesses how our institutions perform—primarily by using existing oversight data aggregated to look for broader performance and trends. Because of their size and the risks involved, most readily available data are on MDAPs and their measurable outcomes rather than on smaller programs and the full breadth of contracted services. Still, these data provide partial insights on the acquisition of both goods (i.e., production of the weapon systems themselves) and services (i.e., development and testing of those weapon systems)—albeit primarily on major weapon systems. Also, we have begun to include data and analysis on contracted services where available (notably in the Superior Supplier Incentive Program results).

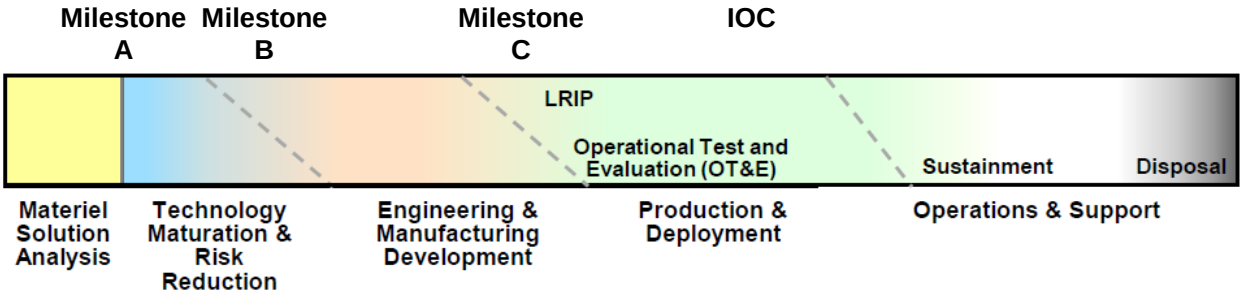
Figure 1-2 depicts a simplified program lifecycle and the portion where we currently have the best data for analysis—namely, for development and production up to full operational capability. Since structures and reviews are tailored to match program specifics in individual cases, this is a notional overview. For example, a program that uses mature technology may not need much technology or engineering development and might jump from the Material Solution Analysis directly to MS C, bypassing MS A and B.

While we have some data that reflect partially on the performance in other phases (e.g., early research, analysis of alternatives, early risk reduction, and sustainment), operation and support

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are reflected at best by early estimates and subsequent updates based on testing results and inflationary changes.

Figure 1-2. Typical Phases of Acquisition Programs



IOC = Initial Operational Capability
NOTE: This figure abstracts key elements from the example program models in the DoD Instruction 5000.02 (USD(AT&L), 2015a).

FOLLOW THE MONEY: ANALYSIS OF SPENDING

The defense acquisition system acquires goods and services to support our military forces—both now and in the future—while fulfilling our responsibility to prudently use taxpayer dollars. The DoD budgets and accounts for expenditures in various ways, each providing useful perspective on the purpose of the largest expenditures.

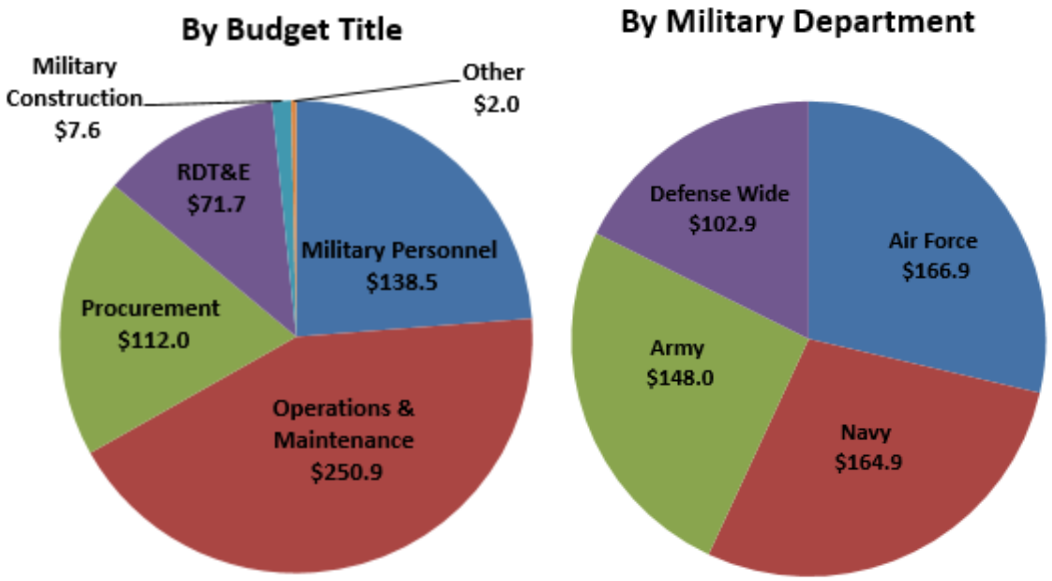
Spending by Comptroller Budget Accounts

Broken down by budget accounts reported by the Under Secretary of Defense (Comptroller) (USD(C)), the President's budget (PB) request for FY 2017 (including funds beyond the base DoD budget for Overseas Contingency Operations [OCO]) asks for (among other things) $112.1 billion for Procurement (including OCO) and $71.8 billion for RDT&E (see Figure 1-3 and USD(C), 2016a). Of this $183.9 billion, 40 percent ($72.7 billion) is for programs designated as MDAPs or MAIS, which provide the bulk of the readily available program data for analysis in this year's report (see USD(C), 2016b). In addition, the PB 2017 also requests $250.9 billion for Operations and Maintenance (O&M) and $ 138.8 billion for Military Personnel. A sizable portion of O&M also is spent on contracts for goods and services; thus, this portion is also part of the defense acquisition system. The OCO total for PB 2017 across these accounts is $58.8 billion (USD(C), 2016a).

Figure 1-4 shows how defense budget accounts have changed over time and compares these to PB 2017. As reported last year, DoD budgets oscillate in a pattern that repeats about every 24 years (plus inflationary changes and noise). The current budget is on the second half of the falling portion of the general pattern. Future budgets, of course, are hard to predict, but these patterns show some structure in recent budgetary ups and downs.

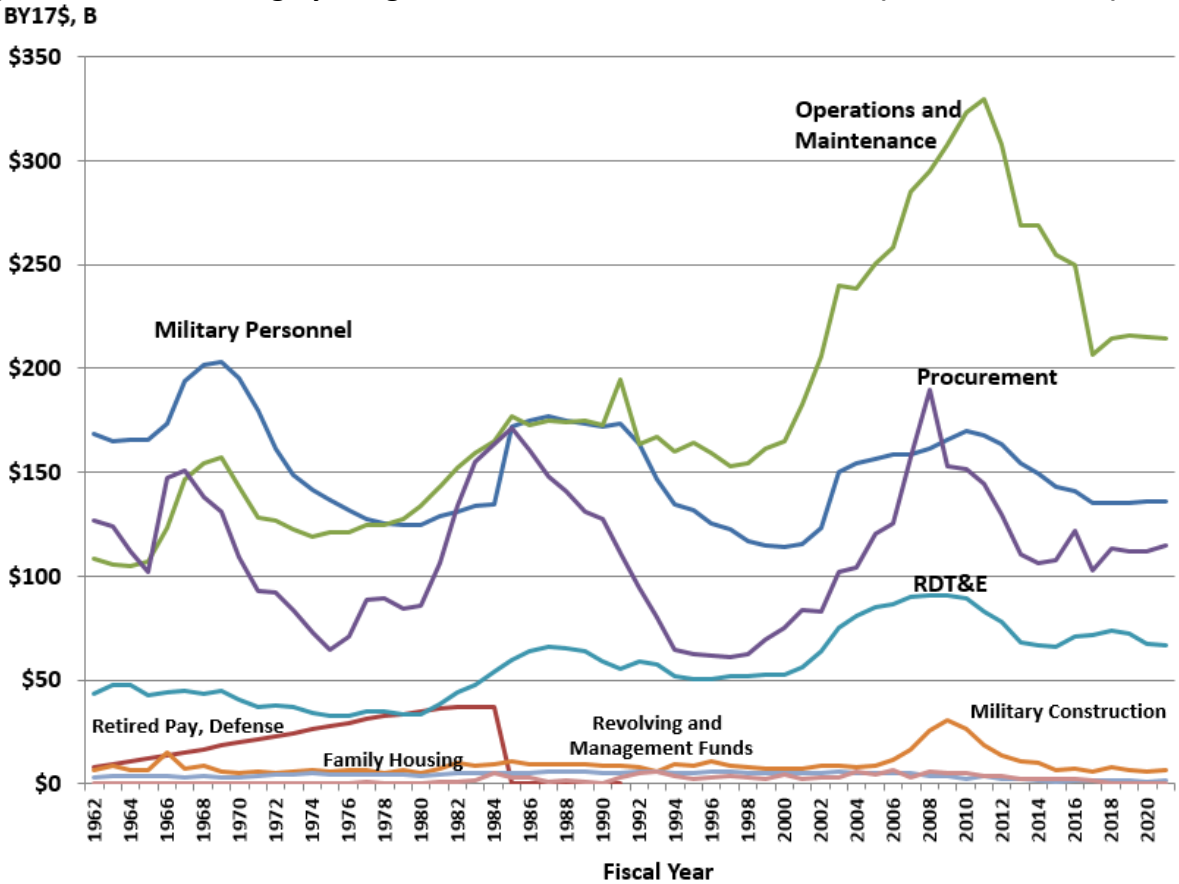
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Figure 1-3. Defense Budget Breakouts PB 2017 (billions of 2017 dollars)



NOTE: OCO dollars are included.

Figure 1-4. DoD Funding by Budget Accounts: Historical and PB 2017 (FY 1962–FY 2021)



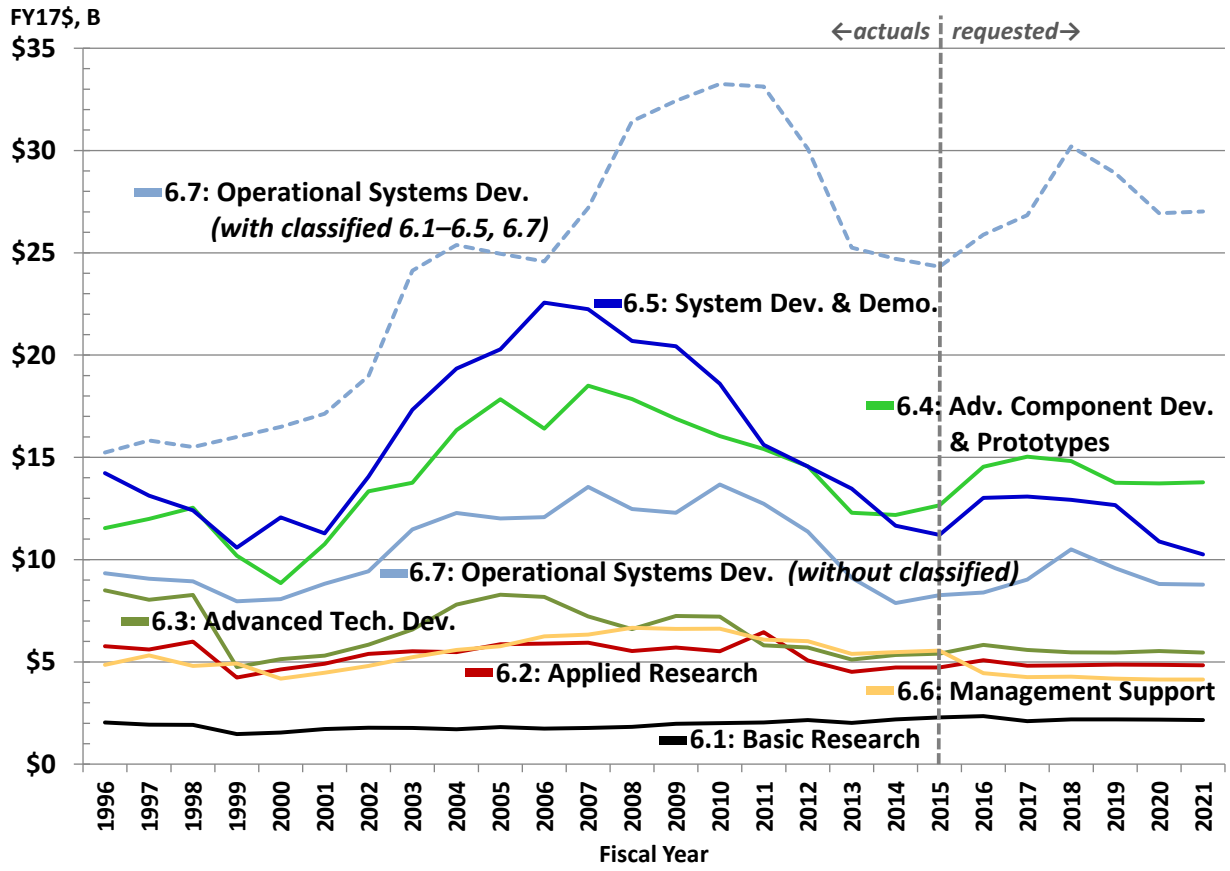
NOTE: OCO is shown in fiscal year actual budgets up through FY 2017. Budget amounts are adjusted for inflation and reported in billions of CY 2017 dollars (CY17$B).

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RDT&E Budgets

Figure 1-5 shows the breakdown of DoD RDT&E funding and budgets by budget activity, going further back than in last year's report. This provides a detailed picture of how these accounts have fared historically—especially during the past budgetary surge and subsequent decline. Here the science and technology BAs (6.1–6.3) are relatively flat or returned to their pre-2001 levels. Accounts for Advanced Component Development and Prototypes (BA 6.4) and Operational Systems Development (BA 6.7, for existing systems) are projected to come down from their peak but remain higher than the levels in the 1990s. The System Development and Demonstration (BA 6.5) budget for new systems in the DoD's product "pipeline" is projected to decline to its lowest level in this time period. While BA 6.4 and 6.7 levels are not coming down as far, the low levels of BA 6.5 funding reinforce the DoD's concerns that we risk losing technological superiority in multiple operational domains.

Figure 1-5. Recent and Projected DoD RDT&E Funding as of PB 2017 (FY 1996–2021)



NOTE: Levels before FY 2016 are actual appropriations as reported in DoD Comptroller R1 exhibits; their totals closely match the RDT&E totals in the Comptroller's Green Book (USD(C), 2016c). OCO is shown in FY budgets up to FY 2017. Budget amounts are adjusted for inflation and reported in billions of FY 2017 dollars (FY17$B). The blue dashed line reflects the published total 6.7 budget, which includes total classified BA 6.1–6.5 and 6.7. The solid line is BA 6.7 minus published totals for classified programs included in BA 6.7 reports (i.e., without the distorting effects of the classified totals).

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Note that further analysis of the content of these accounts reveals that USD(C) reports RDT&E totals for BAs 6.1–6.5 with BA 6.7, causing a distorting effect when comparing the relative magnitude of these RDT&E activities. Figure 1-5 shows BA 6.7 with and without the classified totals, which were not broken out in our prior reports. This provides a more accurate comparison of the relative magnitude of the RDT&E account trends since FY 1995.

Contractual Spending by Product Service Code Portfolios

Almost all of what we acquire comes through contracts with industry. Thus, a different way to understand what the DoD acquires is to examine contract obligations by type rather than budget account.

The contracting community uses a categorization called *product service codes* (PSCs) to track what is procured under Federal contracts.[12] The Federal Procurement Data System—Next Generation (FPDS-NG) records all awards and modifications for every contract worth (or anticipated may become worth) at least $3,000, so this taxonomy affords us a way to quickly look across all DoD external (contracted) spending.

At the top level, spending (obligations in this case) is split between *products* (also referred to as *supplies and equipment*) and *contracted services*.[13] Figure 1-6 shows that in FY 2015, just over half (52 percent) of contract obligations were for contracted services. These data provided some perspective but may be misleading if you do not consider how the data are defined and what they included. For example, while the acquisition community generally considers RDT&E as part of developing a physical system, contract PSCs identify research and development (R&D) as a service (i.e., it is dominated by tasks that do not produce physical end items of supply). Maintenance on weapon systems is also often structured as a contracted service. Also contract obligations often include multiple types of work, but only one PSC is reported per obligation. In addition, the data include OCO, which is spending above the base defense budget and could be affecting the magnitudes and percentage split between contracted products and services.

[12]See the *Product and Service Codes Manual* published by the General Services Administration (2011). PSCs are recorded in the FPDS–NG to categorize what each Federal contract acquires.

[13] The Federal Acquisition Regulation defines a *service contract* as "a contract that directly engages the time and effort of a contractor whose primary purpose is to perform an identifiable task rather than to furnish an end item of supply" (see FAR, Section 37.101). Because the DoD often refers to the military departments (i.e., Army, Navy, and Air Force) as "Services," this report capitalizes "Services" when referring to military departments but uses lower-case "services" when referring to contracted services.

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Figure 1-6. Total DoD Contract Obligations Split Between Goods and Services (FY 2015)

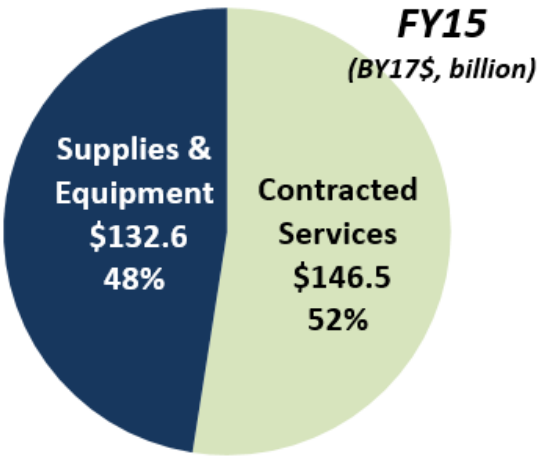
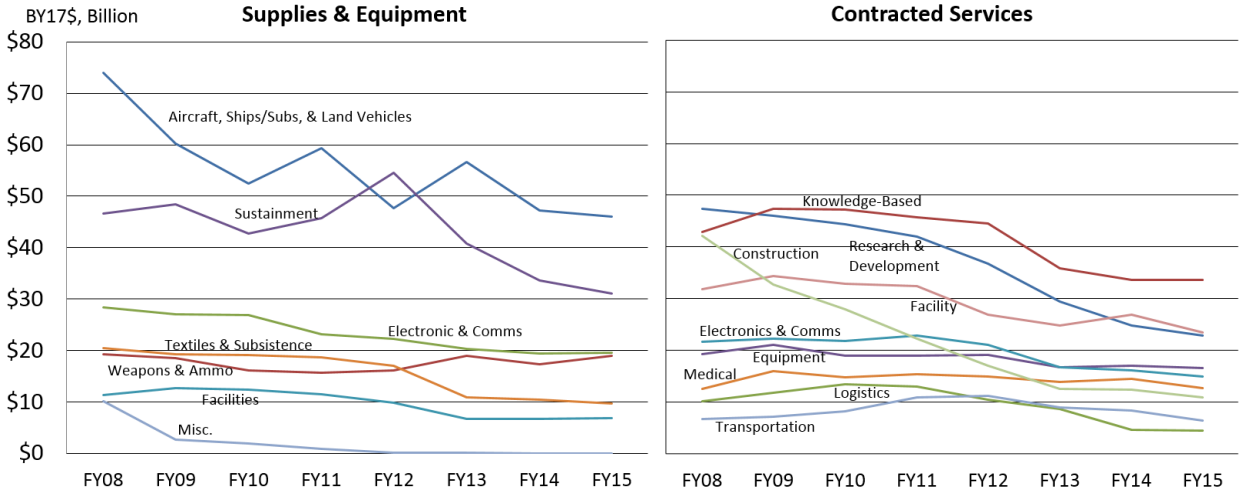


Figure 1-7 shows a further breakdown of all DoD contract obligations by groupings developed to aggregate PSCs into meaningful major portfolios. Here we see some contracting portfolios have remained relatively flat over the years while others are declining with the recent budget cutbacks.

Figure 1-7. Total DoD Contract Obligations by Portfolio Group (FY 2008–FY 2015)



NOTE: FPDS-NG data on all DoD obligations (including OCO). Obligations for contracted services in this period ranged from 57 percent in FY 2010 to 52 percent in FY 2015. All numbers are in billions of adjusted base-year (BY) 2017 dollars.

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On Measuring Performance

Scope of Outcomes: Programs or Their Constituent Contracts

Our analyses often examine two main types of performance data:

- **Program-level data**—describing measurements across the entire program (e.g., growth in planned total funding from MS B baseline as reported in the SARs and MARs, including past actual funding, current funding requests, planned funding in the FYDP, and estimated needed funding beyond the FYDP to the end of the program). Data sources include the SARs, MARs, DOT&E's BLRIP reports, oversight data, the Contractor Performance Assessment Reporting System (CPARS), and review documentation.
- **Contract-level data**—describing measurements on one of the many contracts that constitute a program (e.g., the total cost growth from original negotiated contract target cost for an early lot of units procured). Data sources include Earned Value (EV) Central Repository, FPDS-NG, GAO bid-protest data, and cost data reports.

Program-level measures show how well the acquisition system developed the ability to produce the overall program against original baselines despite quantity changes, while providing insight into whether cost growth may have been a factor in quantity changes.

Contract-level measures provide early indicators of potential program-level issues by examining performance when the DoD contracts for specific work from industry. Nearly all the actual research, development, and production on weapon systems are performed by industry partners through contracts with the DoD. Thus, examining performance at the contract level provides detailed and potentially useful indicators of performance that eventually will be seen at the more aggregate program level.

This report often switches between these types of data as we examine different types of institutions (e.g., DoD-wide or military departments) and different phases of acquisition (e.g., development or early production).

While contracts are the key execution elements of a program (i.e., most goods and even services are provided by contractors), they have different baselines (e.g., contract cost targets) set at different times than the program's MS B baseline. Performance on individual contracts can be measured earlier than their effects might show up in program-level measures. However, because there often are numerous contracts within a program, and program baselines are not equivalent to contract cost targets, an individual contract performance may not necessarily reflect the performance revealed in program-level measurements. *Thus, it is important to recognize what type of data is discussed at each point in the report.*

Also, care must be taken to note whether cost data have been adjusted for inflation. Often the available program-level budget data we used have been adjusted for inflation (i.e., reported in "base-year" [BY] dollars), but some contract-level cost-growth data have not been adjusted (i.e., are reported only in "then-year" [TY] dollars, and insufficient temporal information was

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available for us to adjust the reported figures for inflation). Thus, partly because of inflation, the program-level cost-growth figures in this report may be lower than those for some contract-level analyses.

Avoiding Maturity Bias in Testing for Recent Improvements

A primary reason for systematically measuring our performance is to determine objectively whether we are improving (i.e., whether our efforts are helped by recent policy and processes changes such as WSARA of 2009, three iterations of BBP[14], major efficiency drives, and continued investments in the acquisition workforce training and hiring). By their nature, recent programs and contracts have less cost and schedule growth because they are newer and have not had time to realize any growth. Unfortunately, waiting until they are complete will take many years—sometimes decades. This is but one challenge in comparing performance (other variables in the portfolio include shifting commodity mixes, budgetary changes, multiple parallel policy and process changes, etc.) and is a key analytic concern.

Rather than wait for the completion of programs and contracts before measuring their performance, we take the middle ground of controlling for immature programs in many of our analyses. The cost community generally has found that programs and contracts with large cost or schedule growth will begin seeing and reflecting it in their estimates by the time they have executed about 30 percent of their originally planned schedule. Thus, analyses in this report that control for maturity exclude newer programs and contracts that have not yet reached this point. This, of course, is not the final word, but it does allow us to reflect much of the anticipated performance problems and get a reasonable sense of recent performance.

Additional methods include examining incremental (marginal) growth rather than just total growth since inception. Our program-level analyses, for example, examine biennial change as a way of seeing if growth is added (or removed) on top of original estimates. If recent programs or contracts are worsening, we should be able to see that in the marginal change data.

Measuring Performance on Contracts

Price, schedule, and technical performance are key contract outcomes of interest. Ultimately, the *cost* to the contractor of providing a good or service relates in various ways to the *price* paid by the government. Thus, we often examine cost, price, or both (when possible). In most cases and where noted, contract price and cost data are adjusted for inflation. This allows us to distinguish real price and cost growth performance independent of inflationary effects. As for technical performance data, they are reported to the program office and are not generally available in the Office of the Secretary of Defense (OSD) for analysis.

[14] See USD(AT&L), 2010, 2013a, and 2015d.

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Analysis of Work Content Growth and Cost-Over-Target

In other datasets, we do not have profit or fee data but can break down total cost growth into two broad elements of *work-content growth* and *cost-over-target*. Work-content growth is simply the change in the contract budget base (CBB), which reflects the contract target cost since contract initiation. Cost-over-target is the latest PM estimate at completion (EAC) minus the latest CBB, all divided by the original CBB. Unless otherwise indicated, all these contract cost data are reported in TY dollars and are thus *not* adjusted for inflation.

Note that contract targets themselves are not pure, unbiased estimates of project cost. In addition to expected project scale (size) they also reflect other contract terms, such as the share lines, incentive terms, as well as market contestability and the general negotiating environment. Thus, in part they are the result of bidding strategies.

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2. Acquisition System Outcomes and Trends

A key to improving acquisition is learning from our successes and failures. Without looking at results of past actions, we have no feedback to inform whether our hypotheses and beliefs pan out in the complicated world of defense acquisition. Objectively examining the relative effectiveness of DoD acquisition Components and institutions while attempting to distinguish which factors and variables affect outcomes not only allows us to identify successes and failures, but also begins to lead us to specific lessons we can try to replicate—and control points we can exploit.

The following analyses examine key outcomes of cost, schedule, and technical performance of MDAPs across the DoD and by Components, commodities, and prime contractors—measured at program and contract levels. Combined, these analyses provide insight into potential cause-and-effect relationships, focusing attention on problems as early as possible, clarifying misunderstandings, and informing assessments and learning.

For our analyses of program data, note that the MDAPs examined are in varying states of maturity—from early programs that may or may not develop future problems, to mature programs adding new capabilities to existing systems, to completed programs.

We often use readily available EV data for our analyses of major MDAP contracts. This includes the six largest contracts per MDAP (prime, associated, or for government-furnished equipment) valued at over $40 million (TY dollars) but usually not firm-fixed-price contracts—see Title 10 of United States Code (U.S.C.) Section 2432. This also may include other EV-reporting contracts for MDAPs. These contracts may be for development or production. Unless noted, all datasets consist of all readily available cases rather than a statistical sampling from a larger set. In some analyses when we are trying to ascertain the general tendency of the population, we remove statistical outliers using standard tests; and these instances are noted. Otherwise, we include all data, including outliers. Also, we often report medians because this is a better measure of central tendency or “average” for skewed distributions than arithmetic means, which exaggerate the effect of outliers.[15]

[15]Part of the skewing in the distribution of cost change is the mathematical boundary of cost change because cost cannot decrease more than 100 percent, but it can increase more than 100 percent.

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COST-RELATED FUNDING GROWTH AND DEFENSE ACQUISITION EXECUTIVES

Policy and execution decisions by DoD executives should bear (in part) on the effectiveness of the overall acquisition system during their tenures. This is particularly true for the program structure and associated baselines set at MS B, against which future cost performance is measured. Such decisions include changes to the defense acquisition system policies and procedures (e.g., through changes in departmental regulations); approvals, certifications, and exemptions within that system; institutional organization, policies, and processes; incentives; personnel selection, training, and mentoring; guidance and execution on larger programs, including acquisition strategies and choices; and myriad other effects. More specifically, the acquisition executives chair the boards that review programs at major milestones, guiding both program directions and specific approaches to contracting. Therefore, in our annual reports we track the performance of programs started under different acquisition executives to help reinforce accountability and provide an initial look for possible trends for further analysis.

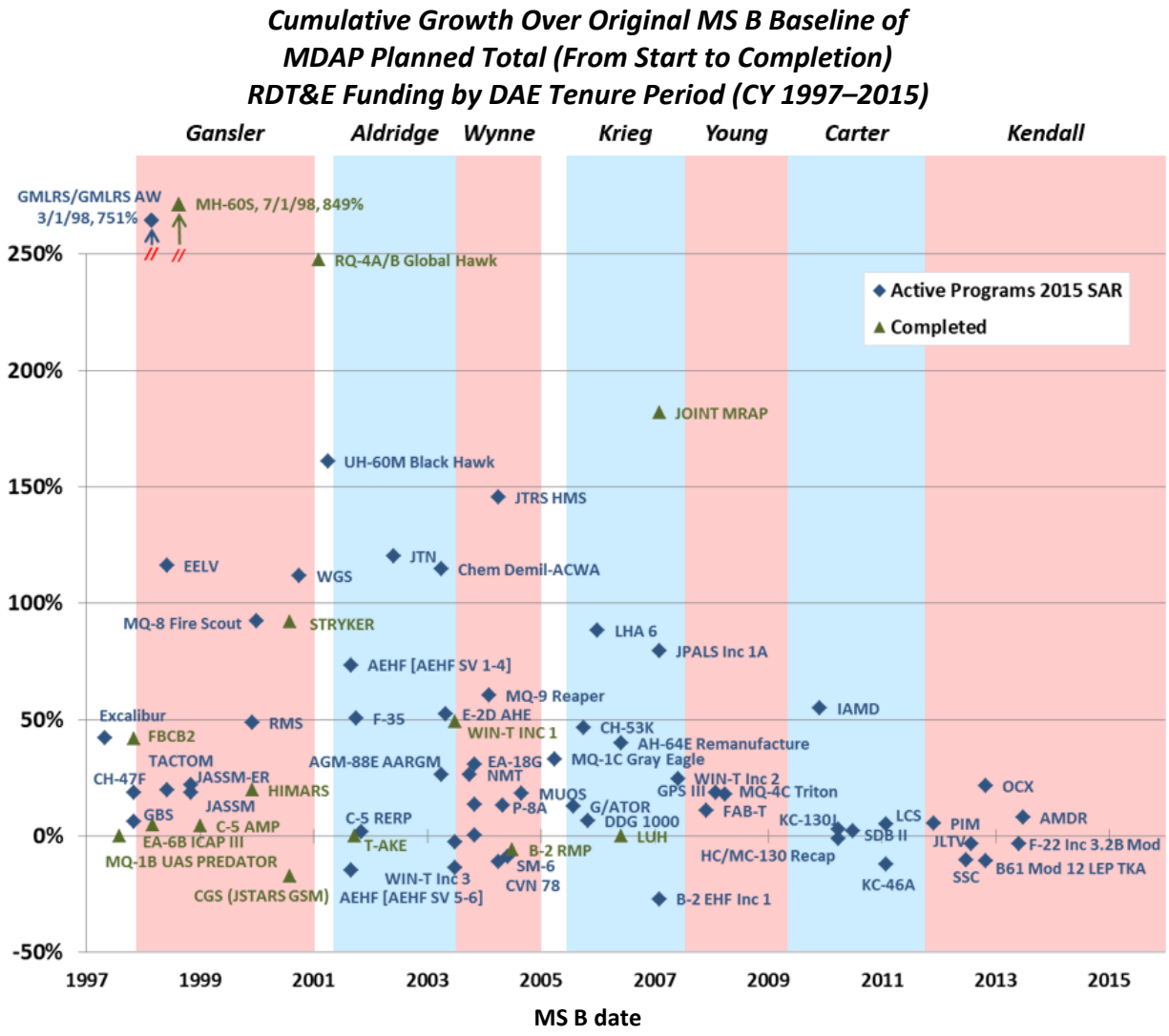
Figure 2-1 and Figure 2-2 show growth in planned total funding against original baselines for development and procurement as reported to Congress in the SARs on active and completed MDAPs. Note that SAR funding data reflect what the PM currently estimates will be needed in total by the end of the program for the current program configuration, including past actual funding, the current budget request, planned funding in the FYDP, and planned funding beyond the FYDP to the end of the program. Growth is measured against the baseline set at the original MS B and can be positive or negative.

These figures also show the DAE at the time of the MDAP's MS B approval; this infers influence through the DAE's policies and could include direct influence if the DAE was the MDA for the program. Later in the report we show similar charts for the programs started under different SAEs in the three military departments. We use total needed program funding instead of contract cost growth for these charts since needed funding is measured directly against the MS B baseline set by the DAE (see the discussion starting on p. 66).

Caution is warranted, however. These charts neither reflect the effectiveness of subsequent oversight or major program changes by later DAEs during execution oversight, nor do they report statistical analysis that controls for other internal and external variables that could have led to program success or problems. Also, as we mention above, each measure has its strengths and weaknesses, so attributing performance to a single measure is subject to the limitations of that measure. For example, some programs may appear to be performing well in terms of total needed RDT&E funding but may be having problems reflected in other measures (e.g., total needed procurement funding, estimated operational costs, and cost growth on one of the program's major contracts). Thus, a combined examination of available data is important before reaching conclusions.

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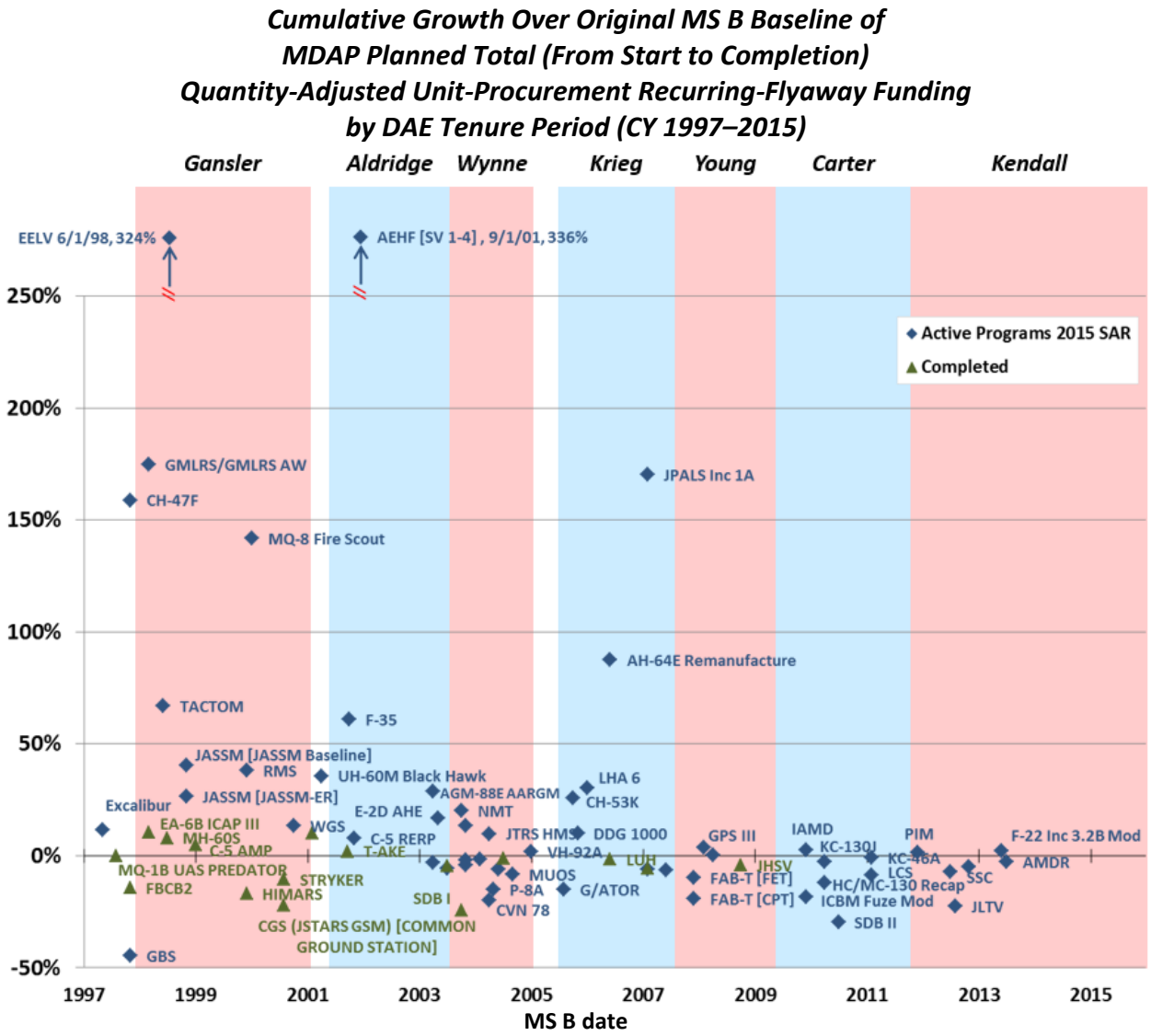
Figure 2-1. Program Cost-Related Development Performance Baselined in DAE Periods



NOTE: This shows total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. These are percentage changes after adjusting for inflation from original MS B baseline of actual past and estimated future funding as reported in each program's latest SAR. Total RDT&E is an insightful measure because it is necessary regardless of quantity. White bars between DAE shaded regions represent periods with no confirmed executive. Not shown are relatively new programs that have not spent at least 30 percent of their original EMD schedule. Program abbreviations are defined in Appendix F starting on p. 159.

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Figure 2-2. Program Cost-Related Procurement Performance Baselined in DAE Periods



NOTE: This shows growth in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. White bars between DAE shaded regions represent periods with no confirmed executive. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. Program abbreviations are defined in Appendix F starting on p. 159.

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OPERATIONAL PERFORMANCE OF ACQUIRED SYSTEMS

While most of this report discusses outcome measures of cost and schedule, this section summarizes some readily available independent assessments of operational performance of weapon systems.

Operational Testing Results

Definitions

One measure of technical performance of acquired systems is how they rate, as a group, in operational effectiveness and suitability as assessed by DOT&E.[16] Operational *effectiveness* is defined in the *Joint Capabilities Integration and Development System (JCIDS) Manual* (CJCS, 2015) as: "Measure of the overall ability of a system to accomplish a mission when used by representative personnel in the environment planned or expected for operational employment of the system considering organization, doctrine, tactics, supportability, survivability, vulnerability, and threat." Operational *suitability* is a composite evaluation that considers a system's safety, interoperability, availability, maintainability, and reliability. Operational effectiveness and suitability are not measured solely on the basis of system requirements (e.g., Key Performance Parameters [KPPs] and Key System Attributes [KSAs]). Rather, measurements are accomplished through an evaluation that includes the system under test and all interrelated systems (including weapons, sensors, command and control, and platforms) needed to accomplish a combat mission in expected environments.

Reliability is a measure of the probability that the system will perform without failure over a specific interval, under specified conditions. *Materiel availability* is the measure of the percentage of the total inventory of a system operationally capable, based on materiel condition, of performing an assigned mission. *Operational availability* is the measure of the percentage of time that a system or group of systems within a unit are operationally capable of performing an assigned mission and can be expressed as *uptime*/(*uptime* + *downtime*). *Maintainability* is the ability of the system to be brought back to a state of normal function or utility. Maintainability is normally expressed as Mean-Down-Time, Mean-Time-to-Repair or a calculation of ease of maintainability. *Supportability* is the ability of the system to identify and/or predict failures down to a certain subsystem level within a given percentage of accuracy. *Survivability* is intended to ensure the system maintains its critical capabilities under applicable threat environments and may include reducing a system's likelihood of being engaged by hostile fire, through attributes such as speed, maneuverability, detectability, and

[16] DOT&E is independent statutorily from the acquisition organizations and is responsible for, among other things, reporting the operational test results for all MDAPs to the Secretary of Defense, USD(AT&L), Service Secretaries, and Congress. Operational test and evaluation is "the field test, under realistic combat conditions, of any item of (or key component of) weapons, equipment, or munitions for the purpose of determining the effectiveness and suitability of the weapons, equipment, or munitions for use in combat by typical military users; and the evaluation of the results of such test" (10 U.S.C., Section 139(a)(2)(A)).

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countermeasures; reducing the system's vulnerability if hit by hostile fire, through attributes such as armor and redundancy of critical components; enabling operation in degraded electromagnetic, space, or cyber environments; and allowing the system to survive and continue to operate in, or after exposure to, a Chemical, Biological, Radiological, or Nuclear (CBRN) environment, if required (CJCS, 2015).

We also discuss below the conditional probability of being effectiveness given test results for test adequacy, survivability, and lethality. The performance levels for these metrics are defined in each system's requirements documents.[17]

Developmental testing occurs throughout the earlier phases of a program's acquisition. It is intended to provide feedback to designers to verify performance and to discover and correct issues so that, by the time of operational testing on production representative test articles, major performance issues should be rarely discovered.

Note that in some cases results were not determined by DOT&E and thus were excluded from our data plots. In addition to new program evaluations, the number of programs in each sample also varies from last year because we now restrict our plots to DOT&E BLRIP summary data to improve consistency.

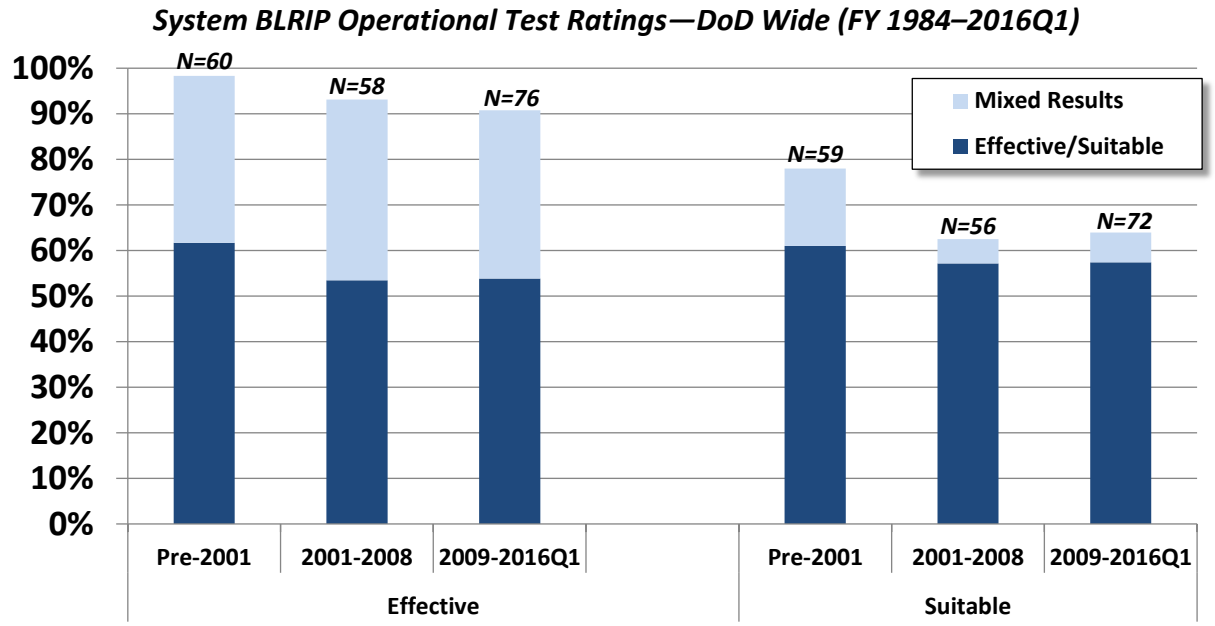
Trends in Operational Testing of Effectiveness and Suitability

The following figure shows no statistically significant trends (up or down) in DOT&E's assessments of operational performance of weapon systems across the DoD. Given the relative infrequency in which programs come up for operational testing, we grouped ratings into three sets of periods: FY 1984–2001, FY 2001–2008, and FY 2009 through the first quarter of FY 2016. Generally, it appears that performance dropped somewhat since FY 2001 compared to prior years (e.g., in the number of systems rated fully effective and the number of partially suitable systems). This perceived drop may be due in part to an overall trend of more complex, multi-mission systems. These changes nevertheless are not statistically significant. In other words, statistically the DoD's newly acquired systems perform in operational tests about as well as they always have through FY 1984 to present. In our ability to acquire quality systems, there is no degradation (or improvement) dramatic enough to be measurable statistically considering the relatively few programs in question.

[17] These are defined as follows. The *DoD Test and Evaluation Management Guide* defines *test adequacy* as having the amount of data and realism of test conditions sufficient to support the evaluation of the critical operational issues (COIs). 10 U.S.C. Section 2366(e)(3) defines realistic *survivability testing* as "…testing for vulnerability of the system in combat by firing munitions likely to be encountered in combat (or munitions with a capability similar to such munitions) at the system configured for combat, with the primary emphasis on testing vulnerability with respect to potential user casualties and taking into equal consideration the susceptibility to attack and combat performance of the system." 10 U.S.C. Section 2366(e)(4) defines realistic *lethality testing* in the case of a major munitions program or a missile program (or a covered product improvement program for such a program), as "…testing for lethality by firing the munition or missile concerned at appropriate targets configured for combat."

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Figure 2-3. System Operational Test Performance



Source: DOT&E BLRIP reports.
NOTE: Differences are not statistically significant due to the low sample sizes (infrequent evaluations). Sample sizes differ between Effective and Suitable for some DoD Components because effectiveness and suitability could not be determined in all cases.

Causes. DOT&E also identifies why some programs are not rated as fully suitable due to a failure to meet the required reliability threshold (see Table 2-1). The categories and unclassified number of occurrences remain too small for a meaningful breakout by DoD Component, but the table gives some sense of the more dominant causes cited to date. The three high-frequency causes (i.e., inadequate design margins, system management, and software faults) are special-interest items for further analysis in next year's annual report and for systemic correction.

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Table 2-1. Causes of Failure to Meet Required Reliability Threshold in Operational Testing (FY 1984–2016Q1)

Cause	System Count	Description
Part Quality (random failures)	2	Part failing to perform its intended function before its expected "end-of-life" limit is reached (random failures)
Inadequate Design Margins	23	Failures from engineering requirements, inadequate design (e.g., tolerance stack-up), unanticipated logic conditions (sneak paths), inadequate design margins for the environment, etc.
Manufacturing Anomalies	1	Failures not related to inherent part reliability but which result from anomalies in the manufacturing process
System Management	27	*Requirements management*: - incorrect or insufficient implementation or interpretation of requirements, processes or procedures; - imposition of "bad" requirements (e.g., missing, inadequate, ambiguous or conflicting); OR *Interface and environment management*: - failure to provide the resources required to design and build a robust system
Wear out	0	Wear-out-related failure mechanisms due to basic device physics
No defect	0	Reported failures that cannot be reproduced upon further testing. These may or may not be an actual failure; however, they are removals and, therefore, count toward the logistic failure rate
Induced Human Factors	3	Resulting from an externally applied stress. Examples are electrical overstress and maintenance-induced failures (i.e., dropping, bending pins, human factors, etc.). Can be design engineering requirements and design related.
Software Faults	16	Failures of a system to perform its intended function due to a software fault caused by inadequate engineering requirements or design.

Source: DOT&E BLRIP reports.
NOTE: These are unclassified results so far but do not include determinations for all programs since 1984. Not all types of causes in each category are exhibited by the programs.

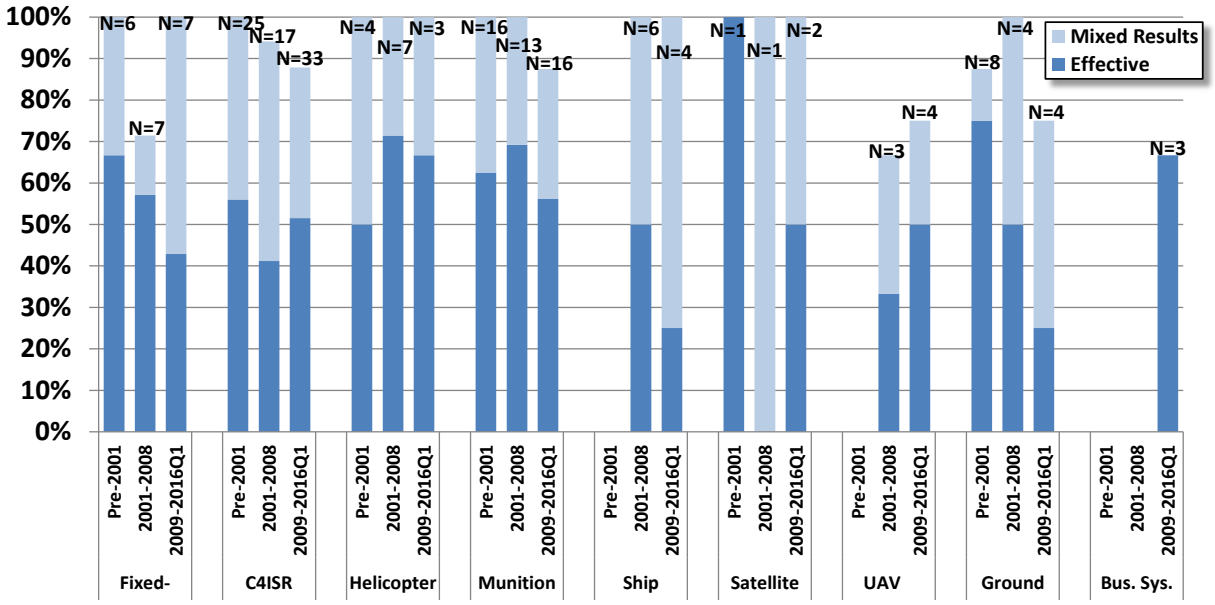
Operational Testing of Effectiveness and Suitability by Commodity

The following figures show DOT&E's assessments of operational test performance of weapon systems by commodity types. Figure 2-4 and Figure 2-5 show effectiveness and suitability ratings, respectively, for BLRIP operational tests by commodity type. This year we split out Business Systems from the Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) category (where it was reported in our prior annual reports). While there are some differences, they are not statistically significant given the small sample sizes.

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Figure 2-4. System Operational Test Performance: Effectiveness by Commodity

Weapon and Information System BLRIP Operational Effectiveness Ratings by Commodity (FY 1984–2016Q1)

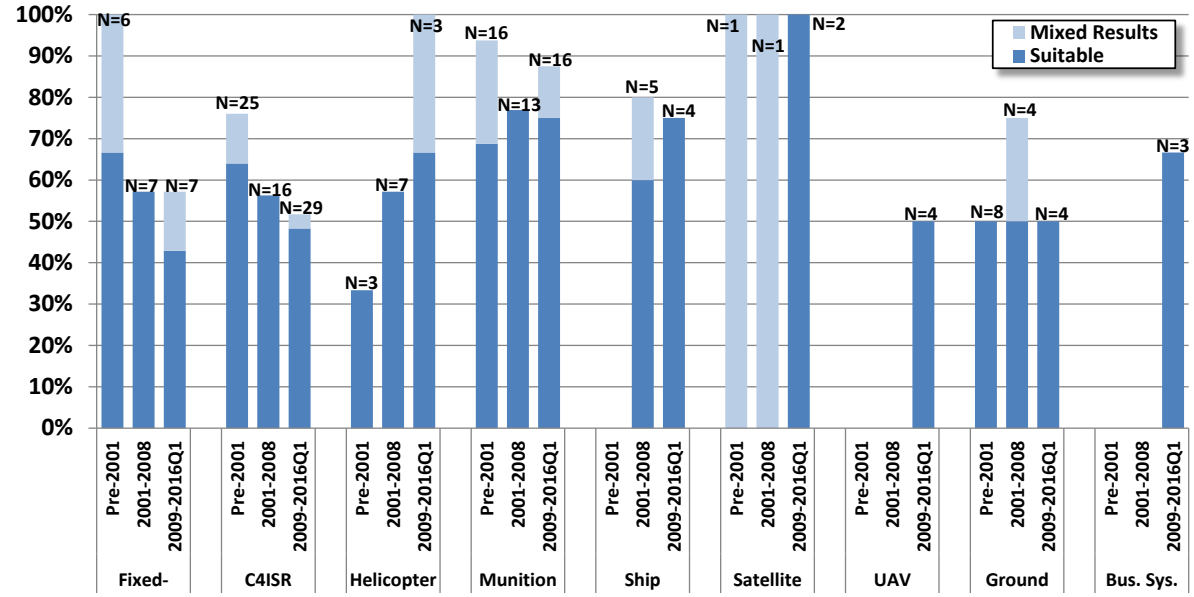


Source: DOT&E BLRIP reports.

NOTE: Differences are only apparent and not statistically significant. Sample sizes differ between Effective and Suitable for some DoD Components because effectiveness and suitability could not be determined in all cases.

Figure 2-5. System Operational Test Performance: Suitability by Commodity

Weapon and Information System BLRIP Operational Suitability Ratings by Commodity (FY 1984–2016Q1)



Source: DOT&E BLRIP reports.

NOTE: Differences are only apparent and not statistically significant. Sample sizes differ between Effective and Suitable for some DoD Components because effectiveness and suitability could not be determined in all cases.

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Correlations Between Summary Test Ratings

This year we included the following statistics on the correlation between suitability and effectiveness as well as the relationship between these high-level measures and their lower-level measures (e.g. suitability and its lower-level elements of reliability, availability, and maintainability).

Table 2-2 shows whether programs that tested effective also tended to be suitable (and vice versa). Here we see that a program was fairly likely to test as *effective* if it tested as *suitable*, but the converse was not true (i.e., we had a number of effective systems that had problems with safety, interoperability, availability, maintainability, and reliability. However, systems that address these suitability issues also tended to be effective against threats). Ninety-four percent of suitable programs (and 100 percent of partially suitable programs) tested at least partially effective. Only about one-seventh of not-suitable programs were not rated as effective. Conversely, only about two-thirds of effective or partially effective programs were rated as at least partially suitable, and about four-sevenths of not-effective programs were rated as having "not suitable" results.

Table 2-2. Correlation Between System Effectiveness and Suitability During Initial Operational Tests (FY 1997–2016Q1)

Counts:

	Suitable	Partially Suitable	Not Suitable	Not determined
Effective	64	7	30	5
Partially effective	39	11	21	3
Not effective	6	—	8	—
Not determined	1	—	—	1

Observed Conditional Probabilities:

Probability that:	***Given that the system is found to be:***			
	Suitable	**Partially Suitable**	**Not Suitable**	**Not determined**
Effective	58%	39%	51%	56%
Partially effective	35%	61%	36%	33%
Not effective	5%	—	14%	—
Not determined	1%	—	—	11%
	Effective	**Partially Effective**	**Not Effective**	**Not determined**
Suitable	60%	53%	43%	50%
Partially suitable	7%	15%	—	—
Not suitable	28%	28%	57%	—
Not determined	5%	4%	—	50%

NOTE: When columns in a category do not sum to 100%, there are small round off differences in the values of the observed conditional probabilities.

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Correlations Between Summary Test Ratings and Subordinate Abilities

Next, we examined how predominant certain subordinate abilities are for the summary test ratings of effectiveness and suitability.

Table 2-3 shows the observed conditional probability estimates that a system was found to be operationally effective against tested threats given the adequacy of the test plan itself in operational test and evaluation (OT&E) and live-fire test and evaluation (LFT&E) as well as the system's survivable and lethal ratings in LFT&E.[18] Similarly, Table 2-4 shows the observed conditional probabilities that a system was rated as suitable given its reliability, availability or maintainability test results. As shown in Table 2-3, it is less clear how effectiveness ratings are affected by a test's adequacy and the system's survivability ratings during testing, but lethality ratings have a strong influence on effectiveness (e.g., no systems were rated as effective if they did not have at least partially adequate lethality). However, the results in Table 2-4 clearly show a strong correlation between suitability and the lower-level test results for reliability, availability and maintainability.

Table 2-3. Observed Operational Test Effectiveness Conditional Probabilities (FY 1997–2016Q1)

Observed probability that:	*Given that the system is found to be:*			
	Test adequacy in OT&E	**Partially adequate test in OT&E**	**Test not adequate in OT&E**	**Not assessed in OT&E**
Effective	60%	26%	—	—
Partially effective	33%	65%	—	—
Not effective	7%	7%	—	—
Not determined	0%	3.2%	—	100%
	Survivable in LFT&E	**Partially survivable in LFT&E**	**Not survivable in LFT&E**	**Not assessed in LFT&E**
Effective	72%	10%	23%	55%
Partially effective	23%*	90%	46%	38%
Not effective	5%*	—	31%	6%
Not determined	—	—	—	2%
	Lethal in LFT&E	**Partially lethal in LFT&E**	**Not lethal in LFT&E**	**Not assessed in LFT&E**
Effective	83%	60%	—	51%
Partially effective	17%	40%	100%	40%
Not effective	—	—	—	8%
Not determined	—	—	—	1%

* There are 6 systems that failed cyber security testing that are included in these numbers. DOT&E is currently revising how it tracks cyber security testing.

NOTE: When columns in a category do not sum to 100%, there are small round off differences in the values of the conditional probabilities.

[18] Generally, inadequate test plans are not approved, and if during the test something was not executable, the system performance for the requirement is not reported.

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Table 2-4. Observed Operational Test Suitability Conditional Probabilities (FY 1997–2016Q1)

Observed	*Given that the system is found to be:*			
Probability that:	**Reliable**	**Partially Reliable**	**Not Reliable**	**Not Assessed**
Suitable	91%	62%	9%	25%
Partially suitable	5%	38%	10%	8%
Not suitable	4%	—	78%	8%
Not determined	—	—	3%	58%
	Available	**Partially Available**	**Not Available**	**Not Assessed**
Suitable	81%	20%	17%	42%
Partially suitable	7%	60%	3%	12%
Not suitable	12%	20%	78%	32%
Not determined	—	—	3%	14%
	Maintainable	**Partially Maintainable**	**Not Maintainable**	**Not Assessed**
Suitable	74%	60%	22%	41%
Partially suitable	9%	20%	5%	12%
Not suitable	16%	20%	73%	27%
Not determined	1%	—	—	20%
	Reliable, Available, and Maintainable	**Reliable and Available**	**Reliable and Maintainable**	**Available and Maintainable**
Suitable	92%	92%	91%	84%

NOTE: When columns in a category do not sum to 100%, there are small round off differences in the values of the conditional probabilities. The "Not Assessed" ratings are those cases where there was no suitability judgement made due to a lack of sufficient data to measure the requirements value.

COST PERFORMANCE: OVERALL

Nunn-McCurdy Program Breaches

Each MDAP is required by law to submit a SAR to Congress 45 days after the annual PB submission and under various other circumstances (see 10 U.S.C., Section 2432). A SAR reflects what is included in the PB as well as a comprehensive summary of MDAP cost, schedule, and technical performance (requirements) measures. Historical SAR data serve as the primary sources for much of our program-level analysis due to their relative availability and comprehensiveness.

Common program cost measures[19] such as PAUC[20], which includes both RDT&E and procurement, and Average Procurement Unit Cost[21] (APUC), which includes only procurement, are codified in statute. The statute also requires that programs exceeding certain thresholds (measured by PAUC or APUC changes relative to their original and current program baselines)

[19] Here, "cost" is synonymous with the total amount of funding because it reflects the prices paid on contracts as well as program execution costs. Later, when we discuss contracts, we will distinguish contract prices from their underlying contractor costs and margins (profits and fees).

[20] 10 U.S.C., Section 2432(a)(1), defines PAUC as "the amount equal to (A) the total cost for development and procurement of, and system-specific military construction for, the acquisition program, divided by (B) the number of fully configured end items to be produced for the acquisition program."

[21] 10 U.S.C., Section 2432(a)(2), defines procurement unit cost as "the amount equal to (A) the total of all funds programmed to be available for obligation for procurement for the program, divided by (B) the number of fully configured end items to be procured."

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must go through a rigorous reexamination and certification to Congress along a variety of specified criteria. This process commonly is referred to as the "Nunn-McCurdy" process, named for the original sponsors of the legislation dating back to 1982 (see Schwartz, 2010, for an extensive overview of the process).

Two types of breaches are called out in the Nunn-McCurdy process: *significant* and *critical*. A significant breach is the lower threshold and is intended to warn Congress that a program is experiencing significant unit-cost growth relative to its baseline. A critical breach signifies the cost growth is even higher, triggering the formal reexamination and certification process mentioned above. The criteria for a significant breach are 15 percent from the current baseline, or 30 percent cost growth in APUC or PAUC from the original baseline. A critical breach occurs when the program experiences 25 percent cost growth from the current baseline, or 50 percent cost growth from the original baseline.

As with last year's report, we continue to report Nunn-McCurdy statistics based on our official list of breaches from 1997 through June 2016 (see Table 2-5). Recall that the numbers of breaches per year are slightly different than in our 2013 and 2014 reports.[22] It is important to note that the NDAA for FY 2006 made changes to the Nunn-McCurdy statute by adding the requirement to report unit-cost growth from the original baseline in addition to the current baseline. This additional requirement caused a large spike in 2005 when 11 programs had to report preexisting significant breaches. Thus, for historical comparisons, we need to compare current performance against those since 2006 because 2005 is a boundary condition and the years before 2005 were operating under different statutory rules.

Figure 2-6 shows the critical Nunn-McCurdy yearly breach rates and counts. The statistically significant downward trends since 2009 of non-quantity-related critical breaches (shown) and for all critical breaches continued through the second quarter of CY 2016, inclusive. For the trend analysis, we used the breach rates instead of counts to control for changes in portfolio size between years. We also controlled for program maturity and the recency of past breaches. Immature MDAPs that had not yet executed 30 percent of their originally scheduled time between MS B and MS C were removed from the dataset since they would likely bias the breach numbers so they would be artificially low. Also, any MDAPs that had a critical breach within the past 3 years were removed from the denominator of this measure since they are immature relative to their new baselines, and we have yet to see a program breach a second time before this period. Thus, these adjustments provide a more conservative (harder) test and higher percentages by removing the bias from programs that are naturally less likely to breach by nature of their newness.

[22] Our prior reports used quarterly SARs, whose dates may not align with the exact breach reporting dates to Congress. We also used to report breaches by SAR years, which do not align completely with calendar years because SARs can include information from the beginning of the next calendar year. In addition, canceled programs may not have a final SAR, and programs stop reporting at 90 percent of cost expended or quantity delivered.

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Table 2-5. Official DoD List of Nunn-McCurdy Breaches (SAR Years 1997–2016Q2)

Year	Critical	Significant[#]
1997		• Chem Demil-Legacy/NSCMP
1998		• FMTV • Javelin • Longbow Apache
1999	• ATIRCM/CMWS • B-1B CMUP	• NAVSTAR GPS/ Satellite
2000		
2001	• CH-47F • Chem Demil-CMA/CSD • F-22 • GMLRS • H-1 Upgrades (4BW/4BN) • LPD 17 • Navy Area TBMD[a] • SBIRS High	• B-1B CMUP • MH-60R • V-22
2002	• ATACMS-BAT/BAT P3I[b]	• Comanche • SSN 774
2003	• EELV	• F-35
2004	• Chem Demil-CMA • Chem Demil-CMA Newport	• AEHF • RQ-4A/B UAS Global Hawk • SBIRS High
2005*	• NPOESS • RQ-4A/B UAS Global Hawk • SBIRS High	• ATIRMC/CMWS* • C-130 AMP* • Chem Demil-CMA* • Chem Demil-CMA Newport* • EFV* • F/A-18E/F* • F-35* • JASSM* • JPATS* • MH-60S* • SSN 774* • ASDS[b] • GMLRS
2006	• C-130 AMP • Chem Demil-ACWA • EFV • GMLRS • JASSM • JPATS • Land Warrior[b] • WIN-T	• FBCB2
2007	• C-5 RERP	• AEHF • ARH • JAVELIN • JTRS GMR
2008	• AEHF • ARH[a] • VH-71[a,d]	• H-1 Upgrades (4BW/4BN)
2009	• Apache Block III (AB3) • ATIRCM/CMWS • DDG 1000 • E-2D AHE • F-35 • RMS • WGS	• C-130 AMP
2010	• Chem Demil-ACWA • EFV[b] • Excalibur • RQ-4A/B UAS Global Hawk	• C-27J • Inc1 E-IBCT[b] • JLENS • NPOESS
2011	• AIM-9X Block I[b] • C-130 AMP[b] • JLENS[c] • JTRS	
2012	• EELV	
2013	• JPALS Inc 1A • VTUAV	• AWACS Block 40/45 Upgrade • JTRS HMS
2014	• JSOW[b]	• WIN-T (Inc 2)
2015	• RMS[b]	
2016Q2	• OCX	

Programs that declared a significant breach and subsequently a critical breach in the same SAR year are listed only as critical breaches. Programs that declared multiple significant breaches in the same SAR year are listed only once.

* Programs in purple shading (2006–2015 for critical; 2005–2015 for significant) breached against the original baseline as per the FY 2006 NDAA. Programs in blue shading (1997–2005 for critical; 1997–2004 for significant) breached according to prior criteria that allowed rebaselining. Eleven programs that did not have a breach prior to the new FY 2006 criteria had significant breaches as a result of this legislative change. The FY 2006 NDAA also permitted the following 25 programs to revise their original baselines to equal their current baseline estimates as of January 6, 2006, without declaring a critical breach: AEHF; AMRAAM; ASDS; Black Hawk Upgrade; Bradley Upgrade; C-17A; CH-47F; EELV; F-22A; FCS; FMTV; Global Hawk; GMLRS; Javelin; JSOW; H-1 Upgrades; Longbow Apache; LPD-17; MH-60R; Minuteman III Guidance Replacement Program; NPOESS; SBIRS High; T-45TS; Trident II Missile; V-22.

a Following a declared breach, the program was terminated rather than certified.

b Breach resulted from a decision to terminate the program.

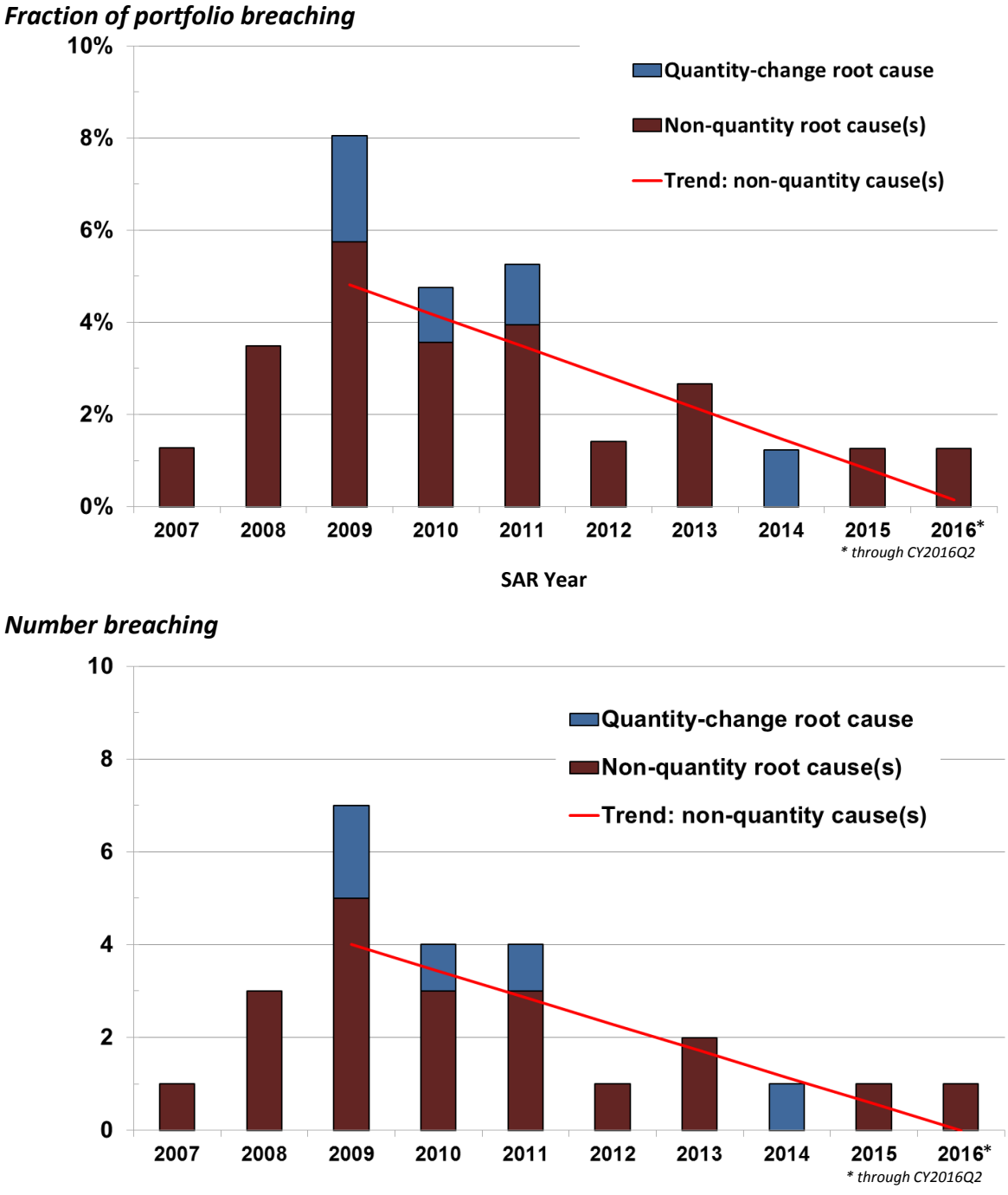
c Breach resulted from a decision to terminate procurement phase; EMD units were completed.

d The DoD did not submit a December 2008 SAR to Congress due to a change in administration. The VH-71 breach was reported in the March 2009 SAR, but the breach occurred in the 2008 reporting period.

NOTE: Program abbreviations are defined in Appendix F starting on p. 159.

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Figure 2-6. Critical Nunn-McCurdy MDAP Breaches (SAR Years 2007–2016Q2)



NOTE: Breaches due to quantity changes are based on PARCA root-cause analysis or review of information from the program's DoD Component. JSOW has been recategorized as quantity related (a change from last year's report). Since PARCA was not established until WSARA of 2009, it is unknown whether quantity changes were a root cause of breaches before 2009. There is a statistically significant downward trend in both total critical breaches and non-quantity-related critical breaches since 2009. Cost breaches are after adjusting for inflation. Since it usually takes a few years before a program might breach again, we removed programs from the portfolio count that have breached recently to avoid the potential bias towards an artificially low breach rate. Also not shown are relatively new programs that have not spent at least 30 percent of their original EMD schedule.

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Causes of Recent Breaches

Here we discuss the causes of recent Nunn-McCurdy breaches. There was one critical breach each year from 2014 through the second quarter 2016 (with one due to quantity changes) and one significant breach in 2014 (see Table 2-6). Note that the 2016 count is tentative since the calendar year is not yet complete.

Table 2-6. Causes of Recent Nunn-McCurdy Breaches (CY 2014–2016Q2)

SAR Year	Causes
2014	**JSOW (*Critical*).** The Navy reported that the critical breach on the JSOW Unitary variant AGM-154C is the result of the termination of procurement at 3,185 units now that more effective weapons are available against current and evolving threats. Original 1992 Acquisition Program Baseline (APB) quantity was 7,800; the current 2009 APB quantity was 7,000 units.
	WIN-T, Increment 2 (*Significant*). The Army reported that this program breached due to cost increases from an 8-year extension of the procurement schedule due to Configuration Steering Board direction to transfer total Army requirements from Increment 3 to Increment 2 in conjunction with a reduction of less expensive nodes attributed to the revised Army modernization strategy. Additionally, there was an increase in costs caused by a 2-year extension of the procurement schedule due to reduced funding in FY 2021–FY 2028 identified by the Army's Long-Range Investment Requirements Analysis.
2015	**RMS (*Critical*).** RMS was canceled in March 2016 (after producing 10 out of 54 planned vehicles) due to unsatisfactory progress on system reliability and availability. Essentially, the government pursued build-to-print production of an immature laboratory prototype and lacked a clear understanding of the end-to-end operational mission thread for employing the vehicles. A combination of factors affected reliability, including obsolescence of underlying design and technology, age-related test vehicle failures, and system complexity. In addition to an earlier decrease in quantity (from dropping RMS from the Navy's anti-submarine warfare mission) and an unrealistic cost estimate for the 2006 APB, the root-cause analysis for the 2009 breach indicated that the program office's failure to deal effectively with the reliability issues was mainly due to an insistence on contracting for the hardware and engineering services based on built-to-print terms where the government accepted responsibility for the RMS design (see earlier details from the director of PARCA [DPARCA], 2010c).
2016 through Q2	**OCX (*Critical*).** This program breached on June 30, 2016, due to three root causes. First, the program was driven by intense schedule pressures from a perceived impending gap in the GPS constellation (which later lessened due to legacy systems lasting longer than anticipated); these pressures led to contract award prior to Milestone B and the program accepting systems engineering shortcuts. Second, both the Government and the prime contractor underestimated the cost to fully implement information-assurance requirements. The Government did not recognize information assurance as a driving factor and therefore did not include it in the risk reduction phase, and the contractor did not understand how the requirements applied to numerous commercial-off-the-shelf (COTS), free-and-open-source-software products, and reused code. Finally, there was poor performance both by the DoD and the prime contractor, Raytheon. The Government lacked software expertise and failed to act early on data indicating poor contractor execution. The contractor did not execute to plan (deferring requirements and inconsistently following their processes) and had poor configuration management.

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Root Causes of Critical Breaches Since 2010

Developing systems beyond the current state-of-the-art often results in problems specific to each effort, resulting in the saying that programs succeed by employing well-established tradecraft but fail for rather unique reasons. Despite this, it is useful to abstract the failures into categories to identify commonality that might be rectified systemically. It is especially useful to conduct such reviews independently and to differentiate root causes from proximal causes. Table 2-7 summarizes such reviews on all statutory and discretionary root-cause analyses to since the PARCA office was set up in January 2010 (DPARCA, 2010a–g, 2011a–e, 2012a–c, 2013, 2014a–b, and 2016), including detailed breakouts of the management performance issues. Generally, the common root cause areas remain the same as those discussed in last year's annual report (USD(AT&L), 2015b).

Acquisition Improvements

Finally, despite the differing details of individual breaches, it is useful to discuss how recent program causes relate to ongoing efforts to incrementally improve acquisition by addressing specific issue areas (e.g., through BBP initiatives and principles).

The Joint Standoff Weapon (JSOW) critical breach in 2014 was from elimination of distant out-year production and resulting termination. The emergence of more cost-effective munitions obviated the need for the JSOW units predicted at the tail-end of the program buy. Thus, the cause is more one of an inability to predict the pace of future threat changes than a flaw in initiation or execution. The BBP effort to address technical superiority supports such decisions to evolve and react to threat changes.

The Warfighter Information Network-Tactical (WIN-T), Increment 2, significant breach in 2014 was due to production extensions from requirements changes and realization of long-term affordability limitations. While a breach factor, the imposition of the long-term affordability policy in BBP and associated corrections for WIN-T, Increment 2, is a positive sign that the DoD is working to take long-term affordability analysis seriously, which should result in early decisions and reduced sunk costs.

The RMS critical breach reported in the 2015 SAR was due to a termination for unsatisfactory progress on system reliability and availability. BBP is attempting to address the kind of prototype and mission thread issues experienced by RMS by improving how, when, and whether we use early prototyping and improving our understanding of threats and operational needs. Merely replicating immature prototypes can deliver new capabilities to the field quickly, but like rapidly acquired systems can often come with the results of limited engineering on the robustness of the system during operation (and possibly also limited utility for other missions).

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Table 2-7. Root Causes of Critical Nunn-McCurdy Breaches and Selected Programs

Root Causes	Fraction	Count	WGS	ATIRCM	CMWS	RMS	AB3	DDG-1000	F-35 JSF	FAB-T	Excalibur	ACWA Chem-Demil	RQ-4A/B GH	Navy ERP	GCSS-MC	JTRS GMR	JLENS	P-8A	EELV	ECSS	JPALS Inc. 1A	MQ-8 VTUAV	OCX
Discretionary analysis Department	24%	5	AF	Army	Army	Navy	Army	Navy	DoD	AF *	Army	DoD	AF	Navy *	Navy *	Army	Army	Navy *	AF	AF *	Navy	Navy	AF
Milestone B Year (original)		21	2000	1995	1995	1999	2006	2005	2001	2007	1997	2003	2001	2004	2007	2002	2005	2004	1998	none	2007	2000	2012
Critical Breach (SAR Year)			2009	2009	2009	2009	2009	2009	2009	n/a	2010	2010	2010	n/a	n/a	2011	2011	n/a	2012	n/a	2013	2013	2016
Inception																							
Unrealistic performance expectations	**10%**	2		X																X			
Unrealistic baseline estimates for cost or schedule	**29%**	6							X			X	X	X	X								X
Immature technologies or excessive manufacturing or integration risk	**10%**	2		X											X								
Other	**10%**	2												X						X			
Execution																							
Unanticipated design, engineering, manufacturing or technology integration issues arising during program performance	**14%**	3	X		X																X		
Changes in procurement quantity	**19%**	4					X	X			X						X						
Inadequate program funding or funding instability	**0%**	0																					
Poor performance by government or contractor personnel responsible for program management	**48%**	10				X			X	X			X	X	X	X	X		X	X			X
• *Systems engineering*	*43%*	*9*				X			X	X			X	X	X	X	X			X			X
– *Requirements management*	*33%*	*7*								X			X	X	X	X	X			X			X
> *Ambiguities in combining requirements documents*	*5%*	*1*															X						
> *Development, translation and allocation of requirements*	*14%*	*3*								X							X			X			
> *Inadequately funding the program for all requirements*	*5%*	*1*											X										
– *Interface and environmental management*	*10%*	*2*							X	X													
– *Holistic performance attributes (e.g., reliability, weight)*	*10%*	*2*				X				X													
– *Risk assessments*	*5%*	*1*							X														
• *Inadequate contract incentives*	*38%*	*8*							X	X			X		X	X			X	X			X
• *Limited situational awareness*	*29%*	*6*				X			X	X					X	X				X			
• *Failure to act on information*	*29%*	*6*							X				X	X	X					X			X
Other	**19%**	4	X																X		X	X	
		21																					
PAUC Growth (%) **			18.4	290.6	25.0	79.5	25.5	86.5	57.2	25.1	198.7	39.2	14.0	—	—	92.1	215.7	-1.6	58.0	—	104.3	55.2	48.6
APUC Growth (%) **			27.2	281.5	32.4	54.6	31.2	24.9	57.2	—	129.6	—	22.9	—	—	23.2	—	-1.1	58.0	—	129.0	71.5	—
RCA Memo Year (CY)			**2010**									**2011**						**2012**		**2013**	**2014**		**2016**

* Discretionary root-cause analysis

** As reported at the time of the breach in the SAR

NOTES: Grayed rows are breakout elaborations of poor performance. ECSS did not reach milestone B.

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The OCX critical breach was due to intense schedule pressures, underestimation of the costs to fully implement information-assurance requirements, and poor performance both by the DoD and the prime contractor. BBP directly addresses the third cause by seeking to improve the acquisition workforce capabilities (especially in software development expertise) and pursuing more effective contractor performance incentives. The second cause was aggravated by shortfalls in software and cybersecurity expertise in the program office, but the major contributing factor was that full implementation of cybersecurity requirements was new to both the buying command and the prime contractor.

In principle, our improvement initiatives such as BBP should continue to raise the cost consciousness of the DoD and sustain the downward trend in recent breach rates, but there is more to do. We have been working to improve the quality, training, and staffing levels in the acquisition workforce, especially of key leaders such as our PMs and PEOs. We have seen anecdotal progress in improved execution, but it will take continued investment, focus, and time for these effects to be realized in future Nunn-McCurdy breach data.

Breaches by Commodity

Table 2-8 below summarizes a different analysis of Nunn-McCurdy breaches by commodity. In this case, we do not “double count” programs that have breached multiple times. This allows us to compare the types of programs that have poor cost performance (as evidenced by crossing any Nunn-McCurdy threshold) to those that have never breached during this period.

As in prior years, helicopter programs showed an abnormally high breach rate, as do the four chemical demilitarization programs. The 100 percent breach rate for space-launch is not statistically meaningful given that only one program is in the dataset.

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Table 2-8. Nunn-McCurdy Breach Rate by Commodity

Fraction of MDAPs by Commodity Type With Any Nunn-McCurdy Breach (SAR Year 1997–2016Q2)

Commodity Type	Total # of Programs	# of Programs That Ever Breached	Breach Rate	# of Programs with at Most a Significant Breach	# of Programs With At Least One Critical Breach
Chem Demil	4	4	100%	1	3
Space Launch	1	1	100%	—	1
Helicopter	17	10	59%	5	5
Satellite	13	5	38%	1	4
Fixed-Wing Aircraft	27	10	37%	3	7
UAV	6	2	33%	—	2
Ground Vehicle	12	3	25%	2	1
Munition/Missile	32	7	22%	1	6
C4ISR	50	11	22%	3	8
Ship/Submarine	19	4	21%	2	2
Missile Defense	8	1	13%	—	1
Total	**189**	**58**	**31%**	**18**	**40**

NOTE: Compares number of programs that have crossed any Nunn-McCurdy threshold to those that have never crossed a threshold. Breaches are determined using "base-year" dollars (i.e., adjusted for inflation). These commodity types are slightly different from those reported last year. For example, sensors logically belong in the C4ISR category, and unmanned aerial vehicles (UAVs) are broken out from aircraft to help reveal how they have fared.

MAIS and Business Systems

This section evaluates the performance of MAIS, including business systems. MAIS are ACAT IA programs that either meet a specified budgetary threshold[23] or are designated by the Secretary of Defense (or designee) as a MAIS (e.g., due to risk or other concerns) (see 10 U.S.C., Section 2445a). Title 10 mandates various reports and baselining mechanisms for MAIS. Figure 2-7 shows the current dollar size of the MAIS programs reported in at least one MAR in 2011–2015.[24] At least half of the MAIS programs have original total baselines below about $500 million (except in the Navy), while others can cost billions of dollars.

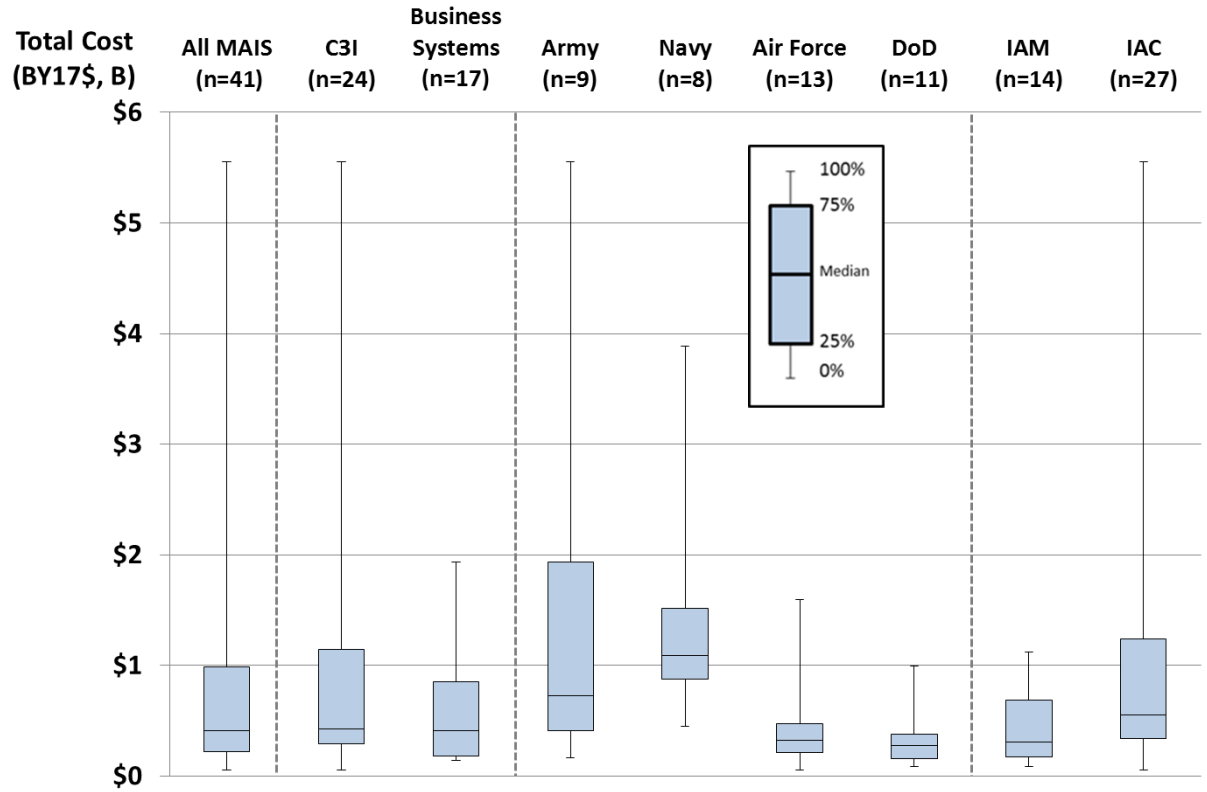
[23]For example, one MAIS threshold is $378 million in FY 2000 dollars for total lifecyclelife-cycle costs (see 10 U.S.C., Section 2445 for details and other thresholds).

[24]MARs are the MAIS equivalent of SARs and are provided to Congress to satisfy the requirement in 10 U.S.C., Section 2445b.

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Figure 2-7. Major Information System Sizes

Size Distributions (by Dollars) of Active MAIS Programs (MAR Years 2011–2015)



	All MAIS (n=41)	C3I (n=24)	Business Systems (n=17)	Army (n=9)	Navy (n=8)	Air Force (n=13)	DoD (n=11)	IAM (n=14)	IAC (n=27)
Median	$0.41	$0.42	$0.41	$0.72	$1.09	$0.32	$0.28	$0.31	$0.55
IQR	$0.77	$0.86	$0.67	$1.52	$0.64	$0.26	$0.21	$0.51	$0.91

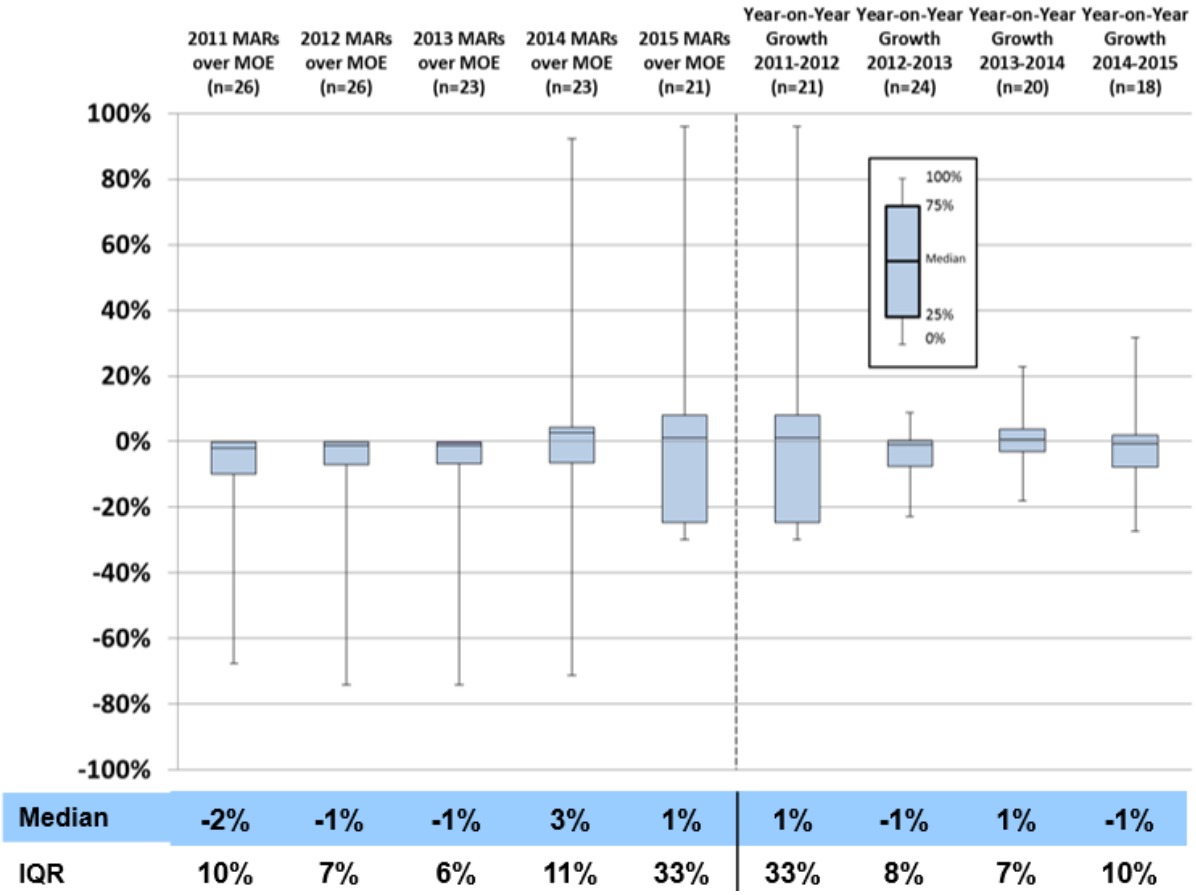
NOTE: Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. The interquartile range (IQR) is the difference between the 75th and 25th percentile; IQR is analogous to variance by conveying a sense of the variability in the distribution. Immature programs that have not completed at least 30 percent of their original EMD schedule time were excluded to help control for maturity.

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Figure 2-8 shows the funding growth from original baselines as reported in the 2011–015 MARs. We weighted results by program spend (dollars) and controlled for program maturity (a program is relatively mature when it passes 30 percent of the planned or actual time from FFO to FDD). Total funding growth from original baseline dropped to 1 percent at the median in 2015. Median year-on-year funding growth also dropped and ran negative between 2014 and 2015.

Figure 2-8. Program Cost-Related Performance: Information Systems

Cumulative Growth from Original Baseline and Annual Changes of Planned Total (From Start to Completion) Funding for Active MAIS (Weighted by Program Spend; MAR Years 2011–2015)



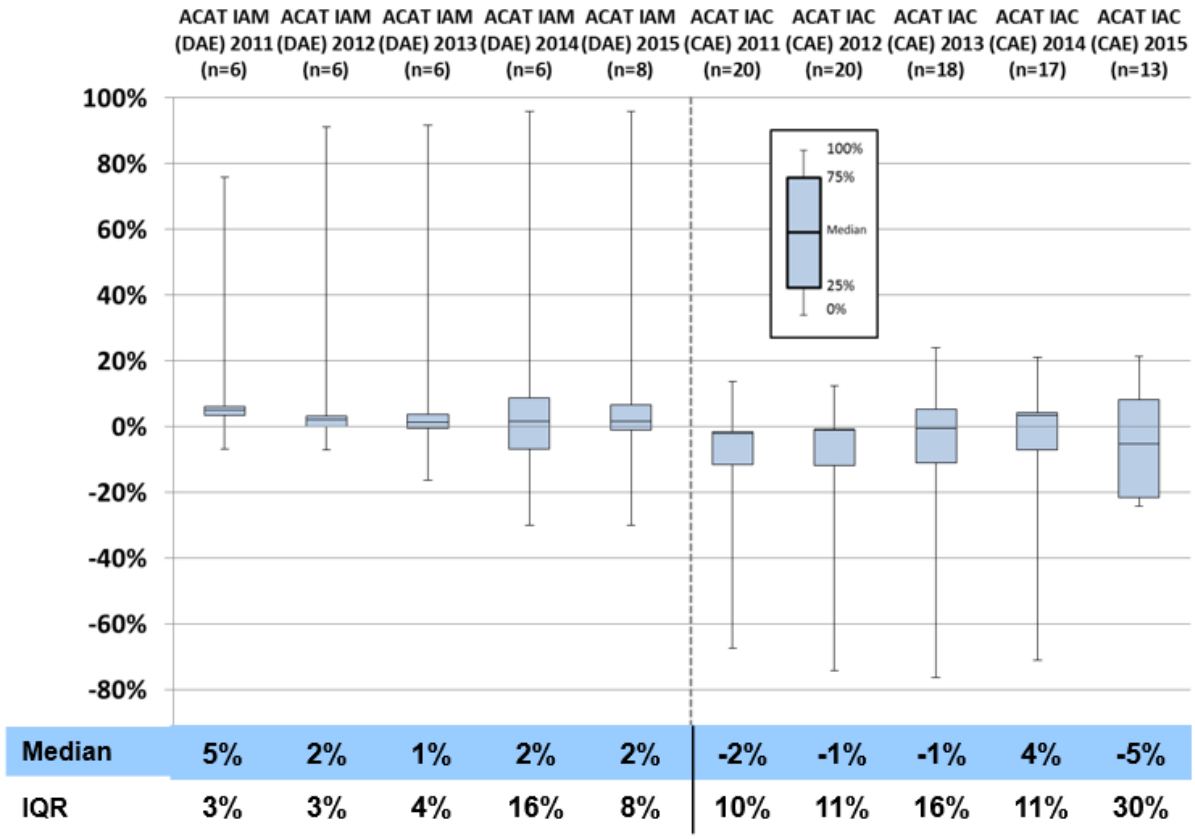
NOTE: The IQR is the difference between the 75th and 25th percentiles. Immature programs that have not completed at least 30 percent of their original EMD schedule time were excluded to help control for maturity. Original baselines are from the MAR original estimate.

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Figure 2-9 compares MAIS funding growth from original baselines based on whether USD(USD(AT&L)) or designee is the Milestone Decision Authority (i.e., "IAM" programs) or oversight has been delegated to the DoD Component Head or the Component Acquisition Executive[25] (i.e., for "IAC" programs). Again, we control for program maturity and weight by program spend (dollars). The median growth for currently active IAM programs has remained flat at 2 percent while the variation tightened with an IQR of 8 percentage points. The median for the portfolio of active IAC programs dropped from 4 percent in 2014 to −5 percent in 2015, although the IQR increased to 30 percentage points.

Figure 2-9. Program Cost-Related Performance: Information Systems by Decision Authority

Cumulative Growth From Original Estimate of Planned Total (From Start to Completion) Funding for Active IAM and IAC MAIS (Weighted by Program Spending; MAR Years 2011–2015)



Median	5%	2%	1%	2%	2%	-2%	-1%	-1%	4%	-5%
IQR	3%	3%	4%	16%	8%	10%	11%	16%	11%	30%

NOTE: Total funding includes O&M and Working Capital Fund. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. The IQR is the difference between the 75th and 25th percentiles. Immature programs that have not completed at least 30 percent of their original EMD schedule time were excluded to help control for maturity.

[25] In the military departments, the SAE is the Component Acquisition Executive.

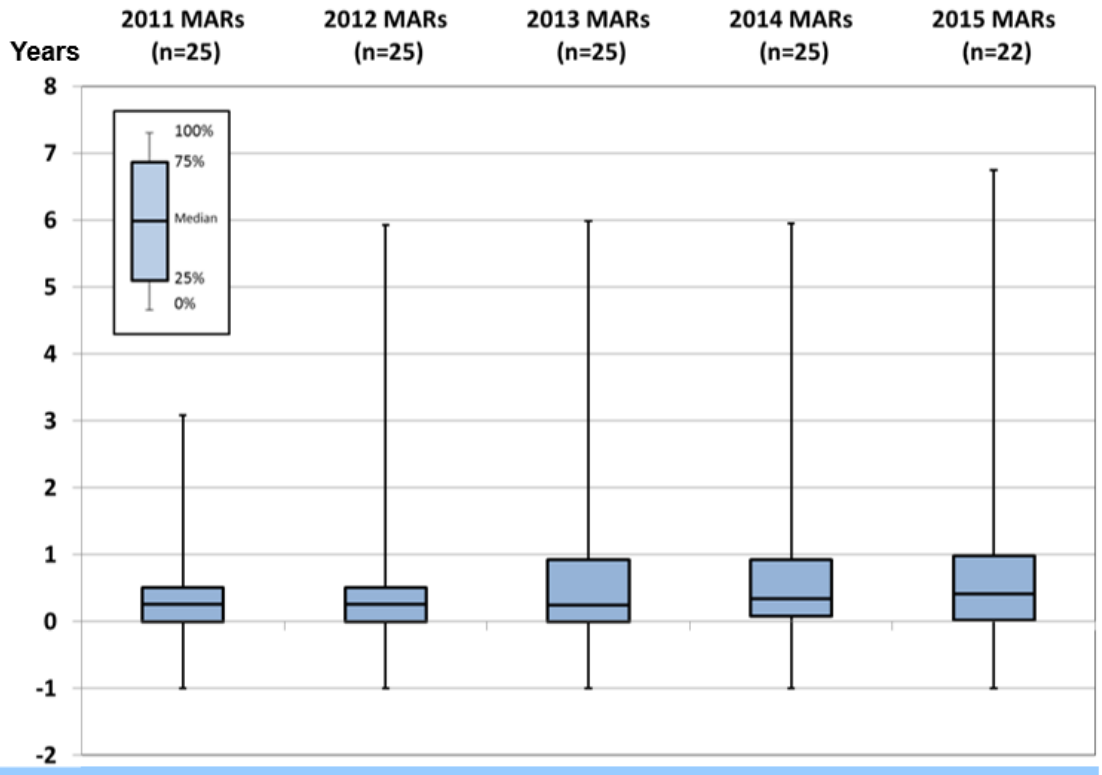
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These data showing low funding growth supports anecdotal assertions that, unlike MDAPs, MAIS may be changing their scope to match available funds and schedule thresholds. We currently do not have centralized data to measure requirement changes across MAIS to test this hypothesis. If true, however, examinations of performance relative to baselines would not be as meaningful as they are on MDAPs (where general capabilities are assumed to be relatively stable).

With respect to schedule growth, MAIS have shown a slight increase from about 3 months in 2011 to 5 months in 2015 at the median (see Figure 2-10). The variation across the portfolio has also increased with an IQR increasing from 6 months of schedule growth in 2011 to about a year in 2016.

Figure 2-10. Program Schedule Growth: Information Systems

Active MAIS Cumulative Planned Schedule Growth to FDD From Original Estimates (MAR Years 2011–2015)



	2011 MARs (n=25)	2012 MARs (n=25)	2013 MARs (n=25)	2014 MARs (n=25)	2015 MARs (n=22)
Median	0.25	0.25	0.25	0.33	0.42
IQR	0.50	0.50	0.92	0.84	0.96

NOTE: Original estimates are those reported in the first MAR for each MAIS. Schedule period is from MS B or FFO to FDD. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. The IQR is the difference between the 75th and 25th percentiles. Immature programs that have not completed at least 30 percent of their original EMD schedule time were excluded to help control for maturity.

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COST PERFORMANCE: DEVELOPMENT

Planned Program Funding Growth: Development

We now examine MDAP development cost-related performance at the program level, using total RDT&E funding growth as the metric. Program "cost" (e.g., as defined for PAUC and APUC) is synonymous with the total amount of funding because it reflects the prices paid on contracts as well as program execution costs. Generally, RDT&E must be funded regardless of how many units are produced. In that sense, they are a fixed cost for the DoD to arrive at the point where we can procure and field a capability. Thus, for RDT&E, we track total funding growth rather than by units produced (e.g., as for PAUC and APUC) to avoid confusing the effects of even small quantity changes with growth in RDT&E. Since we measure growth compared to initial baselines, this measure can show significant increases when a program originally was planned to involve little RDT&E but received even modest additions to address changing threats or operational needs. Still, this approach provides a means for measuring total RDT&E funding control relative to original plans.

While examining total RDT&E funding from each program's original baseline estimate is important to capture the overall growth since inception, it may not be the best choice for gaining insight into *recent* cost-growth management. When we analyze a program from inception, we are forced to carry all growth until the program or phase of the program ceases to be active. Programs currently executing well but that had a one-time increase in the distant past can appear to be poor performers in the long term. Therefore, we also measure biennial changes in total planned and actual RDT&E funding.

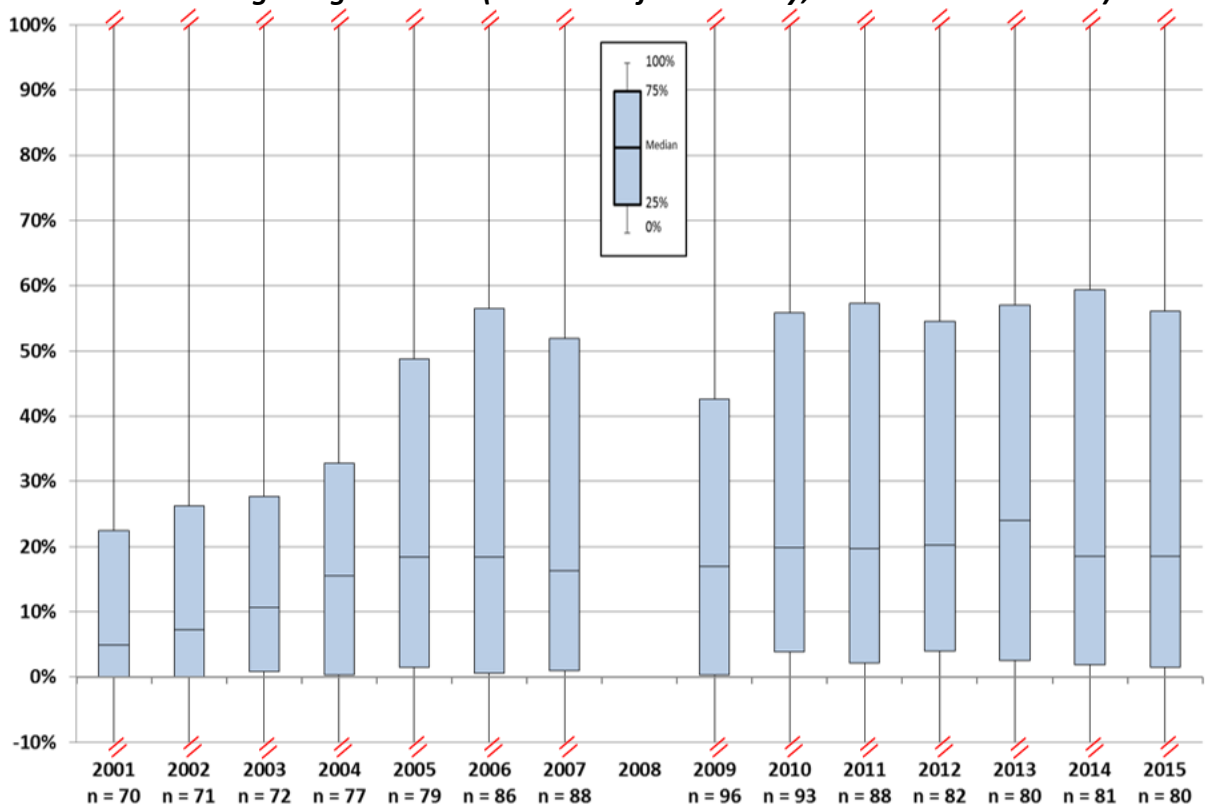
Figure 2-11 shows total cumulative RDT&E funding growth over original MS B baseline for each year's MDAP portfolio. This is the most conservative measure since it ignores any revised original baselines set after Nunn-McCurdy breaches. For each analysis, we first show the main portion of the distribution (between −10 percent and +100 percent growth) followed by a separate figure showing all outliers (especially those with growth greater than 100 percent). Medians are the lines within each box. Gray-shaded columns in the table beneath each chart were periods with very low sample counts because SARs for all active programs were not made in those years due to new Presidential administrations. The "x" markers above the box mark the five largest instances of program funding growth (although outliers above 100 percent only appear on the outlier charts). These outlier charts are controlled for program maturity only. Notably, the data show considerable (and sometimes seemingly conflicting) differences between the medians and the arithmetic means. This is because the data are highly skewed, and a single but very large outlier can have a large effect on the mean while not affecting the median.[26] In these cases, the best measure of central tendency is the mean.

[26] Part of the skewing in the distribution of cost change is the mathematical boundary of cost change because cost cannot decrease more than 100 percent but can increase more than 100 percent.

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Figure 2-11. Program Cost-Related Performance: Development

Cumulative Growth Over Original MS B Baseline of Active MDAP Planned Total (From Start to Completion) RDT&E Funding: Program Basis (Controlled for Maturity; SAR Years 2001–2015)



Median	5%	7%	11%	15%	18%	18%	16%		17%	20%	20%	20%	24%	19%	19%
IQR	22%	26%	27%	33%	47%	56%	51%		42%	52%	55%	51%	55%	58%	55%
Mean	94%	51%	56%	65%	69%	84%	84%		83%	86%	89%	92%	94%	94%	80%
Std Dev	643%	251%	245%	268%	263%	397%	386%		363%	339%	369%	360%	355%	342%	332%
Trends	***Generally lower than 2009-2015***			***No trends across these years***											

NOTES: This shows total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. These are percentage changes after adjusting for inflation from original MS B baseline of actual past and estimated future funding as reported in each program's latest SAR. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. The IQR is the difference between the 75th and 25th percentiles.

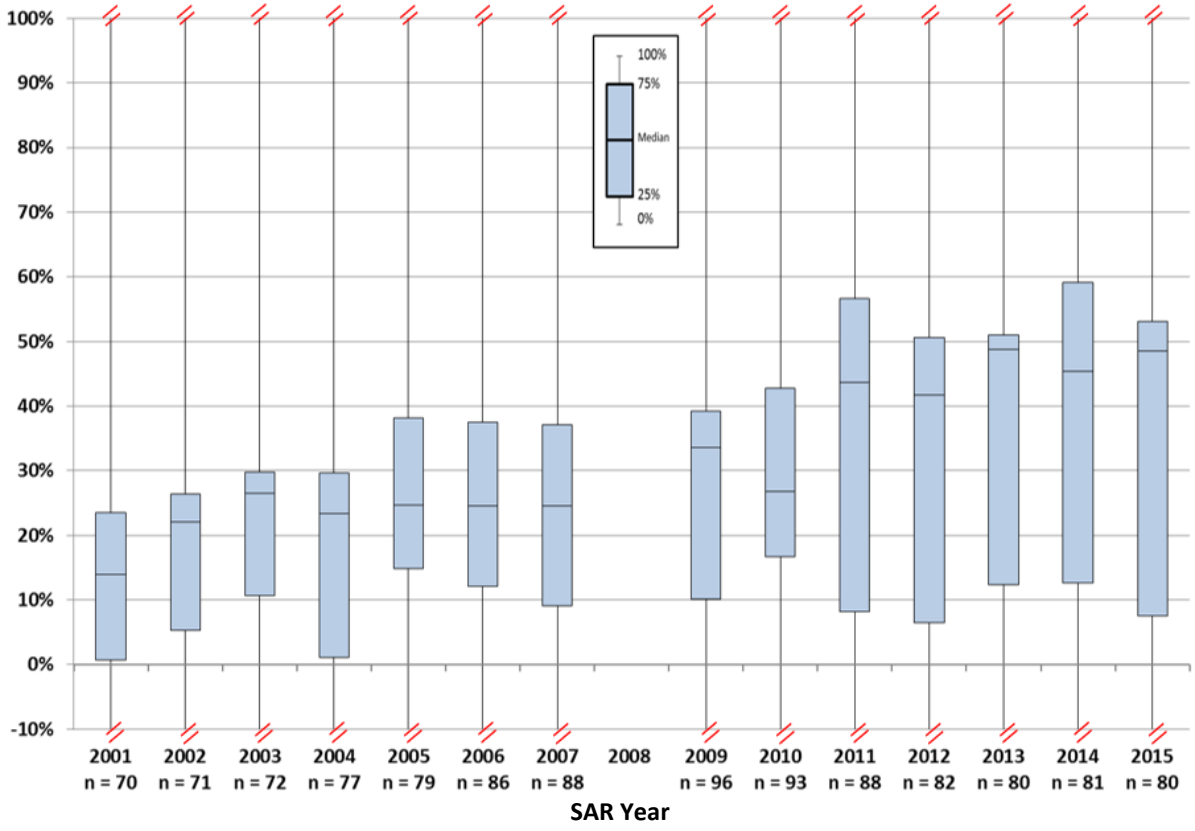
As with last year's results, growth has been statistically flat since the earlier years of 2001–2004, when the set of MDAPs active at that time had lower total RDT&E at the median. In contrast to the results on a program basis, Figure 2-12 showing results on a dollar basis (i.e., weighted by program size in dollars) and controlling for maturity (i.e., removing programs that have not executed at least 30 percent of their original EMD schedule from MS B to MS C). Here growth has been statistically increasing since 2001. In other words, larger programs (in terms of spending) have systematically larger total RDT&E funding growth, and that growth has been

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increasing. Thus, our outlier programs also are our largest by spending, and they are increasing. The F-35, for example, constitutes about 20 percent of the dollars in the current MDAP portfolio and thus has a large effect when weighted by program size (dollar basis). However, the F-35 median total funding growth is very close to the median of the rest of the portfolio. Thus, it is not driving the value upward but will tend to affect whether the median changes in the future. Also remember that here we are measuring growth against the original MS B baselines independent of any revised original baselines (due to program reconfigurations from Nunn-McCurdy breach).

Figure 2-12. Program Cost-Related Performance: Development (Weighted by Program Size in Dollars)

Cumulative Growth Over Original MS B Baseline of Active MDAP Planned Total (From Start to Completion) RDT&E Funding: Dollar Basis (Controlled for Maturity; SAR Years 2001–2015)



Median	14%	22%	26%	23%	25%	25%	25%		34%	27%	44%	42%	49%	45%	49%
IQR	23%	21%	19%	29%	23%	25%	28%		29%	26%	48%	44%	39%	47%	46%
Trends	***Increasing trend across all years, 2015 down from peak year of 2014***														

NOTES: This shows total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. These are percentage changes after adjusting for inflation from original MS B baseline of actual past and estimated future funding as reported in each program's latest SAR. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. The IQR is the difference between the 75th and 25th percentiles.

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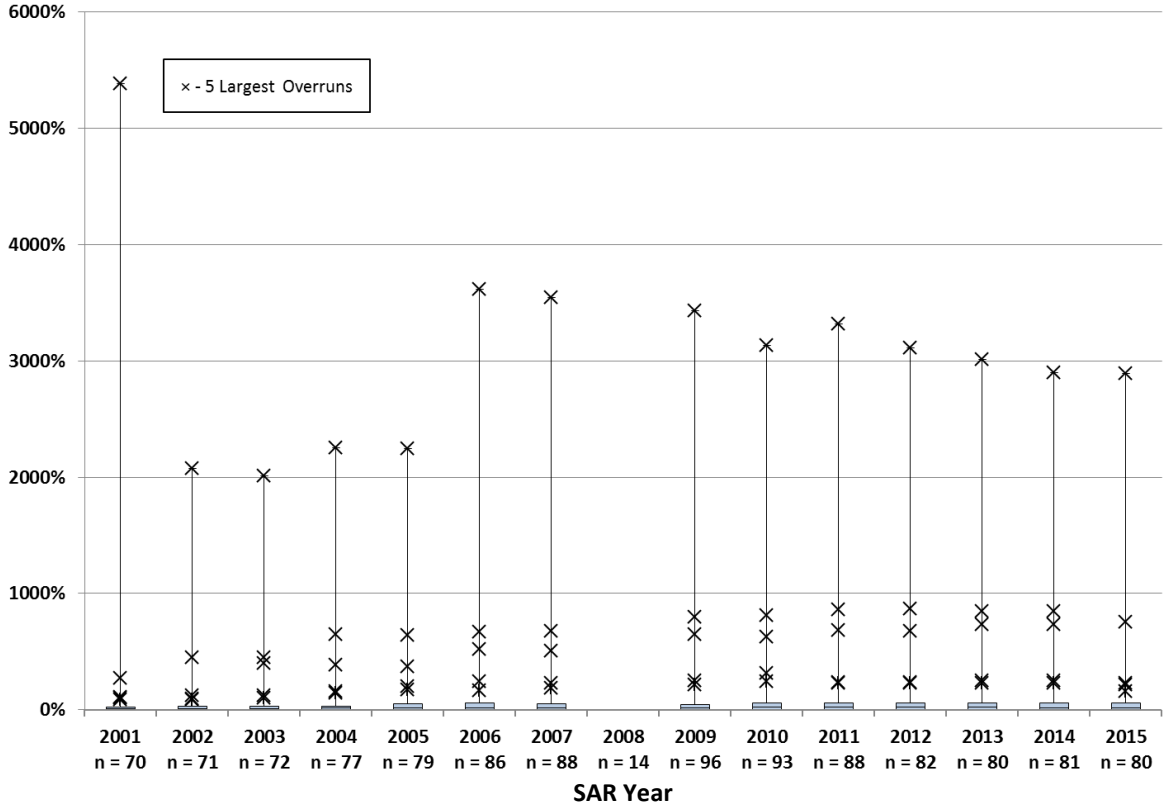
Figure 2-13 shows the outliers that are off the chart in Figure 2-11 and Figure 2-12. While C-130J remains the largest outlier, this year AIM-9X and UH-60M entered the top five because MH-60S and RQ-4A/B Global Hawk are no longer active. These outliers have very large growth percentages but are not representative of the overall MDAP portfolio. These extreme growths are not due to measurement error and so were not excluded from the analysis. Still, they do skew the aggregate data, which is an important fact for determining how to measure and discuss funding growth across a program population. Similar skewing is observed in various complex commercial projects (see, for example, Flyvbjerg et al., 2002). Much of the funding growth from original MS B baselines are from prior years since recent marginal funding growth in RDT&E has moderated significantly at the median.

Understanding *why* a program may exhibit such a large percentage increase in RDT&E funding requires an individual examination of each case. For example, in Figure 2-13, the C-130J remains the highest outlier since 2002. This program originally was envisioned as a nondevelopmental aircraft acquisition with a negligible RDT&E effort planned. Several years into the program, a decision was made to install the Global Air Traffic Management system, adding several hundred million dollars to development and causing the total development funding growth recently to climb upward of 3,000 percent. This is an example of a major change in the program rather than poor execution, although significant program changes like this are not necessarily the reason for all extreme cases of funding growth.

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Figure 2-13. Program Cost-Related Performance Outliers: Development

Cumulative Growth Over Original MS B Baseline of
Active MDAP Planned Total (From Start to Completion)
RDT&E Funding: Outliers (Controlled for Maturity; SAR Years 2001–2015)



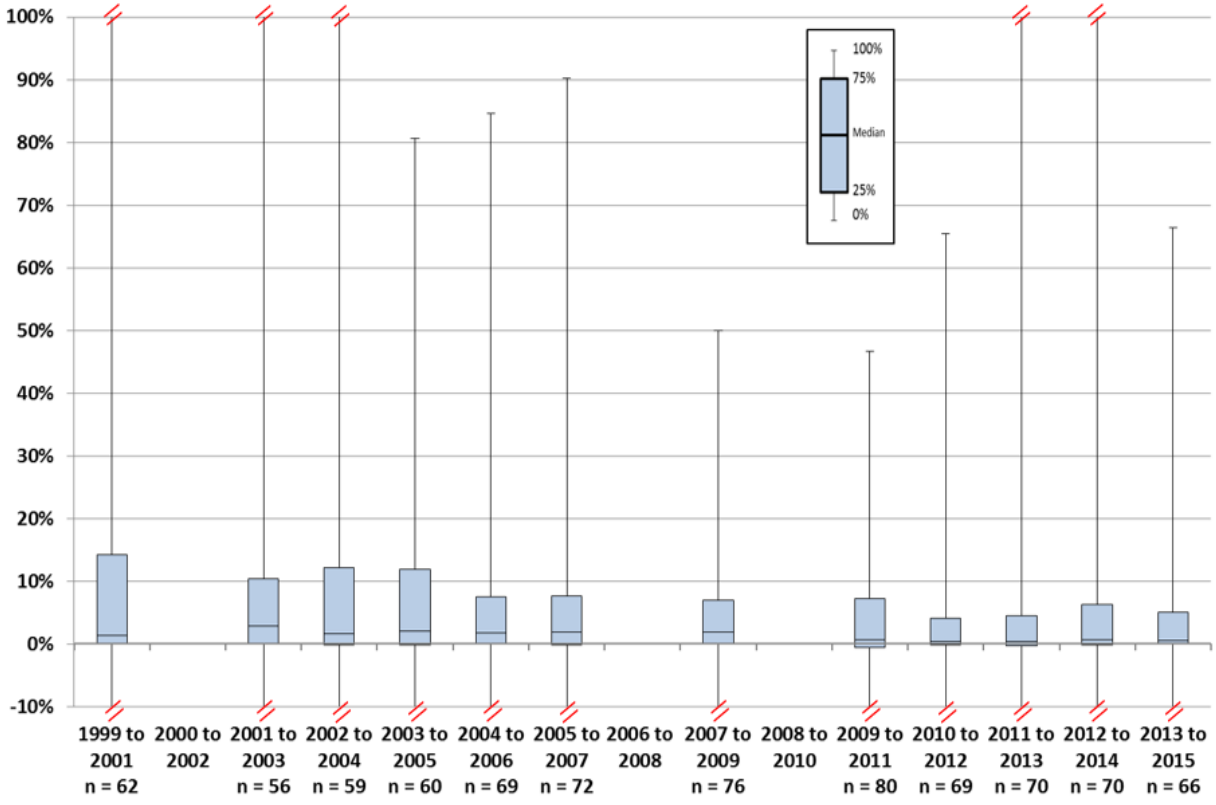
| | | |

Biennial Planned Program Funding Changes: Development

Figure 2-14 and Figure 2-15 show a continuing downward trend when examining biennial changes in total (past plus planned) program RDT&E funding growth—both on program and dollar bases (weighted by program size in dollars). The recent five periods since 2009 are each lower than almost all of the prior periods.

Figure 2-14. Program Cost-Related Biennial Performance: Development

Biennial Change in
Active MDAP Planned Total (From Start to Completion)
RDT&E Funding: Program Basis (Controlled for Maturity; SAR Years 1999–2015)

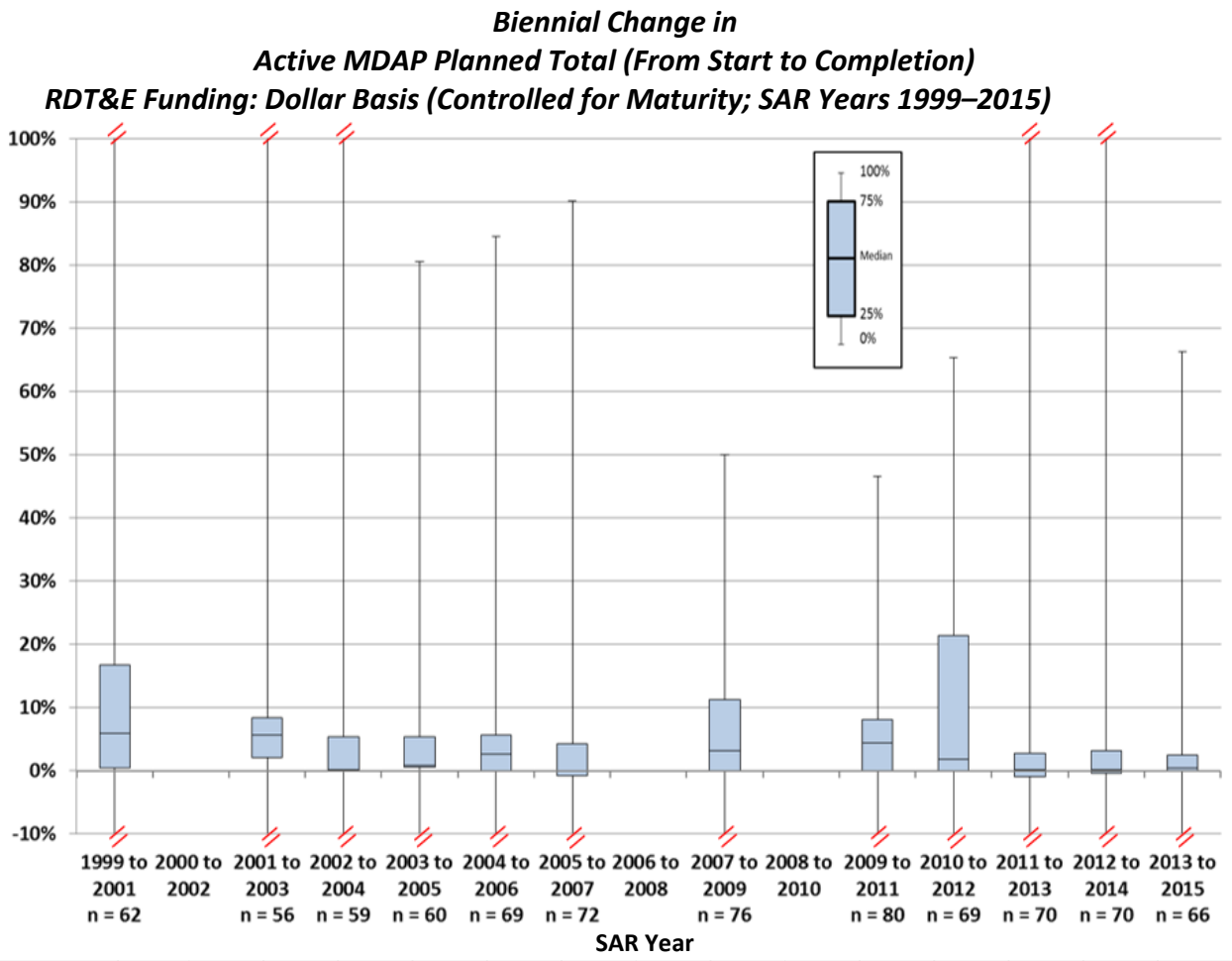


Median	1%		3%	2%	2%	2%	2%		2%		1%	0%	0%	1%	1%
IQR	14%		10%	12%	12%	7%	8%		7%		8%	4%	5%	6%	5%
Mean	87%		44%	10%	9%	8%	8%		5%		4%	2%	4%	5%	4%
Std Dev	603%		269%	28%	19%	20%	19%		10%		14%	10%	16%	20%	13%
Trends	***No trend across these years***										***Generally lower than periods ending 2001–2005***				

NOTE: This measures biennial changes in total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. These are percentage changes after adjusting for inflation from original MS B baseline of actual past and estimated future funding as reported in each program's latest SAR. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. The IQR is the difference between the 75th and 25th percentiles.

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Figure 2-15. Program Cost-Related Biennial Performance: Development (Weighted by Program Size in Dollars)



Median	6%		6%	0%	1%	3%	0%		3%		4%	2%	0%	0%	1%
IQR	16%		6%	6%	5%	6%	5%		11%		8%	21%	4%	4%	2%
Trends				***Generally lower than priors and 2007–2009***							***Generally lower than before 2012***				

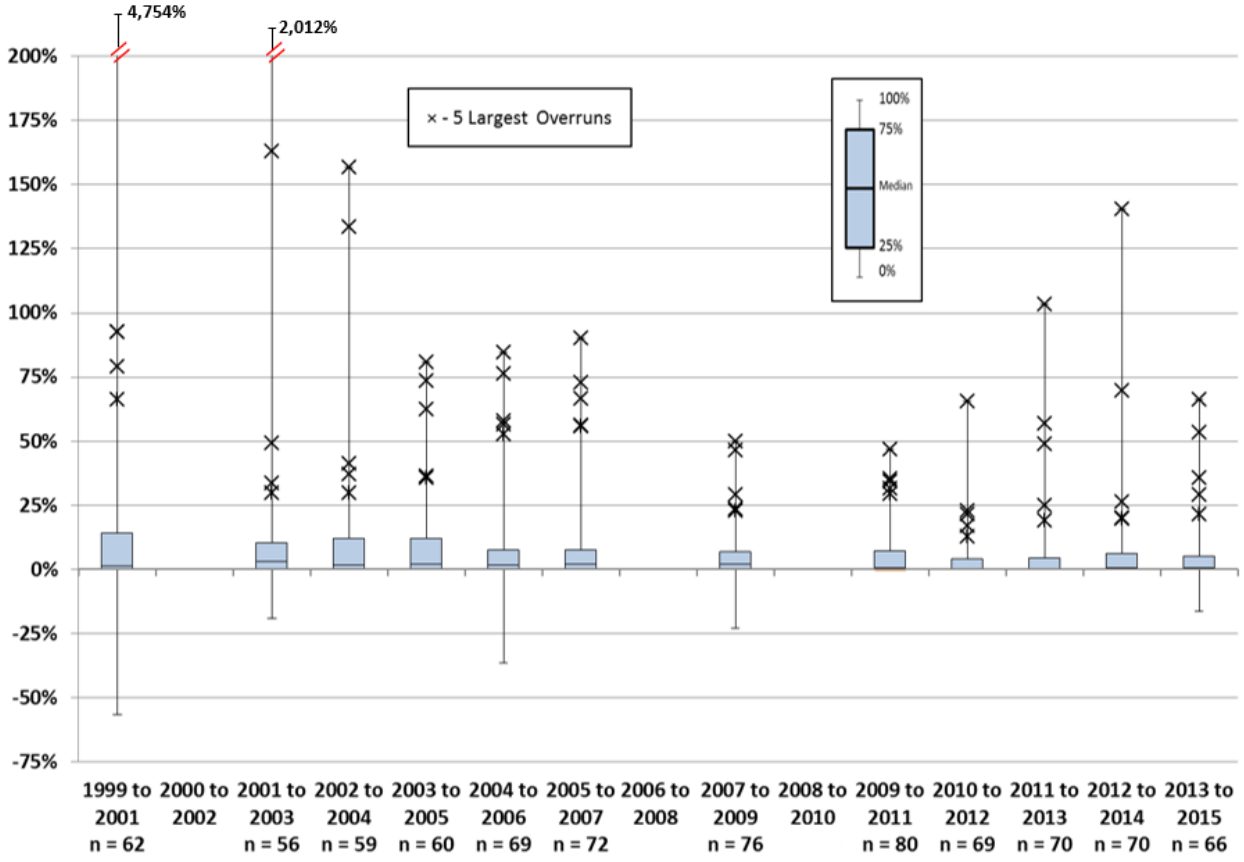
NOTE: This measures biennial changes in total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. These are percentage changes after adjusting for inflation from original MS B baseline of actual past and estimated future funding as reported in each program's latest SAR. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. The IQR is the difference between the 75th and 25th percentiles.

Figure 2-16 shows the five largest programs with biennial changes in planned and actual RDT&E funding, controlling for program maturity. This includes outliers that are off the charts in Figure 2-14 and Figure 2-15. Note that EELV rose to be the top outlier for 2015, and OCX entered the top 5, bumping JPALS from the top five for 2015.

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Figure 2-16. Program Cost-Related Biennial Performance Outliers: Development

Biennial Change in
Active MDAP Planned Total (From Start to Completion)
RDT&E Funding: Outliers (Controlled for Maturity; SAR Years 1999–2015)



Largest Outlier	GMLRS/ GMLRS AW		C-130J	GMLRS/ GMLRS AW	JTN	WIN -T [WIN-T]	ARH		WIN-T INC 1		AH-64E Remanuf acture	MQ-9 Reaper	AIM-9X Blk II	AIM-9X Blk II	EELV
2nd Largest	CVN 68 [CVN-77]		GMLRS/ GMLRS AW	UH-60M Black Hawk	UH-60M Black Hawk	SSDS [SSDS MK 2	Chem Demil-ACWA		Patriot/ MEADS CAP		STRYKER	MIDS	JPALS Inc 1A	MQ-8 Fire Scout	AIM-9X Blk II
3rd Largest	GMLRS/ GMLRS AW		MH-60S	WGS	JTRS GMR	C-130J	SSDS		LHA 6		JTRS HMS	E-2D AHE	MQ-9 Reaper	JPALS Inc 1A	MQ-8 Fire Scout
4th Largest	CHEM DEMIL-CMA		NAVSTAR GPS	MH-60S	WGS	JTN	NAVSTAR GPS		WGS		MQ-1C Gray Eagle	FAB-T	MQ-8 Fire Scout	NMT	
5th Largest	SBIRS High		WGS	MIDS	MIDS	Chem Demil-ACWA	C-130J		GMLRS/ GMLRS AW		FAB-T	WIN-T Inc 3	E-2D AHE	EELV	OCX

NOTE: This measures biennial changes in total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. These are percentage changes after adjusting for inflation from original MS B baseline of actual past and estimated future funding as reported in each program's latest SAR. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. OCX is now in the top five for 2015, bumping JPALS out of the top five. X's mark the growth for the five largest outliers on each box-and-whisker chart. Program abbreviations are defined in Appendix F starting on p. 159.

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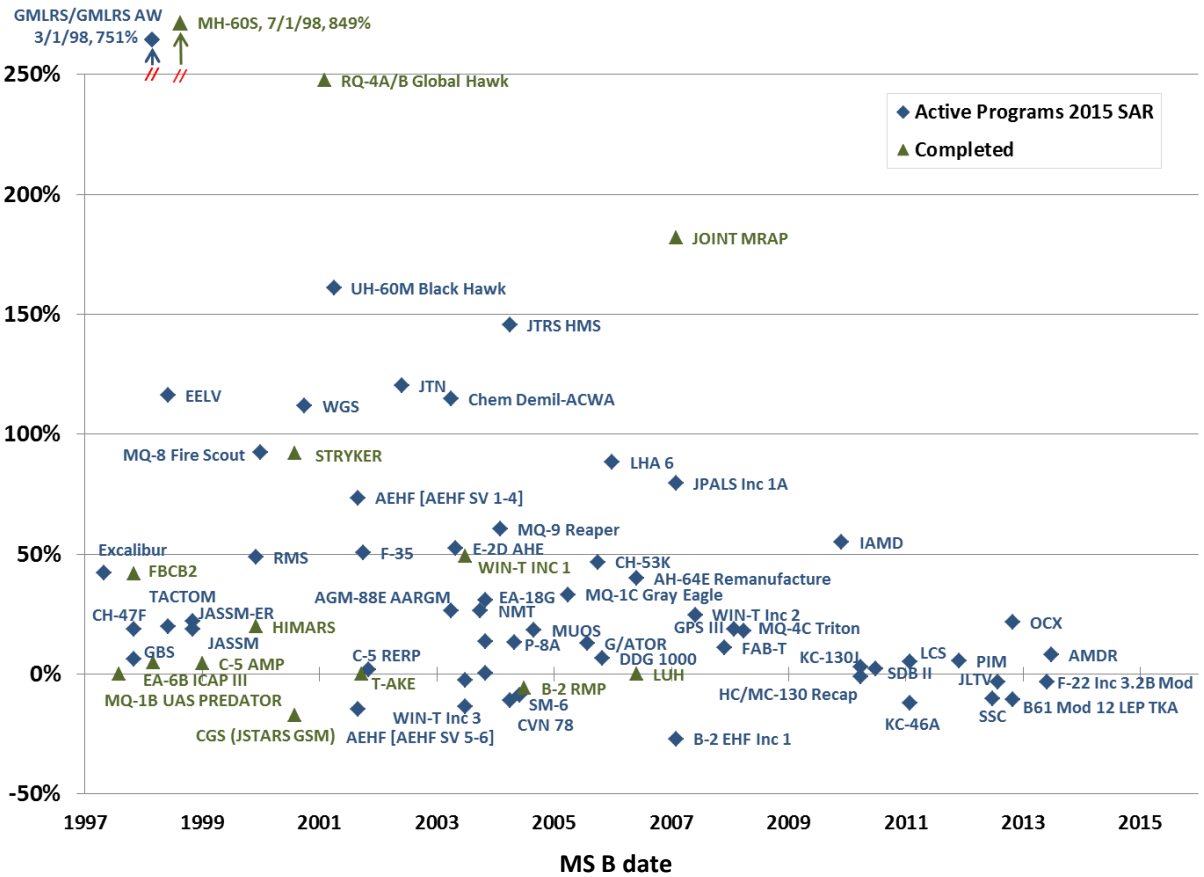
Program Funding Growth by Start Date: Development

A different way to examine program performance is to ask whether recently started MDAPs are controlling RDT&E better or worse than completed and active older MDAPs. This is important since we found in our 2013 report that MDAP contracts that start off well continue to do better, and this is commonly believed to also hold at the program level.

Figure 2-17 plots total RDT&E funding growth (past and planned) relative to the original MS B baselines of all currently active and completed MDAPs by their original MS B date. As before, we controlled for maturity by removing newer programs.

Figure 2-17. Program Cost-Related Performance: Development

Cumulative Growth Over Original MS B Baseline of MDAP Planned Total (From Start to Completion) RDT&E Funding (Controlled for Maturity; CY 1997–2015)



NOTE: This measures total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. These are percentage changes after adjusting for inflation from original MS B baseline of actual past and estimated future funding as reported in each program's latest SAR. Not shown are relatively new programs that have not spent at least 30 percent of their original EMD. Program abbreviations are defined in Appendix F starting on p. 159.

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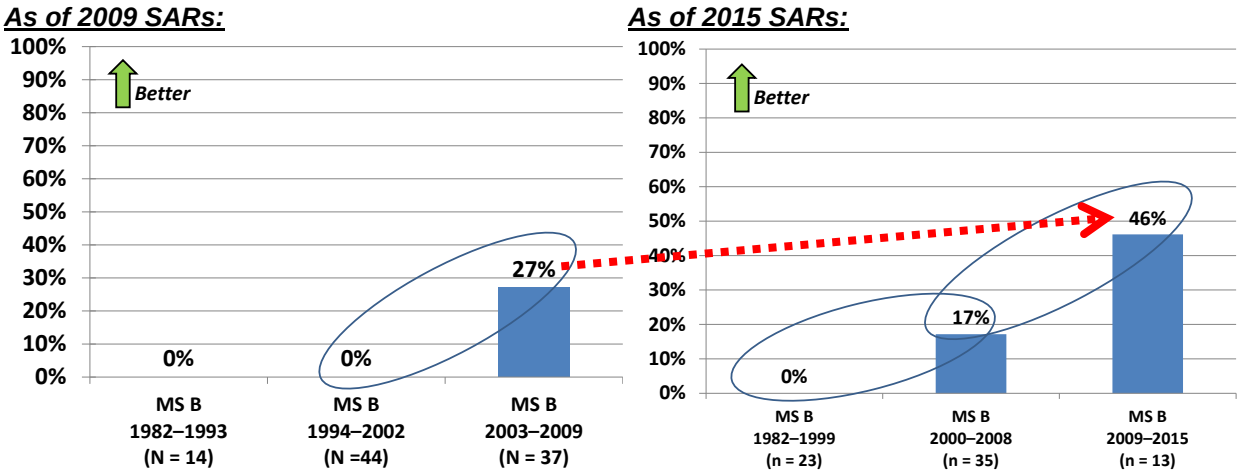
There is an apparent recent improvement in Figure 2-17, but it is not statistically significant when testing back to 1997; the variation explained by any potential trend (i.e., the R^2) was too low.

However, we did find that recent programs are, in fact, improving when using a proportion test comparing programs started since 2009 to earlier programs. Figure 2-18 shows the result of separating the active MDAPs based on program start date (i.e., their original MS B date) as of the 2015 SARs. After deleting immature programs (i.e., those that are too new to know the magnitude of potential problems), we find that the recent proportion of active MDAPs showing reductions (negative funding growth from original MS B baseline) in total RDT&E is higher statistically at 46 percent for the period since 2009 than at 17 percent for the prior period of 2000–2008. This result is somewhat weaker than last year, when the recent bin was 57 percent instead of 46 percent, but one program last year just below zero has risen to just above zero, and another program left the sample size (now 13).

To help test whether this is just a result of any remaining maturity bias, we conducted the same proportion test using earlier 2009 SARs and the same time windows shifted earlier. While the later proportion (2003–2009) was significantly higher at 27 percent than the then-prior 9 years (1994–2002) at zero percent, the reduction magnitudes were lower than what we see now in the 2015 SARs. Thus, while the proportions show some maturity bias, there is evidence that the overall levels in 2015 are higher than in 2009 and that recently started MDAPs are controlling development funding better.

Figure 2-18. Reductions to Planned Program Funding: Development

Proportions of Active MDAPs With Reductions Since Original MS B Baseline in Cumulative Planned Total (From Start to Completion)
RDT&E Funding (Program Basis; Controlled for Maturity)



NOTE: This reflects total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. Statistically significant differences between adjacent periods are marked with an oval. A program shows a reduction if current total RDT&E funding is under original MS B baseline. Relatively new programs that have not been through at least 30 percent of their original EMD schedule are not included to help control for low maturity.

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Conceptually, various factors may be at work here. Recent initiatives (e.g., WSARA 2009; BBP initiatives, including Should-Cost and improved contractor cost control) may indeed be leading to better-structured, better-managed, and more cost-effective programs. These factors should lead to reductions in RDT&E (whether motivated initially by budgetary pressures or as a result of savings or avoidance realized), and data at the contract level later in this chapter show we indeed are reducing RDT&E growth significantly. Also, we might be seeing reductions due to budget cuts with content adjustments. For example, engineering and design requirements may be moderating, enabled by actions from the PM and Configuration Steering Boards and reinforced by affordability analysis. In addition, baselines themselves may be more realistic recently for any number of reasons—better data for cost estimating, more realistic assumptions, lower risk taking at inception, or less optimistic setting of baselines by program MDAs. Recall, for example, that analysis in last year's report inferred a downward trend in risks on early production contracts but not on development contracts (see USD(AT&L), 2015b, pp. 109–114). (Note that we discuss baseline realism below starting on p. 92 as a possible driver of budgetary effects on cost growth.) We cannot directly identify causes of the changes, but we are encouraged that more programs project total needed funding below baselines.

CYCLE TIMES AND SCHEDULE GROWTH: DEVELOPMENT

Warfighting capabilities must not only have the needed technical performance but must be delivered in a timely fashion to address operational threats. Thus, the acquisition system must be responsive in time while addressing cost and technical performance. Cycle time—between the identification and fielding of a need—therefore continues to be an area of concern in our BBP initiatives and elsewhere.

Note that we measure cycle time and schedule growth in various ways to gain insight into schedule-related performance. One is whether we include recent programs that are still active or have not yet achieved the metric's end point (e.g., IOC). Including all programs provides some insight into recent trends but may involve some level of maturity bias (i.e., may not reflect final results). Another metric difference is whether we measure differences in years or percent. The latter provides perspective on the relative magnitude of the change compared to the total length, but note that percent scales differ below and above zero. The lowest negative value is −100 percent, while the largest positive value approaches infinity. Thus, −10 percent and +10 percent are not true inverses, and statistics such as the arithmetic mean can be misleading when both negative and positive values are present in the distribution.

MDAP Cycle Time: MS B or C to IOC

We analyzed planned and actual cycle times for the 100 MDAPs that reported achieving IOC (or some similar benchmark) in the SARs since 1997. Table 2-9 summarizes the average portfolio cycle time for these MDAPs. For MDAPs without an MS B/II, we used MS C/III dates. Not included are some MDAPs with complicated schedule reports where there were no clear or consistent IOC-related dates.

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Cycle times for these programs that achieved IOC grew across the portfolio by about 10 percent (8 months for a nominal 7 year program) compared to original plans. Note that most of the shortest programs were started at MS C (i.e., used mature technology), but some programs that started at MS B also had short EMDs and probably leveraged relatively mature technology. Also, the six longest programs (shown) all began at MS B and involved EMD.

Table 2-9. Average Portfolio Cycle Time (from MS B/C to IOC) for MDAPs Past IOC (1997–2015 SARs)

	Median	Mean	Count	IQR	Standard Deviation	Min	Max
	(years)	*(years)*	*(n)*	*(years)*	*(years)*	*(years)*	*(years)*
Planned	**7.0**	**6.8**	100	3.6	3.1	0.7	14.8
Actual	**7.6**	**6.9**	100	4.2	3.5	0.7	14.8

6 Shortest Programs *[subprogram]*	**Started at**	**Actual Cycle Time** *(years)*
JOINT MRAP	MS C	0.7
TWS	MS C	0.7
CGS (JSTARS GSM) *[Common Ground Station]*	MS C	0.9
LUH	MS C	0.9
JTN	MS B	1.1
CEC	MS B	1.3

6 Longest Programs *[subprogram]*	**Started at**	**Actual Cycle Time** *(years)*
F-35 [F-35 Aircraft]	MS B	13.8
AEHF [AEHF SV 1-4]	MS B	13.8
MQ-8 Fire Scout	MS B	14.2
F-22	MS B	14.5
Excalibur	MS B	14.6
ATIRCM/CMWS [ATIRCM QRC]	MS B	14.8

NOTE: The 1997–2015 SARs include MDAPs with Milestone B/C dates as early as FY 1979 and IOC dates up through FY 2015. Programs abbreviations: Joint Tactical Network (JTN).

MDAP Schedule Growth: MS B or C to IOC

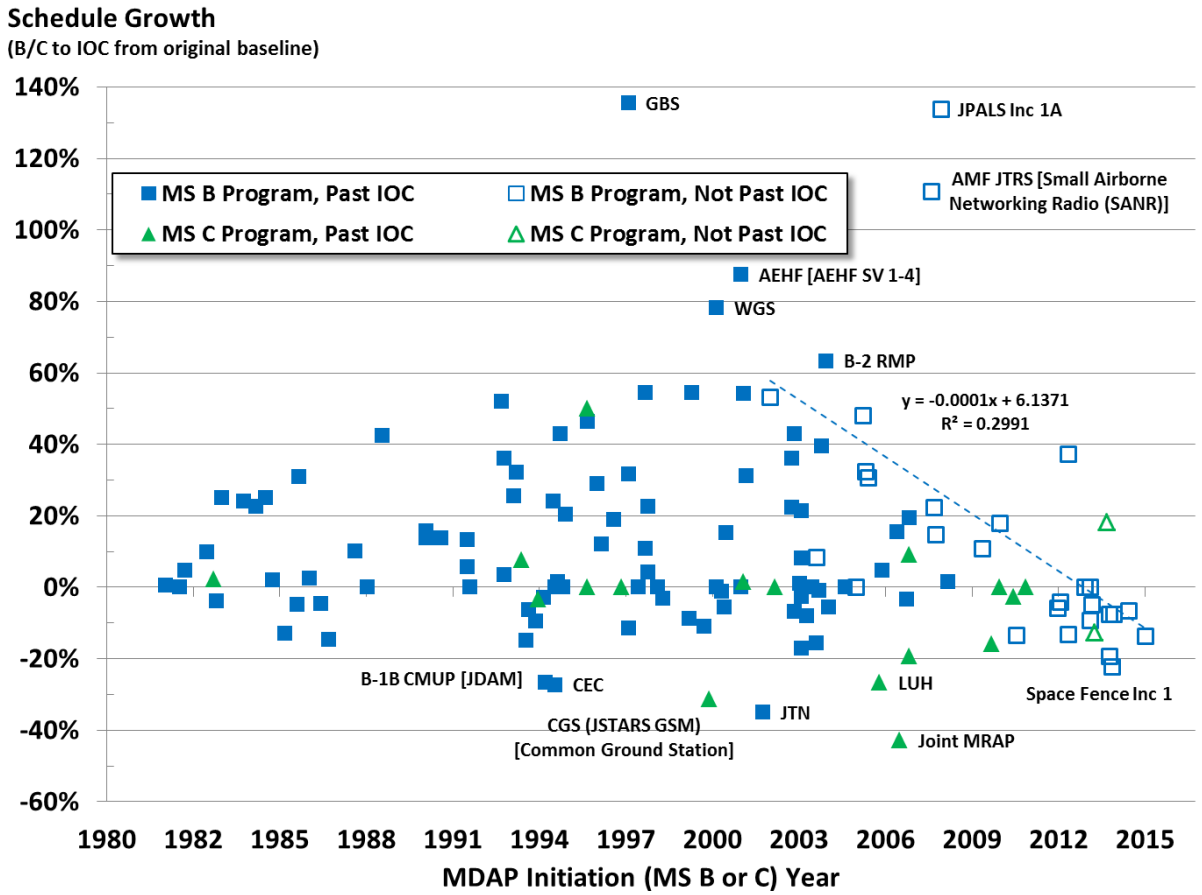
We now assess MDAP cycle time and schedule growth from CY 1997–2015 using SAR data. This includes two types of MDAPs: Programs that had an MS B, and programs with more mature technology that did not have an MS B but instead started at MS C.

Figure 2-19 shows the schedule growth (MS B/C to IOC relative to original baseline) by program start date (MS B or C). Across all MDAPs since 1981 (active and completed), there was no statistically significant trend in B/C to IOC schedule growth when plotting by program start (MS B or C). The overall median was 0 percent for these programs as of the 2014 SARs, but this overall median increased to 1 percent as of the 2015 SASs. This increase between 2014 and 2015 was largely driven by growth in the following programs: OCX, DDG 1000, JLTV, and LCS MM (despite an 18 percentage point drop in PAC-3 MSE).

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We did find a statistically significant downward trend for recent MS B programs that have not yet passed IOC (see the open blue boxes and the downward line on the right side of Figure 2-19). It explains about 29 percent of the variation in the data, but it is unclear whether this trend is due to a maturity bias for these newer programs or whether recent programs are performing better on schedule.

Figure 2-19. MDAP Schedule Growth from MS B or C to IOC (Original Baseline; CY 1981–2015)



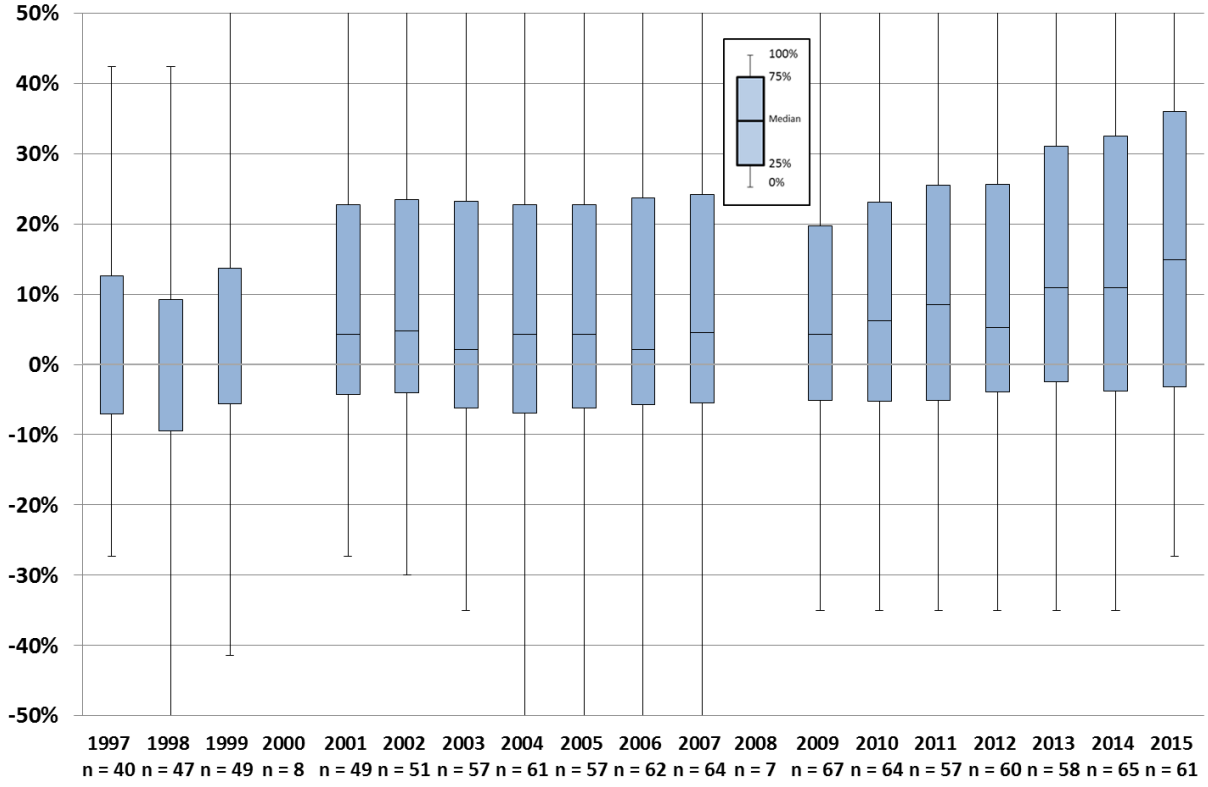
NOTE: The only statistically significant trend is for MS B programs not past IOC; it has a downward trend with an R-squared of 29 percent (i.e., explains 29 percent of the variation). It is unclear whether this trend is due to program immaturity bias or better schedule performance on recent programs. Program abbreviations are defined in Appendix F starting on p. 159.

When just looking at active programs being reported in annual SARs since 1997, we found an increasing trend in median B-to-IOC schedule growth when weighing all programs equally (see Figure 2-20). Schedule growth in CY 2015 was statistically higher than it was in 1997–1999 and 2004–2005. However, when we weigh longer programs more than shorter programs (analogously to the way we weigh cost growth by program dollar size), the portfolio medians have been flat (recall Figure H-10). Thus, schedule growth generally appears to be concentrated on shorter programs. We also found that shorter programs tended to have higher schedule-growth percentage variation than longer programs (i.e., schedule growth in percent versus cycle time is heteroskedastic).

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Finally, we examined (but do not show) planned B-to-IOC schedule lengths by MS B date for different commodities (ballistic missile defense, C4ISR, fixed-wing aircraft, ground vehicles, rotary wing aircraft, munitions, satellites, ships, and UAVs). Only satellites had a statistically significant downward trend (with an R-squared of 44 percent) due primarily to three programs from the early 1980s that had much longer planned B-to-IOC schedules.

Figure 2-20. Median MDAP Schedule Growth for Active Programs (MS B to IOC From Original Baseline; SAR Years 1997–2015)



Median	0.0%	0.0%	0.0%		4.3%	4.8%	2.1%	4.3%	4.3%	2.1%	4.5%		4.3%	6.2%	8.5%	5.2%	10.9%	10.9%	14.9%
IQR	20%	19%	19%		27%	27%	29%	30%	29%	29%	30%		25%	28%	31%	30%	34%	36%	39%
Mean	1.6%	0.0%	3.2%		8.2%	11.0%	9.2%	7.7%	9.1%	9.7%	10.7%		10.4%	12.8%	14.4%	14.6%	16.8%	20.1%	22.1%
Std Dev	16%	18%	18%		20%	25%	26%	28%	29%	28%	29%		26%	27%	28%	29%	29%	37%	35%
Trends	***Lower than 2010-2015***			***No statistically significant trend from 1999-2014. 2015 higher than 1997, 1998, 2004 and 2005.***															

NOTE: Includes active programs regardless of whether they have achieved IOC. Program basis weighted each program equally. There were no complete SARs in 2000 and 2008 due to changes in administration. Growth in CY 2015 is statistically higher (at the 5 percent level of significance) than that in 1997–1999 and 2004–2005.

Interestingly, schedule growth levels in development are lower than cost growth in development. Overall median schedule growth since 1981 for active and completed programs is running at 1 percent, while schedule growth on only active programs has ranged from 0 percent in 1997 to about 15 percent in 2015. In contrast, MDAP program- and contract-level cost growth in development tends to run in the 20 percent to 45 percent range, depending on what measures, data, and adjustments are included.

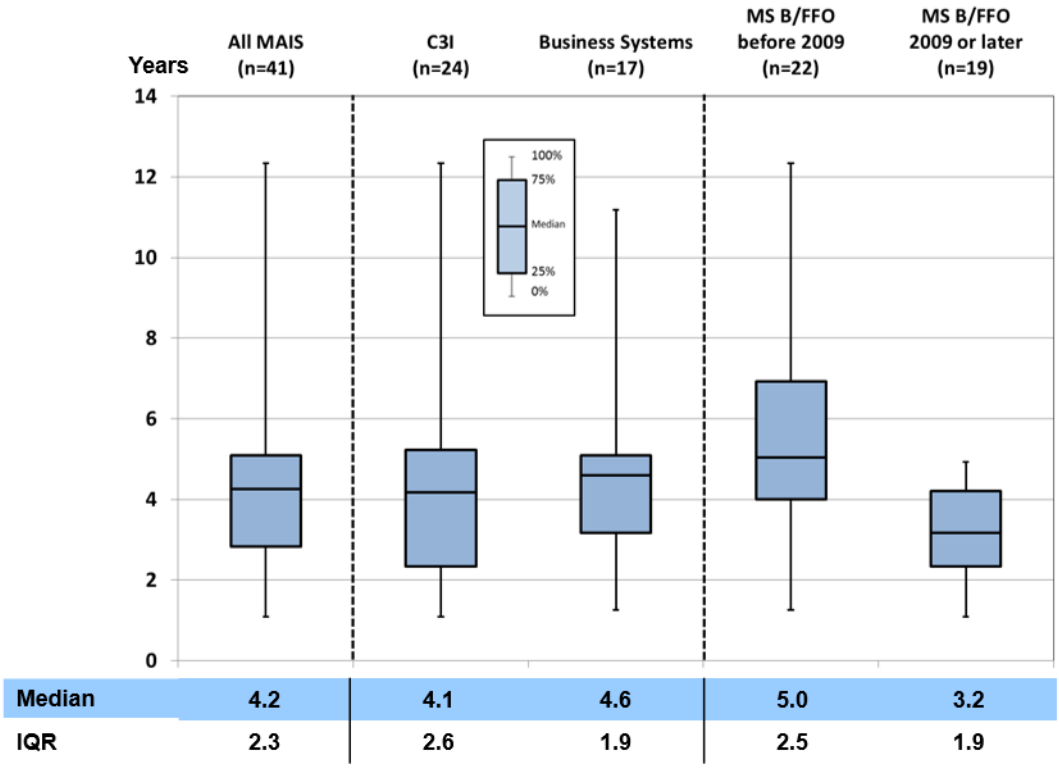
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MAIS Cycle Times

Figure 2-21 shows MAIS cycle time since 2011 as the number of years for each MAIS from MS B (or the date of FFO) to the FDD in the original estimate (i.e., the first MAR for the MAIS). Similar to last year's results, MAIS programs with MS B or FFO before 2009 had a median cycle time of 5 years; since then, the estimated median cycle times dropped to just above 3 years.[27] In other words, before 2009, half of the MAIS were planned with cycle times longer than 5 years. Since 2009, that estimate has dropped significantly, and no program is planned to take longer than 5 years since MS B or FFO. This may to be a direct result of the legal requirement for Critical Change Reports if the 5-year period is breached. Whether the DoD achieves these estimates and it improves acquisition performance are yet to be determined. Recall that the median schedule growth on all currently reporting MAIS since their original estimate is about 3 months (see Figure 2-10).

Figure 2-21. Program Length: Information Systems

Active MAIS Originally Planned Cycle Time from MS B or FFO to FDD (2011–2015 MARs)



	All MAIS (n=41)	C3I (n=24)	Business Systems (n=17)	MS B/FFO before 2009 (n=22)	MS B/FFO 2009 or later (n=19)
Median	4.2	4.1	4.6	5.0	3.2
IQR	2.3	2.6	1.9	2.5	1.9

NOTE: Original estimates are those in the MAIS' first MAR. Included are the latest data on programs that appeared in at least one MAR from 2011 through 2015. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. The IQR is the difference between the 75th and 25th percentiles. Immature programs that have not completed at least 30 percent of their original EMD schedule time were excluded to help control for maturity.

[27]Many MAIS increments have an MS B but not MS A, so we have more consistent data using MS B. For comparison, 5 years since MS A or FFO (not MS B as shown here) to FDD is the statutory threshold beyond which a certification of variance is required. The end points of the 5-year period have changed over the years, but it is currently from MS A or Preferred Alternative Decision to FDD.

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The optimal cycle time cannot be predetermined absent information on the system in question. In some cases, long cycle times may be a concern given how fast information technology advances. On the other hand, setting arbitrary schedule deadlines may incentivize undesirable management decisions and risky shortcuts, causing failures to meet end user needs and possibly increasing costs for subsequent upgrades.

COST PERFORMANCE: PRODUCTION

Program Production Funding Growth (Quantity Adjusted)

Now examining production at the program level, the following figures summarize the unit procurement funding growth across the MDAP portfolio from the original MS B baseline and biennial changes. These use recurring unit flyaway funding data reported in the SARs and are adjusted for quantity changes since the MS B baseline.

These program-level data are for measures that (unlike PAUC and APUC) are fully adjusted for any changes in procurement quantity. These results help compare procurement unit costs at the initially estimated quantities, extrapolating data if quantities have been reduced. This approach provides a superior way of comparing what the units would have cost if we had not changed quantities by, essentially, measuring the shift in the procurement cost-versus-quantity curve from planned to actual.[28] In other words, we measure changes in procurement cost at the currently planned quantity to be purchased (often lower than the initial) *and* assume that the original planned quantity still was being purchased. This approach allows us to examine on a unit basis the cost of the capability to acquire those units regardless of whether we increased or decreased quantity. Of course, quantity decreases may be due to unit-cost increases, and this approach will show such cost increases clearly.

Similar to the prior RDT&E results, growth distributions in production are highly skewed, with arithmetic means higher than the medians. As noted elsewhere for the contract-level data, the overall magnitudes of production funding growth are not nearly as large as those for RDT&E. There also is considerable variability in the production funding growth across the MDAP portfolio.

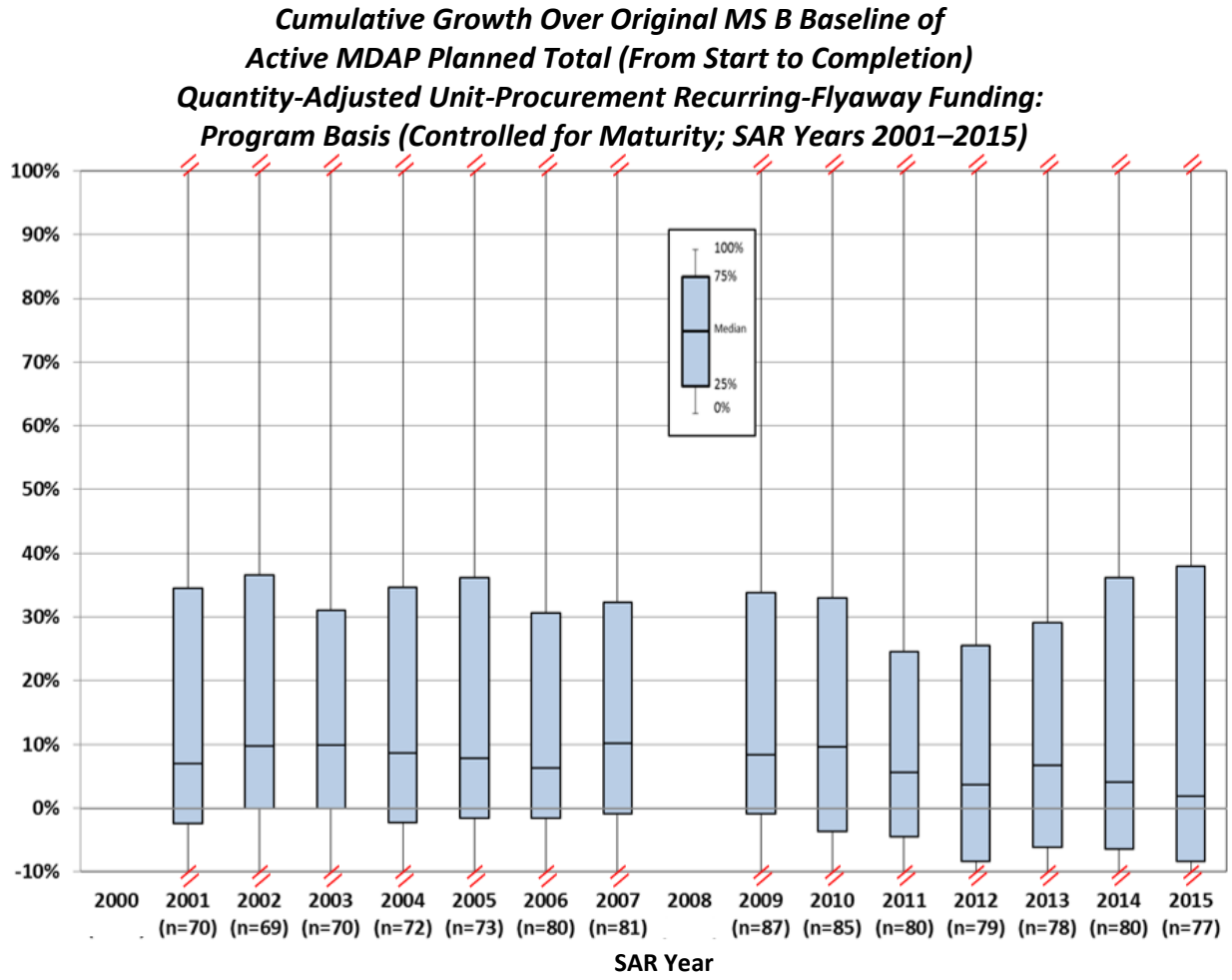
Figure 2-22 shows quantity-adjusted procurement cumulative unit-funding growth over original MS B baseline for each year's MDAP portfolio on a program basis (controlled for program maturity). As with last year's results, growth has been statistically flat since at least 2001, although the median has dropped in 2014 and 2015 and now runs about 2 percent—the lowest value measured in the years 2001–2015. Figure 2-23 shows that on a dollar basis (i.e., weighted by program size in dollars), the quantity-adjusted unit-funding growth since 2009 is statistically

[28]This basic approach for quantity adjustment is one of the standard techniques employed by the cost analysis community—see, for example, the discussions in Hough (1992), Arena et al. (2006, pp. 5–6), and Younossi et al. (2007, pp. 13-14).

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lower than in prior years (2001–2007). Moreover, 2015 is statistically lower than 2014, with a median that was cut in half and now runs 4 percent, which like the program basis is the lowest value measured in the years 2001–2015. Given these are based on budget data, one would be concerned that this might just reflect budgetary pressures on programs, but these procurement measures are adjusted for any quantity changes, so regardless of the budget changes they should be reflecting actual reductions in unit costs.

Figure 2-22. Program Cost-Related Performance: Procurement



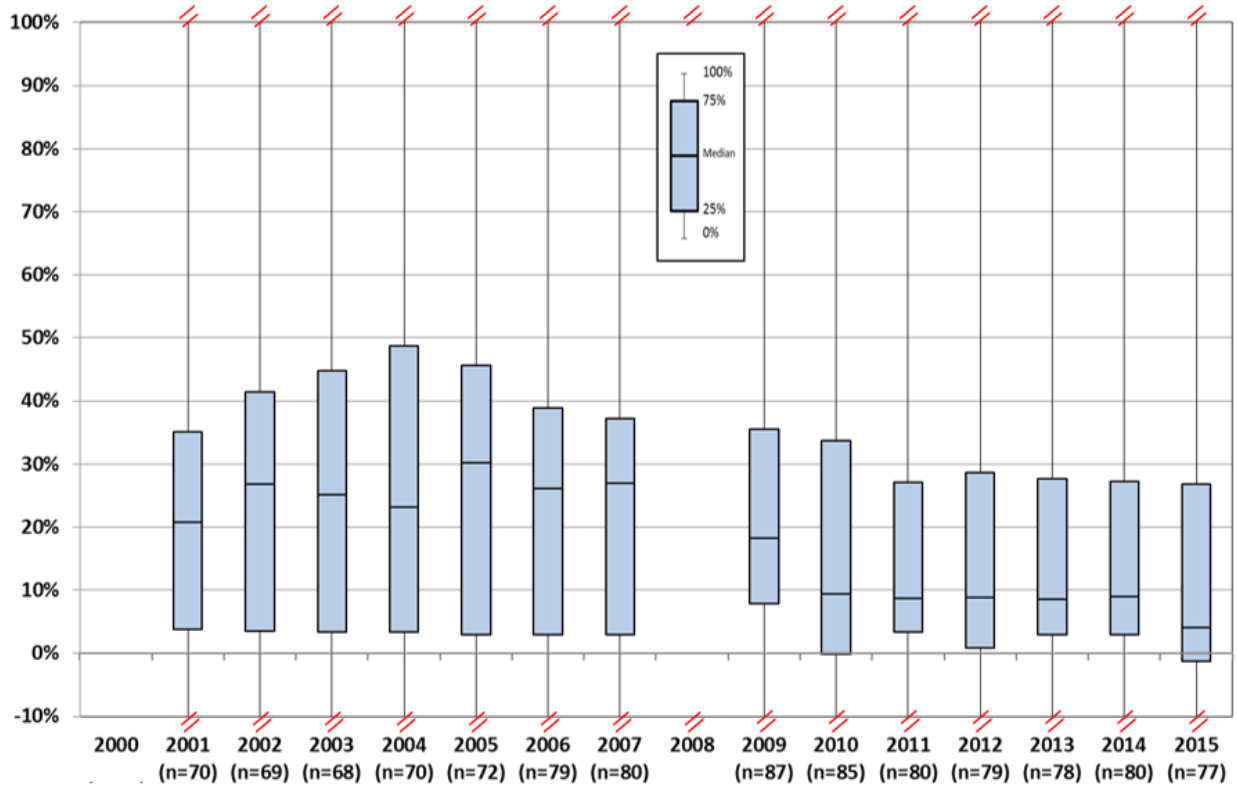
Median		7%	10%	10%	9%	8%	6%	10%		8%	10%	6%	4%	7%	4%	2%
IQR		37%	37%	31%	37%	38%	32%	33%		35%	37%	29%	34%	35%	35%	37%
Mean		27%	23%	20%	21%	29%	33%	32%		26%	29%	28%	24%	27%	27%	27%
Std Dev		76%	47%	35%	41%	75%	85%	76%		57%	66%	102%	77%	75%	76%	75%
Trends	***No trend across the years***															

NOTE: This shows growth in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not included. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. The IQR is the difference between the 75th and 25th percentiles.

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Figure 2-23. Program Cost-Related Performance: Procurement (Weighted by Program Size in Dollars)

Cumulative Growth Over Original MS B Baseline of Active MDAP Planned Total (From Start to Completion) Quantity-Adjusted Unit-Procurement Recurring-Flyaway Funding: Dollar Basis (Controlled for Maturity; SAR Years 2001–2015)



SAR Year

Median		**21%**	**27%**	**25%**	**23%**	**30%**	**26%**	**27%**		**18%**	**9%**	**9%**	**9%**	**8%**	**9%**	**4%**
IQR		31%	38%	42%	45%	43%	36%	34%		28%	34%	24%	28%	25%	24%	28%
Trend										***All generally lower than before 2009; 2015 is also lower than 2014***						

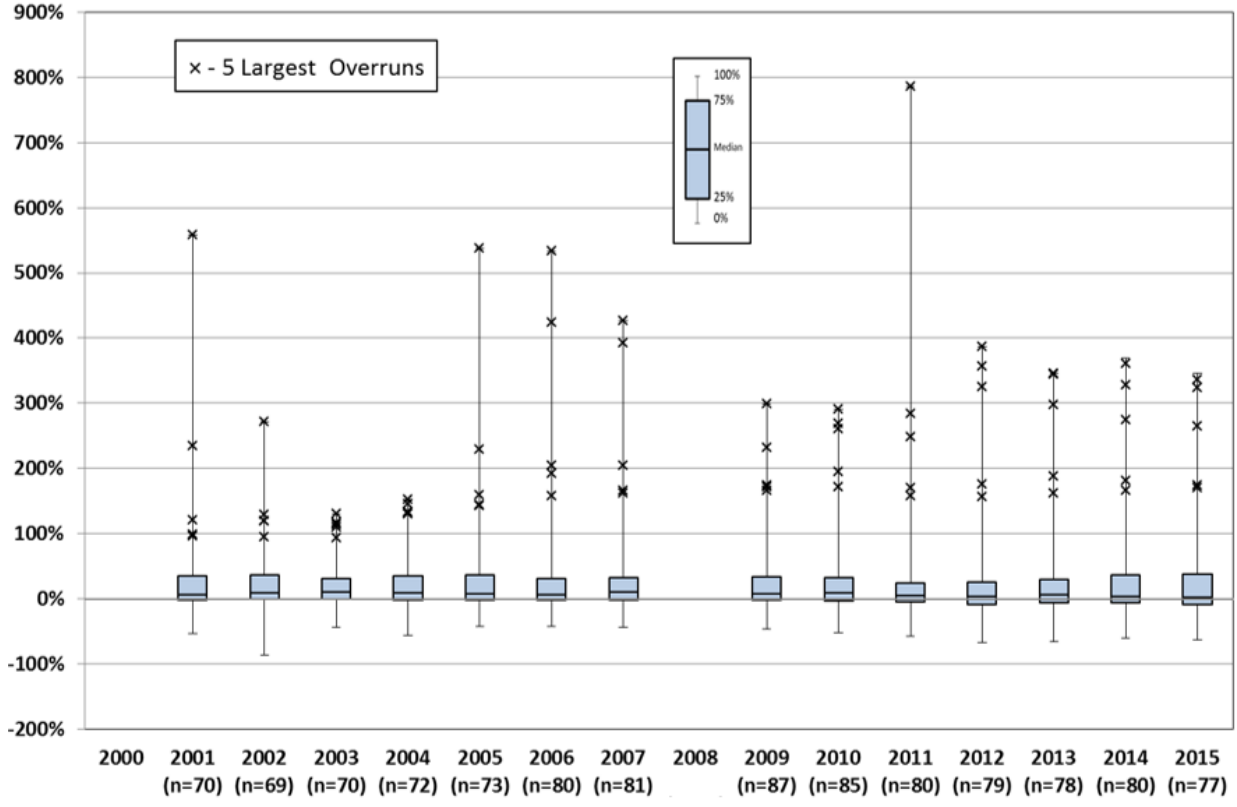
NOTE: This shows growth in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not included. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. The IQR is the difference between the 75th and 25th percentiles.

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Figure 2-24 extends the y-axis scale to show all outliers in Figure 2-22 and Figure 2-23, and the table at the bottom identifies the five largest funding-growth programs for each year. This chart is also controlled for program maturity.

Figure 2-24. Program Cost-Related Performance Outliers: Procurement

Cumulative Growth Over Original MS B Baseline of Active MDAP Planned Total (From Start to Completion) Quantity-Adjusted Unit-Procurement Recurring-Flyaway Funding: Outliers (Controlled for Maturity; SAR Years 2001–2015)



Largest		SADARM Projectile	ATACMS BLK II/IIA	PAC-3 Fire Unit	SBIRS High		NPOESS		SBIRS High	ATIRCM QRC	C-130 AMP	EELV	AEHF SV 1-4	
2nd Largest		ATIRCM CMWS	PAC-3 Fire Unit	GMLRS AW	EELV	NPOESS	SBIRS High		AEHF SV 1-4	SBIRS High		AEHF SV 1-4	EELV	
3rd Largest		PAC-3 Fire Unit	ATACMS BAT P3I	CH-47F		GMLRS AW	EELV		H-1 Upgrades	AEHF SV 1-4		SBIRS High		
4th Largest		GMLRS AW		EELV	GMLRS AW	EELV	GMLRS AW		C-130 AMP		GMLRS AW			
5th Largest		CH-47F	H-1 Upgrades	SBIRS High	PAC-3 Fire Unit	CH-47F		C-130 AMP	GMLRS AW	EFV	CH-47F		H-1 Upgrades	JPALS Inc 1A

NOTE: This shows growth in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not included. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. X's mark the growth for the five largest outliers on each box-and-whisker chart. Program abbreviations are defined in Appendix F starting on p. 159.

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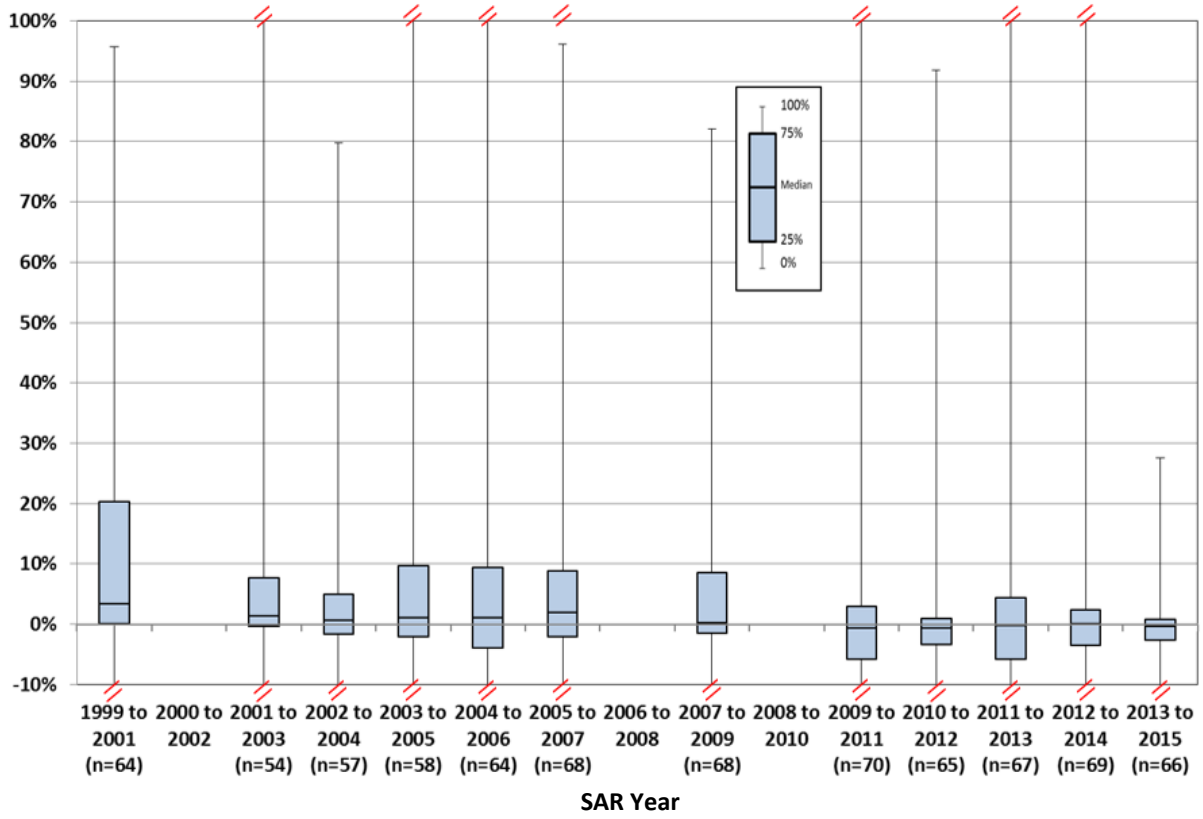
Biennial Funding Changes: Production

Figure 2-25 shows biennial changes in total quantity-adjusted unit procurement funding (actual and planned), controlling for program maturity. The most recent biennial period of 2013–2015 and the two periods 2009–2011 and 2010–2012 are statistically lower than the years 2001–2009. Thus, the most recent period has shown an improvement. Figure 2-26 shows total quantity-adjusted unit procurement funding, but on a dollar basis. On a dollar basis, the years 2009–2015 are lower than prior years. In both bases, the median unit funding growth has been zero or less since 2009, but the variation (as measured by IQR) has improved (tightened) by half from 2014 to 2015.

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Figure 2-25. Program Cost-Related Biennial Performance: Procurement

Biennial Change in Active MDAP Planned Total (From Start to Completion) Quantity-Adjusted Unit-Procurement Recurring-Flyaway Funding: Program Basis (Controlled for Maturity; SAR Years 1999–2015)



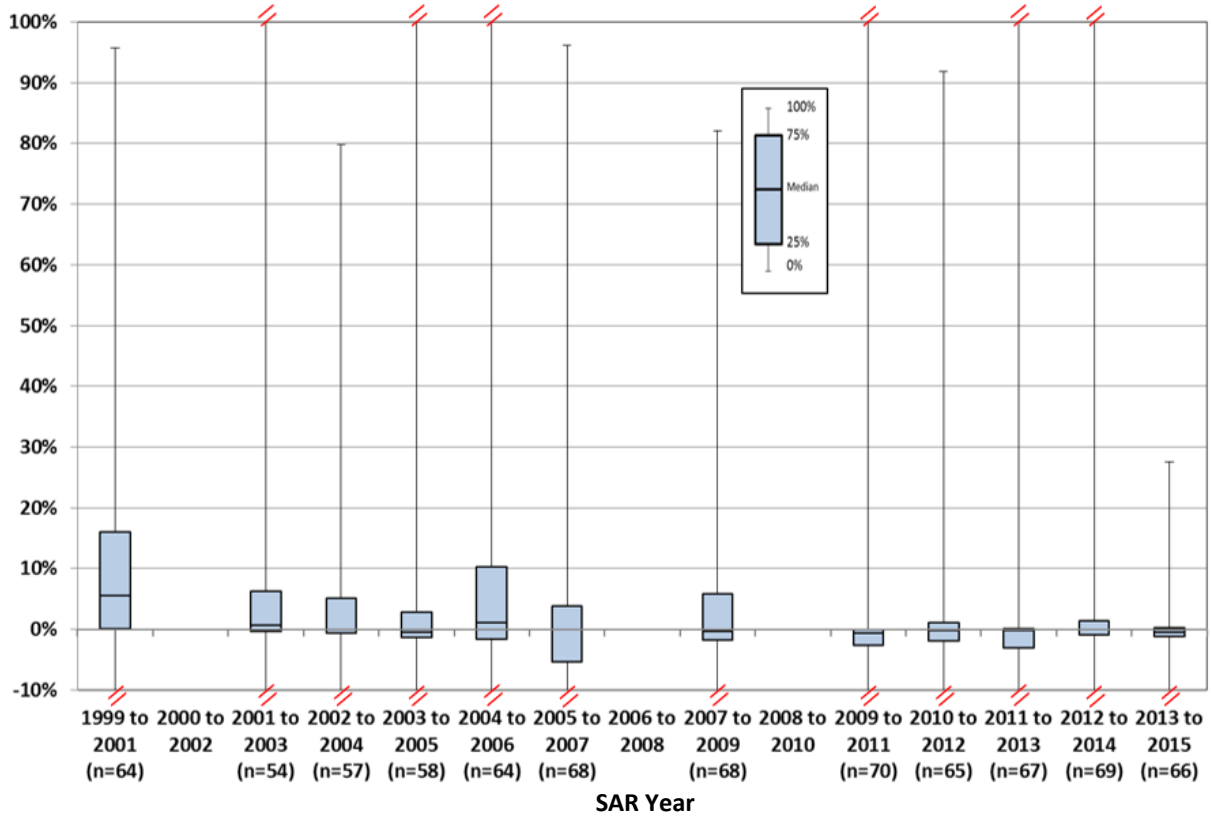
Median	3%		1%	1%	1%	1%	2%		0%		-1%	-1%	0%	0%	0%
IQR	20%		8%	7%	12%	13%	11%		10%		9%	4%	10%	6%	3%
Mean	12%		5%	2%	7%	10%	4%		5%		1%	0%	3%	4%	-1%
Std Dev	25%		23%	19%	32%	43%	20%		17%		31%	17%	23%	32%	11%
Trends	***Higher than later periods***										***Lower than 2001–2009***				***Lower than 2001–2009***

NOTE: This shows biennial changes in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not included. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. The IQR is the difference between the 75th and 25th percentiles.

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Figure 2-26. Program Cost-Related Biennial Performance: Procurement (Weighted by Program Size in Dollars)

Biennial Change in Active MDAP Planned Total (From Start to Completion) Quantity-Adjusted Unit-Procurement Recurring-Flyaway Funding: Dollar Basis (Controlled for Maturity; SAR Years 1999–2015)



Median	6%		1%	0%	0%	1%	0%		0%		-1%	0%	0%	0%	0%
IQR	16%		7%	6%	4%	12%	9%		8%		3%	3%	3%	2%	1%
Trend											***Lower than most years prior to 2009***				

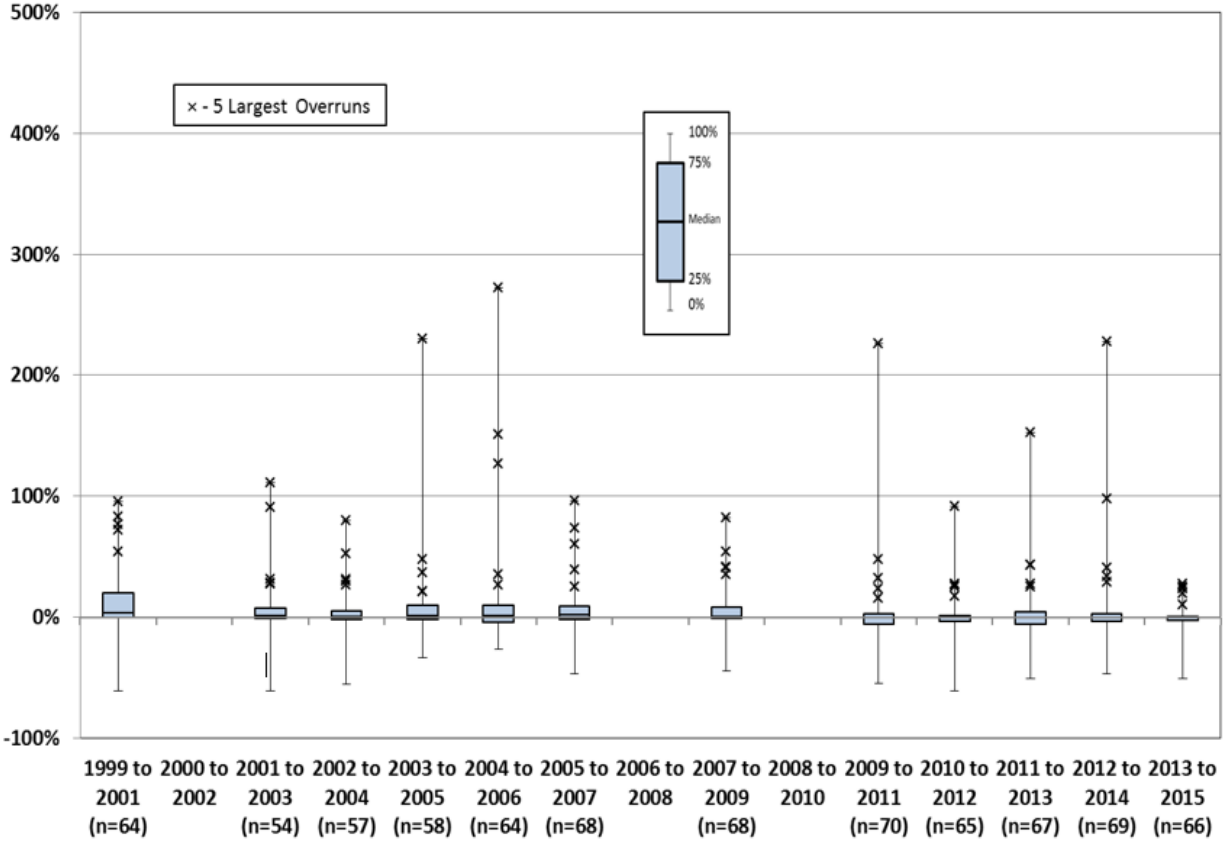
NOTE: This shows biennial changes in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not included. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. The IQR is the difference between the 75th and 25th percentiles.

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Figure 2-27 extends the y-axis scale to show all outliers in Figure 2-25 and Figure 2-26, and the table at the bottom identifies the five largest funding-growth programs for each year. This chart also is controlled for program maturity.

Figure 2-27. Program Cost-Related Biennial Performance Outliers: Procurement

Biennial Change in Active MDAP Planned Total (From Start to Completion) Quantity-Adjusted Unit-Procurement Recurring-Flyaway Funding: Program Basis Outliers (Controlled for Maturity; SAR Years 1999–2015)



Largest	CH-47F		SBIRS High	EELV	NPOESS		C-130 AMP		B-2 RMP		C-130 AMP	JTRS HMS	JPALS Inc 1A			
2nd Largest	ATIRCM CMWS		EELV	CH-47F	SBIRS High	LAND WARRIOR	EFV		AEHF SV 1-4		JTRS HMS	B-2 EHF Inc 1	MQ-8 Fire Scout			
3rd Largest	GMLRS AW		AEHF SV 1-4	SBIRS High	UH-60M	SBIRS High	NPOESS		VTUAV		Excalibur	AEHF SV 1-4	AH-64E Reman	G/ATOR	RMS	
4th Largest	MH-60R		TACTOM	AEHF SV 1-4	FCS	C-130 AMP	AEHF SV 1-4		AH-64E Reman		FAB-T	MQ-9 Reaper	AEHF SV 1-4	RMS	DDG 1000	
5th Largest	H-1 Upgrades		B-1B CMUP Computer	UH-60M	LAND WARRIOR	EFV	LHA 6		H-1 Upgrades		WGS	CH-53K	JTRS HMS	AH-64E Reman	SDB II	

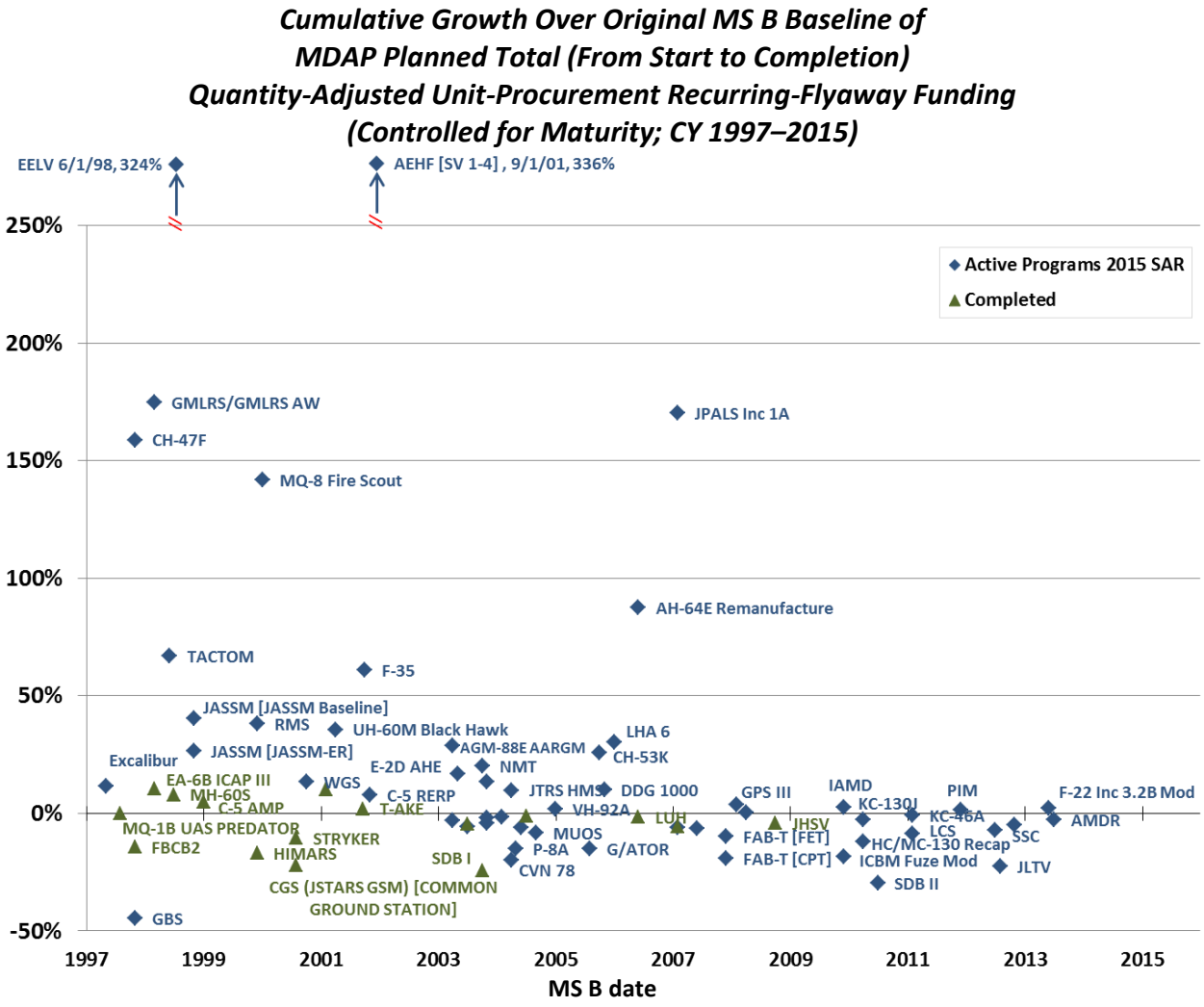
NOTE: This shows biennial changes in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not included. Boxes show second quartile, median, and third quartile; bars show first and fourth quartiles, minimum, and maximum. X's mark the growth for the five largest outliers on each box-and-whisker chart. X's mark the growth for the five largest outliers on each box-and-whisker chart. Program abbreviations are defined in Appendix F starting on p. 159.

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Program Funding Growth by Start Date: Production

Finally, as for development, we examine program procurement performance based on initiation date. Figure 2-28 plots quantity-adjusted procurement unit funding growth of all active and completed MDAPs by their original MS B date. As before, we controlled for maturity by removing newer programs.

Figure 2-28. Program Cost-Related Performance: Procurement



NOTE: This shows growth in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. Program abbreviations are defined in Appendix F starting on p. 159.

Again, there is an apparent recent improvement, but it is not statistically significant when testing back to 1997; the variation explained by any potential trend (i.e., the R^2) was too low.

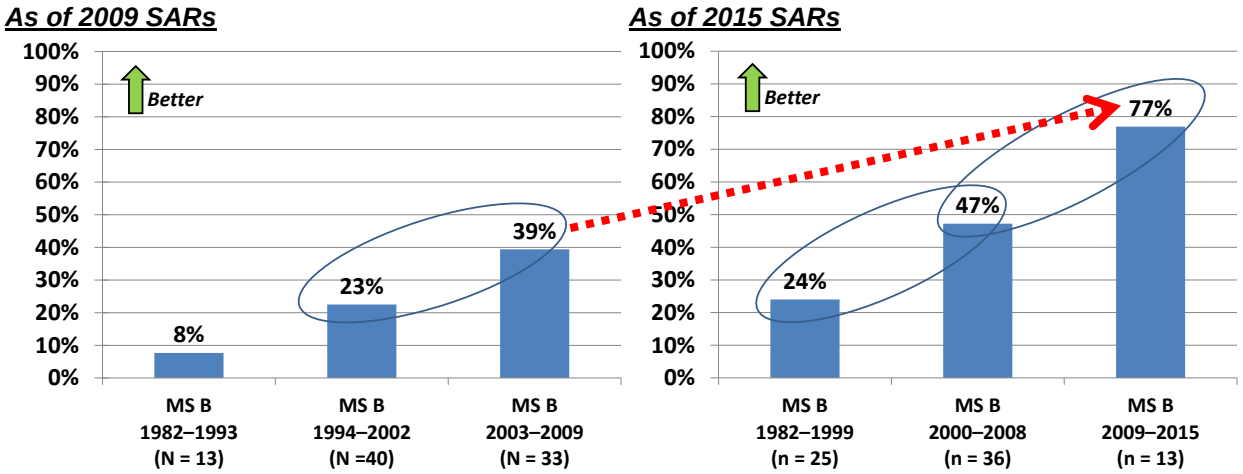
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However, as in development, we did find in production that recent programs are, in fact, improving when using a proportion test comparing programs started since 2009 to earlier programs. Figure 2-29 shows the result of separating the portfolio of active MDAPs based on program start date (i.e., their original MS B date). After deleting immature programs (i.e., those that are too new to reveal the magnitude of potential problems), we find that the proportion of active MDAPs showing quantity-adjusted unit procurement reductions (negative funding growth from original MS B baseline) is significantly higher at 77 percent since 2009 than the 47 percent for 2000–2008. Last year, the results were similar at 79 percent and 44 percent, respectively.

To help test whether this is just a result of any remaining maturity bias, we conducted the same proportion test using earlier 2009 SARs. While the proportional differences were also significant, the percentages were lower than what we see now in the 2015 SARs. Thus, as in development, there is evidence that this is not just a maturity bias; MDAPs started since 2009 are performing better in production at controlling cost. This may be a result of our affordability caps on MDAP production costs. In addition, the Should-Cost BBP initiative was introduced in 2010.

Figure 2-29. Reductions to Planned Program Funding: Procurement

Proportions of Active MDAPs With Cost-Related Reductions Since Original MS B in Cumulative Planned Total (From Start to Completion)
Quantity-Adjusted Unit-Procurement Recurring-Flyaway Funding
(Program Basis; Quantity Adjusted; Controlled for Maturity)



NOTE: This shows growth in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. Statistically significant differences between adjacent periods are marked with an oval. A program shows a reduction if current total unit funding is under original MS B baseline after adjusted for quantity changes since MS B baseline. Relatively new programs that have not been through at least 30 percent of their original EMD schedule are not included to help control for low maturity.

Conceptually, two behaviors different than those in development may be at work here if these are related to budget cuts instead of better program initiations. First, if quantity was reduced on an MDAP to accommodate budget reductions, we would see an increased unit funding. However, we adjusted unit funding for any quantity changes and still saw reductions.

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Therefore, a reduction in this case would be real. Second, if the production rate decreased due to budget cuts, the learning curve theoretically would decrease, as well. Our adjustment for quantity directly compares the initial estimated learning curve against the latest curve, so we would see this as an increase, not a decrease. The reductions we see in the data are real, and they do correlate well to the management actions taken under BBP. The data do not provide a basis for conclusively assessing cause and effect, but the trend is very encouraging.

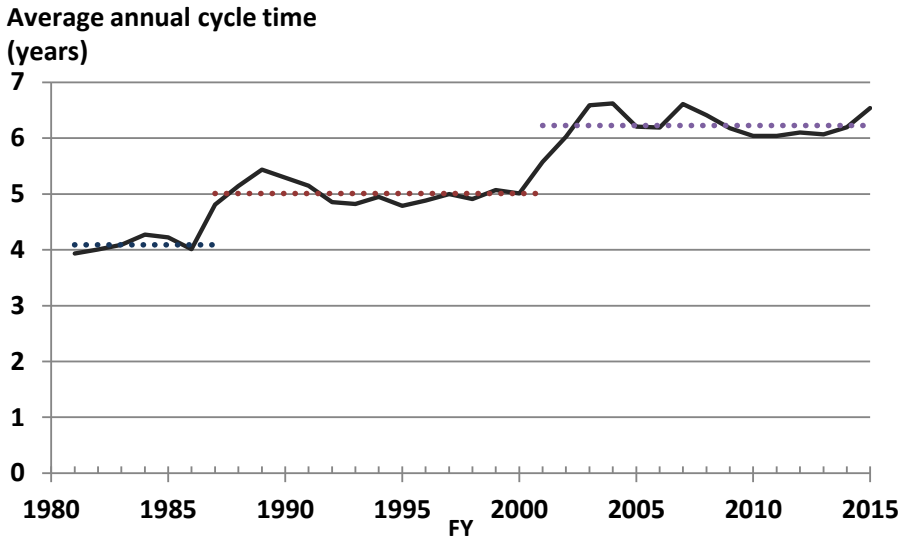
CONTRACT-LEVEL CYCLE TIMES AND SCHEDULE GROWTH: DEVELOPMENT AND EARLY PRODUCTION

Cycle Time Trends: Development Contracts

Using EV reports from FY 1981–2015, we examined planned cycle times for major MDAP development contracts. Planned cycle time in this contract analysis is defined as the annual average of the original schedule for major executing MDAP contracts in each year. These included development contracts only (unweighted by program size), approximating the time from inception to when operators first begin getting units into the hands of the operator (neglecting significant concurrency with procurement).

These data show that the average annual cycle time has increased in two steps from about 4 years in 1981 to about 5 years in the 1990s to just over 6 years since 2001 (see Figure 2-30). This "active portfolio" measure is different than measuring cycle time by contract start date, which prior analysis in last year's report showed a downward trend from 2001–2013 (although the medians was similar at about 6 years). This may be an effect of longer contracts remaining in the active portfolio. Regardless, such cycle-time measures do not reflect the realistic time associated with an effort, given the scope and maturity of available technology. Schedule growth therefore is a better metric in that regard.

Figure 2-30. Average Annual Development Contract Cycle Time (FY 1981–2015)



NOTE: 9,582 earned-value reports on 472 major development contracts for 190 MDAPs.

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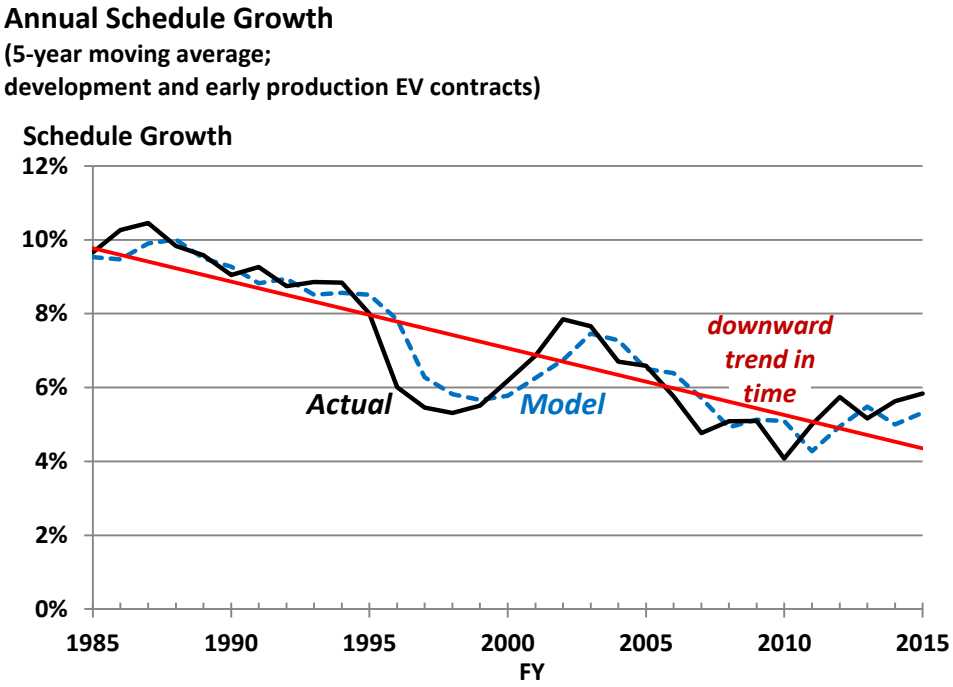
Schedule Growth Trends

We analyzed schedule growth on development and early production contracts reporting EV from FY 1985–2015. These data summarize 18,470 earned-value reports on 1,123 major contracts for 239 MDAPs.

Our statistical model shows that the 5-year moving average of annual growth of contracted costs is closely modeled by a downward trend over time together with a self-correction function that adjusts for prior random deviations from this downward trend. Details on this statistical model are in the latter part of Appendix B starting on p. 148.

Therefore, we have strong longitudinal evidence of declining schedule growth on MDAP development and early production contracts over the past three decades. This contrasts with the program-level data on schedule growth from MS B/C to IOC, which showed no trend (see p. 46).

Figure 2-31. Statistical Model Fit to Actual EV Contract Schedule Growth (FY 1985–2015)



NOTE: 18,470 EV reports on 1,123 major contracts for 239 MDAPs.

INSTITUTIONAL ANALYSES: MILITARY DEPARTMENTS

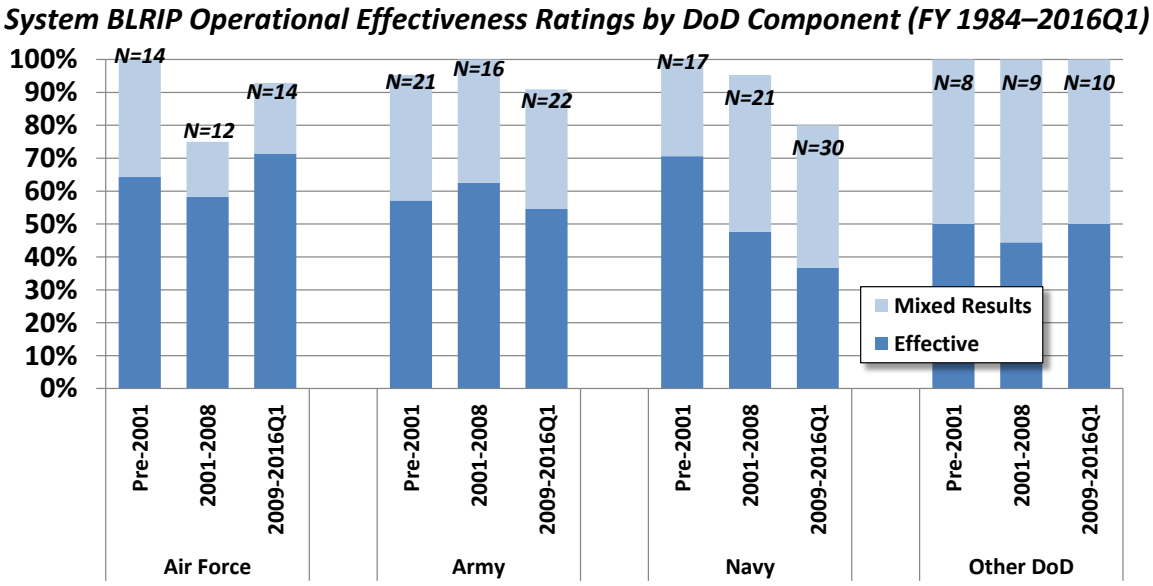
This section summarizes various acquisition performance metrics analyzed by DoD Component. Here we examined significant program-level cost growth as exhibited by Nunn-McCurdy breaches as well as contract-level cost, price, and schedule growth.

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Operational Testing of Effectiveness and Suitability by DoD Component

Figure 2-32 shows effectiveness ratings for the DoD Components during BLRIP operational tests. There are no statistically significant trends in the data, although some differences can be seen. Also, DOT&E testing policies and procedures changed in FY 2000 and 2005, further complicating comparisons between these periods.

Figure 2-32. System Operational Test Performance: Effectiveness by DoD Component



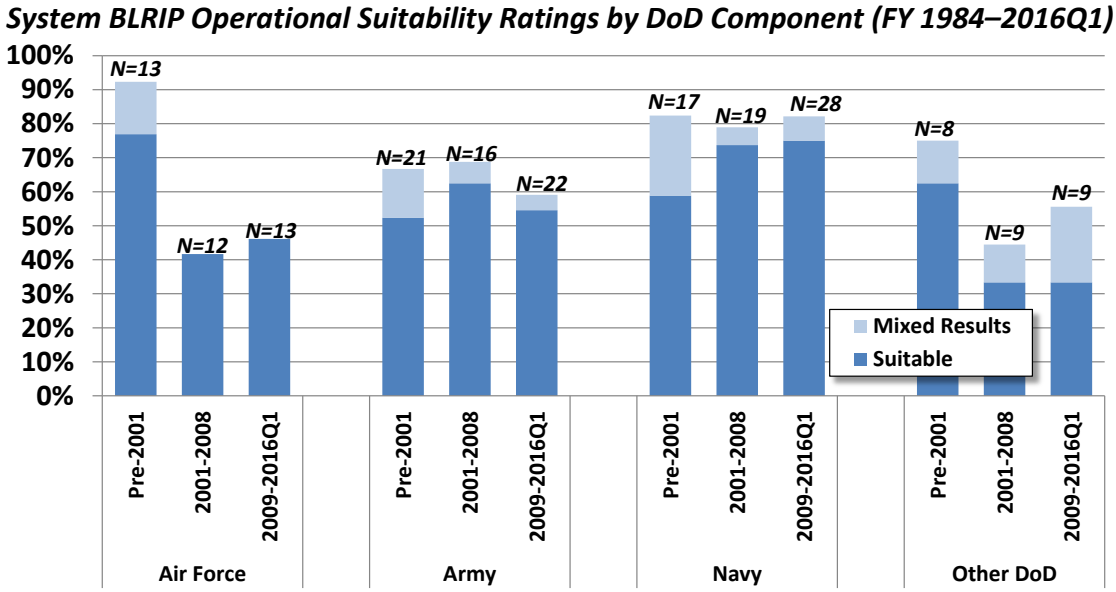
Source: DOT&E reports.

NOTE: Differences are only apparent and may not be significant due to the low sample sizes (infrequent evaluations). DoD programs were Joint or other programs that are not exclusive to a single DoD Component. Sample sizes differ between effectiveness and suitability for some DoD Components because there was not always a definitive binary judgment for effectiveness and suitability in all reports.

Figure 2-33 shows suitability test results. Overall, the performance of systems across DoD Components is much lower for suitability than for effectiveness. Again, any apparent trends are not statistically significant.

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Figure 2-33. System Operational Test Performance: Suitability by DoD Component



Source: DOT&E reports.

NOTE: Differences are only apparent and may not be significant due to the low sample sizes (infrequent evaluations). DoD programs were Joint or other programs that are not exclusive to a single DoD Component. Sample sizes differ between effectiveness and suitability for some DoD Components because there was not always a definitive binary judgment for effectiveness and suitability in all reports.

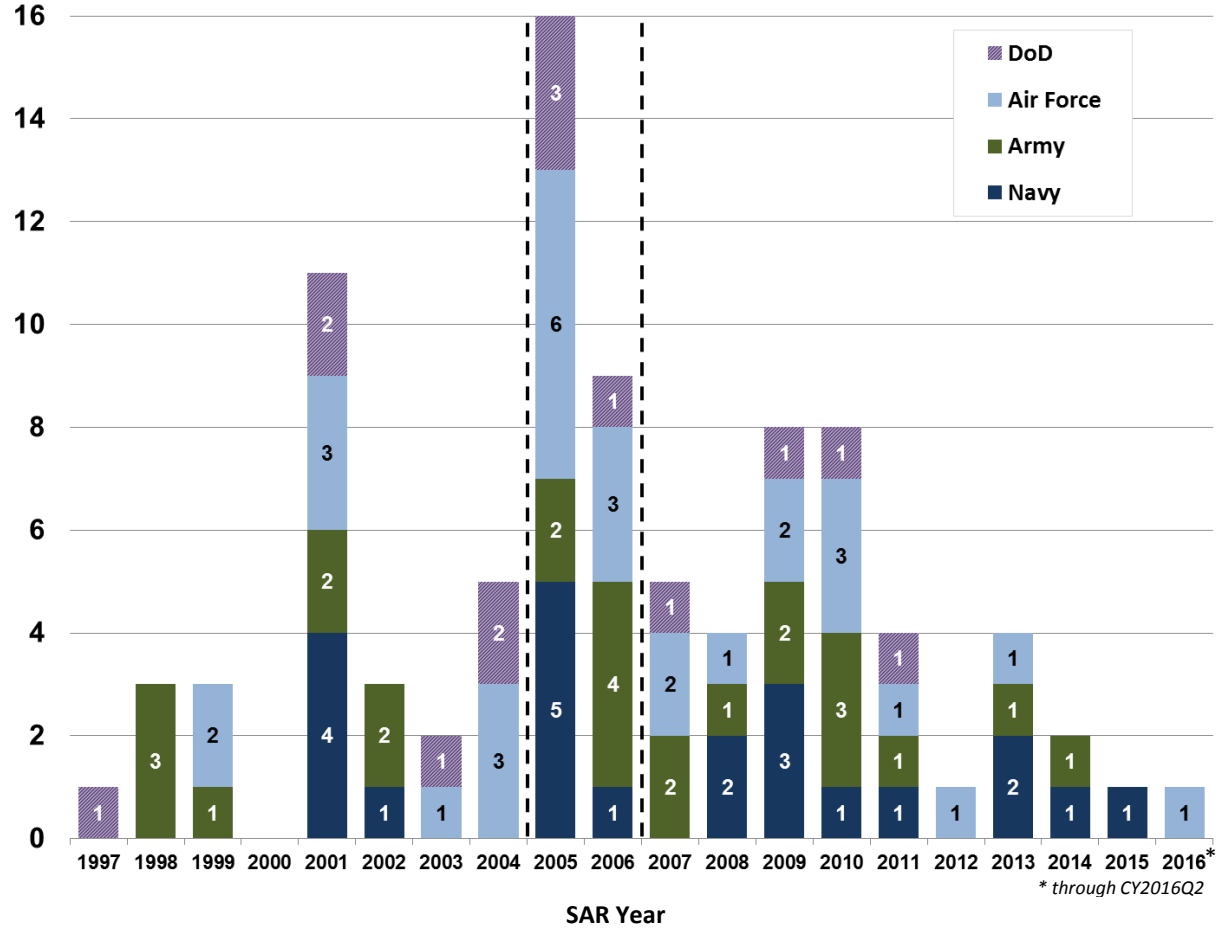
Nunn-McCurdy Cost Breaches

One measure of acquisition program cost performance is the Nunn-McCurdy breach rate by DoD Component. Figure 2-34 shows significant and critical Nunn-McCurdy breach numbers by year from 1997 through the second quarter of CY 2016. As introduced previously, this chart now aligns with the DoD official breach list (Table 2-5 on p. 24 above). There was one breach in each of 2015 and 2016 (through Q2): RMS in the Navy and OCX in the Air Force, respectively.

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Figure 2-34. Program Cost-Related Performance: Nunn-McCurdy Breaches by DoD Component

Nunn-McCurdy Significant and Critical Breaches by DoD Component (SAR Years 1997–2016Q2)



NOTE: The criteria for breaches were changed in NDAA 2006, so the counts before 2005 are different than those since 2006, and 2005 was a transition year and not comparable to either half. Breaches are determined using "base-year" dollars (i.e., adjusting for inflation). This plot includes the number of breaches in each annual SAR cycle, which nominally equates to calendar year but may include updates early in the following calendar year from the President's Budget Request. Breaches in different years for different thresholds or baselines for the same program are included in each respective year. If a program reported both a significant and critical breach in the same year, only one breach is shown here. Nunn-McCurdy breach reporting was established in the NDAA for FY 1982, but the new official Office of the USD(AT&L) list only tracks breaches back through 1997.

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Table 2-10 summarizes a different analysis of Nunn-McCurdy breaches by DoD Component. Here we do not "double count" programs that have breached multiple times. This allows us to get a sense of the tendency of programs to breach within each DoD Component.

Historically, about a third of MDAPs breached at least the significant threshold (i.e., about two-thirds have cost growth below 15 percent). At least two-thirds of programs that breach at the significant level eventually also breach the critical threshold (i.e., fewer remain at the significant level), except for Army programs, which are more evenly split between significant- and critical-breaching programs.

All breaches are listed regardless of cause. If a program had both a significant and a critical breach, it was included only in the "programs with critical breach" column.

As discussed in the earlier Nunn-McCurdy breach section, there are various causes of these breaches.

Table 2-10. Nunn-McCurdy Breaches by DoD Component

Nunn-McCurdy MDAP Breach Rates by DoD Component (SAR Years 1997–2016Q2)

Component	Total # of Programs	# of Programs that Ever Breached	Breach Rate	# of Programs with at Most a Significant Breach	# of Programs with a Critical Breach
DoD	12	7	58%	1	6
Army	56	18	32%	8	10
Navy	64	17	27%	6	11
Air Force	57	16	28%	3	13
Total	**189**	**58**	**31%**	**18**	**40**

NOTE: The list of MDAPs by DoD Component has been revised slightly since last year's report to align with the new official list. If a program had both a significant and critical breach, it was included only in the "programs with critical breach" column. The data are not adjusted for quantity or other variances. "DoD" programs are programs categorized as such in the SARs, which include Joint programs and programs (such as Chem Demil) overseen by an organization other than the Air Force, Army, or Navy. Breaches are determined using "base-year" dollars (i.e., adjusted for inflation).

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Program Cost Growth and New Statutory Penalties

Section 828 of the FY 2016 NDAA (Pub. L. 114–92) enacted a new cost-growth calculation and associated penalty for each of the military departments. For each year beginning with FY 2015, the Secretary of each military department shall pay a penalty for cost overruns on the covered MDAPs of the military department. Programs and subprograms included are those with an original APB dated on or after May 22, 2009 (which is the enactment date of the WSARA of 2009). This includes, for example, the F-35 program because it received a revised original baseline due to its Nunn-McCurdy breach after the passage of WSARA.

The "overrun" is defined as the difference between the Current Estimate PAUC minus the Original Baseline Estimate PAUC, all multiplied by the current quantity to be purchased. Overruns are summed across all applicable programs and subprograms for each military department. If the cumulative overrun is positive, then the military department is penalized 3 percent of the total overrun calculated that FY. Thus, if overruns continue in future fiscal years, then there will be a 3-percent penalty each FY. Since these results are dollar weighted, large programs (by dollar) have a larger effect than smaller programs.

Table 2-11 shows the result of applying this algorithm to the December SARs from FY 2015. In FY 2015, the departments of the Air Force, Army, and Navy showed net negative overruns (i.e., underruns) of −$24.4 billion, −$0.5 billion, and −$2.8 billion. Large underruns for EELV, F-35 aircraft, and KC-46A dominated the Air Force result. The large overrun from the AH-64E Remanufacture was mostly negated by the large underruns by the Integrated Air and Missile Defense (IAMD) and MQ-1C Gray Eagle for the Army. The large underrun from the F-35 aircraft program was the dominant correction for the large overrun on E-2D AHE for the Navy.

Table 2-12 shows that, in FY 2016, all three departments improved, with lower negative overruns (i.e., underruns) of −$29.5 billion, −$3.8 billion, and −$3.9 billion. Again, large underruns for the EELV, F-35 aircraft, and KC-46A (with other underruns, including a now-underrunning F-35 engine subprogram) dominated the Air Force result. For the Army, JLTV joined IAMD and MQ-1C Gray Eagle in negating the overrun from the AH-64E Remanufacture. The change in JLTV from FY 2015 to 2016 is the result of further cost savings because of the competition for production. The large (and improving) underruns from F-35 aircraft and engine subprograms were the dominant corrections for the large overrun on E-2D AHE for the Navy.

There was no net overrun for any of the military departments in either year and therefore no military department incurred penalties. Thus, all three military departments showed net improvements across their portfolios of programs with original baselines since 2009. This result aligns with our other analysis, indicating that cost growth has improved recently, and it is the programs that started before 2009 that have higher cost growth.

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Table 2-11. Military Department MDAP "Overrun" Calculations and Penalties (FY 2015)

Constant BY15 ($M)					
Air Force Programs	**Original PAUC**	**Current PAUC**	**Current Quantity**	**Over/Under $**	**%**
AEHF SV 1-4	2,894.460	2,974.776	4	$ 321.26	3%
AEHF SV 5-6	1,729.992	1,331.886	2	$ (796.21)	-23%
AWACS Blk 40/45 Upgrade	95.110	116.356	24	$ 509.91	22%
B61 Mod 12 LEP TKA	1.551	1.523	890	$ (25.10)	-2%
CRH	73.251	74.045	112	$ 88.92	1%
EELV	422.281	360.880	165	$ (10,131.21)	-15%
EPS	704.274	701.181	2	$ (6.19)	0%
F-22 Inc 3.2B Mod	10.411	10.136	152	$ (41.93)	-3%
F-35 - Aircraft (AF Qtys)	117.505	112.566	1,772	$ (8,752.08)	-4%
F-35 - Engine (AF Qtys)	22.914	23.636	1,772	$ 1,279.12	3%
HC/MC-130 Recap	119.360	108.372	131	$ (1,439.37)	-9%
ICBM Fuze Mod	2.357	2.372	781	$ 11.88	1%
JASSM Baseline	1.604	1.521	2,121	$ (177.15)	-5%
JASSM-ER	1.557	1.382	2,897	$ (505.93)	-11%
KC-46A	258.544	239.356	179	$ (3,434.63)	-7%
MQ-9 Reaper	31.705	32.866	364	$ 422.55	4%
OCX	3,496.646	3,678.206	1	$ 181.56	5%
SBIRS High - Block Buy (GEO 5-6)	1,903.839	1,691.418	2	$ (424.84)	-11%
SDB II	0.290	0.228	17,163	$ (1,064.11)	-21%
Space Fence Inc 1	1,589.648	1,562.878	1	$ (26.77)	-2%
WGS	559.499	505.547	8	$ (431.61)	-10%
				$ (24,441.93)	
Army Programs	**Original PAUC**	**Current PAUC**	**Current Quantity**	**Over/Under $**	**%**
AH-64E New Build	41.347	36.230	63	$ (322.42)	-12%
AH-64E Remanufacture	17.771	21.552	639	$ 2,416.27	21%
Excalibur	0.251	0.255	7,583	$ 25.85	1%
IAMD	17.756	14.156	443	$ (1,594.56)	-20%
JLTV (Army Qtys)	0.435	0.430	49,168	$ (205.45)	-1%
MQ-1C Gray Eagle	183.772	152.058	34	$ (1,078.28)	-17%
PIM	12.206	12.701	558	$ 276.24	4%
				$ (482.34)	
Department of Navy Programs	**Original PAUC**	**Current PAUC**	**Current Quantity**	**Over/Under $**	**%**
AIM-9X Block II	0.703	0.575	6,000	$ (765.69)	-18%
AMDR	268.329	234.052	22	$ (754.11)	-13%
CVN 78 - EMALS	1,002.376	953.926	3	$ (145.35)	-5%
DDG 1000	7,696.823	7,567.990	3	$ (386.50)	-2%
E-2D AHE	254.669	282.660	75	$ 2,099.33	11%
F-35 - Aircraft (DoN Qtys)	117.505	112.566	689	$ (3,403.04)	-4%
F-35 - Engine (DoN Qtys)	22.914	23.636	689	$ 497.36	3%
G/ATOR	54.749	60.706	45	$ 268.05	11%
JLTV (USMC Qtys)	0.435	0.430	5,552	$ (23.20)	-1%
KC-130J	96.310	92.168	104	$ (430.83)	-4%
LCS	631.272	644.500	32	$ 423.30	2%
LCS MM	108.125	106.579	64	$ (98.93)	-1%
RMS	27.656	28.696	54	$ 56.15	4%
SSC	57.187	55.097	73	$ (152.55)	-4%
VH-92A	204.991	206.137	23	$ 26.35	1%
				$ (2,789.64)	

SOURCE: December 2014 SARs.
NOTE: "Overruns" in this case are defined (by Section 828 of the FY 2016 NDAA) relative to original PAUC baselines at current total quantities. Program abbreviations are defined in Appendix F starting on p. 159.

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Table 2-12. Military Department MDAP "Overrun" Calculations and Penalties (FY 2016)

Constant BY16 ($M)					
Air Force Programs	**Original PAUC**	**Current PAUC**	**Current Quantity**	**Over/Under $**	**%**
AEHF SV 1-4	2,920.527	3,020.982	4	$ 401.82	3%
AEHF SV 5-6	1,745.572	1,348.252	2	$ (794.64)	-23%
AWACS Blk 40/45 Upgrade	95.967	116.613	24	$ 495.52	22%
B61 Mod 12 LEP TKA	1.565	1.415	890	$ (134.15)	-10%
CRH	73.911	74.827	112	$ 102.56	1%
EELV	426.084	363.855	161	$ (10,018.93)	-15%
EPS	710.616	706.115	2	$ (9.00)	-1%
F-22 Inc 3.2B Mod	10.505	10.258	152	$ (37.57)	-2%
F-35 - Aircraft (AF Qtys)	118.563	112.296	1,768	$ (11,080.79)	-5%
F-35 - Engine (AF Qtys)	23.121	22.093	1,768	$ (1,816.98)	-4%
HC/MC-130 Recap	120.435	107.558	131	$ (1,686.90)	-11%
ICBM Fuze Mod	2.378	2.400	781	$ 17.58	1%
JASSM Baseline	1.619	1.557	2,121	$ (130.00)	-4%
JASSM-ER	1.571	1.398	2,897	$ (500.98)	-11%
KC-46A	260.873	239.424	179	$ (3,839.33)	-8%
MQ-9 Reaper	31.990	33.729	350	$ 608.66	5%
OCX	3,528.137	4,275.779	1	$ 747.64	21%
SBIRS High - Block Buy (GEO 5-6)	1,890.733	1,610.042	2	$ (561.38)	-15%
SDB II	0.293	0.246	17,163	$ (816.34)	-16%
Space Fence Inc 1	1,603.964	1,525.797	1	$ (78.17)	-5%
WGS	564.538	524.164	8	$ (322.99)	-7%
				$ (29,454.36)	
Army Programs	**Original PAUC**	**Current PAUC**	**Current Quantity**	**Over/Under $**	**%**
AH-64E New Build	41.720	35.299	63	$ (404.48)	-15%
AH-64E Remanufacture	17.931	21.682	639	$ 2,396.77	21%
AMPV	3.697	3.705	2,936	$ 23.77	0%
Excalibur	0.253	0.250	8,040	$ (27.66)	-1%
IAMD	17.916	14.416	443	$ (1,550.28)	-20%
JAGM	0.217	0.217	26,437	$ -	0%
JLTV (Army Qtys)	0.438	0.368	49,214	$ (3,475.58)	-16%
MQ-1C Gray Eagle	185.427	155.340	34	$ (1,022.98)	-16%
PIM	12.316	12.761	570	$ 253.35	4%
				$ (3,807.08)	
Department of Navy Programs	**Original PAUC**	**Current PAUC**	**Current Quantity**	**Over/Under $**	**%**
AIM-9X Block II	0.709	0.626	6,000	$ (502.18)	-12%
AMDR	270.746	242.253	22	$ (626.84)	-11%
CVN 78 - EMALS	995.475	920.399	3	$ (225.23)	-8%
DDG 1000	7,766.140	7,742.828	3	$ (69.93)	0%
E-2D AHE	256.962	287.346	75	$ 2,278.75	12%
F-35 - Aircraft (DoN Qtys)	118.563	112.296	689	$ (4,318.25)	-5%
F-35 - Engine (DoN Qtys)	23.121	22.093	689	$ (708.09)	-4%
G/ATOR	55.242	61.522	45	$ 282.60	11%
JLTV (USMC Qtys)	0.438	0.368	5,549	$ (391.88)	-16%
KC-130J	97.178	91.379	104	$ (603.06)	-6%
LCS	637.013	654.472	40	$ 698.37	3%
LCS MM	109.099	108.986	64	$ (7.21)	0%
RMS	27.905	87.039	10	$ 591.33	212%
SSC	57.702	53.831	73	$ (282.62)	-7%
VH-92A	206.837	205.810	23	$ (23.63)	0%
				$ (3,907.85)	

Key: Under-run / Over-run

SOURCE: December 2015 SARs.

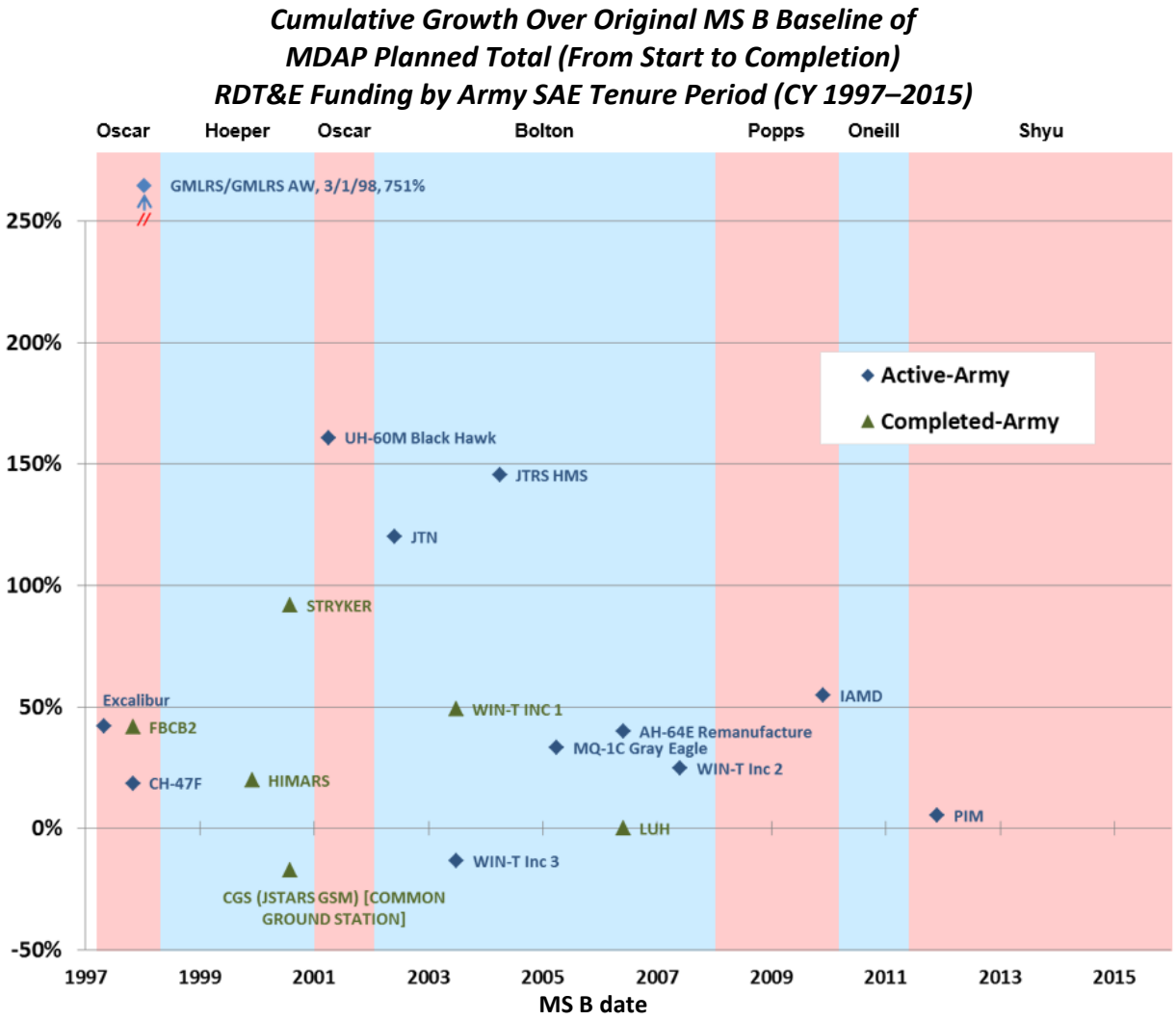
NOTE: "Overruns" in this case are defined (by Section 828 of the FY 2016 NDAA) relative to original PAUC baselines at current total quantities. Program abbreviations are defined in Appendix F starting on p. 159.

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Program Cost Growth and Service Acquisition Executives

As with the earlier plots showing DAE tenure periods, we plotted growth in MDAP planned total funding in development and procurement (respectively) for active and completed MDAPs against original baselines as reported to Congress in the SARs, identifying the person who was the SAE at the time of the MDAP's MS B approval. Figure 2-35 shows the result for Army SAEs, Figure 2-36 for Navy SAEs, and Figure 2-37 for Air Force SAEs.

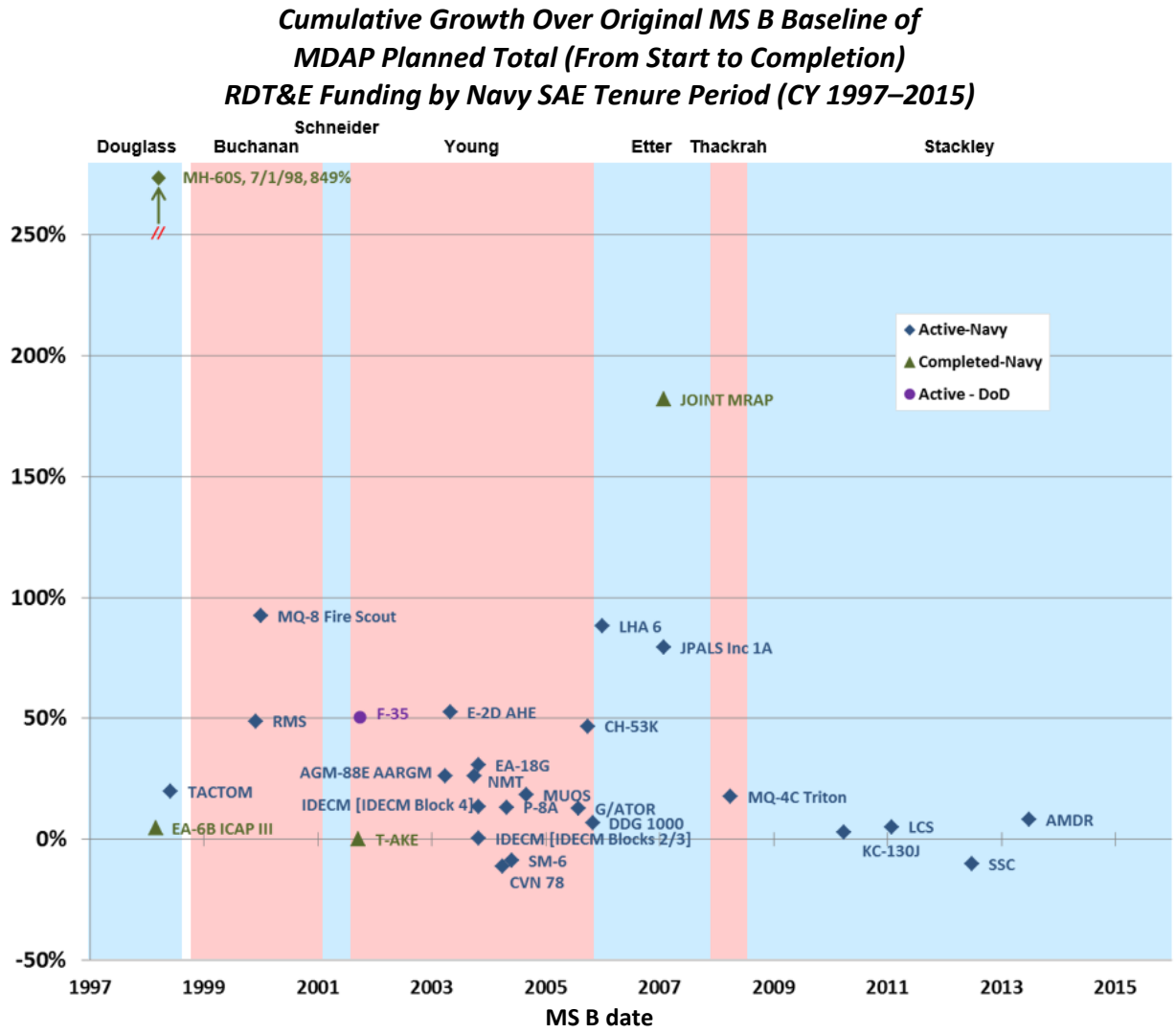
Figure 2-35. Army Program Cost-Related Development Performance Baselined in SAE Periods



NOTE: This shows total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. These are percentage changes after adjusting for inflation from original MS B baseline of actual past and estimated future funding as reported in each program's latest SAR. Total RDT&E is an insightful measure because it is necessary regardless of quantity. Any white bars between SAE shaded regions represent periods in which there was no confirmed executive. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. Program abbreviations are defined in Appendix F starting on p. 159.

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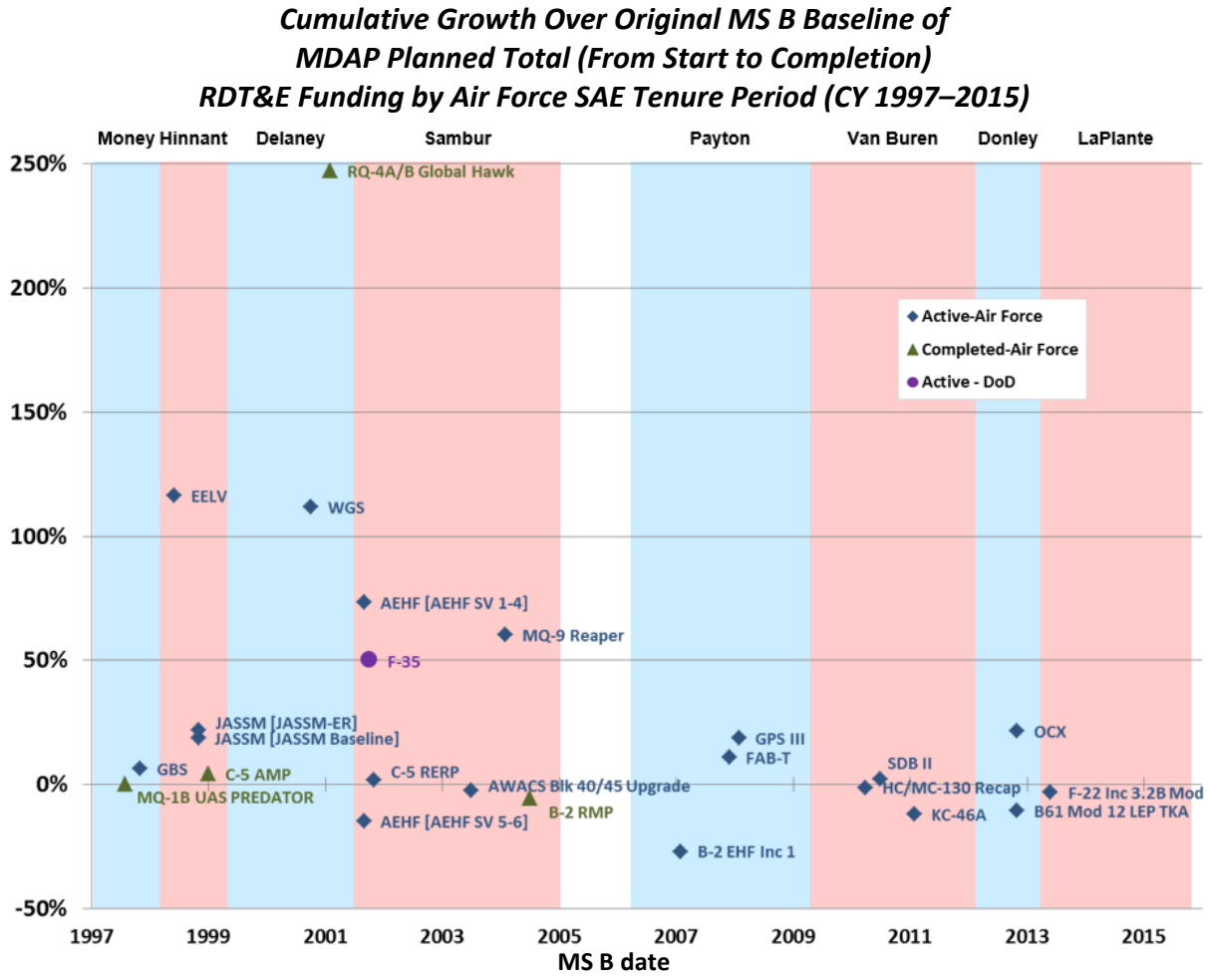
Figure 2-36. Navy Program Cost-Related Development Performance Baselined in SAE Periods



NOTE: This shows total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. These are percentage changes after adjusting for inflation from original MS B baseline of actual past and estimated future funding as reported in each program's latest SAR. Total RDT&E is an insightful measure because it is necessary regardless of quantity. White bars between SAE shaded regions represent periods in which there was no confirmed executive. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. Program abbreviations are defined in Appendix F starting on p. 159.

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Figure 2-37. Air Force Program Cost-Related Development Performance Baselined in SAE Periods

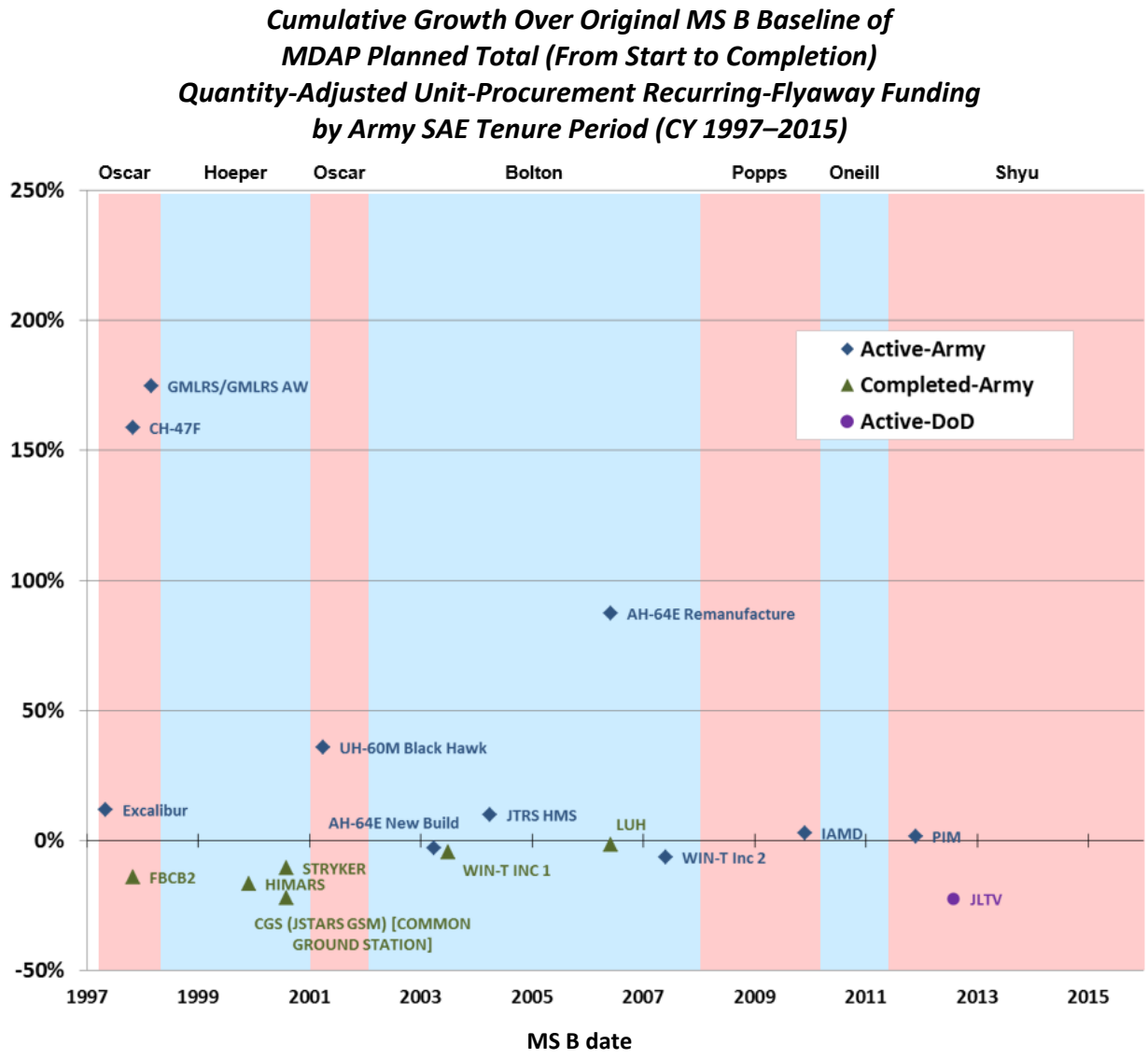


NOTE: This shows total RDT&E funding growth independent of procurement funding and quantity changes; it reflects any work-content changes. These are percentage changes after adjusting for inflation from original MS B baseline of actual past and estimated future funding as reported in each program's latest SAR. Total RDT&E is an insightful measure because it is necessary regardless of quantity. White bars between SAE shaded regions represent periods in which there was no confirmed executive. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. Program abbreviations are defined in Appendix F starting on p. 159.

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Next we plotted the program-level quantity-adjusted procurement unit cost growth on MDAPs in each military department shown by who was the SAE in office at the time of MS B approval. Figure 2-38 shows the result for Army SAEs, Figure 2-39 for Navy SAEs, and Figure 2-40 for Air Force SAEs.

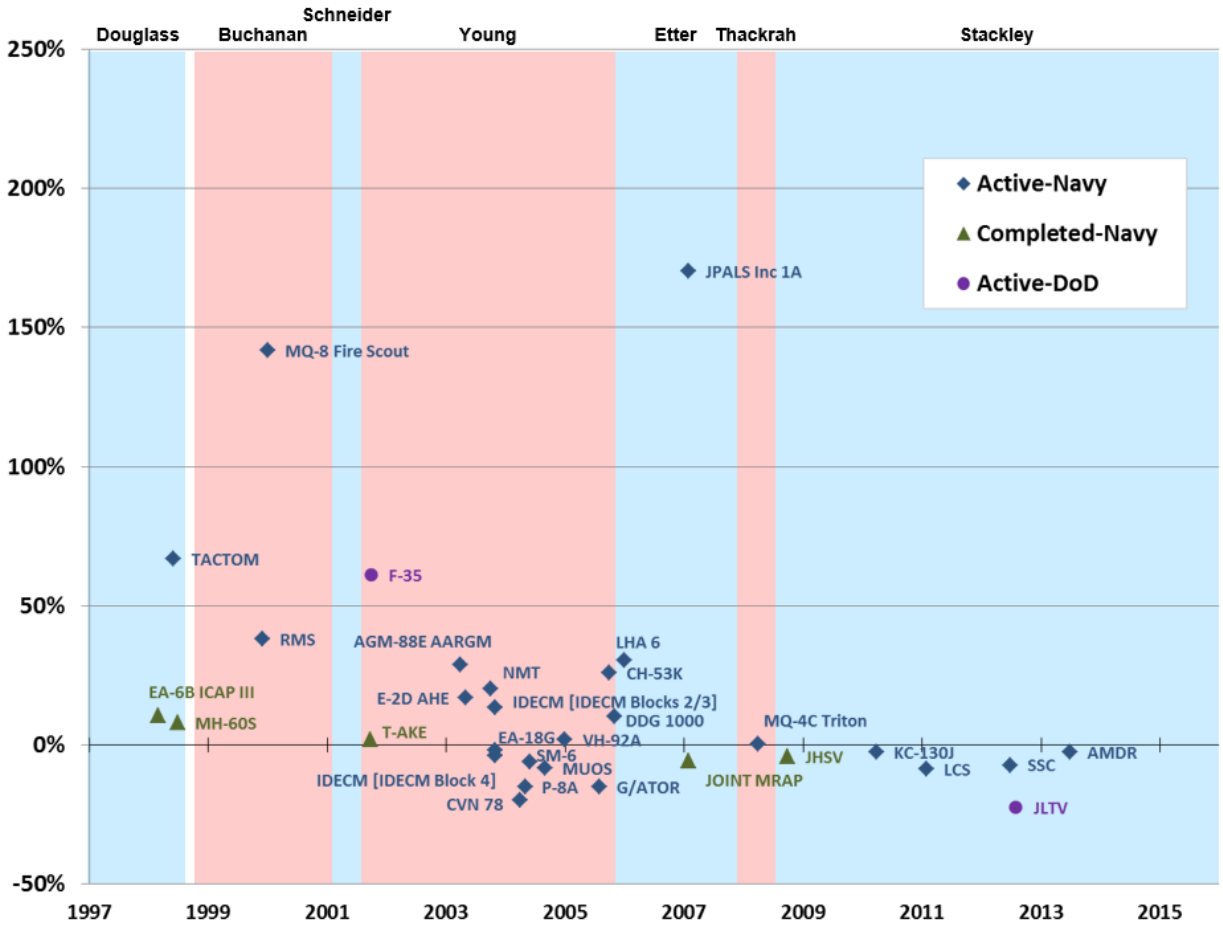
Figure 2-38. Army Program Cost-Related Procurement Performance Baselined in SAE Periods



NOTE: This shows growth in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. Program abbreviations are defined in Appendix F starting on p. 159.

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Figure 2-39. Navy Program Cost-Related Procurement Performance Baselined in SAE Periods

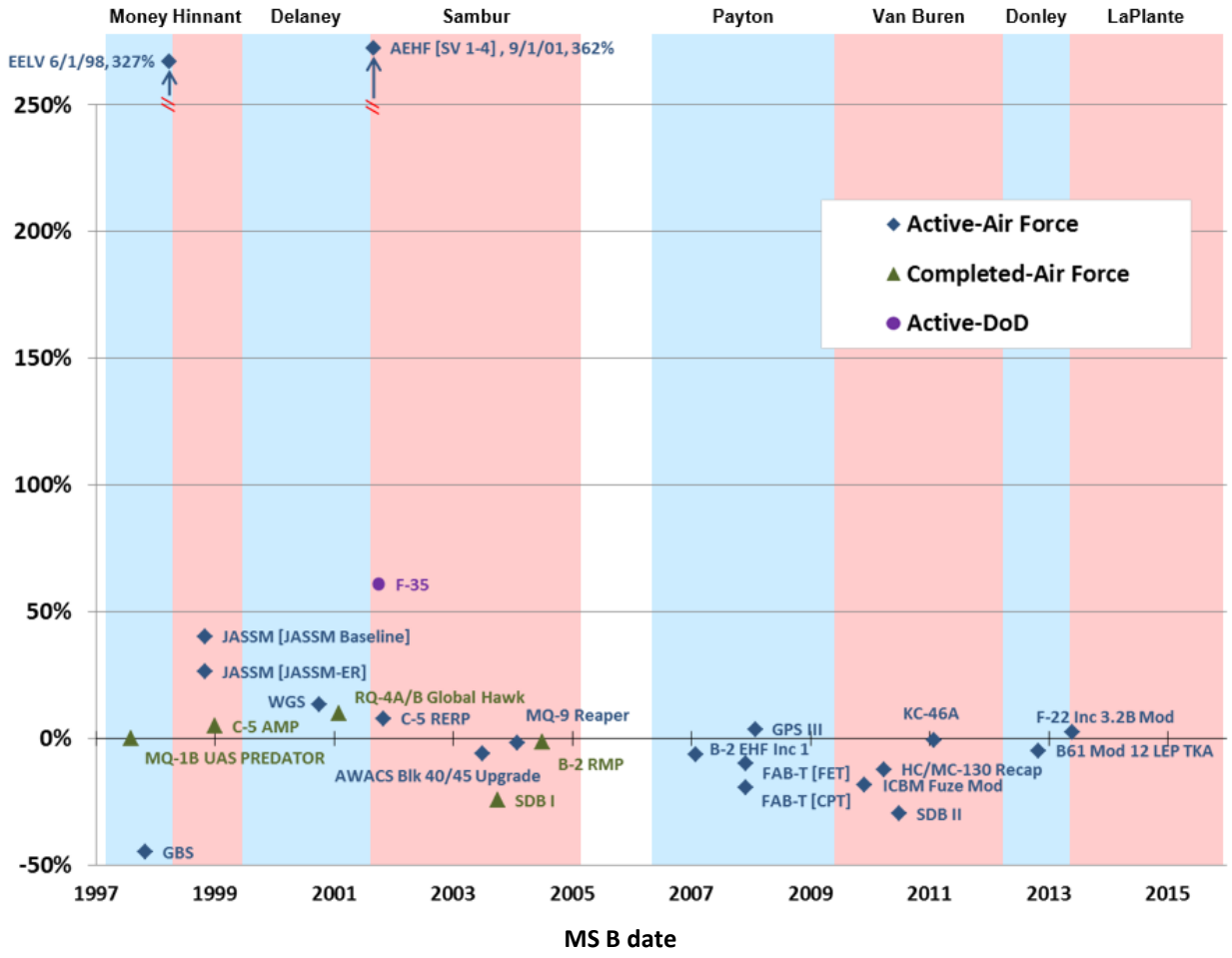


NOTE: This shows growth in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. White bars between SAE shaded regions represent periods in which there was no confirmed executive. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown. Program abbreviations are defined in Appendix F starting on p. 159.

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Figure 2-40. Air Force Program Cost-Related Procurement Performance Baselined in SAE Periods

Cumulative Growth Over Original MS B Baseline of MDAP Planned Total (From Start to Completion) Quantity-Adjusted Unit-Procurement Recurring-Flyaway Funding by Air Force SAE Tenure Period (CY 1997–2015)



NOTE: This shows growth in unit recurring flyaway funding after adjusting for quantity changes; it is independent of RDT&E funding but reflects any work-content changes. These are percentage changes after adjusting for inflation and any quantity changes from original MS B baseline of actual past and estimated needed future funding as reported in the programs' latest SARs. White bars between SAE shaded regions represent periods in which there was no confirmed executive. Relatively new programs that have not spent at least 30 percent of their original EMD schedule are not shown.

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INSTITUTIONAL ANALYSES: PRIME CONTRACTORS

Superior Supplier Incentive Program

As part of BBP, the three military departments and the Defense Logistics Agency (DLA) each established a Superior Supplier Incentive Program (SSIP) to incentivize contractor performance through public recognition. The basis for SSIP designations are contract performance assessments reported by the PM (or equivalent) to CPARS (DoD, 2011). Assessments rate the quality, schedule, cost control, management, utilization of small businesses, and regulatory compliance of the contractor's performance on a specific contract for a specified period. The contractor is allowed to review and comment on each assessment before it is finalized.

In past years, there were some differences between the rating methodologies adopted by each military department, but they have generally refined their approaches each year—with the 2016 SSIP process being nearly uniform. So, the comparisons are not completely equivalent between years, but it is still useful to see how a contractor's performance changes between years. Thus, the SSIP tables were arranged by company in this year's presentation to show more clearly any movement between the years. The three Services use the last three fiscal years of performance data from CPARS to rate the largest firms doing business on systems contracts within each Service (i.e., the 2016 results used FY 2013–2015 CPARS ratings). Ratings are aggregated to a business segment level for scoring. Suppliers without defined business segments are rated at the company level. The ratings are dollar weighted (i.e., contracts with larger dollar obligations in the FY carried proportionally greater contributions to the division's SSIP score for that year). The 3-year results are then time weighted (3,2,1), with the most recently rated year receiving the highest weight, and each successively less-recent year receiving less weight. Company divisions appear or drop off the list between years depending on whether they meet the cutoff criteria in the SSIP algorithm, not based on their performance.

DLA also uses CPARS data to rate their suppliers, but their algorithm may differ somewhat from the methodologies used by the military departments.

Based on the scoring results, the top suppliers are sorted into three tiers. Generally, these tiers separate the list of evaluated company divisions into thirds. In the published list, DLA orders companies alphabetically within a tier rather than ordering company divisions by their quantitative rating. The very top-performing company divisions are in Tier 1 (or Gold for DLA). The Tier 2 (or Silver for DLA) company divisions are the next highest performers. Finally, there are the Tier 3 (or Bronze for DLA) company division performers. Results from the first three SSIP releases are shown in Table 2-13 for Army suppliers, Table 2-14 for Navy suppliers, Table 2-15 for Air Force suppliers, and Table 2-16 for DLA suppliers. Note that these rankings are only for the performance of the company divisions for the specified department or agency, and only for the specified time period.

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Table 2-13. Army Contractors by SSIP Tiers (FY 2014–2016)

Contractor—division	SSIP Tier 2014	2015	2016	Change 2015–16
AeroVironment	2	3	2	+
Alliant Techsystems Defense Group	3			
Am General			3	
BAE Systems—Global Combat Systems	1			
BAE Systems—Land & Armaments	3			
BAE Systems—Electronic Systems	1	2	2	
BAE Systems—Intelligence & Security		2		
BAE Systems—Platforms & Services		2		
Bechtel Group			2	
Boeing—Global Services & Support	1	1		
Boeing—Military Aircraft	2	2	1	+
Boeing—Network & Space Systems	3	3		
Booz Allen Hamilton	2	1	1	
CACI International			1	
Chemring Group	2			
Chemring Group—Sensors & Electronics		3		
CSC North American Public Sector	3			
Cubic	2	2		
DynCorp		1		
Engility		3		
Finmeccanica—AugustWestland		3		
Finmeccanica—DRS Technologies	1	2		
Flir Systems			2	
General Atomics Technology—Aeronautical Systems	3	3	3	
General Dynamics—Info. Systems and Technology	2	2	2	
General Dynamics—Combat Systems	3	3	3	
General Electric—Aviation	1	1	1	
Harris	1			
Harris—Exelis C4ISR Electronics & Systems		3		
Harris—Exelis Information & Technology Systems		1		
Harris—Communication Systems		1	3	– –
Hellfire Systems, LLC—Hellfire Systems			1	
Honeywell International—Aerospace	3	3	3	
L-3—Communications Systems		3		
L-3—Electronic Systems		3	3	
Leidos—National Security Solutions		1	2	–
Leidos—Health & Engineering		3		
Lockheed Martin—Info Systems and Global Solutions	1			
Lockheed Martin—Missiles & Fire Control	1	1	1	
Lockheed Martin—Mission Systems & Training	1	2	1	+
ManTech Int'l—ManTech Advanced Systems Int'l		1		
Navistar Int'l		3	3	
Northrop Grumman—Aerospace Systems	2			
Northrop Grumman—Technical Services		1	1	
Northrop Grumman—Electronic Systems	2	2	3	–
Northrop Grumman—Information Systems	2	2	2	
Oshkosh	3			
Oshkosh—Oshkosh Defense		3	2	+
Raytheon—Integrated Defense Systems	2	1	1	
Raytheon—Intelligence, Information and Services	3	2		
Raytheon—Missile Systems	3	3	3	
Raytheon—Space and Airborne Systems	2	2	2	
Raytheon/Lockheed Martin Javelin JV		1	1	
Rockwell Collins Government Systems		1	2	–
Rolls Royce		2		
SAIC—Government Services	2			
SAIC—Research & Development	1			
Sierra Nevada		2	2	
SRCTec	1			
Textron—Aviation		1		
Textron—Bell Helicopter	3	1		
Textron—Textron Systems	3	3	3	
Thales-Raytheon Joint Venture		2		
Thales-Raytheon Systems	2			
United Technologies—Aerospace Systems	3	1		
United Technologies—Sikorsky	3	2		

SOURCES: Army (2016); Assistant Secretary of the Army for Acquisition, Logistics, and Technology (2015); Vergun (2015).
NOTE: Rankings are unordered within each tier and reflect performance of each company division for the specified department or agency for the prior 3 years (e.g., 2016 rankings include data from FY 2013–2015).

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Table 2-14. Navy SSIP Tiers by Contractor Division (FY 2014–2016)

Contractor—division	SSPI Tier 2014	2015	2016	Change 2015–16
ATK Defense	3			
Austal USA	3	3	3	
BAE Systems—Electronic Systems	2	2	2	
BAE Systems—Intelligence & Security		1	1	
BAE Systems—Land and Armaments	2			
BAE Systems—Platforms & Services		1	1	
Bell Helicopter	2			
Bell Boeing Joint Project Office	3	2	3	–
Boeing—Global Services & Support		2	1	+
Boeing—Military Aircraft	2	2	2	
Erapsco (Spartan/Ultra Electronics joint venture)		1	1	
General Atomics Technology		3		
General Atomics—Electromagnetic Systems			3	
General Dynamics—Combat Systems	1	2		
General Dynamics—Information Systems and Technology	2	2	2	
General Dynamics—Marine Systems	1	2	3	–
General Electric—Aviation	1	1	1	
ITT Exelis *(now part of Harris)*	2			
Harris—Communication Systems			2	
Harris—Exelis C4ISR Electronics & Systems		2		
Harris—Exelis Information & Tech. Services		2		
Huntington Ingalls—Newport News Shipbuilding	3	3	3	
Huntington Ingalls—Ingalls Shipbuilding	2	2	2	
L-3—Aerospace Systems		2		
L-3—Communications Systems		2		
L-3—Electronic Systems	2	2	2	
Leidos—National Security Solutions			1	
Lockheed Martin—Aeronautics	3	3	3	
Lockheed Martin—Information Systems & Global Solutions		2		
Lockheed Martin—Missiles & Fire Control		1		
Lockheed Martin—Mission Systems and Training	1	1	2	–
Lockheed Martin—Space Systems	3	3	3	
Maritime Helicopter Support (Sikorsky/Lockheed JV)	1	2	2	
Navistar Defense	3			
Northrop Grumman—Aerospace Systems	1	1	1	
Northrop Grumman—Electronic Systems	2	2	2	
Northrop Grumman—Information Systems		2	2	
Orbital ATK—Defense Systems		3	3	
Oshkosh—Defense		1		
Raytheon—Integrated Defense Systems	1	2	1	+
Raytheon—Intelligence, Information and Services	1	1	1	
Raytheon—Missile Systems	2	2	1	+
Raytheon—Space and Airborne Systems	2	2	1	+
Rockwell Collins—Government Systems		2	2	
Rockwell Collins—Simulation	2			
Rolls Royce—Defense Aerospace	1	1	2	–
Textron—Bell Helicopter		3	3	
Textron—Systems		2	3	–
United Technologies—Pratt Whitney		3		
United Technologies—Aerospace Systems		2	3	–
United Technologies—Propulsion and Aerospace Systems	3			
United Technologies—Sikorsky	3	3		
ViaSat		2		

SOURCES: Assistant Secretary of the Navy for Research, Development and Acquisition (2014, 2015, 2016).
NOTE: Rankings are unordered within each tier and reflect performance of each company division for the specified department or agency for the prior 3 years (e.g., 2016 rankings include data from FY 2013–2015).

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Table 2-15. Air Force SSIP Tiers by Contractor Division (FY 2014–2016)

Contractor—division	SSPI Tier 2014	SSPI Tier 2015	SSPI Tier 2016	Change 2015–16
BAE Systems—Electronic Systems	1	2	1	+
BAE Systems—Intelligence & Security	3	2	1	+
Ball Corp.			1	
Boeing—Commercial Aircraft	1	1		
Boeing—Global Services & Support	2	2	2	
Boeing—Military Aircraft	2	3	3	
Boeing—Network & Space Systems	2	1	1	
Booz Allen Hamilton			3	
CACI International			1	
FlightSafety International			3	
General Atomics—Aeronautical Systems	3	3	3	
General Atomics—Energy		1		
General Dynamics—Aerospace	1	1		
General Dynamics—Information Systems & Technology	3	3	2	+
General Electric—Aviation	2	3	2	+
Harris—Communication Systems			2	
Harris—Electronic Systems		3	3	
Harris—Exelis C4ISR Electronics & Systems	3			
Harris—Exelis Information & Technical Services	3	1		
Harris—Space and Intelligence Systems		1	2	–
Honeywell—Aerospace	2	1	1	
Jacobs Engineering—Tybrin	3			
L-3—Aerospace Systems	2	1	1	
L-3—Communication Systems	1	1	3	– –
L-3—Electronic Systems	3	3	2	+
L-3—National Security Solutions	2	1		
Leidos Corporation (formerly SAIC)	3			
Leidos Corporation—National Security Solutions		2	1	+
Lockheed Martin—Aeronautics	1	2	2	
Lockheed Martin—Information Systems & Global Solutions	1	1	1	
Lockheed Martin—Missiles & Fire Control	2	2	2	
Lockheed Martin—Mission Systems & Training	1	1	1	
Lockheed Martin—Space Systems	1	1	1	
Northrop Grumman—Aerospace Systems	2	3	3	
Northrop Grumman—Electronic Systems	2	3	3	
Northrop Grumman—Information Systems	1	1	2	–
Northrop Grumman—Technical Services	3	3	2	+
Orbital ATK—Defense Systems		2	3	–
Orbital ATK—Flight Systems		1	1	
Orbital ATK—Space Systems Group		2		
Raytheon—Integrated Defense Systems	2	2	2	
Raytheon—Intelligence, Information & Services	3	3	3	
Raytheon—Missile Systems	3	3	3	
Raytheon—Space & Airborne Systems	2	2	2	
Rockwell Collins—Commercial Systems	1			
Rockwell Collins—Government Systems	3	2	3	–
Rolls Royce—Defense Aerospace	1	1	1	
Sierra Nevada Corporation	1	2	1	+
Teledyne Technologies—Digital Imaging		2		
Textron—Aviation	2	3	3	
Textron—Systems	3	3	2	+
United Launch Alliance (ULA) / United Launch Services (ULS)	3	3	1	+ +
United Technologies—Pratt & Whitney	1	2	3	–
United Technologies—Aerospace Systems	2	2	3	–
United Technologies—Sikorsky	3	3		

SOURCES: Gibson (2016); Haux (2015); Vergun (2015).

NOTE: Rankings are unordered within each tier and reflect performance of each company division for the specified department or agency for the prior 3 years (e.g., 2016 rankings include data from FY 2013–2015).

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Table 2-16. DLA SSIP Ratings by Contractor Division (FY 2014–2016)

Contractor	SSPI Level 2014/2015	SSPI Level 2016	Change 2015–16
3M Company	Silver		
AM General, LLC	Silver	Silver	
American Apparel, Incorporated (Inc.)	Gold	Silver	–
American Purchasing Services, Inc. (American Medical Depot)	Silver		
AmerisourceBergen Drug Corp.	Gold	Gold	
AmeriQual Group, LLC		Gold	
Atlantic Diving Supply	Gold		
Bell Boeing Joint Project Office	Bronze	Silver	+
The Boeing Company	Gold	Bronze	– –
Bethel Industries, Inc.		Silver	
Burlington Industries, LLC	Gold	Gold	
Canadian Commercial Corp.	Silver		
Cardinal Health, Inc.		Gold	
Carter Enterprises, LLC	Bronze		
CPD Alaska, LLC		Bronze	
DMS Pharmaceutical Group, Inc.	Silver	Gold	+
Equilon Enterprises, LLC	Bronze		
Federal Resources Supply Company		Silver	
Foster Fuels	Gold	Bronze	– –
General Dynamics Land Systems	Silver		
General Electric Aviation	Silver		
General Electric Company		Bronze	
Graybar Electric Company, Inc.	Bronze	Silver	+
Herndon Products, Inc.		Gold	
Husky Marketing & Supply Company	Silver		
I-Solutions Direct, Inc.	Gold		
Kampi Components Company	Gold		
Kovatch Mobile Equipment Corp.	Gold		
Lockheed Martin Corporation	Gold	Silver	–
McKesson Corporation	Bronze	Silver	+
McRae Industries, Inc.		Gold	
Meggitt, Inc.		Bronze	
Michelin North America, Inc.		Bronze	
NACCO Materials Handling Group	Silver		
National Industries for the Blind	Silver	Bronze	–
Northrop Grumman Systems Corp.		Gold	
OSHKOSH Corp.	Silver		
PAPCO, Inc.	Bronze		
Peckham Vocational Industries, Inc.		Gold	
PPG Industries, Inc.		Bronze	
Propper International, Inc.	Silver	Silver	
Raytheon Company	Bronze	Bronze	
Rockwell Collins, Inc.		Bronze	
Rolls Royce Corporation, U.S.	Gold		
Science Applications International Corp. (SAIC)	Bronze	Gold	+ +
Seven Seas Shipschandlers, LLC	Bronze		
SourceOne Distributors, Inc.	Silver	Gold	+
Sterlingwear of Boston, Inc.		Gold	
Supplycore, Inc.	Bronze	Silver	+
Sysco Corp.		Bronze	
Tennier Industries, Inc.	Gold	Gold	
Textron, Inc.		Bronze	
Theodor Willie Intertrade AG	Gold	Silver	–
Triumph Structures, Inc.		Silver	
United Technologies Aircraft Systems	Gold		
USFI, Inc.		Bronze	
US Foods, Inc.	Gold	Gold	
Veyance Technologies, Inc.		Silver	
The Wornick Company		Gold	
W.S. Darley & Company	Silver		
Washington Gas Energy Services	Bronze		
Y. Hata and Company, Limited		Bronze	

SOURCES: DLA (2014, 2015, 2016).

NOTE: Rankings are unordered within each tier and reflect performance of each company division for the specified department or agency for the prior 3 years (e.g., 2016 rankings include data from FY 2013–2015).

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Table 2-17 summarizes the number of rating changes between 2015 and 2016. There was more movement by Air Force and DLA suppliers than by Army and Navy suppliers. The number of increases and decreases are not directly comparable, in part, because ratings are not available in both years for all listed company divisions. Generally, this is almost a "zero-sum game" because of the forced distribution of thirds between the levels (i.e., wherein if one company goes up a level then another will come down). This does not always happen, however, because companies (or their business units) can drop or appear in the ratings between years depending on changes in their contracting levels in the areas assessed.

Table 2-17. Count of SSIP Rating Changes by DoD Component Between FY 2015 and 2016

DoD Component	Number of Changes			
	++	+	–	– –
Army		4	3	1
Navy		4	6	
Air Force	1	9	6	1
DLA	1	6	4	2

++ increase by 2 levels
+ increase by 1 level
– decrease by 1 level
– – decrease by 2 levels

DoD Prime Contractor Profitability

One of the initiatives in all three editions of BBP works to ensure that the DoD is paying reasonable prices by tying contractor performance and risk to profit/fee. At the individual contract level for noncompetitive awards on noncommercial items, we follow the weighted guidelines provided in statutes and regulations. Our prior annual reports included institutional analyses across populations of contracts to examine actual profits in absolute terms and relative to price- and cost-control performance.

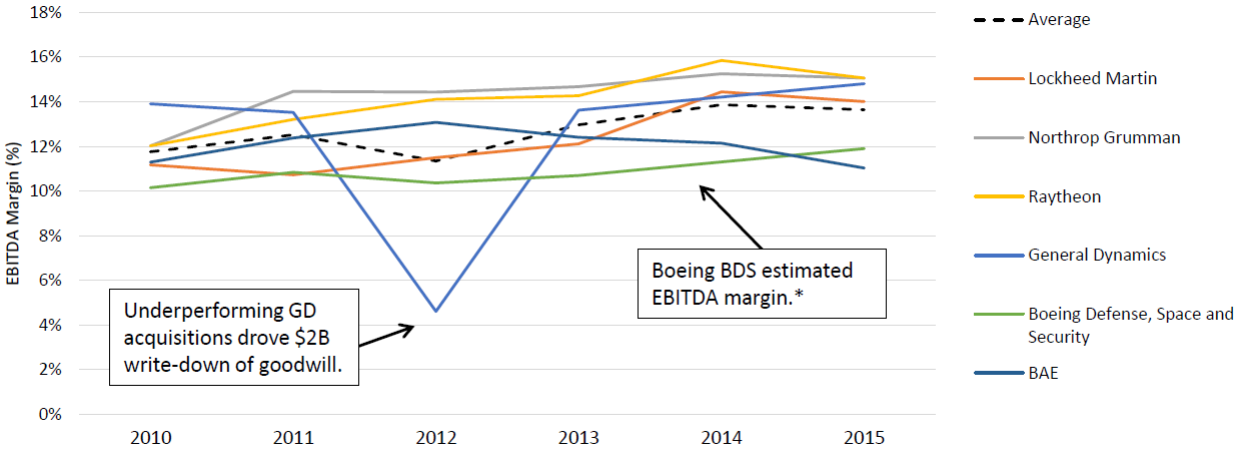
In addition to these analyses of contract data, we have been monitoring operating margins of our prime contractors to ensure that the net effect of these efforts—combined with other issues such as sequestration—is not undermining the health of our industrial base. In addition to the operating margin data published in our 2014 annual report (USD(AT&L), 2014a, pp. 77–79), Figure 2-41 plots the trends in earnings before interest, taxes, depreciation, and amortization (EBITDA)[29] since 2010 for the six largest DoD prime contractors. Generally, these

[29] EBITDA is a measure that attempts to compare cash flow from operations between companies independent of the differences that may ensue from different capital structures as well as decision-dependent actions such as depreciation, amortization, and interest on capital and taxes (see, for example, Constable, 2012; Investopedia, 2016; Reuters, 2016). Note that while widely available, EBITDA has its limitations (see, for example, McClure, 2014).

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primes have performed consistently or slightly better against this measure since before BBP took effect, providing evidence that our BBP efforts have not hurt the profit margins of these companies.

Figure 2-41. Historical EBITDA Margin of the Six Largest DoD Primes (2010–2015)



SOURCE: Company 10-K reports (Bloomberg).
NOTES: EBITDA are earnings before interest, taxes, depreciation, and amortization. Years refer to corporate fiscal years (coinciding with calendar years).

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3. EXPANDED ANALYSES

ANNUAL GROWTH OF CONTRACT COSTS FOR MAJOR PROGRAMS IN DEVELOPMENT AND EARLY PRODUCTION

Are there periods of improved cost control on defense contracts? Have recent efforts produced measurable results? What effects have external events and major policy changes had on controlling costs on major defense programs?

To help answer these questions, we examined the 5-year moving average of annual growth in total EV contract costs on major contracts[30] for the development and early production of MDAPs. Growth is in real terms (i.e., after adjusting for inflation). This different measure of growth reflects changes relative to negotiated cost targets on contracts tracked in EV reports. It includes both scope growth (i.e., work added to a contract after award) and overruns (i.e., latest estimate of cost over the latest negotiated target). Negotiated targets do not necessarily equal Government or contractor negotiation cost estimates. These contract level targets are also different than broader program-level cost estimates, baselines, and statutory measures of cost growth relative to program-level baselines, because it excludes noncontracted costs and the majority of production contracts. Nonetheless, we expect that the cost-reimbursement and fixed-price incentive contracts that this study examines should show the same trends as other measures of total program cost growth—in part because production contracts have much lower cost growth than these development and early production contracts. EV reports are typically limited to development (engineering and manufacturing phase) and early production contracts. They include fixed-price incentive and cost-reimbursement contracts but generally not firm-fixed-price contracts (which often are not appropriate until full-rate production and usually do not report EV). Each year's growth is the sum of all the changes in active contract values divided by the sum of all the original target costs. Thus, the portfolio percentage change will be closer in value to the percentage change of the larger contracts. Of final note, reports of scope changes and estimates of final cost in EV reports can be sporadic, leading to wide year-to-year changes; therefore, we used a 5-year moving average to smooth out these effects and reveal longer-term trends.

We used standard statistical modeling techniques to identify statistically significant factors that are likely causes of growth. For example, are reductions merely reflections of budgetary

[30] Major contracts include the six largest contracts (prime, associated, or for government-furnished equipment) for each MDAP valued at more than $40 million. Earned value data also are available for other MDAP contracts of at least $60 million in RDT&E or $250 million in procurement or ship construction (in FY 1990 constant dollars). Note that EV data are usually not provided for firm-fixed-price contracts, so this MDAP contract dataset has very few such contracts.

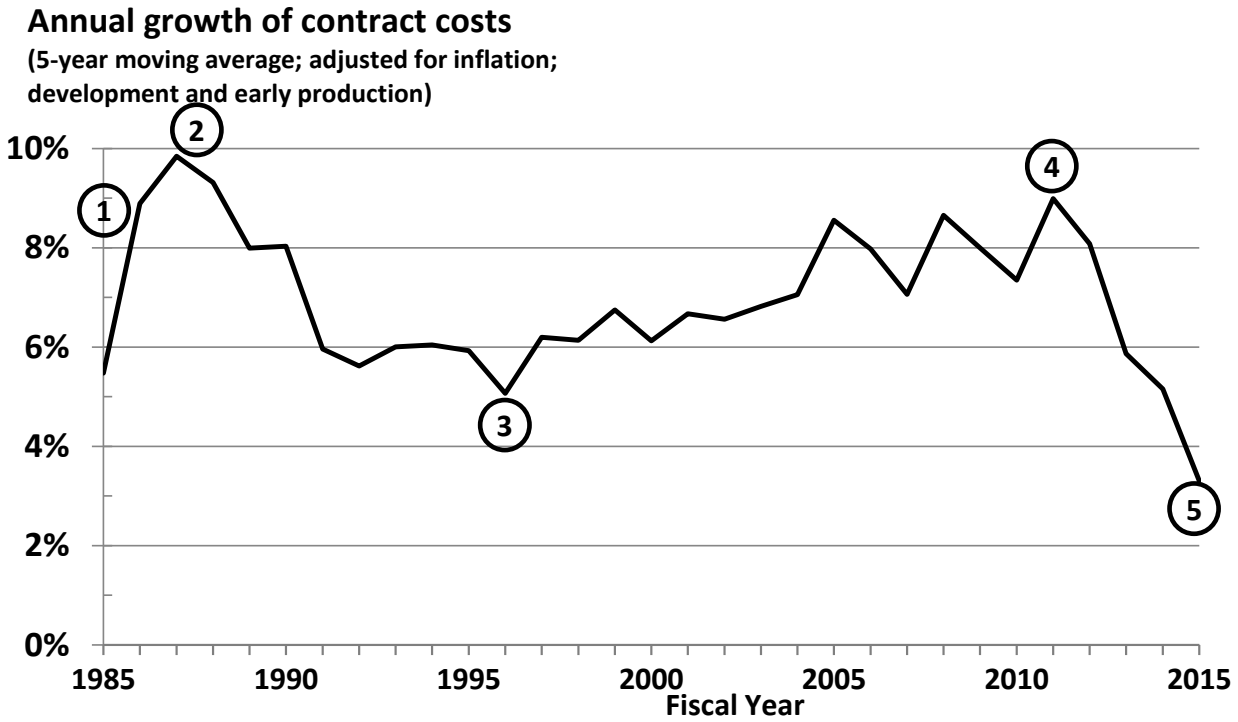
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reductions, or are there measurable structural shifts from major policy changes? Is the defense system stable in dealing with external and internal spikes and shocks? Of course, proving causation is difficult, but correlation and coincidence combined with a deep understanding of defense acquisition can provide valuable insights into causes.

Annual Growth of Development and Early Production Contracted Costs

Figure 3-1 plots the 5-year moving average of annual growth in EV contracted costs on major contracts for MDAPs. It shows that BBP policy changes over the last several years appear to have produced dramatic downturns in the growth of costs on executing contracts for these programs.

Figure 3-1. Five-year Moving Average of Annual Growth of EV Contract Costs (FY 1985–2015)



NOTES: Numbered points are referenced in the discussion before the figure. The 5-year moving average of annual growth in contracted total costs is relative to *negotiated cost targets* on major contracts of MDAPs (including MAIS that are large enough to also be MDAPs) in EMD and early production that reported EV data (i.e., including almost no firm-fixed-price or full-production contracts). This is *different* than statutory measures of program-level cost growth measures such as PAUC and APUC relative to Milestone B baselines. These data summarize 18,470 earned-value reports on 1,123 major contracts for 239 MDAPs. TSPR = Total System Performance Responsibility.

The Goldwater-Nichols Act of 1986 (which reorganized the DoD), as well as the contemporaneous legislation that strengthened oversight of defense acquisition programs by the Office of the Secretary of Defense, coincided with a major downturn in annual growth of EV contract costs at point #2 on the chart. Also, the start of the recent BBP initiatives to instill cost consciousness, improve efficiency, strengthen the workforce, and seek ways to drive costs

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downward coincided with the recent downturn starting at point #4. At 3.5% in FY 2015 for the portfolio, the DoD is now at the lowest level of growth since before FY 1985.

Conversely, policy changes that reduced oversight on contractor performance, starting in the mid-1990s, appear to coincide with an upturn in annual added costs on contracts from point #3. We test below whether that period increase is statistically significant (e.g., whether the trend is really flat from 1995 if you dismiss 1996 as anomalous).

Increased demands for new capabilities can also add costs to contracts; that is visible in the chart during the defense buildup in the 1980s by President Reagan and during the post-9/11 wars to combat global terrorism.

Factors Contributing to Annual Growth in Contracted Costs

To understand whether the trends in Figure 3-1 are significant and what may be driving them, we employed the following statistical analyses. First, we wanted to determine whether the two steep drops are statistically significant or whether they are merely an artifact of budget cuts. We also wanted to test whether the growth in the mid-to-late 1990s was flat or significantly trending upward.

We found that the combined effects of three types of drivers—together with a constant base and random noise—very closely fit the dynamics of the growth curve.[31]

1) **Budget effects.** The growth in costs is, in part, positively correlated with budget levels and dynamics. This includes two factors:
   a) the average of the DoD budget over the past 5 years, and
   b) the change in that average from the prior year to the current year.
2) **Two structural changes.** Two overlapping periods correlate with partial reductions:
   a) one since 1990, coincident with post-Goldwater-Nichols implementation, and
   b) one since 2012, coincident with BBP implementation.[32]
3) **A self-correcting behavior.** A factor that corrects for prior differences between the anticipated cost growth from the budgetary, structural, and constant factors and the actual growth. This autoregression factor adjusts for unforeseen external "shocks" to the systems (including unanticipated changes in budgets) and internal variations (such as larger-than-modeled annual contract obligations). It serves as a kind of negative feedback that keeps the system under control.

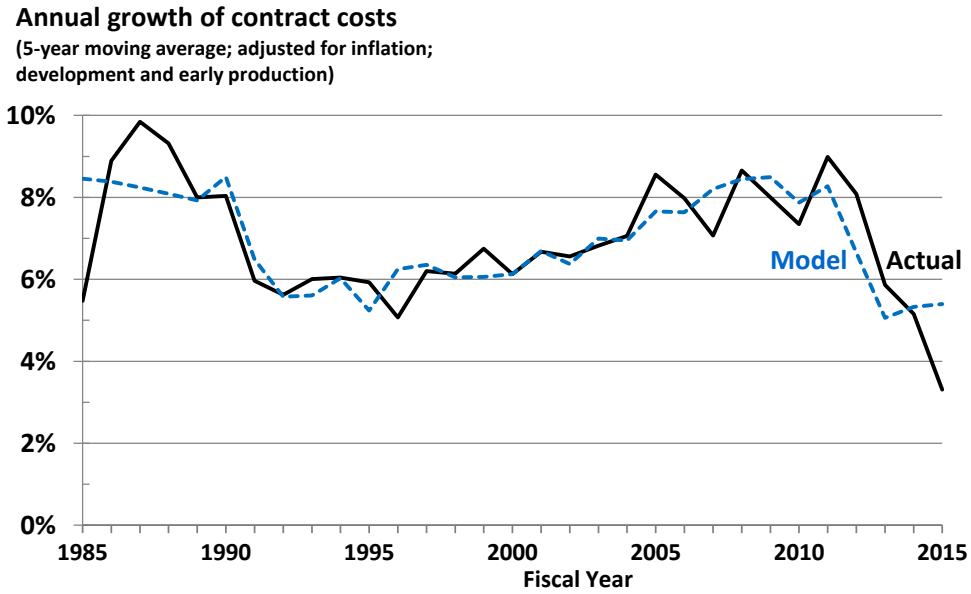
[31] The following variables were either spurious or statistically insignificant: UCAs (although UCAs can be significant in some commodity classes, especially ships in development); contract spending share of program spending; cost-over-target; share of cost growth due to work-content growth; share of cost growth due to cost-over-target; margin; change in margin over the contract's period of performance; contract size (total dollars); schedule growth; military department (i.e., Army, Navy, Air Force, or DoD); commodity type (except space systems in development and aircraft in early production); and quantity changes (USD(AT&L), 2015, pp. 75–77).

[32] Since the effects of new policies take time to show, we measured these periods to start 2 to 3 years after their enactment. Goldwater-Nichols Act was signed into law at the start of FY 1987, and the first BBP memoranda were issued in late FY 2010.

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Figure 3-2 shows that the model closely fits the actual annual growth data. Further statistical details are presented in Appendix A.

Figure 3-2. Statistical Model Fit to Actual Growth of EV Contract Costs (FY 1985–2015)

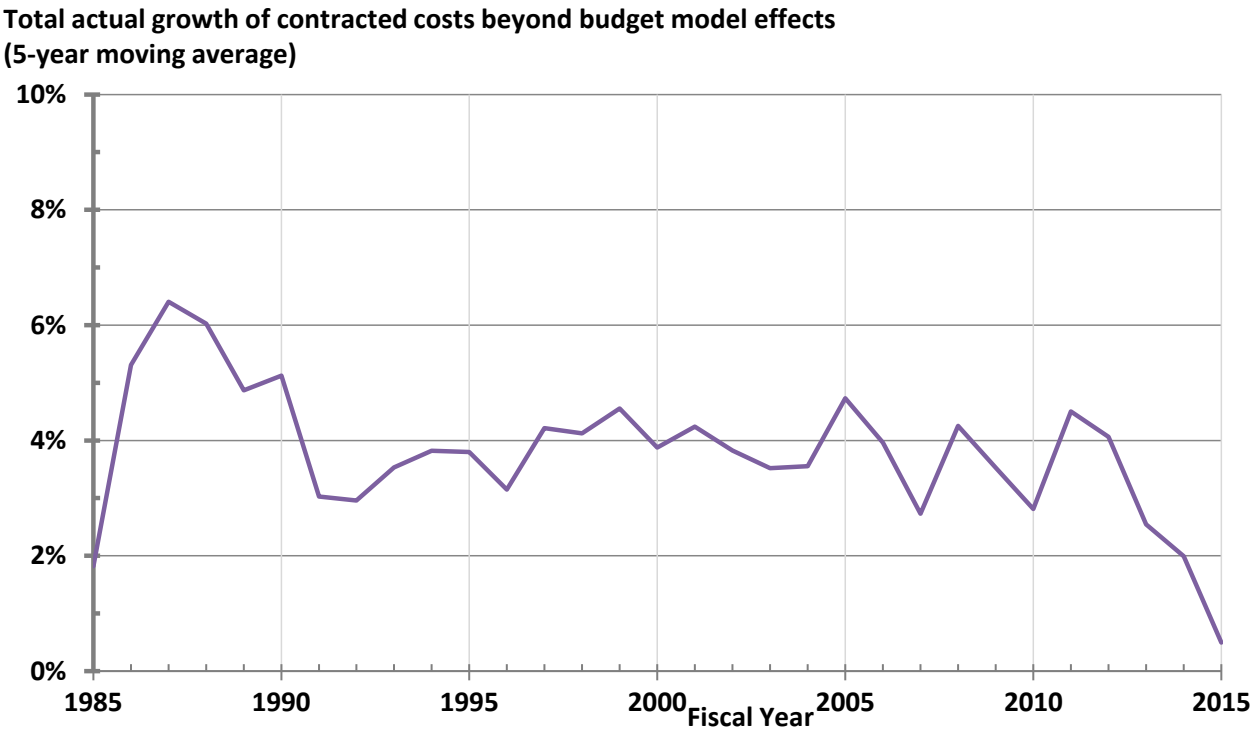


NOTES: The 5-year moving average of annual growth in contracted total costs is relative to *negotiated cost targets* on major contracts of MDAPs (including MAIS that are large enough to also be MDAPs) in EMD and early production that reported EV data (i.e., including almost no firm-fixed-price or full-production contracts). This is *different* than statutory measures of program-level cost growth measures such as PAUC and APUC relative to Milestone B baselines. These data summarize 18,470 earned-value reports on 1,123 major contracts for 239 MDAPs.

Of note, we also tested for structural change during the period of the mid-to-late 1990s (FY 1995–2001) in the era of Reinventing Government. The effects in that era failed the statistical tests in these data (i.e., we cannot claim that they are statistically different from zero). Figure 3-3 shows that the growth during this period appears relatively flat after subtracting the partial budgetary effects.

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Figure 3-3. Actual Growth Less Modeled Budget Effects (FY 1985–2015)



NOTES: The 5-year moving average of annual growth in contracted total costs is relative to *negotiated cost targets* on major contracts of MDAPs (including MAIS that are large enough to also be MDAPs) in EMD and early production that reported EV data (i.e., including almost no firm-fixed-price or full-production contracts). This is *different* than statutory measures of program-level cost growth measures such as PAUC and APUC relative to Milestone B baselines.

Testing for Underlying Causes

What may be the underlying causes for the factors identified above? While it is difficult to trace effects to individual policy changes, we can identify some underlying drivers and rule out others.

Development and Early Production Differences

BBP-era drops are driven by declining development cost-growth rates, not higher proportions of early production contracts. The recent downward trend is not driven by an increased fraction of early production dollars in the annual portfolios. Because growth on early production contracts has been lower than that for development since 1990, such a shift might have been a logical cause for the recent drop. In fact, however, the proportions between development and early production dollars have been relatively flat since 2012 (Figure 3-4). Instead, the overall BBP-era drop is being driven by steep drops in the growth rates on development contracts (Figure 3-5).

Initial Goldwater-Nichols-era drops are largely driven by declining early production cost-growth rates, not higher proportions of early production contracts. Similarly, the dramatic initial drop

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from FY 1987–1991, as the Goldwater-Nichols-era changes were first being implemented, was driven mostly by steep drops in growth rates on early production contracts (Figure 3-5). The proportion of early production dollars in the portfolio was mostly flat in this early period. After this initial period, both the development cost rate and proportions were increasing, so the overall structural effect in the Goldwater-Nichols era is not due to the development/production split or their cost dynamics.

Schedule Effects

DoD generally was not adjusting schedule to lower costs. We were also able to reject the possibility that the DoD was simply adjusting contract schedules to lower growth of EV contract costs in the BBP era or overall. Overall, we found that the 5-year moving averages of growth in annual schedules and EV contract costs are statistically independent.[33] Moreover, our statistical model of schedule growth trends showed that it is a simple downward trend in time, along with a self-correction term and white noise (see p. 60). We can see this in Figure 3-6, where cost and schedule growth were moving in opposite directions since about 2002. We also note that in the BBP era (since 2012), schedule growth is essentially flat while cost growth has dropped dramatically.

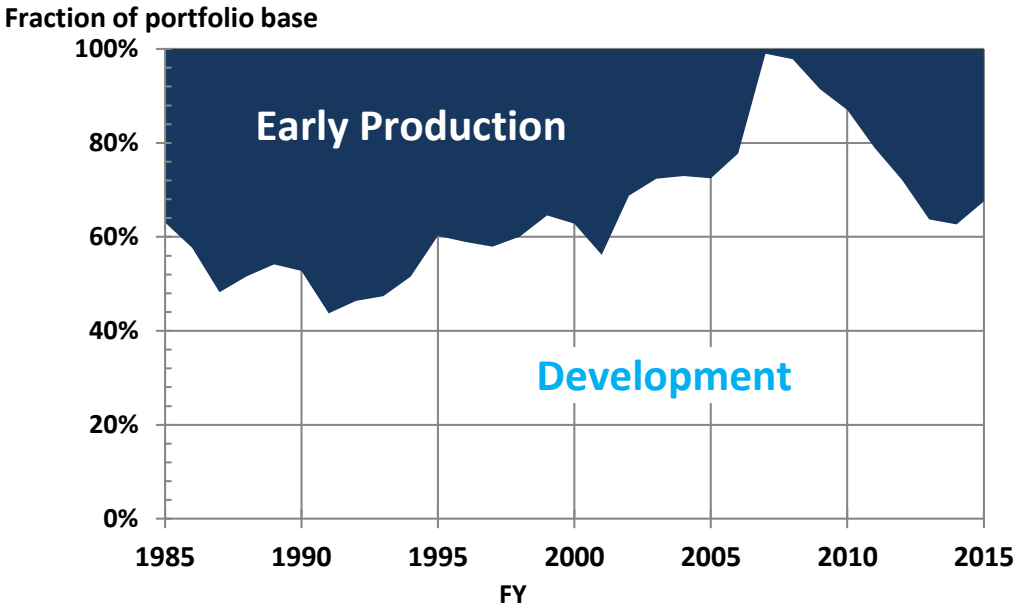
Quantity Effects

These factors are independent of quantity changes. Lastly, we note that prior research showed that contract quantity almost never changes on these early production contracts—at least since about the year 2000 (USD(AT&L), 2015b). Also, quantity generally is not an element on development contracts (except for relatively few test articles). Therefore, quantity is not an underlying cause for the factors in the statistical model or for the separate growth dynamics by development and early production.

[33] I.e., they failed the Spearman correlation test.

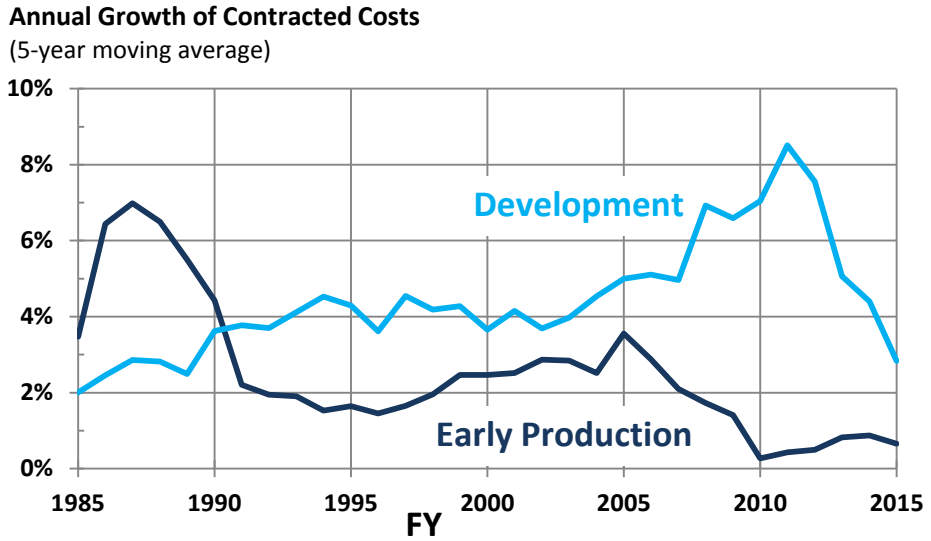
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Figure 3-4. Portfolio Split Between Development and Early Production Contracts



NOTE: This reflects the relative total dollars in the contract bases each year.

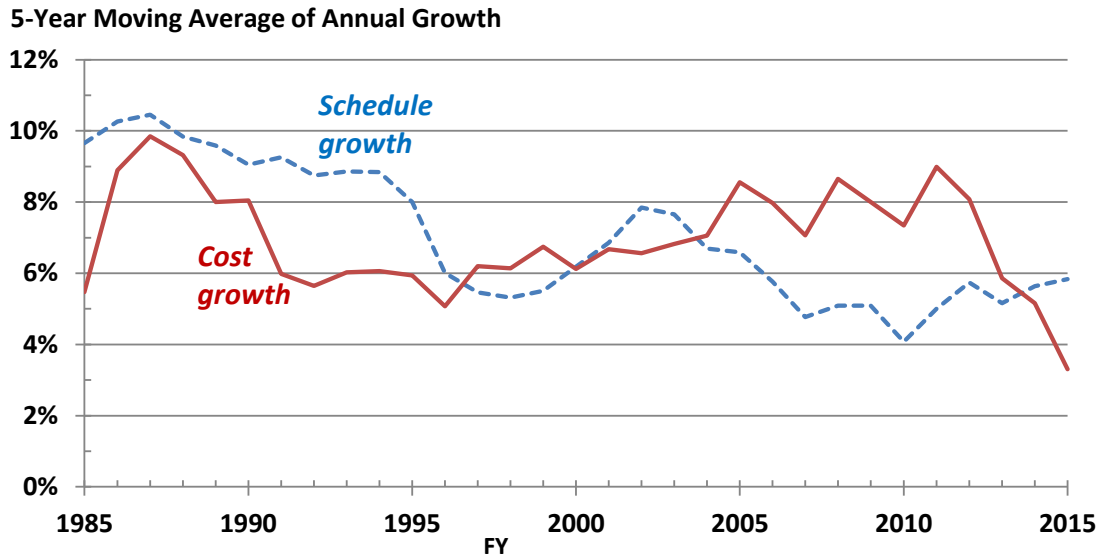
Figure 3-5. Separate Growth Rates for Development and Early Production Contracts



NOTES: The 5-year moving average of annual growth in contracted total costs is relative to *negotiated cost targets* on major contracts of MDAPs (including MAIS that are large enough to also be MDAPs) in EMD and early production that reported EV data (i.e., including almost no firm-fixed-price or full-production contracts). This is *different* than statutory measures of program-level cost growth measures such as PAUC and APUC relative to Milestone B baselines. These data summarize 18,470 earned-value reports on 1,123 major contracts for 239 MDAPs.

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Figure 3-6. Comparing Growth in Schedule and Cost on Major Contracts (FY 1985–2015)



NOTE: Spearman's correlation test showed that schedule growth and cost growth are independent (not correlated) over this period. In the BBP era (since 2012), schedule growth is essentially flat, while cost growth has dropped dramatically.

Cycle Time, Scope Growth, and Commodity Effects

Cycle time, scope growth, and certain commodities correlate with growth of costs in these data. Prior research did find three variables that generally correlate with growth in this type of contract data: the original length of the contract (i.e., cycle time, not schedule growth), scope growth, and two commodities (space systems in development and aircraft contracts in early production). Cycle time was the largest correlate (USD(AT&L), 2015b, pp. 75–77).

Contract Incentives and Should-Cost

Reduced cost growth in the BBP era may correlate with the requirement to identify and pursue Should-Cost savings and a renewed effort to improve contract incentives. The DoD has continued to see increasing savings on programs from Should-Cost initiatives in BBP. These savings have grown across the acquisition portfolio, so these may have additional effects in lowering scope growth and cycle time at the contract level. We have also seen recent shifts in contract types used for development and early production toward those types that data show are more effective at cost control.

Contract Baselining Effects

Analogous to our discussion of baselining effects on program-level cost growth, these reductions in the growth of contract cost may be due to systematic shifts in the contract cost baselines (targets) against which we measure growth.[34] These contract baselines either are cost

[34] Like voltage, cost growth must be measured against some reference point.

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targets negotiated with the contractor (especially on complex systems, which dominate MDAP acquisitions) or directly reflect initial bid prices. Thus, any systematic shifts in target baselining could reflect a number of factors, including better historical data for Government cost estimating; changes in cost and pricing data provided from bidders to the Government; more realistic assumptions made by the Government or contractor; changes in risk taking and optimism by the Government or contractors; and shifts in contractor bidding and negotiation strategies. However, while the DoD has worked in recent years to improve cost estimating, negotiations, and contract structures, those efforts date back to 2008 and earlier, whereas the drop in growth of contracted costs is evident after 2011.

Program Management

Another possible driver of recent improvements could be better program management (e.g., better configuration control and more active monitoring and engagement of contractor performance, requirements, and cost drivers). Better EV data and increases in the acquisition workforce are enablers.

Other Variables

Prior research statistically tested a number of other variables that do not correlate strongly with growth of costs on these contracts. Further, prior research tested a number of other variables for correlation with price and cost growth on these contracts since the year 2000 (recall footnote 31).

Discussion

The procyclical nature of annual growth of contracted costs may be, in part, because a higher annual planning budget allows PMs the freedom to add or complete work to address design and engineering problems and evolving threats, including higher risk tasks and more efficient approaches that save money in the long run. Conversely, a lower annual planning budget would constrain PM flexibility, increasing prioritization, constrain capabilities, and defer higher risk tasks and those with high long-term payoff but short-term costs.

This analysis provides some insights into the behavior of the defense acquisition system.

- The autoregression feedback indicates a self-correcting control system.
- It adjusts to budgetary changes, prior differences from expectations, and unforeseen external shocks.
- Added oversight from Goldwater-Nichols-era changes appears to have had a major effect at moderating contract cost behavior. Similarly, recent efforts to instill a cost-conscious culture have improved cost control. The reforms of the mid-1990s coincided with an undesirable trend, though unlike the positive trends, our modeling did not show statistically significant indications of causal factors.

Taken together, this analysis provides both an encouraging and cautionary tale that some reforms have moderated costs in this metric while others have not. It also demonstrates how statistical analysis, combined with theoretical insights, offers useful information on the effects

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of policy changes and thus can inform future decision making without repeating past mistakes or resorting to speculation, intuition, or change for the sake of change.

BUDGET CLIMATE EFFECTS ON TOTAL GROWTH OF CONTRACT COSTS

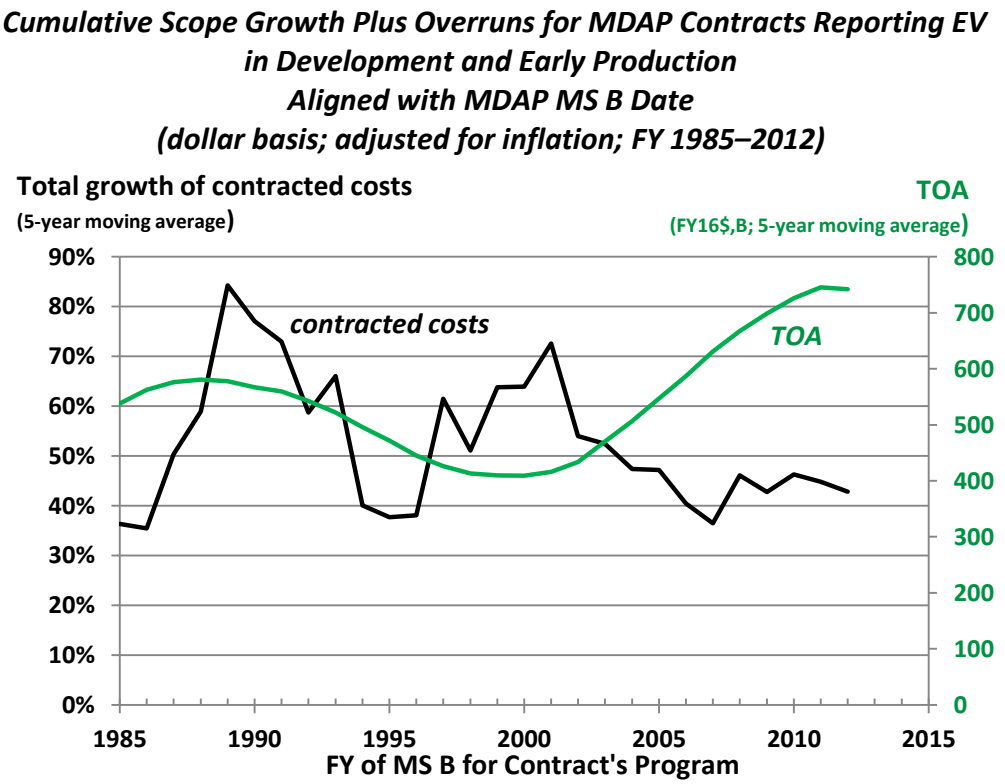
In addition to annual growth of contracted costs (above), we tested for correlates in the same contract EV date for development and early production when all costs are attributed to the MS B date of the program that the contracts are for. This is the contract-level analysis analogous to the program-level studies by McNicol and Wu (2014) cited in last year's report, which examined the effects of budgetary climates on PAUC growth from 1970 to 2007; they found that constrained budgetary climates during program baselining correlate with significantly higher PAUC growth.

Total Growth of MDAP Contracted Costs in Development and Early Production Aligned to MS B Date

Figure 3-7 plots the 5-year moving average of total growth on MDAP contracted costs aligned to MS B date. For comparison, the 5-year moving average of DoD's annual Total Obligation Authority (TOA) is overlaid in green to help visualize budgetary swings during the same period. Again, a moving average was used to help smooth the data and reveal evolving trends. Remember that these data reflect both work-content (i.e., scope) growth (which generally dominates such cost growth on EV-reporting contracts—see our prior annual reports) and cost-over-target (i.e., overruns relative to the contract target).

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Figure 3-7. Five-year Moving Average of Total Growth of Contracted Costs for MDAPs Aligned to Milestone B date (FY 1985–2012)



NOTES: Total growth of contracted costs is aligned to the original MS B date regardless of contract start dates. DoD TOA is shown in green, and its scale is on the right-hand y-axis in FY 2016 real dollars. The 5-year moving average of total growth in contracted costs is relative to negotiated cost targets on major contracts of MDAPs (including MAIS that are large enough to also be MDAPs) in EMD and early production that reported EV data (i.e., including almost no firm-fixed-price or full-production contracts). This is *different* than statutory measures of program-level cost growth measures such as PAUC and APUC relative to Milestone B baselines. These data summarize 18,470 earned-value reports on 1,123 major contracts for 239 MDAPs.

Factors Contributing to Total Growth in Contracted Costs at Program MS B Start

To understand what may be driving the trends in Figure 3-7, we tested for statistical correlation of different available variables against the total growth curve. We found that the combined effects of two types of drivers—together with a constant base and random noise—very closely fit the dynamics of the growth curve.

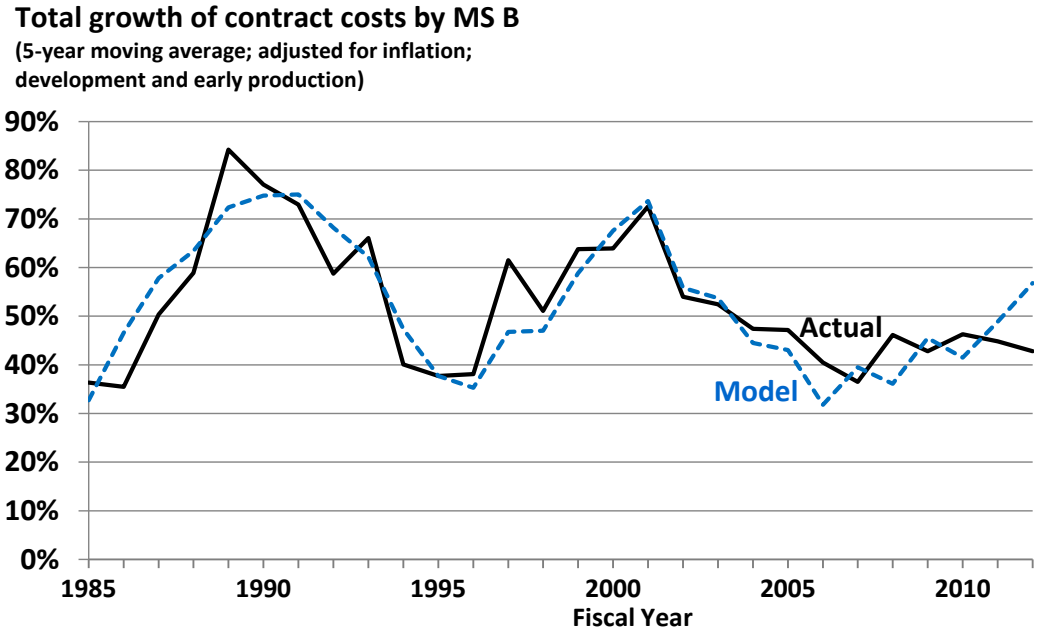
1) **Countercyclical budget effect.** The total growth in costs aligned to MDAP start is, in part, countercyclical with the change in the 5-year moving average of the TOA from the prior year.
2) **Three self-correcting factors.** The data behave as if the system corrects for prior differences between the anticipated growth levels from the countercyclical budget factor and the actual growth (with three different lags of 1, 4, and 5 years) due to "shocks" to the system. In other words, it appears that the system not only responds countercyclically to budgetary changes but also sees and responds to cost growth on programs started in the recent past relative to that countercyclical behavior.

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Figure 3-8 shows that the model closely fits the data for the actual total growth by MS B date. Further statistical details are presented in Appendix C.

There were no statistically significant structural changes in this period for this performance measure. Since the contract data are aligned to MS B dates, the plot extends only to 2012, so it is too early to tell if recent efforts such as BBP and management discipline during the current sequestration downturn in budgets will moderate the historical countercyclical behavior. There are early indicators that this may be happening, however, in the last few years of data where the model departs from actual results.

Figure 3-8. Statistical Model Fit to Actual Growth of Total MDAP Contract Costs by MS B (FY 1985–2012)



Discussion

The countercyclical nature of total growth of MDAP contracted costs by MS B start date seems to imply that, in tight budgetary environments, resource planners may be willing to take risks to maintain program start rates and may use overly optimistic initial cost estimates to fit budgets. Since initial estimates are optimistic and risks are high, we can expect higher cost growth.

Conversely, in accommodating budgetary environments, there is less pressure to assume risk to maintain the number of program starts, so DoD Components may have more realistic program start rates and cost estimates. Since initial estimates are realistic and risks are low, we historically saw lower cost growth. Industry may reinforce these tendencies by taking more risk and bidding low to win the only available program opportunities.

These data (along with results from McNicol and Wu, 2014) support caution about the tendency to start programs with overly optimistic program-cost baselines and contract cost targets in times like the present.

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SUSTAINMENT COSTS

While much attention and data focus on the efficient development and procurement of defense systems, O&S costs can outweigh earlier acquisition costs. As a result, we are expanding our analyses to provide insights on how effective the acquisition system is at understanding and controlling total life-cycle costs. This includes understanding the major drivers of O&S cost growth and (in part) our ongoing affordability policy and process.

Correlates of Growth in O&S Cost Estimates During Acquisition

We examined 161 MDAPs that provide O&S cost estimates in their SARs. After adjusting for inflation using the Comptroller's O&M deflator (USD(C), 2016c), we tested a range of variables for correlation with the changes over time in O&S cost estimates during acquisition.

DoD-Wide

Table 3-1 summarizes the variables that correlate with DoD-wide growth of O&S cost estimates on MDAPs during acquisition. Across the DoD during CY 2001–2014, inflation-adjusted maintenance, labor, and fuel costs correlated with changes in O&S cost estimates. Specifically, O&S cost estimates generally increase with maintenance cost growth, wages (both absolute levels and growth), and health-care cost growth. Also, cost estimates tend to change based on fuel price levels, but interestingly the model predicts that estimates will decrease when fuel prices increase. We suspect that this negative correlation may reflect program actions to improve system fuel efficiency (if changes can be made early enough to affect consumption) or program-manager expectations that operational tempo or concepts of operations would be adjusted if prices remain high.[35] Note that all but the maintenance cost growth factor has an associated time lag of 2–5 years. This model fits very closely with the actual growth in O&S cost estimates reported in the SARs (Figure 3-9). The model explains 81 percent of the variation in annual change in O&S cost estimates.

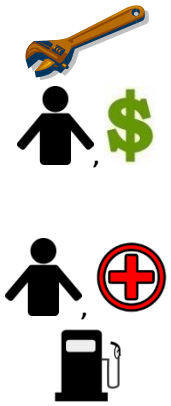
Interestingly, O&S cost-estimate changes from CY 2001–2014 did not correlate DoD-wide with growth in any of fuel-price, quantity, or service-life.[36] As we will see shortly, however, these did correlate with DoD Component and commodity O&S cost estimates in some cases.

[35] As with all estimates, there is no guarantee that actual operational changes would be made in the future, but operational tempo and concept-of-operations are levers often employed to modulate O&S expenses.

[36] Service life is the expected length of time that the system will be in operation.

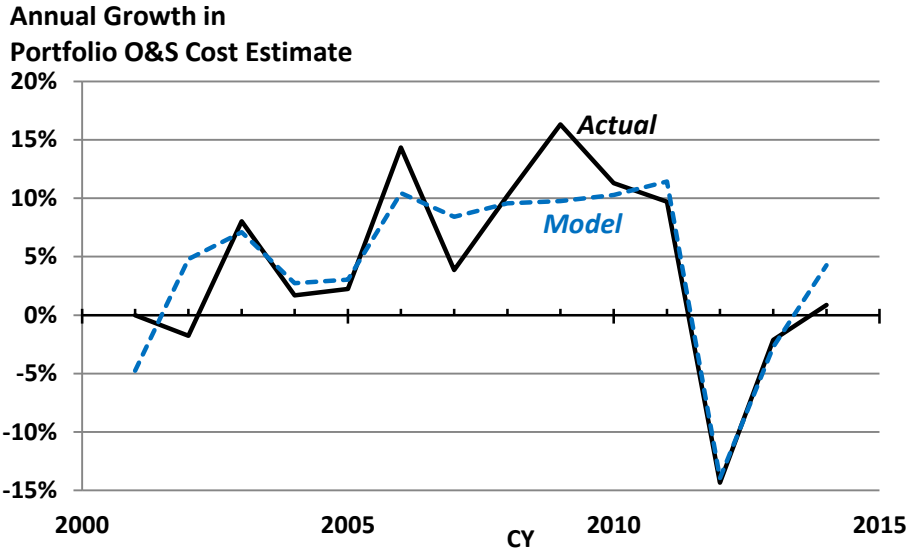
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Table 3-1. Correlates of O&S Cost-Estimate Growth: DoD Wide (CY 2001–2014)



Sign	Cost Variable	Metric	Lag
+ *Increased with*	**Maintenance**	growth (annual)	—
+ *Increased with*	**Wage**	levels	2 years prior
+ *Increased with*	**Wage**	growth (annual)	3 years prior
+ *Increased with*	**Health care**	growth (annual)	5 years prior
– *Decreased with*	**Fuel price**	level	5 years prior

Figure 3-9. Model Fit: Annual Change in Portfolio O&S Cost Estimates: DoD-Wide (CY 2001–2014)



NOTE: *N* = 161 MDAPs. *R*-squared = 81%. *p* = 0.0000.

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Table 3-2 illustrates the model and the relative magnitude of the individual partial contributions from the variables by inserting the actual values for the variables in CY 2014. The largest partial contributor for CY 2014 was from wages, followed by health care and fuel. Remember that in such models all factors must be added together to obtain the total model prediction.

Table 3-2. Example: Modeled cost growth in DoD-wide MDAP O&S estimate for CY 2014

	Variable	CY 2014 Value	Coefficient	Partial Contribution
Maintenance	Annual change in portfolio maintenance cost estimate	4.6%	0.09133	0.4%
Wages	Average annual wage per worker above $43.5K *(real; 2 years prior; $1,000s)*	$1.03K	5.91% / $K	6.1%
	Annual change in annual median wage per worker *(real; 3 years prior)*	−0.31%	2.27	-0.7%
Heath care	Annual change in per capita health consumption *(real; 5 years prior)*	2.15%	2.64	5.7%
Fuel	Annual average price per barrel of crude *(real; 5 years prior)*	$63.35	−0.0891% / $	-5.7%
Partial constant			-1.5%	-1.5%
				Total 4.3%

NOTE: Partial contributions are the result of multiplying the 2014 value by the coefficient for the variable. The total is then the sum of all the partial contributions plus the constant. To simplify the example, we used the wage level of $43.5K (the average across 2001–2014) as the base level for the variable, adjusting the constant accordingly.

In summary, while PMs cannot control the exogenous forces of wages, health-care costs, and fuel prices, the PM has some ability to affect fuel efficiency and maintenance costs (e.g., system reliability, ease of maintenance, and repair automation). However, many of these levers must be addressed very early in the design of the system. That is why the DoD's new affordability process sets goals and caps on life-cycle costs early in the program's life (e.g., at MDD and MS A, when designs can be changed).

This analysis also illustrates to stakeholders in the DoD and in Congress that annual swings in SAR O&S cost estimates can only partially reflect the performance of the defense acquisition system. Also, the way that O&S metrics are constructed makes it very hard to separate acquisition program effects from external effects. Improvements would require additional metrics that hold the external variables constant from MS B forward (for purposes of comparison) so as to reveal changes due to factors that the acquisition system can control.

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By Military Department

Table 3-3 summarizes the variables that correlate with growth of MDAP O&S cost estimates by military department. Many of the correlated variables for the DoD Components resembled the DoD-wide results, but there were differences, including different lag periods. Also, while DoD-wide cost-estimate changes did not correlate with fuel-price growth, the Air Force and Other DoD estimates did (and they were positively correlated). Service-life growth was correlated with Army estimates during this time period. The fact that fuel costs are positively correlated for the Air Force and Navy may indicate that they have less ability to adjust estimated operational tempo or fuel efficiency within the system designs. Note that all but the maintenance cost growth factor has an associated time lag.

Table 3-3. Correlates of O&S Cost-Estimate Growth by DoD Component (CY 2001–2014)

Variables	*Overall*	*By DoD Component*			
	DoD-wide (lag, years)	Army (lag, years)	Navy (lag, years)	Air Force (lag, years)	Other DoD (lag, years)
Maintenance cost growth*	+	+	+		
Wage	+ (2)				+ (2)
Wage growth*	+ (3)		+ (3)	+ (3)	
Health-care cost growth*	+ (5)	+ (4)			
Fuel price	− (5)	− (5)	+ (3)	+ (2)	− (5)
Fuel-price growth*				+ (5)	+ (1)
Service-life growth*		+			

* annual (year-on-year) change
\+ positively correlated
− negatively correlated
NOTE: Growths are annual from prior year. DoD-wide results are included to facilitate comparisons. Blank entries indicate no correlation. For the Army, the model explained 85% of the variation and is statistically significant at the 1% level of significance (p = 0.0002). For the Department of the Navy, the model explained 77% of the variation and is statistically significant at the 1% level of significance (p = 0.0023). For the Air Force, the model explained 61% of the variation and is statistically significant at the 5% level of significance (p = 0.0190). For other DoD systems, the model explained 47% of the variation and is statistically significant at the 1% level of significance (p = 0.0083).

By Commodity

Finally, Table 3-4 summarizes the variables that correlate with growth of MDAP O&S cost estimates by four commodities: fixed-wing aircraft, helicopters, ships, and space. As with the DoD Components, many of the correlated variables for the commodities resembled the DoD-wide results, but there were differences, including different lag periods. While DoD-wide cost-estimate changes did not correlate with fuel-price growth, it did for ship estimates (and the correlation was positive, which indicates that ships tend to be less flexible in steaming hours[37]

[37] Steaming hours reflect ship operation, including hours underway and not underway (in port).

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and supports the Navy model above). Also, quantity growth was correlated with aircraft and space O&S estimates during this time period. Note that all but the maintenance cost growth factor has an associated time lag.

Table 3-4. Correlates of O&S Cost-Estimate Growth by Commodity (CY 2001–2014)

Variables	*Overall*	*By Commodity*			
	DoD-wide (lag, years)	Aircraft, fixed-wing (lag, years)	Helo (lag, years)	Ships (lag, years)	Space (lag, years)
Maintenance cost growth*	+			+	
Wage	+ (2)				
Wage growth*	+ (3)	+ (3)	+ (2)	+ (3)	
Health-care cost growth*	+ (5)		+ (3)		
Fuel price	− (5)	+			+ (3)
Fuel-price growth*				+ (3)	
Quantity growth		+			+

* annual (year-on-year) change
\+ positively correlated
− negatively correlated
NOTE: Growths are annual from prior year. DoD-wide results are included to facilitate comparisons. Blank entries indicate no correlation. For fixed-wing aircraft, the model explained 55% of the variation and is statistically significant at the 5% level of significance (p = 0.0229). For helicopters, the model explained 53% of the variation and is statistically significant at the 1% level of significance (p = 0.0044). For ships, the model explained 71% of the variation and is statistically significant at the 10% level of significance (p = 0.0564). For space systems, the model explained 64% of the variation and is statistically significant at the 1% level of significance (p = 0.0001). For space systems, the correlation with fuel prices may seem odd, except that most O&S costs are for ground operations, not the actual operation of the spacecraft in space.

AFFORDABILITY

BBP established an explicit policy and process codified in DoDI 5000.02 (USD(AT&L), 2015a) for determining and ensuring the long-term affordability of the entire life-cycle costs of each system to be acquired. Affordability analysis and constraints impose procurement and sustainment budget controls on the system throughout the FYDP and beyond. Constraints are determined in a top-down manner by the resources a DoD Component can allocate for a system, given inventory objectives and all other fiscal demands on the DoD Component against a long-term future total budget projection. Constraints (especially the caps established at the Development Request for Proposals Release Decision Point before MS B) constitute a threshold for procurement and sustainment costs that cannot be exceeded by the PM. When affordability constraints cannot be met—even with aggressive cost control and reduction approaches—then technical requirements, schedule, and required quantities must be revisited (e.g., with support from the DoD Component's Configuration

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Steering Board). The program will be canceled if constraints still cannot be met, and the DoD Component cannot offset cost increases by lowering the caps on other programs.[38]

It is too early to test the effect of the affordability process on outcomes from the acquisition system (e.g., whether program cancellations are made earlier and thus reduce sunk costs), but we have begun to measure the degree to which the affordability analysis and constraints have been implemented in the DoD. All three military departments have established an affordability analysis capability, centered in their staff directorates for financial management and resource planning (i.e., G-8, N-8, and A-8 for the departments of the Army, Navy, and Air Force, respectively) in support of Service leadership decision making.

Affordability constraints have been imposed on 31 of 45 MDAPs that have undergone major reviews between November 2010 and July 2016, including those that have not yet passed MS B. Thus, about two-thirds of MDAPs have been assigned an affordability constraint commensurate with the policy in place at the time of their reviews. The implementation rate for MAIS is improving but is still much lower at about 44 percent (4 of 9 programs). The DoD is working to improve consistency in application of the affordability policy to both MDAPs and MAIS.

In addition, we track affordability constraints and compare program performance against those constraints on a regular basis. We are reviewing these programs and refining how best to handle each individual case given needs and budgetary constraints.

DYNAMICS OF PROGRAM PERFORMANCE REQUIREMENTS: PRELIMINARY ANALYSIS

One potential source of program cost or schedule growth is program requirement changes. While casting requirements in stone would prevent the DoD from adapting to changes in threats, engineering challenges, and cost-benefit tradeoffs as engineering and operational insights are gained during development, we also do not want requirements to be highly dynamic, given the resulting implication for program cost and schedule. Generally, case studies (e.g., GAO, 2015b) and qualitative experience have shown that high-level requirements (KPPs and KSAs) tend to be changed infrequently while lower-level engineering requirements are adjusted more frequently as insights are learned from technology and engineering development.

To further test the consistency of these results, we compared the unclassified program "performance" requirements of the original MS B APB to the latest SAR for 121 MDAPs for which these data are readily available. These reported performance requirements are supposed to reflect the major unclassified KPPs, but they contain at least some KSAs. For this preliminary analysis, we counted traceable changes, additions, deletions, and specifications between these

[38] Independent of affordability constraints or cost estimates, the DoDI 5000.02 instructs PMs to always look for ways to control or reduce cost. The BBP Should-Cost initiative provides organizational incentives and rewards for Components and PMs to continue looking for cost reductions below the affordability constraints, while the Nunn-McCurdy breach process provides a strong organizational disincentive on excessive growth.

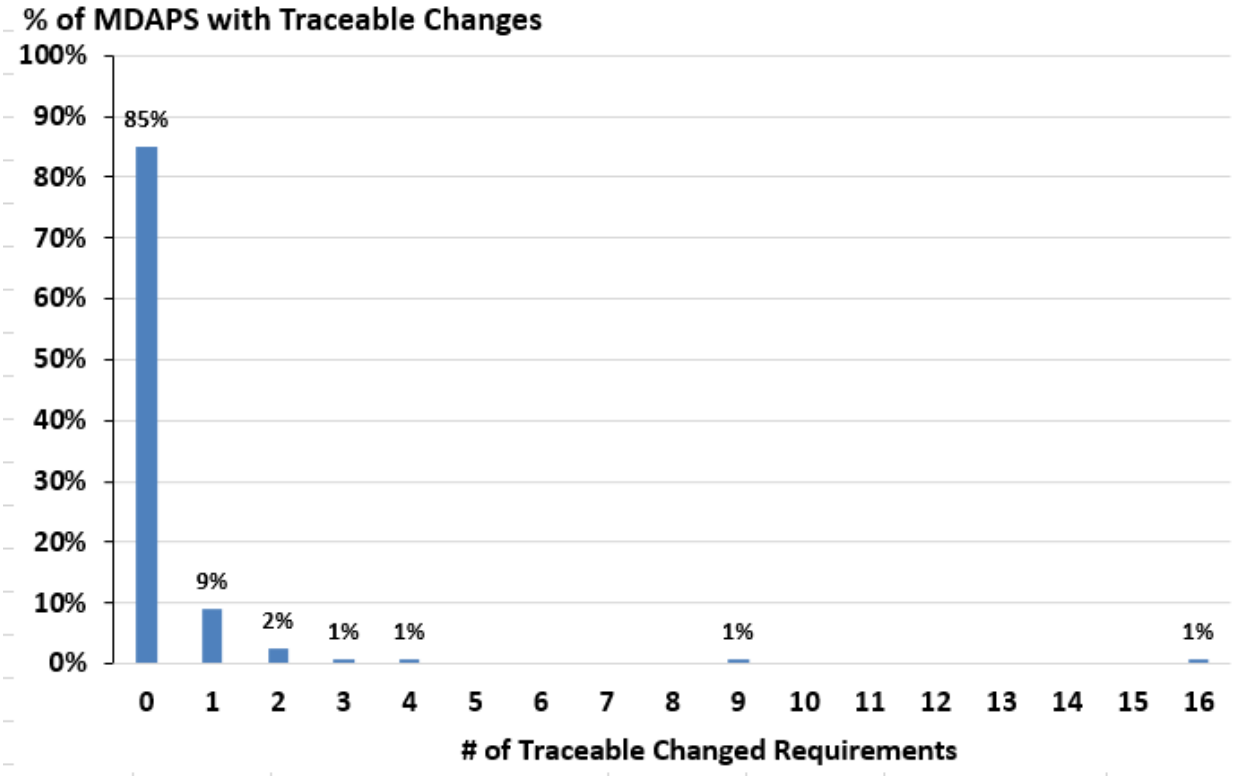
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two documents. Here, specifications are the addition of a threshold value when none was present in the APB (e.g., were not marked or marked as "not specified"). Note that while the APB and SARs are official documents, they are not the authoritative source for program requirements and thus may differ somewhat for various reasons (e.g., data entry errors, omissions, or changes in selecting what to report). Also, it is important to note that these may not be contractual requirements, which have a direct effect on cost and schedule growth relative to contractor performance.

From this preliminary analysis we found that most MDAPs (about five-sixths of the 121 MDAPs in our dataset) did not make traceable changes (Figure 3-10). Most of the remaining MDAPs had very few traceable changes.

Further analysis is needed to determine the motivating factors for these changes (e.g., whether they were driven by changes in threats or to accommodate technical issues, or whether these changes were the result of reporting errors between the requirements documents and the APB and SAR documents). We also want to examine the source requirement documents to understand better which requirements were included in APB and SARs.

Figure 3-10. Fraction of MDAPs with Traceable Performance Requirement Changes Between MS B APB and Latest SAR (CY 1988–2015)

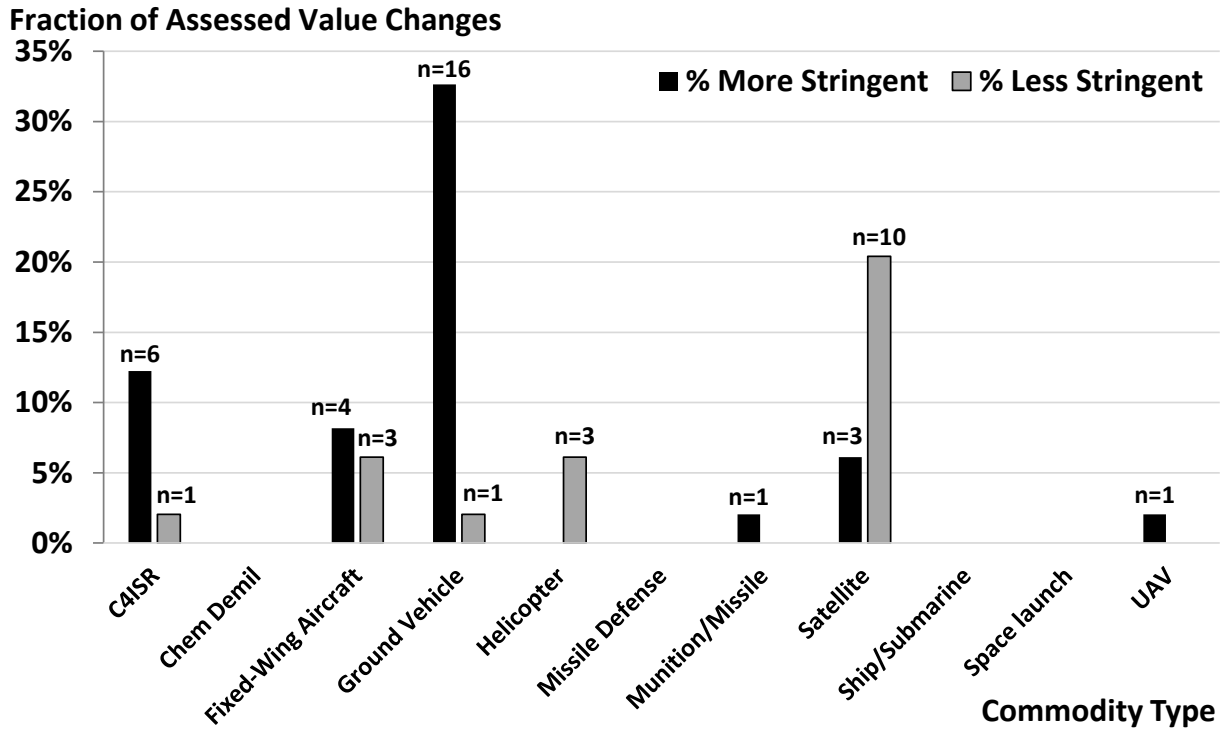


NOTE: This chart shows the percent of 121 MDAPS with traceable changes in performance threshold values between the original MS B APB and the latest SAR. APB dates ranged from CY 1988 to 2015. Corresponding SAR dates ranged from CY 2006 to 2015.

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For the 49 cases in which we could judge whether a change was more or less stringent, Figure 3-11 shows the distribution by commodity type. Satellites, helicopters, and C4ISR systems tended to change requirements to make them easier to meet, while aircraft, ground vehicles, munition/missiles and UAVs all tended to increase the difficulty of meeting the requirement. Table 3-5 shows that, as with the overall change distribution, these changes tend to be concentrated in a small number of programs. Here about half of the requirements judged more stringent were in a single program (FMTV, a ground vehicle), and half of the less-stringent changes were in the NPOESS satellite program. Again, further analysis is needed.

Figure 3-11. Stringency of Performance Requirement Changes by Commodity Types (CY 1988–2015)



NOTE: *N* = 49 requirements changes that were rated as either more or less stringent. This chart shows the distribution of these 49 changes by commodity and stringency with the number of requirements listed above the bar.

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Table 3-5. Programs with Changes Assessed as More or Less Stringent by Commodity Types (CY 1988–2015)

Commodity Type	Total # programs	# of Changes Judged: *More Stringent*	*Less Stringent*
C4ISR	*30*		
ATIRCM/CMWS		1	
JTN		1	
JTRS GMR			1
MIDS		1	
WIN-T Inc 2		2	
WIN-T Inc 3		1	
		6	***1***
Fixed-Wing Aircraft	*19*		
F/A-18E/F		2	
F-22		1	2
F-35			1
P-8A		1	
		4	***3***
Ground Vehicle	*9*		
EFV			1
FMTV		16	
		16	***1***
Helicopter	*13*		
H-1 Upgrades			1
MH-60S			2
		0	***3***
Munition/Missile	16		
GMLRS/GMLRS AW		2	
		2	**0**
Satellite	9		
NAVSTAR GPS		3	1
NPOESS			9
		3	**10**
UAV	6		
RQ-4A/B Global Hawk		1	
		1	**0**
Chem Demil	3	**0**	**0**
Missile Defense	2	**0**	**0**
Ship/submarine	13	**0**	**0**
Space Launch	1	**0**	**0**
Total:	121	**31**	**18**

NOTE: About half of the more stringent changes are in FMTV, and half of the less-stringent changes are in NPOESS (see highlights in yellow). Program abbreviations are defined in Appendix F starting on p. 159.

Further analysis is needed to determine the motivating factors for these traceable changes (e.g., whether they were driven by changes in threats or to accommodate technical issues, or whether these changes were the result of reporting errors between the requirements documents and the APB and SAR documents).

Finally, untraceable changes assessed as APB deletions, SAR additions, and specifications require further analysis to identify the details for why these untraceable changes were made.

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QUANTITY PROCURED

Another useful measure of acquisition performance is the quantity of major weapon systems procured compared to the number planned at the original MS B. An oft-quoted saying by military strategists is that quantity has a quality all its own,[39] so it is useful to see how often the defense acquisition system ends up procuring the originally planned number of major weapon systems.

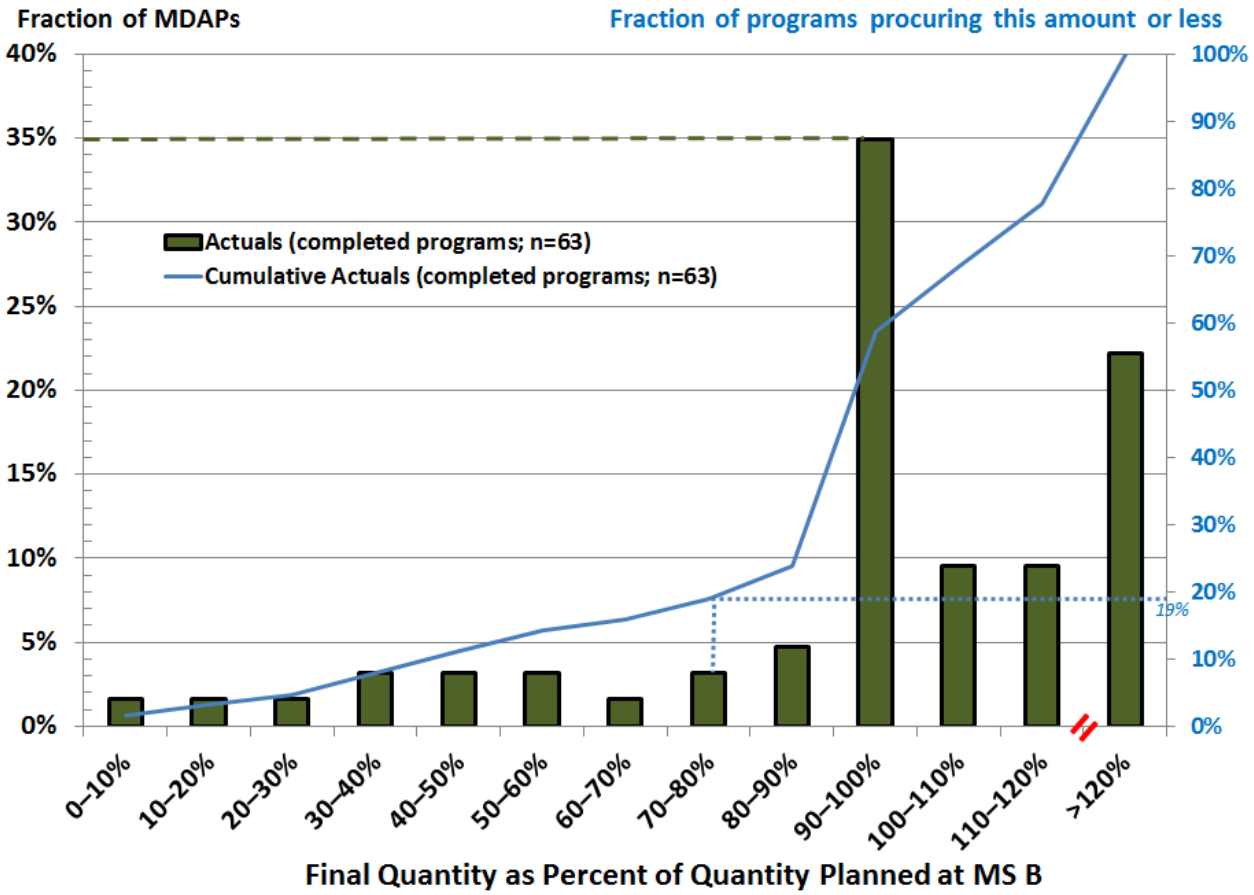
Despite reductions in quantity on some high-visibility programs (e.g., DDG-1000 and F-22), most programs deliver nearly the original quantity or more. Figure 3-12 shows the actual number of units procured by completed MDAPs that passed MS B over the past 19 years. Over 80 percent of programs delivered at least 80 percent of their originally planned units, and just over 40 percent of programs delivered more than originally planned.

This general pattern appears to be holding for currently active programs. Figure 3-13 shows the estimated final quantity distribution for active MDAPs along with the final quantity distribution for completed MDAPs. Again, most active programs estimate they will deliver at least 80% of their originally baselined quantities.

[39] The original source of this quote is difficult to verify.

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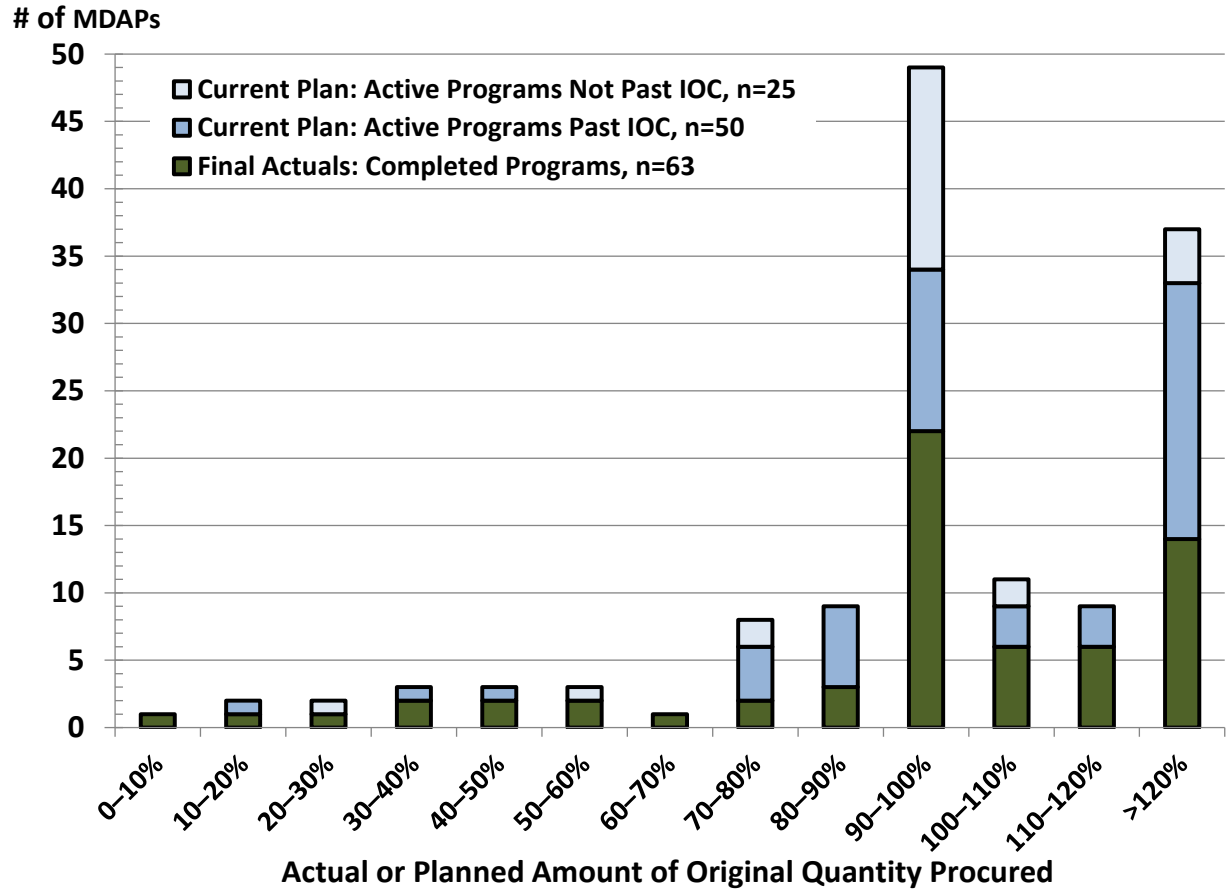
Figure 3-12. Actual Quantity Procured Compared to Original MS B Plans for Completed Programs (1997–2015 SARs)



NOTE: Completed programs are those that stop reporting after approximately 90 percent of units are delivered or 90 percent of funds expended. There were *N* = 63 completed programs in our dataset. The bars show the fraction of the 63 programs that procured the indicated range of original quantity percentages (e.g., 35 percent of the 63 programs procured 90–100% of their originally planned quantity). The blue line measures the cumulative fraction of programs and is read off the y-axis on the right side of the plot (e.g., 19 percent of the programs procured less than 80 percent of their originally baselined quantity).

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Figure 3-13. Actual and Estimated Quantities Procured or Planned Compared to Original MS B Plans for Active and Completed MDAPs (1997–2015 SARs)



NOTE: Completed programs are those that stop reporting after approximately 90 percent of units are delivered or 90 percent of funds expended. The bars show the number of MDAPs that procured or plan to procure the indicated range of original quantity percentages. For example, 3 completed MDAPs procured 80–90 percent of their originally planned quantity while 6 active MDAPs that are past IOC also estimate to deliver 80–90 percent of their originally planned quantity.

PROGRAM CANCELLATIONS AND SUNK COSTS

We updated the data from our first report (USD(AT&L), 2013b) on the approximate sunk costs of MDAPs that were canceled past MS B. Here "canceled" is defined as being inactive and not achieving IOC. Table 3-6 lists the 23 programs that had at least one SAR in 1997–2015 and were canceled. Figure 3-14 plots the total sunk costs in two ways: first by the year of program initiation (MS B), and second by the year of cancellation. Using SARs only produces approximations for various reasons (e.g., final SARs are often not submitted; delayed budget requests in years when the presidential administration changes limit SAR data).

There were 136 MDAPs in these SARS that are either inactive or past IOC. Thus, the current cancellation rate for MDAPs that have passed MS B is about 17%, or one-sixth. The total sunk cost for these programs in FY 2017 dollars is $53.5 billion. Almost 44 percent of those dollars

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are in two programs: Future Combat System (FCS; $20.7 billion) and the RAH-66 Comanche reconnaissance/attack helicopter ($9.8 billion). Eight canceled programs spent at least 100 percent of their original RDT&E baseline, including Comanche (but not FCS). On average, about two-thirds to three-fourths of the original RDT&E baselines were spent before these programs were canceled.

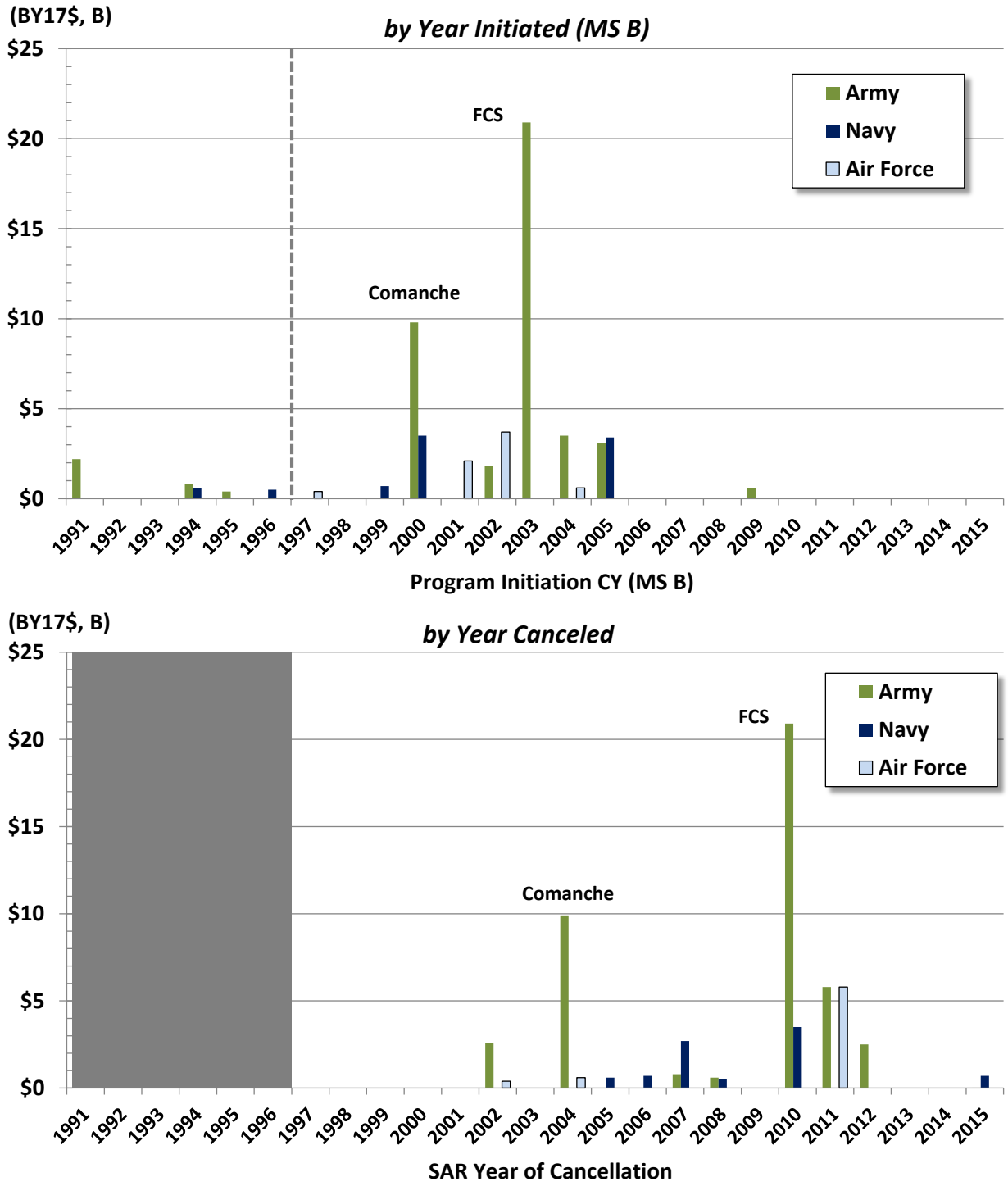
Table 3-6. Approximate Sunk RDT&E Costs of MDAPs Canceled After MS B (1997–2015 SARs)

Program [sub-program]	RDTE Sunk at Cancellation (BY17$, in Billions)	% of Total Sunk	% of Original Baseline Sunk at Cancellation	% of Latest Baseline Sunk at Cancellation	CY of MS B	SAR Year of Cancellation
FCS	$20.7	35%	88%	64%	2003	2010
COMANCHE	$9.8	17%	109%	60%	2000	2004
NPOESS	$3.7	6%	36%	99%	2002	2011
EFV	$3.5	6%	31%	93%	2000	2010
Patriot/MEADS CAP [Fire Unit]	$3.4	6%	60%	100%	2004	2011
VH-71	$2.7	5%	61%	60%	2005	2007
JLENS	$2.5	4%	117%	92%	2005	2012
ATACMS-BAT [BAT/BAT P3I]	$2.2	4%	108%	100%	1991	2002
C-130 AMP	$2.1	4%	41%	100%	2001	2011
JTRS GMR	$1.8	3%	165%	96%	2002	2011
LAND WARRIOR	$0.8	1%	61%	96%	1994	2007
RMS	$0.7	1%	144%	97%	1999	2015
ADS (AN/WQR-3) [ADS Shipsets for LCS]	$0.7	1%	78%	100%	2005	2006
INCREMENT 1 E-IBCT	$0.6	1%	100%	81%	2009	2011
ARH	$0.6	1%	140%	100%	2005	2008
ASDS	$0.6	1%	105%	87%	1994	2005
TSAT (Legacy) [TSAT]	$0.6	1%	3%	3%	2004	2004
ERM	$0.5	1%	86%	92%	1996	2008
ATACMS-BAT [ATACMS BLK II/IIA]	$0.4	1%	67%	100%	1995	2002
B-1B CMUP [DSUP]	$0.4	1%	93%	81%	1997	2002
JOINT COMMON MISSILE [JCM]	$0.1	0.2%	10%	34%	2004	2004
AMF JTRS [Small Airborne Link 16 Terminal (SALT)]	$0.02	0.03%	10%	64%	2008	2015
Total Sunk	***$58.3***					
Median	*$0.8*		*82%*	*93%*		
Mean	*$2.7*		*78%*	*82%*		

NOTE: Just over half of the total sunk costs were from the first two programs (yellow highlights). Also highlighted are the eight sunk-cost percentages relative to original baselines that are over 100 percent. Across the 1997–2015 SARs, there were 23 post-MS B MDAPs that did not achieve IOC, 63 MDAPs that were completed, and 50 MDAPs that are currently active but have passed IOC. An additional 25 currently active MDAPs have not yet passed IOC and are not reflected in this analysis since we do not yet know their fate. Program abbreviations are defined in Appendix F starting on p. 159.

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Figure 3-14. Approximate Sunk RDT&E Costs of MDAPs Canceled After MS B (1997–2015 SARs)



NOTE: These charts reflect cancellations in the 1997–2015 SARs. This only includes programs canceled since the 1997 SAR (i.e., there may be programs started and canceled before 1997).

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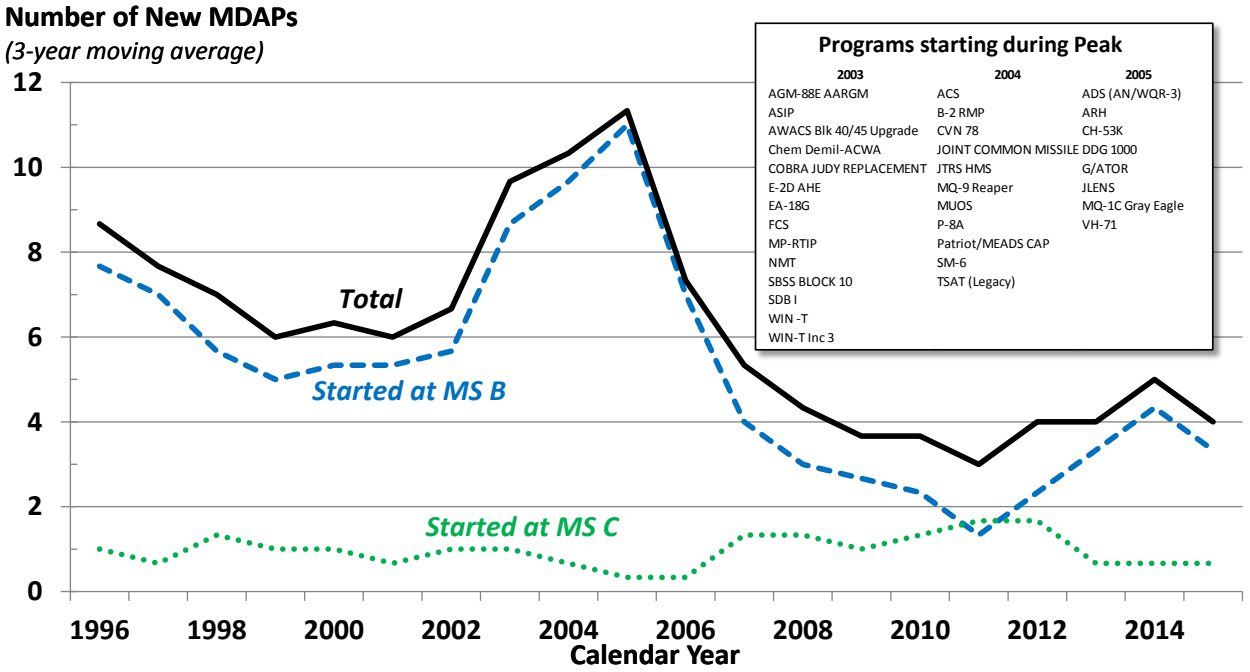
Frequency of New MDAP Starts

With sequestration budget cuts and an increased pace of threat evolution, the DoD is concerned that we may be on a path to losing technical superiority. One early indication of this may be the frequency at which new MDAPs are started.

Figure 3-15 shows the 3-year moving average of the number of new MDAP starts. Programs are identified as to whether they started at MS B or whether they did not require EMD and instead started at MS C. The moving average is used to smooth the data and help identify trends. New starts declined to about six per year before 9/11, then spiked in CY 2003–2005. Since 2008, the DoD started about four new starts per year—about half of what we saw in the mid-1990s and two-thirds of the peak in the mid-2000s. New starts are at a historical low, so the concern about the lack of products in the "new product pipeline" seems to be justified.

In terms of dollars, Figure 3-16 shows the total acquisition value of the new starts aligned to their initiation. We saw a small number of spikes in the years 2001, 2003–2005, and 2011. Over all the years from 1997 to 2015, the median annual spend on new starts was about $35 billion. Because of the spikes, the mean was higher at about $60 billion.

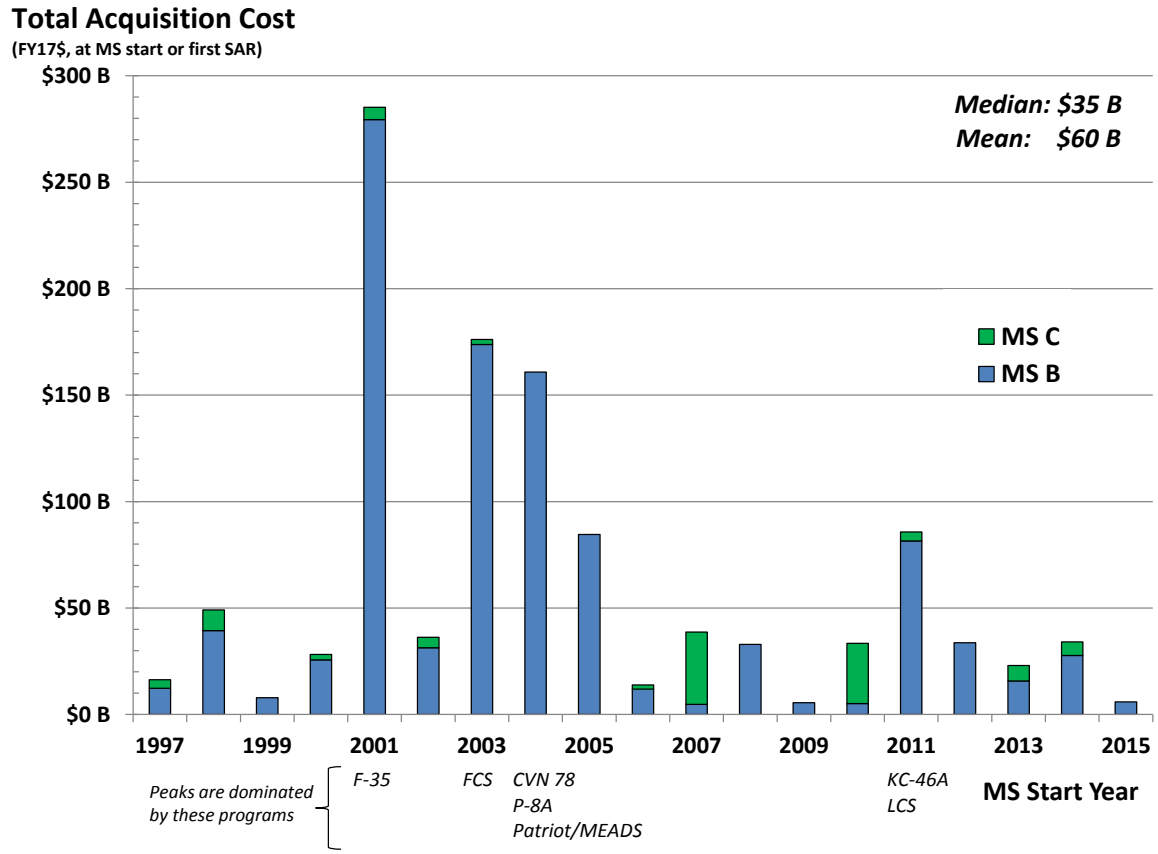
Figure 3-15. Frequency of New MDAP Starts: 3-Year Moving Average (CY 1994–2015)



NOTE: Dates were extracted from CY 1997–2015 SARs, with MS start dates in 1994–1996 extracted from the 1997 SARs. The data points for 1996 reflect the average for CY 1994–1996.

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Figure 3-16. Total Acquisition Cost of New MDAP Starts by Year of First MS B/C (CY 1997–2015)



SOURCE: 1997–2015 SARs.
NOTE: Program abbreviations are defined in Appendix F starting on p. 159.

PROGRAM MANAGER ANNUAL ASSESSMENTS

For a second year, the DAE tasked all PMs to provide directly a short (1–3 pages) assessment (with no staff or management review) of the state of their programs.[40] They give candid insights into the challenges and progress in these acquisition efforts.

Below we summarize our frequency analysis of the topics raised by the PMs. Since these assessments are unstructured, this analysis is not a reliable means of calculating the exact percentage of programs that face certain topics, but it does offer an insight into a broader range of topics that our PMs felt were important enough to raise. Here we tagged items raised

[40] Selected PM assessments from the first year were published to provide insights into the real-world successes and challenges facing defense acquisition (USD(AT&L), 2015c).

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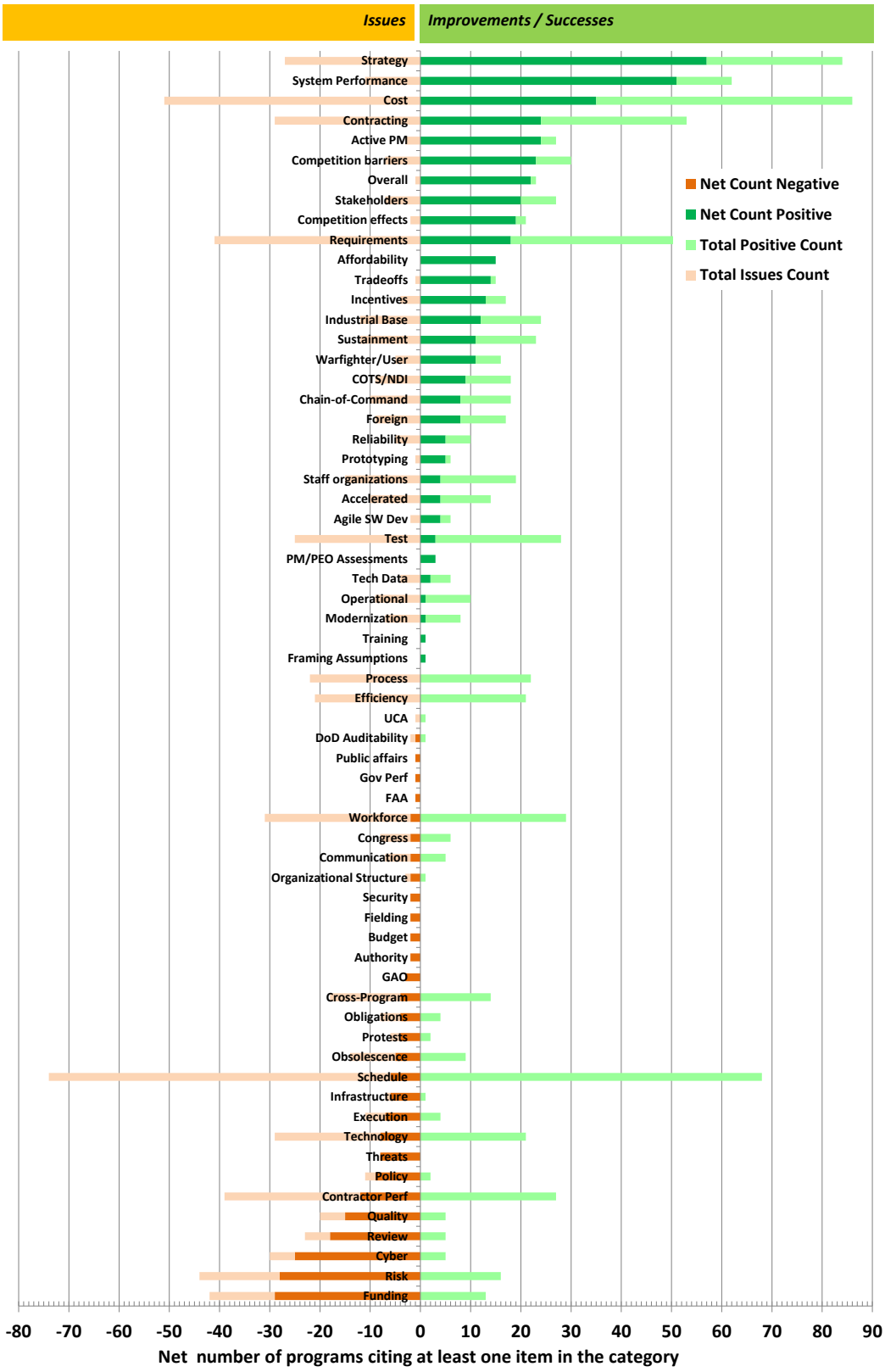
by the PMs with 1–3 topic labels. We then counted how many PMs raised each topic at least once as an issue or as a success. Figure 3-17 plots these counts and their difference.

Figure 3-18 shows the top-15 success topics drawn from Figure 3-17. Note that our PMs tended to be positive about strategy, system performance, program cost, and contracting (although the latter was raised often as both a success and issue).

Similarly, Figure 3-19 shows the top-15 issue topics raised by the PMs. Funding difficulties, risks, and cyber issues top the list. Interestingly, contractor performance was high on the list, but note that contractor performance was raised often as an issue and as a success (i.e., some contractors were performing very well while others were not). Technology and especially schedule issues also had a high number of both positive and negative citations with just slightly more negative than positive.

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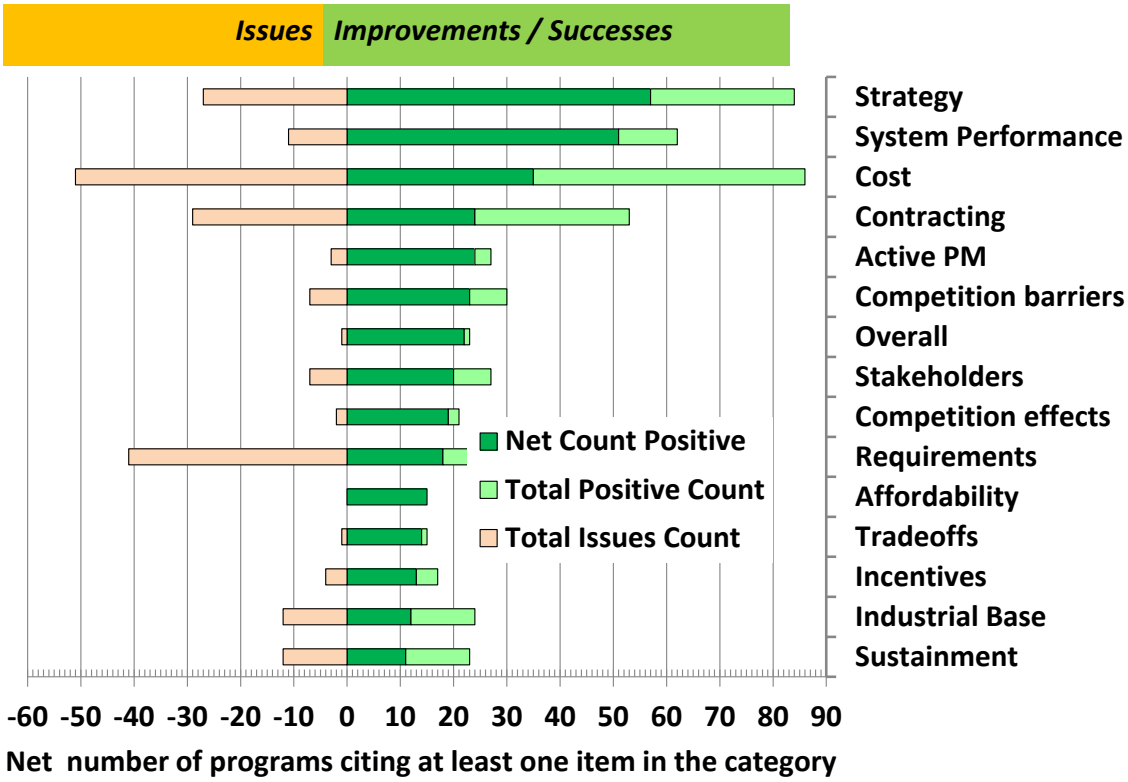
Figure 3-17. Net and Total Number of Issues and Successes Raised in PM Annual Assessments to the DAE (CY 2016)



NOTE: Topics are sorted in declining net order from most frequent success topics to most frequent issue topics.

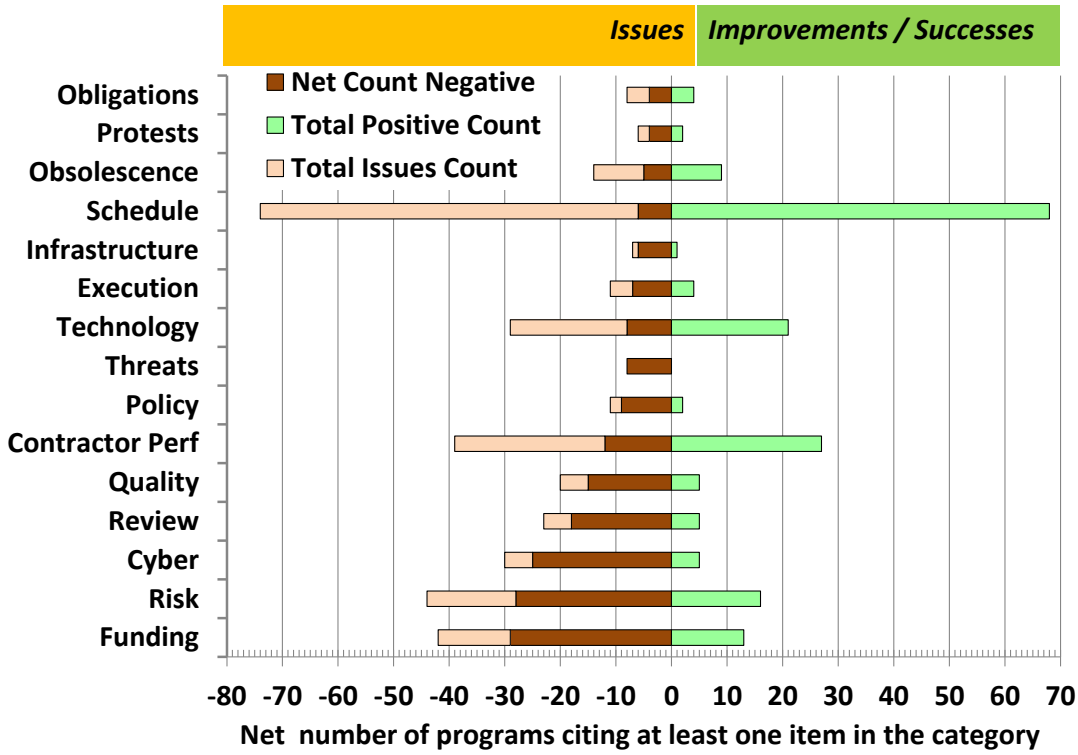
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Figure 3-18. Top-15 Net Successes: PM Annual Assessments to the DAE (CY 2016)



NOTE: Topics are sorted down from most frequent success topics.

Figure 3-19. Top-15 Net Issues: PM Annual Assessments to the DAE (CY 2016)



NOTE: Topics are sorted up to most frequent issue topics.

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PROGRAM EXECUTIVE OFFICER ASSESSMENTS

This year, in addition to the PM assessments discussed above, each PEO was directed to submit a short assessment of their portfolios directly to the DAE along with any suggestions they might have for improving defense acquisition. The DAE received a wide range of valuable observations, best practices, and recommendations, including thoughts on improving acquisition efficiency, eliminating bureaucracy, getting more from industry, developing the acquisition workforce, and many other topics.

Below are highlights of the issues and suggestions made by the PEOs that are applicable to wide portions of defense acquisition. In addition, some extracts rendered anonymous were included in a recent *Defense AT&L* magazine article (Kendall, 2016b). This is a useful collection of perspectives, ideas, and recommendations that we are reviewing with the intent of adopting good ideas where we can and stimulating our thoughts on how we can all be more effective. The USD(AT&L) staff in particular is working with the military departments and other elements of the OSD staff on implementation of many of the ideas in the full set of the PEO Assessments.

Balance in Acquisition

Cultural shift from spending to efficiency. We need to continue working on the workforce culture shift from a focus on spending to meet budget execution benchmarks toward employing critical thinking, tailoring, and incentives to be more efficient in both time and money as we equip our warfighters and try to get as much value as possible with the taxpayers' dollars.

Acquisition and the Larger Defense Mission

Pursue larger operational effects, not just program-level acquisition. At the end of the day, the defense acquisition system's job is to provide warfighter capabilities and effects—not just delivering a narrowly defined program. PEOs and other stakeholders are increasingly examining the integrated effects of programs on kill chains and mission capabilities, looking for unforeseen system-of-system interactions, dependencies, and gaps. This is a cultural shift. The processes for program design, requirements, and management are fairly well developed but are often narrowly specified and constrained when trying to identify and change to achieve broader system-of-systems operational outcomes.

Tyranny of the baseline. Programs need levels against which to measure cost, schedule, and technical performance objectives. However, those baselines often constrain the program when dealing with unforeseen technical problems (on a developmental program) or changing threats. Measuring programs against Milestone B baselines is a statutory obligation within the DoD, but new threats and unforeseen engineering challenges commonly arise after that milestone. Management techniques such as block upgrades and subprograms can help isolate and illuminate associated changes for approval by DoD leadership and Congress, but their widespread use is discouraged by the bureaucratic burdens they incur.

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Sunk cost (and past problems). A corollary to the baseline problem is an inability to recognize recent performance progress on long programs. Many PEOs note that some programs are now performing well after major attention and restructuring, but it is hard to shed past sins. Of course, simply rebaselining on a regular basis creates its own problem by concealing problems, so a balance and multiple views are needed.

Managing Risks During Execution

Test and information technology (IT). Program designs, testing, and fiscal resources are closely considered and traded at program initiation to ensure a viable program. In some cases, program requirements may not fully reflect the intended combat environment, and those environments may change with evolving threats. In contrast, the test and IT communities are responsible for ensuring that tests and cybersecurity address current threats. Unfortunately, this can lead to impasses between the program and test/IT community because program funding is based on requirements while testing/cybersecurity evaluations are based on current threats. Additional funding could be required. Although the acquisition chain-of-command will adjudicate many of these conflicting pressures during major program reviews, the infrequency of these reviews makes it difficult to adjudicate these needs and make risk and funding tradeoffs. One PEO suggested that a new process may be needed (e.g., bringing test and cybersecurity mandates under Configuration Steering Boards (CSBs)) to balance these risks, tradeoffs, and funding demands during execution.

IT upgrades and testing. The pace of IT changes to systems (from threats, system-of-systems needs, and technical opportunities) is significantly shorter than the timelines required to perform tests—especially if numerous deficiencies are found that must be fixed and retested. Policies, processes, and approaches for efficiently testing incremental system changes are not always employed. Approaches currently being used with some success include ensuring that earlier defects are addressed, incremental testing that leverages earlier test results, using automated software regression test tools, and other best practices.

Risk management. New frameworks for assessing risks—combined with IT staff incentives to drive risks to near zero—can lead to excessive focus on risk mitigation rather than balanced management. Many PEOs complained that, rather than facilitating quick consideration of key risks, the recent Risk Management Framework (DoD CIO, 2016) is overly bureaucratic, complex, ill-tailored for weapon systems, and hard to satisfy. More implementation refinement may be needed to make the use of the framework more efficient, effective, and responsive.

Challenge and Inform Requirement Decisions

Use Configuration Steering Boards (CSBs) for lower ACAT programs. As with major programs, it would be useful to have CSBs refine requirements and conduct tradeoffs for lower ACAT programs during execution. As the Army has found, this may need to involve delegation to boards below the Service Chief level due to the much larger number of lower ACATs.

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Treat every decision as if it uses your own money. One way to personalize acquisition performance is to ask staff to treat every decision as if the implications consume their personal money. This motivates early analysis of the cost, schedule, and technical risks associated with requirements, informing tradeoffs and requirements tailoring by the requirements community.

Workforce Levels

Workforce levels not fully recovered from 1990s reforms. While we have seen total increases of 25% in the acquisition workforce since FY 2008, some PEOs mentioned that their staffing levels are below validated requirement levels—even for their highest priority efforts. For example, one PEO cited a 50% increase in program dollars being executed but a 47% decrease in the acquisition workforce in their area since FY 1995. Efficiencies are being pursued, but many hinge on processes outside the program and PEO's control.

Workforce sufficiency review at milestones. Currently, a program is not allowed to proceed without both validated requirements and sufficient budgetary resources matched to cost estimates. Similarly, sufficient workforce levels should be ensured before a program is approved. Otherwise, the program should be re-scoped or not allowed to proceed. This would entail a major change in the way programs are reviewed but would formally recognize the importance of having a sufficient workforce for program success. Workforce sufficiency is difficult to ascertain in a purely quantitative fashion, so expert judgment and reviews would need to be used.

Workforce levels enable savings and are independent of force structure. The significant savings achieved in recent years depend on having a sufficient workforce that can pursue customized approaches rather than just spending money. Multiple PEOs asserted that recent savings outweigh the cost of the entire acquisition workforce. Unfortunately, headquarter budget cuts are reducing Government and contractor staff support to programs from PEOs, buying commands, and defense agencies. These cuts are endangering recent efficiency gains and degrading basic program management support. Such arbitrary cuts (without associated reductions in process streamlining) do not reflect the fact that the acquisition management workload is generally independent of quantity reductions associated with force-structure reductions. The management workload is also highly affected by the increasing pace of system upgrades to address increasing kinetic, electronic, and cyber threats.

Hiring. While having special hiring authorities helps, it still takes too long (e.g., over 100 days) to hire someone, which makes our offers too late for consideration (regardless of our salary levels) when trying to hire students directly out of college. Also, since we are generally precluded from hiring retiring O-5 and O-6 officers, we are seeing excellent candidates with 20+ years of experience walk out the door.

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Workforce Learning and Culture

Learning through "Whiteboard" sessions by leadership. Some leaders are conducting in-person reviews of acquisition strategies to facilitate staff learning while increasing innovation and developing more tailored and effective strategies.

Employee shadowing of senior leaders. One PEO established a practice of selecting employees to join him for two weeks at all meetings and events as a learning experience. This on-the-job training illustrates how to think critically and creatively about key acquisition elements such as acquisition strategies, contract type selection, design of contract incentives, and source-selection approaches while broadening their perspective.

Town hall meetings. Regular, informal town-hall meetings provide valuable venues for senior leaders to clarify the intent behind initiatives, offer examples of innovative acquisition, and illustrate how to think creatively to design better acquisition programs. Such meetings also facilitate feedback to senior leaders of challenges and issues "in the trenches."

Stakeholder training. Stakeholders within the DoD Components and in Congress often lack basic understanding of defense acquisition processes and their respective roles in it. This results in time lost answering questions far outside acquisition responsibilities (as well as the generation of uninformed reform ideas).

Acquisition Strategy

Commercial items. COTS and NDI usually (or even "only) work for defense systems when the requirements, usage, and environments match exactly. This results in fairly low appropriateness at the system level (where functions, requirements, and "-illities" often differ) but increasing appropriateness at part levels.

Limitations of rapidly acquired systems. Because rapidly acquired systems are based on readily available and often commercial components, they share many of the COTS/NDI issues above. Also, they are often difficult and costly to sustain in the long term, difficult to convert to a regular program of record, and are often effective against only a narrow range of threats.

COTS obsolescence. Challenges in replacing obsolete COTS components are increasing, especially for IT elements. For some longer programs, upgrades may even be required before initial fielding. Replacements, lifetime buys, and upgrades must be built into strategies, budgets, and staffing plans throughout the life cycle, but some statutory fiscal rules can limit flexibility and options that save money in the end.

Software development and integration. The DoD continues to find that giving prime contractors responsibility for major software block upgrades is risky. Heavy Government involvement and rapid, incremental approaches (e.g., through Agile development) have been successful, but they also point to the need for reforms in how we conduct testing and risk management. Some PEOs also mentioned that Agile software development has been very beneficial in accelerating and improving software development, but success hinges on use of cost-reimbursable contracting and flexible operational testing approaches.

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Fixed-price contracting. One PEO noted that "a fixed-price contract type is every bit as challenging as a cost-plus vehicle, albeit in different ways." We cannot use Government money to solve problems that endanger the program; we cannot change requirements (despite needs); we must keep the funding profile stable, and we can require only the performance and product we placed on the contract (nothing more).

Risks versus savings. Savings are not always risk or consequence free. While BBP's goal is savings that do not decrease capabilities, some approaches can increase cost, schedule, or technical risks and must be weighted as such.

Processes and Impediments

Agility. PEOs raised the following as factors hampering agile acquisition:

- Requirement decision cycles that are longer than technology and threat change cycles (especially for areas such as cyber).
- Funding cycles that are longer than technology and threat change cycles.
- Strong external and internal disincentives for staff to pursue options that come with any personal risks.
- Testing cycles that are longer than agile software development cycles or require full system tests when only components are upgraded.

Tailoring. While PEOs, other leaders, and the DoDI 5000.02 emphasize tailoring the acquisition process, testing, and oversight to each specific program, the PEOs report that success is mixed in getting PMs and oversight staff to pursue tailoring. Institutionalizing this cultural shift will require continued training and leadership emphasis.

Rapid acquisition. We have good processes in place to acquire (nondevelopmental) systems rapidly, but finding the money is often the biggest impedance, because we do not have a ready reserve of funds. Furthermore, rapid acquisitions require significant staff work that must come out of existing staff, adding workloads and growth to normal program progress when large numbers of Urgent Operational Needs arise in a particular area or portfolio.

Obligation and expenditure monitoring. Measuring program financial performance solely on goals can be problematic. Performance also needs to take into consideration actual execution situations (e.g., delays due to negotiating better prices or constructing effective contract incentives).

Value of oversight. While some issues remain, the PEOs often identified places where OSD staff and individuals offer value in streamlining processes or providing assistance. Continued progress is needed (as can be seen from other comments) to improve and retain value.

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4. Input and Process Measures

Finally, we examine input and process measures of the defense acquisition system. While these do not directly reflect the outputs and outcomes, some are contentious topics for which it is useful to examine the available data, while others such as competition rates and small-business utilization have conceptually important ties to outcomes and thus have assigned goals.

Defense Acquisition Workforce

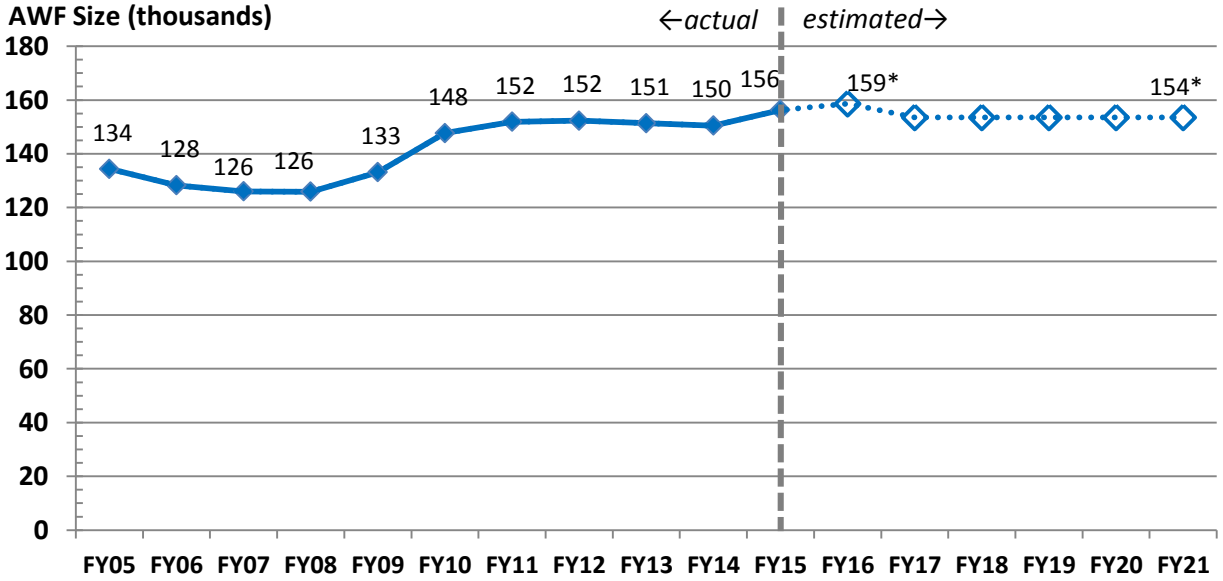
The DoD has made significant progress toward strengthening capability and advancing professionalism of the Acquisition Workforce (AWF). Since we started BBP in 2010, we have rebalanced and increased the size of the workforce to meet challenges and emergent threats. Significant investments also have been made to improve workforce quality. Our strategy is to responsibly sustain and build on these improvements as resources allow. We will continue to improve our analysis of required staffing levels and demographics. We also seek to increase professionalism by concentrating on certification, education, training, and experience, expanding our pool of qualified leaders at all levels, and addressing current and future workforce challenges as they arise.

Improving the Workforce

Recruiting and hiring. Throughout the DoD, Components have used the DAWDF to rebuild, reshape, and sustain the workforce in critical functional areas through targeted hiring strategies and retention efforts. Figure 4-1 and Table 4-1 show the results of these efforts. Of note are the significant personnel increases since the low point in FY 2008, especially in contracting, program management, engineering, life-cycle logistics, and information technology.

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Figure 4-1. Acquisition Workforce Total Size (FY 2005–2021)



* estimated in PB17

Table 4-1. Growth of AWF by Functional Area (FY 2005–2015)

	AWF Size											Change since	
Career Field	**FY05**	**FY06**	**FY07**	**FY08**	**FY09**	**FY10**	**FY11**	**FY12**	**FY13**	**FY14**	**FY15**	**FY08**	**FY14**
Engineering	34,752	35,142	34,710	34,537	36,704	39,201	39,690	39,807	39,544	39,242	41,050	19%	5%
Contracting	26,025	27,748	26,038	25,680	27,655	29,792	30,327	30,292	30,271	29,826	30,230	18%	1%
Life Cycle Logistics	12,493	12,332	12,604	13,361	14,852	16,861	17,369	17,539	17,122	17,724	19,222	44%	8%
Program Management	12,284	12,775	12,427	12,781	13,422	14,915	15,683	15,824	16,171	16,003	16,585	30%	4%
Production, Quality, Mfg	9,397	8,966	8,364	9,138	9,023	9,727	9,601	9,458	9,658	9,671	9,822	7%	2%
Test and Evaluation	7,384	7,280	7,419	7,420	7,892	8,446	8,573	8,603	8,580	8,569	8,692	17%	1%
Facilities Engineering	8,356	3,927	4,394	4,920	5,420	6,911	7,428	7,290	6,970	6,617	6,986	42%	6%
Information Technology	5,472	4,843	4,423	3,934	4,358	5,165	5,563	5,832	5,870	5,776	6,402	63%	11%
Business (Fin Mgt)	8,119	7,747	7,387	7,085	7,262	7,054	7,009	6,761	6,463	6,142	6,205	-12%	1%
Auditing	3,536	3,486	2,852	3,638	3,777	4,143	4,231	4,505	4,368	4,560	4,316	19%	-5%
S&T Manager	314	291	483	480	623	2,561	3,062	3,209	3,293	3,401	3,681	667%	8%
Business (Cost Est)	—	—	—	—	—	1,070	1,252	1,278	1,312	1,309	1,346	*n/a*	3%
Purchasing	2,438	1,680	1,170	1,196	1,238	1,287	1,276	1,340	1,283	1,205	1,330	11%	10%
Property	571	530	481	451	475	501	483	449	402	389	400	-11%	3%
Unknown/Other	3,229	1,495	3,280	1,258	402	71	344	139	48	31	46	-96%	48%
Total	134,370	128,242	126,032	125,879	**133,103**	147,705	151,891	152,326	151,355	150,465	**156,313**	**24%**	**4%**

NOTE: The low point in total AWF was FY 2008. Increases in workforce levels from the prior year are shaded purple, as are positive percentage increases since the low point (FY 2008) and last year (FY 2014). Significant reductions in the Unknown/Other category reflect efforts across DoD to ensure that acquisition data fields are correctly applied on all personnel actions.

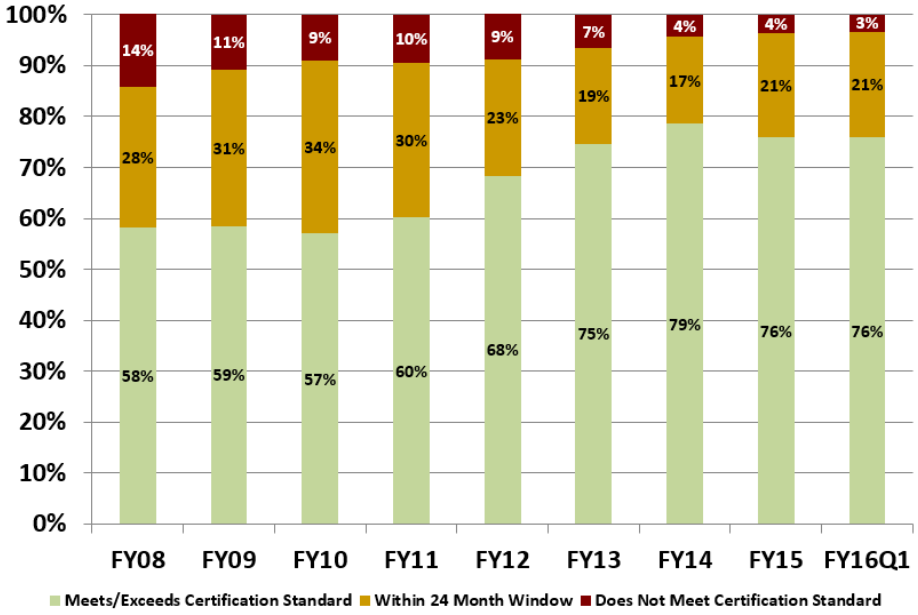
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Training and development. The imperative to improve workforce qualification and certification has been championed through our BBP objective to "establish stronger professional qualification requirements for all acquisition specialties."

Since BBP 2.0 in 2012, OSD and military department leadership have stressed the importance of increasing certification rates across the AWF.[41] An increase in Defense Acquisition University course availability and the elimination of bottlenecks in the training path have contributed to higher certification rates. We also expanded training and deployed acquisition tools and specialized workshops to support the workforce on the job, resulting in a more proficient and capable AWF.

Figure 4-2 illustrates some progress made in training, showing the percentage of AWF members already meeting certification standards for their current position or who are within the 24-month grace period since starting. The fraction out of compliance has dropped from 14 percent to 3 percent while the fraction meeting standards has risen from 58 percent to 76 percent (about 3 percent less than last fiscal year). The number of workforce members who have failed to achieve the required level of certification within 24-months of assignment has decreased to a new low of 3.3 percent in the first quarter of FY 2016, and we strive to continue lowering this metric.

Figure 4-2. Acquisition Workforce Meeting Certification Standards (FY 2008–2016Q1)



[41] Civilian and military acquisition personnel (but not support contractors) must achieve certifications specific to their career field and position requirements. Individuals who lack the necessary certifications when starting a position must become certified within 24 months. While the courses required for certification depend on the specific acquisition career field, acquisition courses generally cover risk management in system acquisition; the JCIDS process; statutory, regulatory, and decisional contracting; acquisition law; EV management; and budgeting (among other topics).

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Key leaders and qualifications. Another major BBP workforce initiative establishes qualification standards for Key Leadership Positions (KLPs) and a board prequalification review of workforce members who may apply for KLPs in the future. Not only does this further establish educational, experience, tenure, and cross-functional competency standards, but obtaining a board prequalification for a KLP serves as an important performance and career credential.

Retention and recognition incentives. In order to restore, sustain, and continuously improve the quality of the AWF, sufficient and stable funding is required. Congress established the dedicated DAWDF in 2008 to help ensure the DoD would have "the capacity, in both personnel and skills, needed to perform its acquisition mission, provide appropriate oversight of contractor performance, and ensure the DoD receives best value for expenditure of public resources."[42] The DAWDF supports efforts to meet the DoD's workforce challenges and restore the organic defense AWF by funding initiatives in three major categories: recruitment and hiring, training and career broadening, and recognition and retention. Congress has continued to support the DoD's efforts to strengthen and improve the quality of the AWF, including strong support for the DAWDF. Since 2010, there have been several adjustments to the fund, most significantly establishing its permanency in the FY 2016 NDAA.

Accomplishments of FY 2010 to 2015 AWF strategies. The AWF was downsized by 56 percent before 2010 as part of the laissez-faire approach to acquisition in the mid-1990s. The DoD fell below acceptable staffing levels (especially as Government oversight was re-invigorated in the early 2000s), and the focus in the past was simply to ensure that we had the numbers to minimally accomplish a narrowed mission. The DoD's 2010 growth strategy addressed the need to rebuild capacity, improve quality, and rebalance the workforce to ensure that effective oversight and inherently governmental responsibilities[43] are performed by appropriate individuals.

The continued efforts to improve the AWF have increased its size by 24 percent, from just under 126,000 in FY 2009 to over 156,000 in FY 2015. We have also worked to increase the quality of the AWF through higher education levels, increased training, and more focused experience. The number of staff holding bachelor's degrees or higher increased from 77 percent of the 97,730 members in FY 2008 to 84 percent of the 131,316 members in the first quarter of FY 2016. The number of staff with graduate degrees for the same period has risen from 29 percent to 39 percent of the workforce.

Another workforce demographic problem was the low number of mid-career staff as measured by years to retirement eligibility (Figure 4-3). Strategic hiring in both early- and mid-career level, as well as strategic investments in critical functional areas, has significantly improved the size of our mid-career staff. The demographic of the hiring profile is more clearly visible in Figure 4-4, which approximates the hiring across the career life cycle between FY 2008 and FY 2015.

[42] 10 U.S.C., Section 1705, Defense Acquisition Workforce Development Fund

[43] See, for example, Office of Federal Procurement Policy (OFPP) Policy Letter 11–01, "Performance of Inherently Governmental and Critical Functions," *Federal Register*, Vol. 76, No. 176, Sept. 12, 2011.

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Figure 4-3. Civilian Acquisition Workforce Demographics (FY 2008–2016Q1)

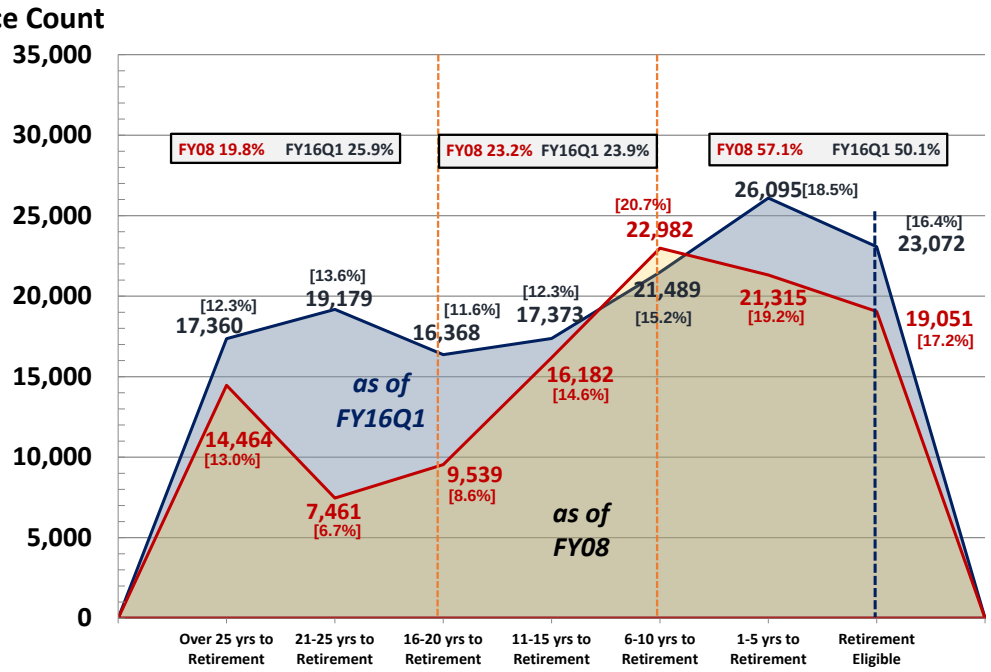
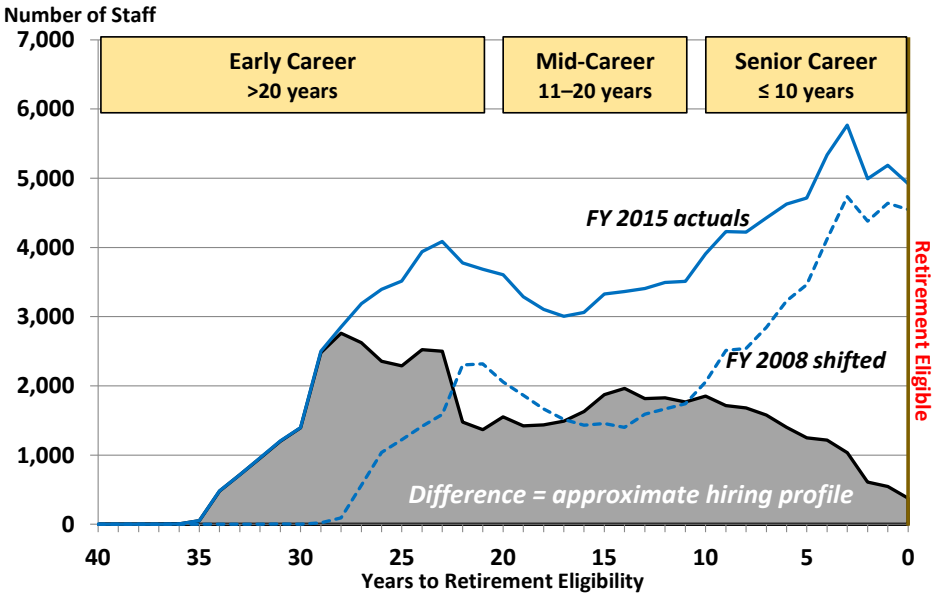


Figure 4-4. Change in Civilian Acquisition Workforce Demographics from FY 2008 to 2015



NOTE: The dashed curve shows the FY 2008 staffing profile has shifted 7 years closer to 0, approximating the experience and career aging of those staff between FY 2008 and 2015. The shaded area shows the difference between the two curves, approximating the hiring demographic between the two years if there had been no attrition. Hiring to account for attrition would be added on top of the shaded region.

Innovating new AWF strategies. The DoD initiated a one-day joint forum to bring together key DoD Component stakeholders and subject-matter experts to jump start solutions for recruiting, hiring, and retention. The first joint "Workforce Summit" was held in July 2015 and a second in May 2016. Bringing together all the players in one forum has been very effective. The summits

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fostered significantly improved understanding of problems and drivers, available authorities, legislative solutions (such as the college student direct-hire authority in the Senate's FY 2017 NDAA bill), and best practices. Best practices include how to effectively use the Expedited Hiring Authority, the Navy's very effective and efficient centralized journeymen and entry-level program, the Student Training and Academic Recruitment program, and initiatives to improve hiring processes and the use of special authorities (such as the Army's stand-up of a "hiring cell" to pilot process improvements). As a result of the July 2015 summit, the DoD updated our Expedited Hiring Authority policy and established a joint Incentives Integrated Product Team (IPT) to focus on how to improve use of incentives. The next joint summit is scheduled for November 2016.

Force of the Future. As part of the DoD's Force of the Future initiatives, we are actively pursuing a direct-hire authority to accelerate offers for college students. We are also increasing the use of Science, Mathematics and Research Transformation scholarships and leveraging the Student Training and Academic Recruitment program.

Performance Incentives

Incentives IPT. This IPT was established to evaluate how we are using incentives, including recruitment and retention bonuses, student loan repayments, and other monetary and nonmonetary incentives to improve hiring and retention outcomes. The team is evaluating how to improve the use of incentives across the workforce, especially to lower barriers to usage and to share best practices to facilitate use. The team is developing a strategic plan to communicate existing policy and guidance as well as best practices for incentives implementation, resulting in an overall strategy for all DoD Components to use for their respective workforce.

Awards. The DoD has also expanded its awards programs and added a Should-Cost and Innovation Award as part of BBP to recognize exceptional performance and help instill a cost-conscious culture. The *David Packard Excellence in Acquisition Award* (first given in 1997) is the DoD's highest acquisition team award and now emphasizes superior program management or successful execution of one or more BBP initiatives to reduce life-cycle costs. The *Should-Cost and Innovation Award* began in 2014 and recognizes outstanding commitment, innovation, and results in Should-Cost management.

In addition, two other major awards are the *Defense Acquisition Workforce Individual Achievement Award* and the *Defense Acquisition Workforce Development Award*. Individual Achievement Awards are given for excellence in 18 categories: acquisition in an expeditionary environment; auditing; financial management; cost estimating; contracting and procurement; engineering; facilities engineering; industrial and contract property management; information technology; life-cycle logistics; production, quality, and manufacturing; program management; science and technology management; test and evaluation; EV management; requirements management; services acquisition; and small business. The *Workforce Development Award* recognizes acquisition organizations that have made exemplary contributions to the career-long development of their workforce.

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BID PROTESTS ON DOD SOURCE SELECTIONS

A bid protest is a legal challenge to a solicitation or contract award for the procurement of goods or services.[44] The GAO is a primary adjudicator of bid protests concerning Federal agencies and departments (including the DoD).[45] Once a protest is filed, the GAO has 100 days to issue a decision. A bid protest can have four different outcomes: *dismissed*, *denied*, or *sustained* by the GAO, and at any time it can be *withdrawn* by the protester.[46] In addition to the full decisions, the GAO tracks these four outcomes by protester. Denials and sustainments are definitive (although appeals are possible). However, we cannot tell from these summary data the frequency with which dismissals and withdrawals resulted in any accommodations or corrective actions by the Federal agency. Note also that some actions incurred more than one filing (i.e., a primary protest and subsequent filings). Finally, even though a company might "win" a protest (either through a sustainment or possibly in early agency actions causing a withdrawal or dismissal), revisions to a source selection may not necessarily result in a change of who is awarded the contract in the end.

Annual DoD solicitations in FedBizOps have been increasing since FY 2007, when they numbered about 35,000, and now number about 52,000 in FY 2016. In contrast, the total number of protests against these actions ranged from just over 600 in FY 2001 to a high of 1,365 in 2013 (Figure 4-5). Thus, the recent protest rate has averaged about 2.5 percent of solicitations. Note that annual contract awards are about an order of magnitude higher, so if we counted protests against contract awards (i.e., using the number of contract awards in the denominator), then the average would be one-tenth the size (i.e., about 0.25 percent).

While there has been a sharp increase in the absolute number of protests since 2009 (especially for the Army), the number of solicitations since FY 2007 has increased only by half, and the number of protests sustained per year by the GAO has remained steady at about 30 per year, dropping to 15 in 2015 (Figure 4-6). As a result, the sustainment rate has been running about 2 percent since 2009 and recently has been below the Federal total, which includes the DoD (Figure 4-7). In 2015, the sustainment rate was just over 1 percent. The individual sustainment rate for the Army (not shown) has been low and comparable to the other DoD Components

[44] "An interested party may protest a solicitation or other request by a Federal agency for offers for a contract for the procurement of property or services; the cancellation of such a solicitation or other request; an award or proposed award of such a contract; and a termination of such a contract, if the protest alleges that the termination was based on improprieties in the award of the contract." (4 CFR 2.1)

[45] Bid protests can also be handled by the procuring agency or the U.S. Court of Federal Claims. Thus, these data provide a view into a significant number of (but not all) bid protests.

[46] Note that bid protests are an integral part of a government acquisition system that has a core value of treating all bidders fairly. (There are no protests in commercial business transactions.) The protest system imparts an incentive to ensure that solicitations and awards are conducted properly. The number of protests *sustained* provides an independent indicator of the quality of the DoD's source selections, independent of how many protests there are. See http://www.gao.gov/legal/bids/bidprotest.html as well as Schwartz and Manuel (2015) for more information on the GAO process and timeline.

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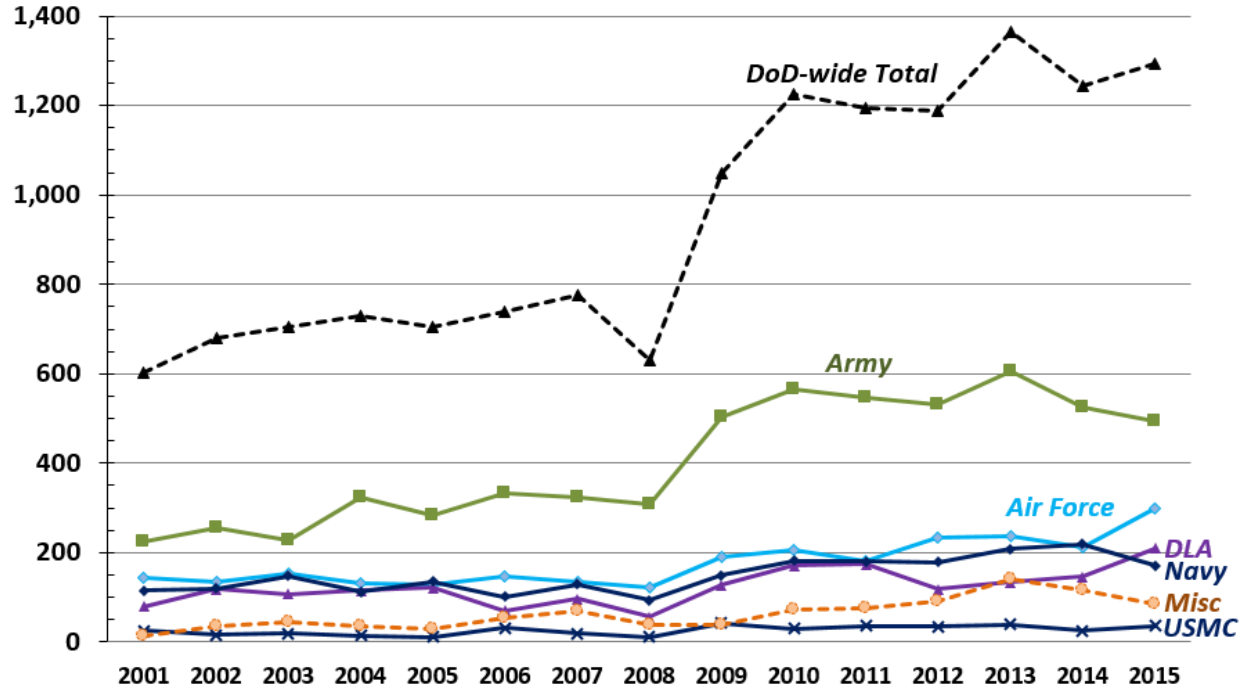
despite the rise in protest numbers against the Army. Thus, the increased number of protests appears to reflect external Industry strategies or competitive pressures (possibly from the declining DoD budgets) rather than poor DoD source-selection performance. Note that while the DoD-wide number of sustainments appears to be dropping slightly over time, the trend is not statistically significant.

Despite the uncertainties in the data from withdrawals and dismissals, these data provide useful bounds on DoD's performance. In addition to the definite sustainment rate of 2 percent, the definite GAO denial rate is about 25 percent. When combined with the numbers of annual solicitations and contract awards, the number of solicitations that involved some kind of DoD accommodation was somewhere between 2 percent (using the denial rate as the upper bound) and 0.05 percent (using the sustainment rate as the lower bound). In other words, the number of some kind of technical issue with source selections is at worst 2 out of every 100 solicitations and could be as low as 5 out of every 10,000. If plotted, even the worst case would barely be visible, and the best case would not be visible at all. Again, these rates would be one-tenth the size if measured against the annual number of contract awards. Note that these are on an action basis, not on the basis of the dollars involved (which would require further data collection and analysis to ascertain).

These results are commensurate with the Congressional Research Service's recent analysis of bid-protest rates (Schwartz & Manuel, 2015). Also, these results align with efforts over the last few years to ensure that source-selection rules are clearly defined, reflect the DoD's priorities, and are followed in execution (e.g., peer reviews of contracts for supplies and services [DDPAP, 2008, 2016c]). Additionally, the emphasis on eliminating unnecessarily complex selection criteria and ensuring source selections are well documented may be factoring into source-selection success. The DoD Source Selection Procedures that were issued earlier this year capture these tenets (DDPAP, 2016a). These procedures also capture the BBP initiative to identify up-front how much we value higher performance levels so that bidders can make informed decisions on how to position themselves to maximize their competitive posture and so that the government has a clear, objective way to evaluate such differences.

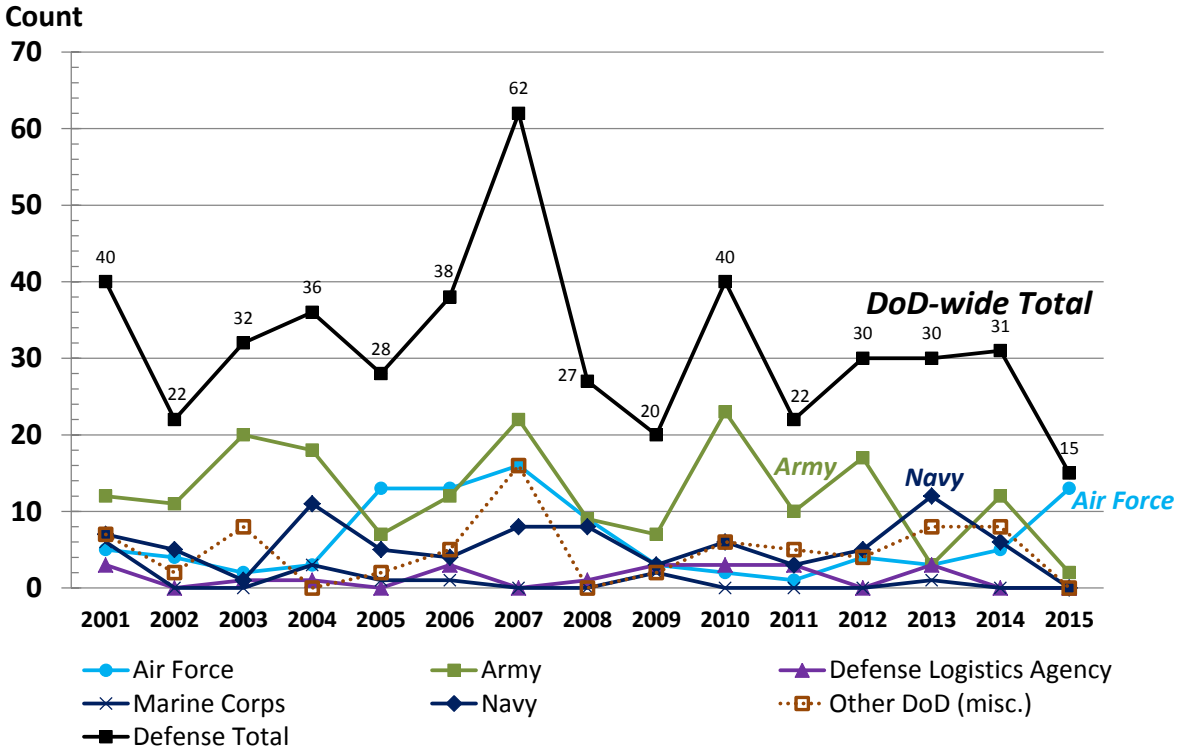
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Figure 4-5. Number of Protest Received by GAO (FY 2001–2015)



SOURCE: GAO (personal communications, 2016).

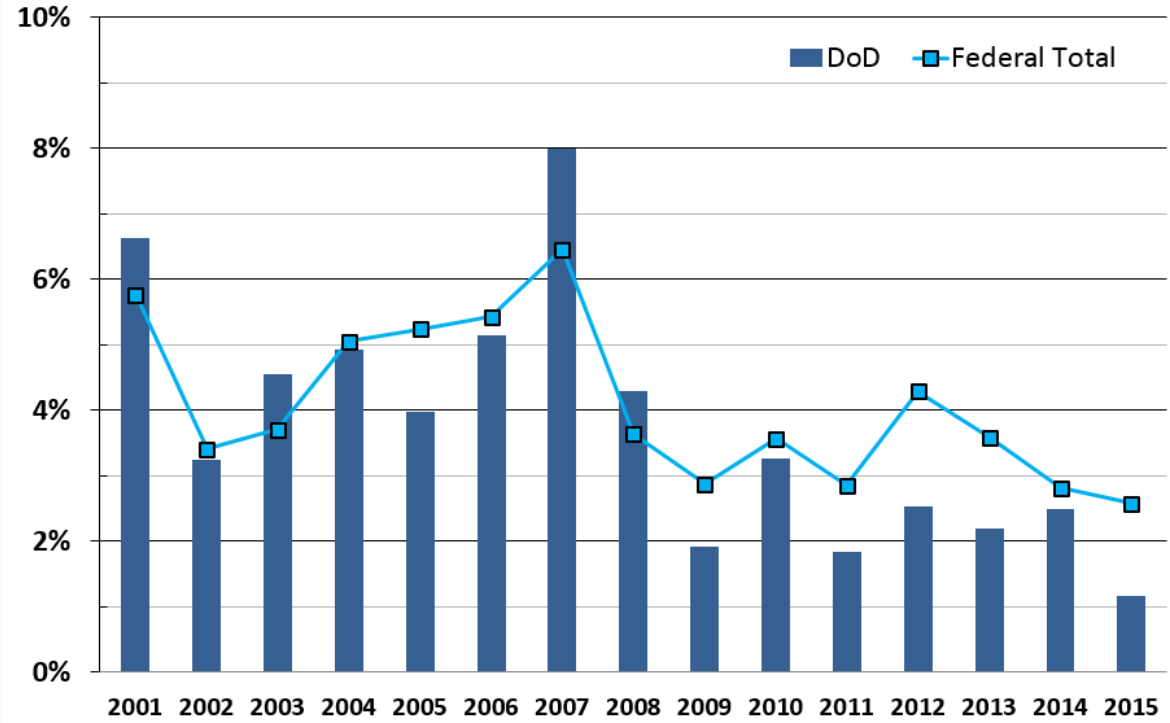
Figure 4-6. Number of Protests Sustained by GAO (FY 2001–2015)



SOURCE: GAO (personal communications, 2016).

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Figure 4-7. GAO Protest Sustainment Rates (FY 2001–2015)



Source: GAO (personal communications, 2016).

Bid Protest Rates and Outcomes by Company

We also examined the number and outcomes of protests from the second quarter of FY 2005 through the end of FY 2015 from individual contractors to try to gain insights into whether some companies may be filing proportionally larger numbers of unfounded protests compared to the population as a whole.

Table 4-2 lists by name the protesters that definitely lost (i.e., were denied by GAO) at least three protests. As noted above, the overall loss (denial) rate is about 25 percent, and the overall win (sustainment) rate is about 2 percent. While there are a number of protesters with loss rates over 25 percent and win rates below 2 percent, there are only six that had double-digit protest numbers. More importantly, all protesters except Latvian Connection were one win away from having a sustainment rate above the 2 percent average. Also, all but two companies (Bay Area Travel and Cruise Ventures) had withdrawals and dismissals (with uncertain consequences). All told, it is not possible from these summary data to identify any companies that have significantly larger numbers of unfounded protests. Table 4-3 and Figure 4-5 together list the 100 largest DoD contractors (by dollars obligated in FY 2014) that filed bid protests with the GAO. Here we see that many (but not all) of our largest prime contractors have filed protests, and those that have lost all their protests tend to have filed very few.

Finally, Table 4-5 and Table 4-6 together list the top 100 companies with the largest numbers of bid protests to GAO regardless of outcome. Note that the number of protests is highly skewed, falling sharply from the maximum.

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The only definitive case of excessive unfounded protests is Latvian Connection, LLC. This company had a very high total number of DoD protests (251) since FY 2005, but these data showed nearly all with uncertain consequences (withdrawn or dismissed). However, GAO reported separately that Latvian Connection was suspended in August 2016 from filing protests with GAO for one year due to abuse of the GAO protest process.[47] We are not aware of any other companies that have ever been suspended by the GAO from protesting, so this appears to be unique.

Interestingly, we note a few cases where Federal agencies or departments appear in the data as protesters. These are requests for reconsideration of GAO sustainment decisions. Table 4-2 shows that the Small Business Administration filed four protests and the Marine Corps filed three. All were denied (as were the two Air Force and one Army protest).

Further analysis is needed to determine whether the withdrawals and dismissals from such companies were associated with accommodations or corrective actions by the DoD. Analysis is also needed to determine the frequency at which actions by the DoD are taken to simply accelerate acquisitions and avoid problems despite no clear basis or problem with a solicitation or award. Finally, further analysis would be needed to determine whether any changes to the source selection led to different awardees in the end.

[47]The GAO decided that the "Protest challenging the issuance of a task order to a large business concern is dismissed for abuse of process, and the protester is suspended from protesting for a period of one year, where the protester has submitted 150 protests this fiscal year, challenging an array of acquisitions (some of which were fully performed years earlier) conducted by a host of contracting agencies worldwide; has repeatedly failed to demonstrate that it is capable of, or interested in, performing the solicited requirements; and has repeatedly failed to engage constructively on the substantive and threshold issues raised by its protests." (GAO, 2016)

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Table 4-2. Filers that Lost at Least Three Bid Protests to GAO (FY 2005Q2–2015)

#	Filer	FY14$ Ranked	# of DoD Actions Protested	Total # of Filings	Lost (Denied)	Won (Sustained)	Indeterminate (Withdrawn &/or Dismissed)	Lost (%)	Won (%)	Uncertain (%)
1	General Dynamics	3	26	44	8	1	17	31%	4%	65%
2	Latvian Connection, LLC		251	265	7	1	243	3%	0.4%	97%
3	SAIC	10	18	33	7		11	39%		61%
4	Brian X. Scott		24	33	6		18	25%		75%
5	Raytheon	4	19	31	6		13	32%		68%
6	LOGMET		16	17	6		10	38%		63%
7	CAMSS Shelters		51	59	5	1	45	10%	2%	88%
8	Dellew		15	19	5		10	33%		67%
9	JRS Staffing Services		51	73	4		47	8%		92%
10	Northrop Grumman	5	20	46	4	3	13	20%	15%	65%
11	URS Group	28	19	30	4		15	21%		79%
12	ITT Corporation	178	17	33	4	2	11	24%	12%	65%
13	TransAtlantic Lines	600	16	19	4		12	25%		75%
14	DynCorp International		15	26	4	1	10	27%	7%	67%
15	CACI Technologies	27	11	15	4		7	36%		64%
16	Serco Inc.		8	16	4	1	3	50%	13%	38%
17	AHNTECH		7	7	4		3	57%		43%
18	Bilfinger Berger		7	8	4		3	57%		43%
19	Outdoor Venture Corp		7	8	4		3	57%		43%
20	US Small Business Admin.*		4	4	4			100%		
21	Sea Box		57	63	3	1	53	5%	2%	93%
22	Booz Allen Hamilton	17	31	49	3	2	26	10%	6%	84%
23	Lockheed Martin	1	20	41	3	4	13	15%	20%	65%
24	Advanced Seal Technology		14	16	3		11	21%		79%
25	L-3 Communications	7	12	22	3	1	8	25%	8%	67%
26	B&S Transport		11	15	3		8	27%		73%
27	Tetra Tech	189	9	13	3		6	33%		67%
28	Critical Process Filtration		9	9	3	1	5	33%	11%	56%
29	Sealift	800	5	5	3		2	60%		40%
30	Metro Machine		5	8	3	1	1	60%	20%	20%
31	International Garment Proc.		4	4	3		1	75%		25%
32	Noble Supply and Logistics		4	6	3		1	75%		25%
33	TMG Construction Corp		4	6	3		1	75%		25%
34	Tzell-AirTrak Travel Group		4	5	3		1	75%		25%
35	Bay Area Travel		3	3	3			100%		
36	Cruise Ventures		3	3	3			100%		
37	US Marine Corps*		3	3	3			100%		

* The Small Business Administration and Marine Corps protests were requests for reconsideration after other protests were sustained by the GAO.

Source: GAO (personal communications, 2016), including data from the second quarter of FY 2005 through the end of FY 2015.

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Table 4-3. 50 Largest Defense Companies with Any GAO Protests (FY 2005Q2–2015)

#	Contractors Name	FY14$ Ranked	# of DoD Actions Protested	Total # of Filings	Lost (Denied)	Won (Sustained)	Uncertain (Withdrawn &/or Dismissed)	Lost (%)	Won (%)	Uncertain (%)
1	Lockheed Martin	1	20	41	3	4	13	15%	20%	65%
2	Boeing	2	2	9		1	1		50%	50%
3	General Dynamics	3	26	44	8	1	17	31%	4%	65%
4	Raytheon	4	19	31	6		13	32%		68%
5	Northrop Grumman	5	20	46	4	3	13	20%	15%	65%
6	L-3 Communications	7	12	22	3	1	8	25%	8%	67%
7	BAE Systems	8	15	25	1	6	8	7%	40%	53%
8	SAIC	10	18	33	7		11	39%		61%
9	Bechtel Group	15	2	6	1	1		50%	50%	
10	Booz Allen Hamilton	17	31	49	3	2	26	10%	6%	84%
11	3FC	18	1	1			1			100%
12	Hewlett-Packard	20	3	7			3			100%
13	Textron	22	1	2	1			100%		
14	General Atomics	24	2	3	1		1	50%		50%
15	Computer Sciences Corp	25	13	20	2	2	9	15%	15%	69%
16	CACI Technologies	27	11	15	4		7	36%		64%
17	URS Group	28	19	30	4		15	21%		79%
18	Honeywell	29	6	13	1		5	17%		83%
19	Alliant Techsystems	30	2	4	1		1	50%		50%
20	Harris Corporation	31	3	6	1		2	33%		67%
21	Cardinal Health	32	1	1			1			100%
22	Anham	33	3	5			3			100%
23	Atlantic Diving Supply	34	6	7			6			100%
24	Fluor	36	6	9		1	5		17%	83%
25	Alion Science & Technology	38	6	11	2	2	2	33%	33%	33%
26	ManTech	43	12	22	1		11	8%		92%
27	Rolls-Royce	46	1	1			1			100%
28	Oshkosh Corporation	52	1	1			1			100%
29	IBM	63	9	18	1	2	6	11%	22%	67%
30	CH2M Hill	69	1	1			1			100%
31	Engility	74	2	5			2			100%
32	World Wide Technology	79	2	3			2			100%
33	Johnson Controls	83	2	2	1		1	50%		50%
34	Mission Essential Personnel	101	9	12	1	2	6	11%	22%	67%
35	Indyne	117	1	2			1			100%
36	AASKI Technology	128	4	5			4			100%
37	Chenega	134	17	23	2	1	14	12%	6%	82%
38	TASC	135	4	6			4			100%
39	World Airways	137	1	1			1			100%
40	EOD Technology	138	14	21			14			100%
41	Scientific Research	140	1	1			1			100%
42	Weeks Marine	149	2	2			2			100%
43	Orbital Sciences	150	1	2			1			100%
44	ARTEL INC	155	8	8	1		7	13%		88%
45	DZSP 21	169	1	1	1			100%		
46	Red River	171	5	6	1		4	20%		80%
47	AT&T	173	5	7		1	4		20%	80%
48	Accenture	175	4	4			4			100%
49	Carothers Construction	177	2	5			2			100%
50	ITT Corporation	178	17	33	4	2	11	24%	12%	65%

Source: GAO (personal communications, 2016), including data from the second quarter of FY 2005 through the end of FY 2015.

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Table 4-4. 51st to 100th Largest Defense Companies With Any GAO Protests (FY 2005Q2–2015)

#	Contractors Name	FY14$ Ranked	# of DoD Actions Protested	Total # of Filings	Lost (Denied)	Won (Sustained)	Uncertain (Withdrawn &/or Dismissed)	Lost (%)	Won (%)	Uncertain (%)
51	American Auto Logistics	180	1	1	1			100%		
52	Tetra Tech	189	9	13	3		6	33%		67%
53	KPMG LLP	202	5	5			5			100%
54	Assist Consultants	203	2	2	1		1	50%		50%
55	Mercom	232	1	1	1			100%		
56	Data Systems Analysts	233	1	1			1			100%
57	Graybar	234	5	6	2		3	40%		60%
58	Delphinus Engineering	237	1	3	1			100%		
59	MacAulay-Brown	243	2	3			2			100%
60	Carahsoft Technology	246	4	6	1		3	25%		75%
61	ICI Services	251	4	5	1	1	2	25%	25%	50%
62	DLT Solutions	254	1	1			1			100%
63	RQ Construction	258	1	2			1			100%
64	SupplyCore	260	1	3	1			100%		
65	AMEC INC.	262	6	8	2		4	33%		67%
66	Quantech Services	264	5	7	1		4	20%		80%
67	McKean Defense Group	265	2	3	1		1	50%		50%
68	Veyance Technologies	268	2	2			2			100%
69	VSE Corporation	270	4	10		1	3		25%	75%
70	ViON Corporation	274	2	4	1		1	50%		50%
71	NetCentrics	275	2	2			2			100%
72	Loyal Source Govt Services	284	3	6			3			100%
73	Intelligent Decisions	287	4	7	1		3	25%		75%
74	Sterling Computers	297	2	6			2			100%
75	Knight Point Systems	313	2	2			2			100%
76	Blue Tech	314	2	2	1		1	50%		50%
77	PricewaterhouseCoopers	316	2	5	1		1	50%		50%
78	Applied Research Associates	317	3	4			3			100%
79	Peckham Vocational Ind.	321	1	1			1			100%
80	NOVA Corporation	328	1	2		1			100%	
81	Oasis Systems	329	2	3			2			100%
82	DRS Technical Services	330	11	15			11			100%
83	Battlespace	336	1	2			1			100%
84	The Centech Group	339	4	4			4			100%
85	Phacil	346	1	1			1			100%
86	Environmental Chemical	349	4	6			4			100%
87	Digital Management	353	2	2			2			100%
88	Theodor Wille Intertrade AG	354	2	3			2			100%
89	COLSA	355	1	1			1			100%
90	Technology Service Corp	357	1	1			1			100%
91	WorldWide Language Res.	361	11	19	1	2	8	9%	18%	73%
92	FCN	362	3	7	1		2	33%		67%
93	Analytic Services	365	2	3			2			100%
94	Thales Group	370	3	3			3			100%
95	Salient Federal Solutions	372	1	1	1			100%		
96	Planned Systems Intern.	389	2	2	1		1	50%		50%
97	Scitor	393	1	1			1			100%
98	BCF Solutions	395	2	2	1		1	50%		50%
99	Pragmatics	399	3	7	2	1		67%	33%	
100	Superlative Technologies	402	3	6	2		1	67%		33%

Source: GAO (personal communications, 2016), including data from the second quarter of FY 2005 through the end of FY 2015.

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Table 4-5. Fifty Top Protesters by Number of GAO Protests Filed (FY 2005Q2–2015)

#	Contractors Name	FY14$ Ranked	# of DoD Actions Protested	Total # of Filings	Lost (Denied)	Won (Sustained)	Uncertain (Withdrawn &/or Dismissed)	Lost (%)	Won (%)	Uncertain (%)
1	Latvian Connection, LLC		251	265	7	1	243	3%		97%
2	Sea Box		57	63	3	1	53	5%	2%	93%
3	CAMSS Shelters		51	59	5	1	45	10%	2%	88%
4	JRS Staffing Services		51	73	4		47	8%		92%
5	FitNet International		39	41	2		37	5%		95%
6	J. Squared DBA- Univ Loft		36	37			36			100%
7	Booz Allen Hamilton	17	31	49	3	2	26	10%	6%	84%
8	JRS Management		30	34			30			100%
9	SSI Technology		29	31	1	1	27	3%	3%	93%
10	Thermal Structures		29	30			29			100%
11	General Dynamics	3	26	44	8	1	17	31%	4%	65%
12	Alaska Structures		25	40			25			100%
13	Brian X. Scott		24	33	6		18	25%		75%
14	Emerson Company		23	23	1		22	4%		96%
15	Regalmark		22	22			22			100%
16	Ricoh		21	22	1		20	5%		95%
17	Northrop Grumman	5	20	46	4	3	13	20%	15%	65%
18	Lockheed Martin	1	20	41	3	4	13	15%	20%	65%
19	Glenn Defense Marine-Asia		20	29	2		18	10%		90%
20	Raytheon	4	19	31	6		13	32%		68%
21	URS Group	28	19	30	4		15	21%		79%
22	Lansdale Semiconductor		19	19			19			100%
23	SAIC	10	18	33	7		11	39%		61%
24	Major Contracting Services		18	21	2	1	15	11%	6%	83%
25	BBE Sales & Leasing		18	19			18			100%
26	ITT Corporation	178	17	33	4	2	11	24%	12%	65%
27	Chenega	134	17	23	2	1	14	12%	6%	82%
28	Lamar International		17	18			17			100%
29	LOGMET		16	17	6		10	38%		63%
30	TransAtlantic Lines	600	16	19	4		12	25%		75%
31	Bering Straits		16	26	2	1	13	13%	6%	81%
32	Dellew		15	19	5		10	33%		67%
33	DynCorp International		15	26	4	1	10	27%	7%	67%
34	BAE Systems	8	15	25	1	6	8	7%	40%	53%
35	Freedom Systems		15	16	1		14	7%		93%
36	TLC Systems		15	15	1		14	7%		93%
37	Midwest Tube Fabricators		15	15			15			100%
38	Advanced Seal Technology		14	16	3		11	21%		79%
39	Rotair Industries		14	16	1		13	7%		93%
40	EOD Technology	138	14	21			14			100%
41	Deloitte Consulting		14	19			14			100%
42	Gill Marketing Company		14	14			14			100%
43	Computer Sciences Corp	25	13	20	2	2	9	15%	15%	69%
44	Alutiiq		13	16	2	1	10	15%	8%	77%
45	DCX-CHOL Enterprises		13	13	1		12	8%		92%
46	Kitco Defense		13	14	1		12	8%		92%
47	AVTEQ		13	14			13			100%
48	Chase Supply		13	16			13			100%
49	Lam-Tex Composites		13	13			13			100%
50	Malone's CNC Machining		13	13			13			100%

Source: GAO (personal communications, 2016), including data from the second quarter of FY 2005 through the end of FY 2015.

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Table 4-6. 51st to 100th Top Protesters by Number of GAO Protests Filed (FY 2005Q2–2015)

#	Contractors Name	FY14$ Ranked	# of DoD Actions Protested	Total # of Filings	Lost (Denied)	Won (Sustained)	Uncertain (Withdrawn &/or Dismissed)	Lost (%)	Won (%)	Uncertain (%)
51	RAO Contract Sales		13	13			13			100%
52	L-3 Communications	7	12	22	3	1	8	25%	8%	67%
53	Computer Cite		12	15	2		10	17%		83%
54	Tyonek Native Corporation		12	15	2	1	9	17%	8%	75%
55	WKF Friedman Enterprises		12	13	2		10	17%		83%
56	ManTech	43	12	22	1		11	8%		92%
57	Derm/Buro		12	14	1		11	8%		92%
58	Assessment & Training Solns		12	14			12			100%
59	CACI Technologies	27	11	15	4		7	36%		64%
60	B&S Transport		11	15	3		8	27%		73%
61	WorldWide Language Res.	361	11	19	1	2	8	9%	18%	73%
62	Camnetics Mfg Corp		11	11	1		10	9%		91%
63	Medfinity		11	12	1		10	9%		91%
64	SOS International		11	17	1	2	8	9%	18%	73%
65	DRS Technical Services	330	11	15			11			100%
66	C M Manufacturing		11	11			11			100%
67	H S Associates		11	11			11			100%
68	Space Concepts		11	12			11			100%
69	World Wide Fittings		11	11			11			100%
70	Tennier Industries		10	16	2		8	20%		80%
71	IBV Limited		10	10	1		9	10%		90%
72	Kingdomware Technologies		10	12	1		9	10%		90%
73	Novex Enterprises		10	17	1	1	8	10%	10%	80%
74	Phoenix Management		10	23	1		9	10%		90%
75	W K Engineering Intern.		10	10	1		9	10%		90%
76	AMTECH		10	10			10			100%
77	Capitol Supply		10	10			10			100%
78	Spares Inc.		10	10			10			100%
79	Wyvern Technologies		10	10			10			100%
80	Tetra Tech	189	9	13	3		6	33%		67%
81	Critical Process Filtration		9	9	3	1	5	33%	11%	56%
82	Dorado Services		9	13	2		7	22%		78%
83	IBM	63	9	18	1	2	6	11%	22%	67%
84	Mission Essential Personnel	101	9	12	1	2	6	11%	22%	67%
85	Canon USA		9	9	1		8	11%		89%
86	Gear Wizzard		9	10	1		8	11%		89%
87	Para Scientific Company		9	12	1		8	11%		89%
88	Aviation Technology		9	11			9			100%
89	CM Manufacturing		9	9			9			100%
90	Evans Security Solutions		9	9			9			100%
91	Hexatron Engineering		9	9			9			100%
92	Navigation Aids		9	10			9			100%
93	RMI Corp		9	12			9			100%
94	Tyler Construction Group		9	14			9			100%
95	Serco Inc.		8	16	4		3	50%	13%	38%
96	Maersk Line Limited		8	10	2		6	25%		75%
97	ARTEL INC	155	8	8	1		7	13%		88%
98	ALMCO		8	9	1		7	13%		88%
99	Coastal Seal Services		8	8	1		7	13%		88%
100	Harris IT Services		8	12	1	1	6	13%	13%	75%

Source: GAO (personal communications, 2016), including data from the second quarter of FY 2005 through the end of FY 2015.

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Rates of Competitive Contracting Across the DoD for Goods and Services

Competition—both head-to-head on contract competitions and environments that introduce competitive pressures in other ways—is a central tenet of our BBP initiatives. When viable, competition is, perhaps, the single best way to motivate contractors to provide the best value (i.e., the best performance at the lowest price). We have set a strategic objective to increase the percentage of spending on competed contracts from current levels. The military departments each analyze projections of future acquisitions to identify opportunities and creative strategies for future competitive awards.

Figure H-17, shown earlier on page xliii, plots the percentage of all DoD contract dollars competitively awarded from FY 2006 through FY 2015. Since goals were established in FY 2010, we had declining actuals until we made progress toward reversing the trend in FY 2014. However, competition rates declined in FY 2015 despite an increased goal for that year.

Challenges to increasing competition rates include high-value sole-source Foreign Military Sales as well as large remaining production runs for ships and aircraft that have already passed their competitive development phase. Increased industry bid-protesting of source selections also force the DoD to award sole-source contracts to provide "bridge" goods and services in the interim until the protests are resolved and the new contracts can be awarded. Fiscal uncertainty, including continuing resolutions and continued downward pressure on base and Overseas Contingency Operations funding, will negatively affect FY 2016 and future competition rates.

Despite these challenges, the DoD is continuing to pursue various approaches for breaking out system components for competition, opening system architectures for competing components and upgrades, and identifying new competitive sources. Beyond this kind of head-to-head competition, we are also expanding the types and use of other competitive environments to drive performance and cost savings (USD(AT&L), 2014b). For example, the Navy's evolving Profit-Related-to-Offer techniques adjust profits and production share between two captive shipyards based on bidding and cost control. Finally, analysis is continuing to set goals based on what is achievable rather than on simply setting goals based on prior actuals.

Small-Business Participation

Pursuing small-business utilization goals has been both a statutory requirement and administration priority because of the potential benefits from small-business contributions in both innovation and efficiency. More small-business engagement can increase the competitive nature of our solicitations, resulting in better cost and schedule performance on contracts. Small businesses also can infuse new, innovative technical solutions as capabilities are pursued for U.S. warfighters.

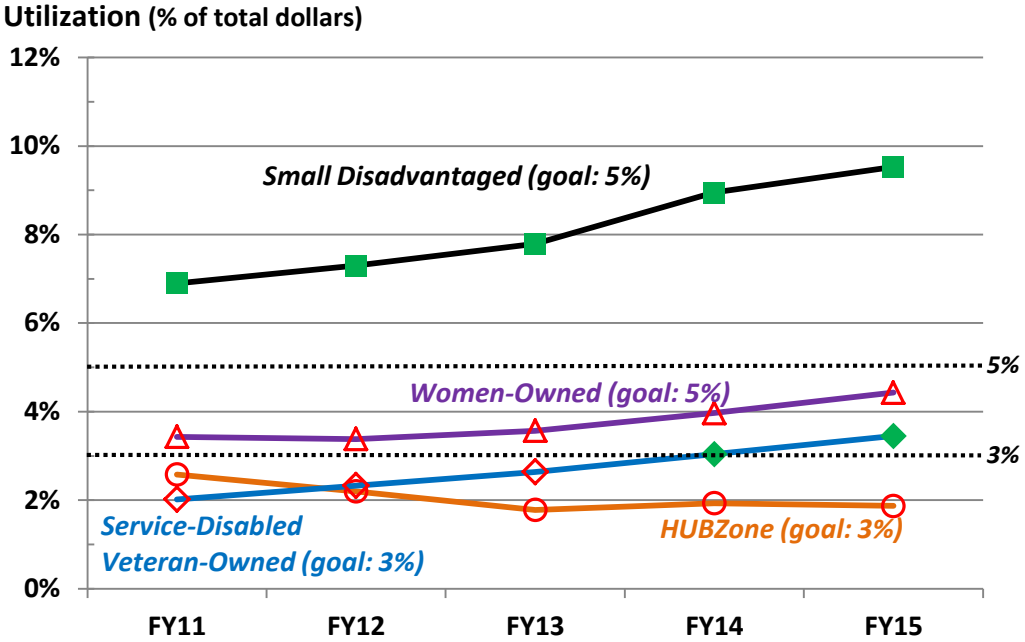
Figure H-14, shown earlier on page xl, plots actual DoD-wide small-business utilization (measured by obligations) relative to yearly goals for prime contracts. Recent trends since FY 2011 have been steadily improving; we exceeded our FY 2014 and 2015 goals by 2.1 and 3.0

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percentage points, respectively, surpassing all prior years except FY 2005. The DoD continues to explore new ways to pursue small-business utilization in the face of continued large-program spending on systems such as the F-35. For example, instead of relying solely on leadership emphasis and policy directives, the DoD is developing and deploying new tools to help PMs, buying commands, and acquisition leadership to monitor small-business utilization in depth, identify and share utilization opportunities, and conduct and share market research.

In specific subcategories of small-business concern, however, the DoD's utilization has been rising in three of four categories but not for Historically Underutilized Business Zone (HUBZone) contracting. Figure 4-8 shows that Small Disadvantaged contracting goals have been met since FY 2011 and Service-Disabled Veteran-Owned goals have been met since FY 2014. Women-Owned Small Business utilization has been rising but has not yet reached the goal of 5 percent. HUBZone utilization has remained a point below the goal of 3 percent.

Figure 4-8. Prime-Contracting Small-Business Subcategory Utilization Trends: Goals and Actuals (FY 2001–FY 2015)



NOTE: Open symbols indicate that the subcategory goal for that FY was not achieved. Closed green symbols indicate that the subcategory goal was achieved for that year. Small Disadvantaged Business awards include 8(a) awards.

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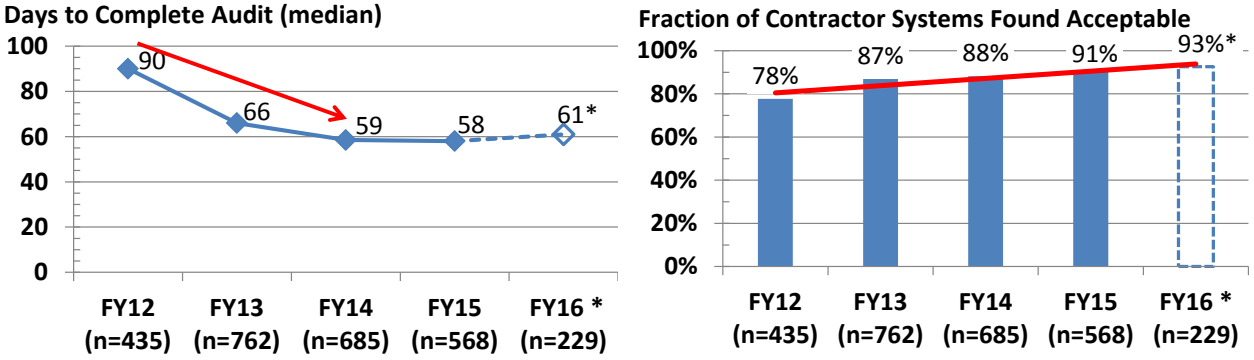
AUDITING RESPONSIVENESS AND BACKLOG REDUCTION

Finally, we review progress made in the last few years to reduce auditing backlogs and improve both the quality and timeliness of contractor audits by the Defense Contract Audit Agency (DCAA).

DCAA provides audit and financial advisory services to acquisition and contract administration entities in the DoD. Generally, most DCAA efforts on firm-fixed-price contracts take place during the proposal stage rather than in the incurred-cost stage. The reverse is true for cost-reimbursable contracts, wherein DCAA audits whether the costs billed by contractors are allowable so that contracts can be closed and final payments or refunds be made.

There are three main types of audits performed by DCAA. First, the *Pre-Award Survey of Prospective Contractor Accounting System* determines whether the design of the contractor's system is acceptable for the award of a cost-reimbursement contract. These audits must be completed before an award is made. The left side of Figure 4-9 shows that the median number of days to complete these audits statistically has dropped significantly from 90 days in FY 2012 to about 60 days in FY 2014–2016. DCAA was able to reduce the audit turn-around time by placing priority on these audit requests. The right side of the figure shows that our small-business contractors improved significantly the rate at which their accounting systems have been found acceptable, from about 78 percent in FY 2012 to just over 90 percent recently. These increases may be due to DCAA's outreach to the small-business community on what constitutes an acceptable accounting system.

Figure 4-9. Pre-Award Audits: Completion Time and System Acceptability Rates (FY 2012–2016)



* FY 2016 values are year-to-date as of February 2016. n = number of audits.
NOTE: Trend lines marked in red are statistically significant. Medians were used because the distributions on time to complete pre-award audits were skewed.

Second, DCAA conducts *Forward Pricing Proposal Audits* to evaluate the contractor's proposed prices, costs, and (if applicable) whether those proposed prices/costs comply with cost accounting standards. These audits assist the PM and contracting officer in negotiating a fair and reasonable contract price primarily on fixed-price contract awards. The average number of days required to complete these audits jumped from FY 2008 to FY 2011 in response to quality concerns raised by GAO (2009) while DCAA was imposing short, fixed schedules on the audits.

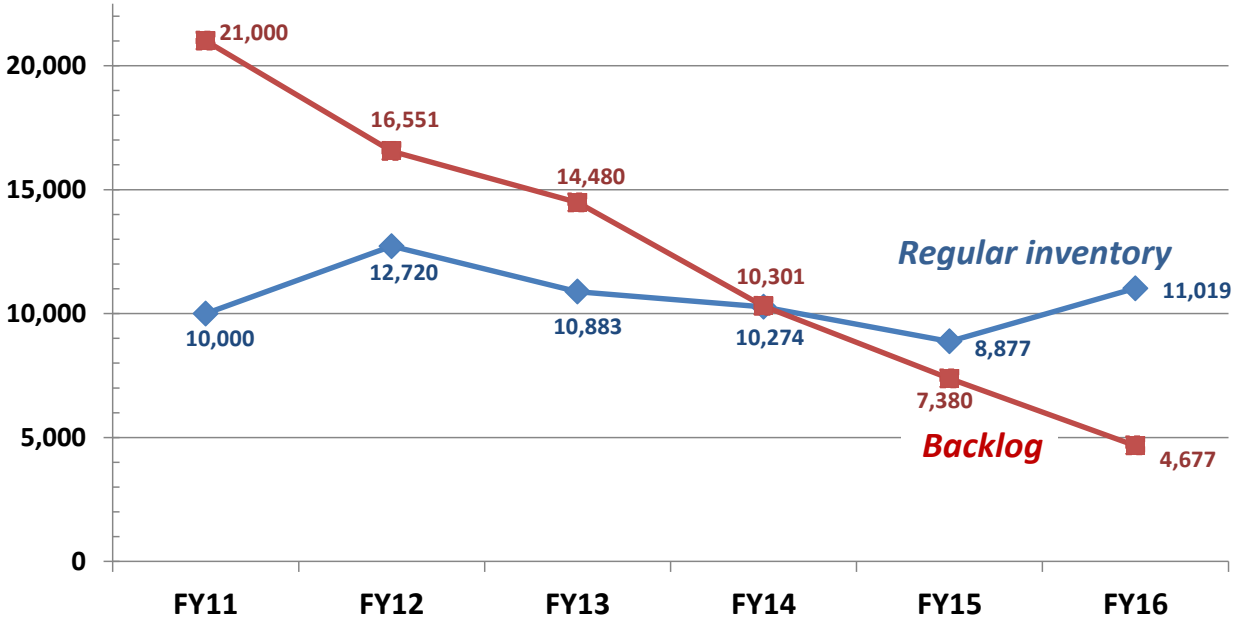
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In response to PM concerns about the length of these audits, DCAA has since shown overall improvement in completion time. The median number of days to complete dropped from a high of 90 days in FY 2011 to about 60 days as of the third quarter of FY 2016. Also, the proportion of audits that met agreed-to target completion dates has risen from about 32 percent in FY 2012 to about 76 percent in FY 2016.

Finally, *Incurred Cost Audits* are conducted annually on cost-reimbursement contracts to determine whether the contractor's total claimed costs are allowable, allocable, and reasonable. The contract cannot be closed until these audits are completed. Depending on the results, a final payment is made to the contractor, or conversely the contractor reimburses the government for overpayments to date. Figure 4-10 shows the total number of pending audits at the end of each FY since 2011. Audits for the past two fiscal years are considered part of the "regular inventory," while audits older than two fiscal years are considered "backlogged."

Figure 4-10. Incurred-Cost Audit Inventory (FY 2011–2016)

Number of Audits to Complete



As part of DCAA strategic initiatives and in support of BBP 2.0, substantial progress has been made since 2011 on reducing the backlog of these audits. Also, the USD(C) certified on September 14, 2016 that the inventory of backlogged audits is less than 18 months. This progress likely is due to our increased emphasis on conducting multiyear (instead of single-year) audits of contractor's incurred-cost submissions and the establishment of dedicated incurred-cost audit teams starting in FY 2012.

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A. Overview of Better Buying Power

BBP seeks to obtain greater efficiency and productivity in defense spending through leadership emphasis on cost control, streamlined processes, reduced bureaucracy, productivity, innovation, competition, the acquisition of contracted services, and workforce capabilities.

There are three full iterations of BBP to date. Table A-1 lists the initiatives for the first iteration (USD(AT&L), 2010) grouped into five focus areas. The goal is to improve acquisition by improving efficiency and productivity—doing more without more. Specific initiatives emphasized acquisition fundamentals while implementing proven lessons and best practices.

The second iteration of BBP (USD(AT&L), 2013a) added an emphasis on improving the acquisition workforce. Table A-2 lists the seven areas and underlying initiatives for BBP 2.0.

Finally, the third iteration of BBP (USD(AT&L), 2015d) continues prior focus areas while strengthening our emphasis on innovation, technical excellence, and the quality of our products. Table A-3 lists the areas and initiatives for BBP 3.0.

Guiding Principles of Better Buying Power

Throughout its initiatives, BBP reinforces the principles of defense acquisition (Kendall, 2016a):

People matter most; we can never be too professional or too competent.

Continuous improvement will be more effective than radical change.

Data should drive policy.

Critical thinking is necessary for success; fixed rules are too constraining.

Controlling life-cycle cost is one of our jobs; staying on budget isn't enough.

Incentives work—we get what we reward.

Competition and the threat of competition are the most effective incentives.

Defense acquisition is a team sport.

Our technological superiority is at risk and we must respond.

We should have the courage to challenge bad policy.

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Table A-1. BBP Initiatives, Version 1.0

Target Affordability and Control Cost Growth

- Mandate affordability as a requirement
  - — At MS A: set affordability target as a Key Performance Parameter
  - — At MS B: establish engineering trades showing how each key design feature affects the target cost
- Drive productivity growth through Will-Cost / Should-Cost management
- Eliminate redundancy within warfighter portfolios
- Make production rates economical and hold them stable
- Set shorter program timelines and manage to them

Incentivize Productivity & Innovation in Industry

- Reward contractors for successful supply-chain and indirect-expense management
- Increase use of fixed-price incentive firm (FPIF) contract type, where appropriate, using a 50/50 share line and 120 percent ceiling as a point of departure
- Adjust progress payments to incentivize performance
- Extend the Navy's Superior-Supplier Incentive Program to a DoD-wide pilot
- Reinvigorate industry's independent research and development and protect the defense technology base

Promote Real Competition

- Present a competitive strategy at each program milestone
- Remove obstacles to competition
  - — Require open-systems architectures and set rules for acquisition of technical data rights
- Increase dynamic small-business role in defense marketplace competition

Improve Tradecraft in Acquisition of Services

- Create a senior manager for acquisition of services in each DoD Component, following the Air Force's example
- Adopt uniform taxonomy for different types of services
- Address causes of poor tradecraft in services acquisition
  - — Assist users of services to define requirements and prevent creep via requirements templates
  - — Enhance competition by requiring more frequent re-competes of knowledge-based services
  - — "1-bid"proposals: require pricing and cost data, as appropriate; re-advertise if solicitations were open to industry for less than 30 days
  - — Limit the use of time-and-materials and award-fee contracts for services
  - — Require services contracts exceeding $1 billion to contain cost efficiency objectives
- Increase small-business participation in providing services

Reduce Non-Productive Processes and Bureaucracy

- Assess all internal reviews to ensure that they focus their purpose on the major acquisition investment decisions
- Review all DoD Component-required acquisition documents for redundancy with OSD-required documents and eliminate redundant documents and non-value-added content. Ensure that such documents are focused on content needed to make DoD Component-level decisions
- Assess the value of all internally-generated reporting requirements with a goal to eliminating at least 50 percent of the reports and substantially shorten the ones remaining. Assign reasonable page-count caps (based upon the nature of the information requested) when you assign lead responsibility for report production

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Table A-2. BBP Initiatives, Version 2.0

Achieve Affordable Programs

- Mandate affordability as a requirement
- Institute a system of investment planning to derive affordability caps
- Enforce affordability caps

Control Costs Throughout the Product Life Cycle

- Implement "should cost" based management
- Eliminate redundancy within warfighter portfolios
- Institute a system to measure the cost performance of programs and institutions and to assess the effectiveness of acquisition policies
- Build stronger partnerships with the requirements community to control costs
- Increase the incorporation of defense exportability features in initial designs

Incentivize Productivity & Innovation in Industry and Government

- Align profitability more tightly with DoD goals
- Employ appropriate contract types
- Increase use of fixed-price incentive contracts in Low Rate Initial Production
- Better define value in "best value" competitions
- Only use LPTA when able to clearly define Technical Acceptability
- Institute a superior supplier incentive program
- Increase effective use of Performance-Based Logistics
- Reduce backlog of DCAA audits without compromising effectiveness
- Expand programs to leverage industry's IR&D

Eliminate Unproductive Processes and Bureaucracy

- Reduce frequency of higher headquarters level reviews
- Re-emphasize AE, PEO and PM responsibility, authority, and accountability
- Reduce cycle times while ensuring sound investment decisions

Promote Effective Competition

- Emphasize competition strategies and creating and maintaining competitive environments
- Enforce open system architectures and effectively manage technical data rights
- Increase small business roles and opportunities
- Use the Technology Development phase for true risk reduction

Improve Tradecraft in Acquisition of Services

- Assign senior managers for acquisition of services
- Adopt uniform services market segmentation
- Improve requirements definition/prevent requirements creep
- Increase small business participation, including through more effective use of market research
- Strengthen contract management outside the normal acquisition chain—installations, etc.
- Expand use of requirements review boards and tripwires

Improve the Professionalism of the Total Acquisition Workforce

- Establish higher standards for key leadership positions
- Establish stronger professional qualification requirements for all acquisition specialties
- Increase the recognition of excellence in acquisition management
- Continue to increase the cost consciousness of the acquisition workforce—change the culture

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Table A-3. BBP Initiatives, Version 3.0

Achieve Affordable Programs

- Continue to set and enforce affordability caps

Achieve Dominant Capabilities While Controlling Lifecycle Costs

- Strengthen and expand "should cost" based cost management
- Anticipate and plan for responsive and emerging threats by building stronger partnerships of acquisition, intelligence and requirements communities
- Institutionalize stronger DoD level Long Range R&D Program Plans
- Strengthen cybersecurity throughout the product life cycle

Incentivize Productivity in Industry and Government

- Align profitability more tightly with DoD goals
- Employ appropriate contract types, but increase the use of incentive-type contracts
- Expand the superior supplier incentive program
- Ensure effective use of Performance-Based Logistics
- Remove barriers to commercial technology utilization
- Improve the return on investment in DoD laboratories
- Increase the productivity of corporate Independent Research and Development Expand programs to leverage industry's IR&D

Incentivize Innovation in Industry and Government

- Increase the use of prototyping and experimentation
- Emphasize technology insertion and refresh in program planning
- Use Modular Open Systems Architecture to stimulate innovation
- Increase the return on and access to small business research and development
- Provide draft technical requirements to industry early and involve industry in funded concept definition
- Provide clear and objective "best value" definitions to industry

Eliminate Unproductive Processes and Bureaucracy

- Emphasize acquisition chain of command responsibility, authority and accountability
- Reduce cycle times while ensuring sound investments
- Streamline documentation requirements and staff reviews
- Remove unproductive requirements imposed on industry

Promote Effective Competition

- Create and maintain competitive environments
- Improve DoD outreach for technology and products from global markets
- Increase small business participation, including more effective use of market research

Improve Tradecraft in Acquisition of Services

- Strengthen contract management outside the normal acquisition chain—installations, etc.
- Improve requirements definition for services
- Improve the effectiveness and productivity of contracted engineering and technical services

Improve the Professionalism of the Total Acquisition Workforce

- Establish higher standards for key leadership positions
- Establish stronger professional qualification requirements for all acquisition specialties
- Strengthen organic engineering capabilities
- Ensure development program leadership is technically qualified to manage R&D activities
- Improve our leaders' ability to understand and mitigate technical risk
- Increase DoD support for STEM education

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B. Analytic Details: Annual Growth of Contract Costs and Schedule for Major Programs in Development and Early Production

We analyzed growth in contract cost using summary EV data on 1,123 major contracts from FY 1981 to 2015 for 239 MDAPs. These included the combined results from 9,680 EMD reports and 8,790 early production reports. Table B-1 lists the actual 5-year moving average of annual growth of EV contract costs as calculated using the equations below.

Table B-1. Five-Year Moving Average of Annual Growth of EV Contract Costs (FY 1985–2015)

FY	Growth (actual)	FY	Growth (actual)
1985	5.47%	2001	6.67%
1986	8.89%	2002	6.56%
1987	9.84%	2003	6.82%
1988	9.33%	2004	7.06%
1989	8.00%	2005	8.55%
1990	8.07%	2006	7.98%
1991	5.99%	2007	7.07%
1992	5.65%	2008	8.66%
1993	6.02%	2009	8.16%
1994	6.07%	2010	7.48%
1995	5.93%	2011	9.10%
1996	5.07%	2012	8.21%
1997	6.20%	2013	6.05%
1998	6.14%	2014	5.27%
1999	6.75%	2015	3.49%
2000	6.12%		

NOTE: Results reflect 18,470 earned-value reports on 1,123 major contracts for 239 major defense programs.

These growths are calculated across all contracts together by totaling the changes of the PM's estimate at completion (PM EAC) in the year (i.e., from the last report from the prior year) for all contracts, then dividing by the sum of all the initial contract cost targets for all the active contracts in a year:

$$g(t) = \frac{\sum_{r=1}^{m} \Delta PMEAC_r(t)}{\sum_{i=1}^{n} CBB_i(original)}$$

for *m* reports on *n* contracts active in year *t*

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where:

$g(t)$ is the average growth of contracted costs across all active EV contracts in year *t* (adjusted for inflation),

$\Delta PMEAC_r(t)$ is the change in contract cost as reported by the PMEAC for EV report *r* for an active program in year *t*, after adjusting for inflation,

$CBB_i(original)$ is the original negotiated cost target[48] at contract award for contract *i* in common base-year dollars, and

t is the fiscal year for the annual growth.

Given g_t, the 5-year moving average growth G_t of EV contract costs for year *t* is simply:

$$G_t = \frac{\sum_{i=0}^{4} g(t-i)}{5}$$

for $t \in [FY1985, FY2015]$.

Model of Annual Growth of Contract Costs

The following equations show our statistical model of the 5-year moving average of annual growth of EV contract costs on major MDAP contracts:

$$G_t = c_0 + c_1 B_{t-1} + c_2 \Delta B_t + c_3 GN_t + c_4 BBP_t + u_t$$
$$u_t = c_5 u_{t-5} + \varepsilon$$
$$\varepsilon \sim i.i.d.\ N(0, \sigma^2)$$

for $t \in [FY1985, FY2015]$.

where:

G_t is the 5-year moving average of annual growth of EV contract costs at time *t*,

c_i are coefficient constants,

B_{t-1} is the 5-year average of the DoD budgets from time *t-5* to time *t-1*,

$\Delta B_t = B_t - B_{t-1}$ is the change in the 5-year moving average of the budget from time *t-1* to time *t*,

$GN_t = \begin{cases} 1 \text{ for } t \geq FY1990, \\ 0 \text{ for } t < FY1990; \end{cases}$ *this is the indicator variable for a hypothesized structural change since FY 1990 (i.e., the era of full implementation of the Goldwater-Nichols Act),*

$BBP_t = \begin{cases} 1 \text{ for } t \geq FY2012, \\ 0 \text{ for } t < FY2012; \end{cases}$ *this is the indicator variable for a hypothesized structural change since FY 2012 (i.e., the era of full implementation of BBP),*

u_t is an autoregressive factor for the difference between the actual growth and the growth predicted by the other factors 5 years earlier, and

ε is a series of independent and identically distributed (*i.i.d.*) samples from a normal distribution with zero mean (i.e., Gaussian white noise).

[48] In EV reports, the CBB is the sum of the Negotiated Contract Cost (NCC) and the Authorized Unpriced Work (AUW).

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Table B-2 lists the coefficients c_i for the statistically significant factors in the model of the 5-year moving average of annual growth of EV contract costs on major MDAP contracts reporting EV. Figure B-1 shows the partial contributions of these drivers to the growth curve for each year from FY 1985 to FY 2015, and Figure B-2 shows the combined effect of the two budgetary variables. Recall that Figure 3-2 shows how closely this statistical model matches the actual growth in EV contract costs over this period; it uses the MLE coefficients.

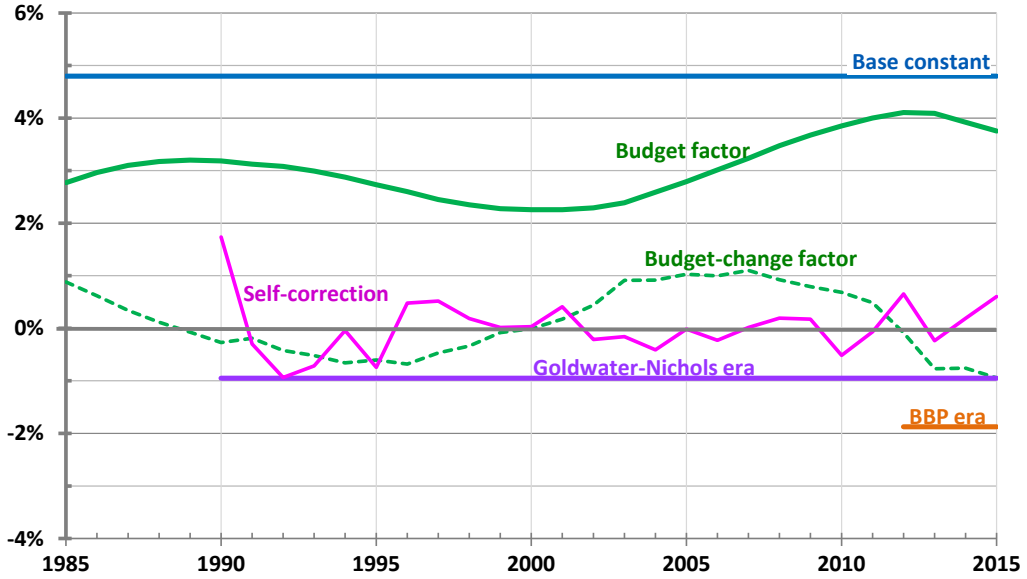
Table B-2. Model Coefficients and Statistics: 5-Year Moving Average of Annual Growth of EV contract costs

Driver Type	Factor	OLS (Newey West)	MLE (OIM)	MLE (OPG)	p-value OLS	p-value MLE (OIM)	p-value MLE (OPG)
Budget Effects	c_1 coefficient for each $100B in the 5-year moving average of prior DoD TOAs from last year *(standard error)*	0.602% *(0.0000195)*	0.551% *(0.0000197)*	0.551% *(0.0000319)*	0.005***	0.005***	0.084*
	c_2 coefficient for each $10B change in 5-year moving average of prior DoD TOAs from last year *(standard error)*	0.233% *(0.0000788)*	0.252% *(0.0000587)*	0.252% *(0.0000729)*	0.007***	0.000***	0.001***
Structural Effects	c_3 coefficient for Goldwater-Nichols era structural change, FY 1990–2015 (standard error)	−1.07% (0.00526)	−0.948% (0.00457)	−0.948% (0.00434)	0.051*	0.038**	0.029**
	c_4 coefficient for BBP era structural change, FY 2012–2015 *(standard error)*	−1.70% *(0.00851)*	−1.87% *(0.00776)*	−1.87% *(0.00961)*	0.057*	0.016**	0.051*
Self-Correcting	c_5 coefficient autocorrelation coefficient: correction amount of actual-to-model difference 5 years prior *(standard error)*	−0.334 *(0.157)*	−0.583 *(0.208)*	−0.583 *(0.231)*	0.044**	0.005***	0.012**
Partial Constant	c_0 coefficient for constant *(standard error)*	4.63% *(0.0122)*	4.80% *(0.0120)*	4.80% *(0.0176)*	0.001***	0.000***	0.006***

* statistically significant at the 10% level of significance.
** statistically significant at the 5% level of significance
*** statistically significant at the 1% level of significance.
NOTES: These results are robust to the different estimation methods shown and to different ways of calculating the variance covariance matrix. The autocorrelation coefficients met stability conditions. After accounting for autocorrelations, the residual error was white noise.

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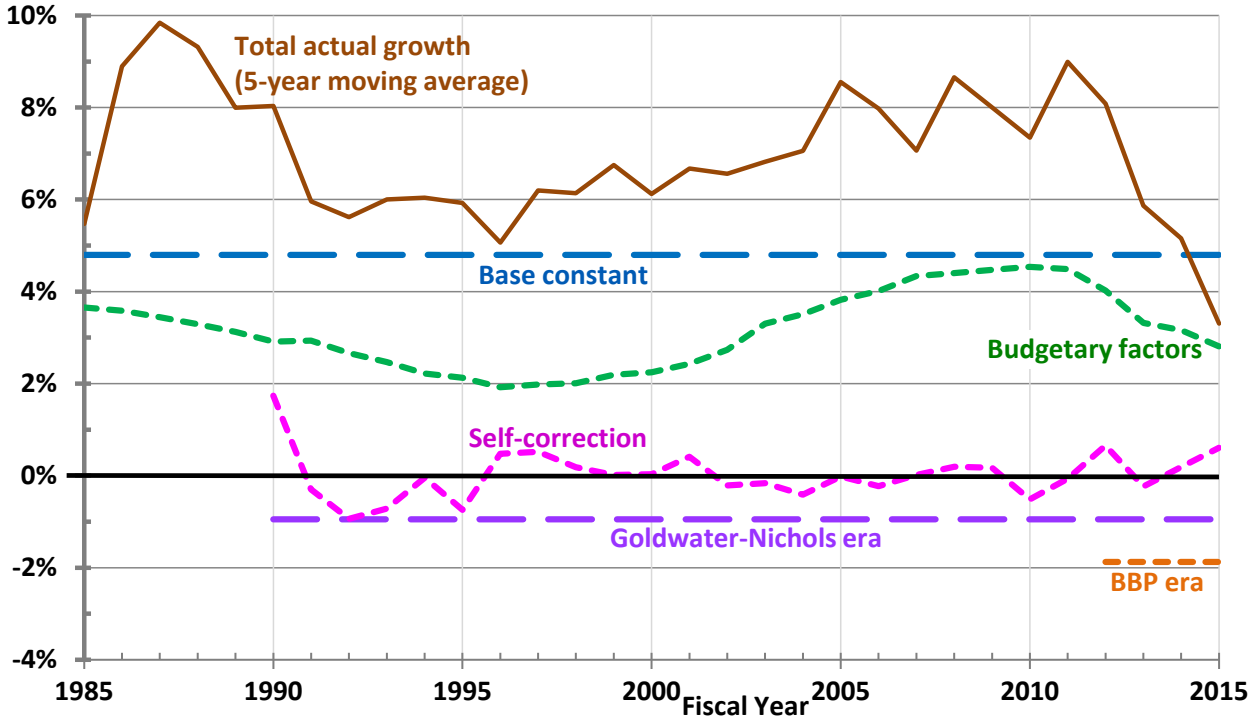
Figure B-1. Factors Contributing to 5-year Moving Average of Annual Growth of EV contract costs (FY 1985–2015)



Factor	Partial Contributions (MLE model)
Base constant (overall)	4.8 %-points
Average budget over prior 5 years	+ 0.55 %-points per $100B
Change in 5-year average of past budgets from the prior year to current year	+ 0.25 %-points per $10B change
Post-Goldwater-Nichols-era structural change (since FY 1990)	− 0.95 %-points
BBP-era structural change (since FY 2012)	− 1.9 %-points
Self-correction factor of difference between actuals and the other factors 5 years ago	− 0.58 times the overage 5 years ago
Randomness	+ pure noise

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Figure B-2. Factors Contributing to 5-year Moving Average of Annual Growth of EV contract costs: Combined Budgetary Factors (FY 1985–2015)



In simple terms, this model (not surprisingly) indicates that the defense acquisition system modulates changes to major program contracts—in part—based on budgets: if there are more resources, then the system addresses more issues such as threats and engineering issues that arise in development and early production. When resources are tight, the system addresses fewer of these problems. The combined partial effect is that growth changes somewhat in the same direction that budgets change (i.e., they are procyclical), which can be seen visually in Figure B-2. Cost change is expected to increase just over half a percentage point for every $100 billion in average budget over the prior 5 years. The model also predicts that cost changes will increase about a quarter of a percentage point for every $10 billion change in the 5-year moving average of past budgets from last year to the current year.

Also, there have been additional behavioral shifts to partially reduce growth on major contracts: one coincident with the implementation of Goldwater-Nichols to present, and one coincident with BBP implementation to present. These effects are large, statistically significant, and independent of budgetary dynamics. In the Goldwater-Nichols era, growth has been systemically moderated by about 1 percentage point, and growth has been reduced almost another 2 percentage points in the BBP era (all other things being equal). Measured against the peak annual growth of almost 10 percent in this period, these reductions constitute a systemic reduction of almost a third.

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In addition, the DoD self-corrects for external and internal variations that ensure stability. If contract work grew in a year more than what we would expect from the model-given budgetary trends, existing structural behaviors (say, because of critical threats), and prior corrections, then the DoD cuts back in the future. Conversely, if contract work grew less than expected, then the DoD tends to increase obligations in the following year to address problems. In other words, it shows that the defense acquisition system self-corrects for differences between what it anticipates it can obligate on contracts, given recent budgetary effects under the then-current structural climates, and what it actually put on existing contracts. In addition to external and random shocks, this factor may reflect a so-called "horsetail" effect, wherein the DoD's 5-year FYDP usually fails to predict both downward and upward cyclic changes in actual budgets (i.e., being overly optimistic when budgets are declining and pessimistic when budgets are rising—see, for example, Lambert, 2014, p. 3, and Harrison, 2014, p. 21).

Lastly, there is a constant base of growth on contracts over all these years, reflecting that defense weapon system development and early production involves some remaining uncertainties, risks, and investments (including changes to keep up with evolving threats). The overall base of just under 5 percent annually, however, is relatively low, given these are the more risky development and early production contracts, not full-rate production.

Model of Annual Contract Schedule Growth

Statistically we found that schedule growth has been on a simple downward trend along with its own 1-year self-correction factor (Table B-3).

Below are the statistically significant factors in the model of the 5-year moving average of annual growth of contract schedules on major MDAP contracts reporting EV.

$$s_t = c_0 + c_1 Y_t + u_t$$
$$u_t = c_2 u_{t-1} + \varepsilon$$
$$\varepsilon \sim i.i.d.\ N(0, \sigma^2)$$
$$\text{for } t \in [FY1985, FY2015]$$

where:

- s_t is the 5-year moving average of annual schedule growth for active major MDAP contracts in year t,
- c_i are coefficient constants,
- Y_t is the variable of time (i.e., the model is a secular time trend),
- u_t is an autoregressive factor for the difference in the prior year between the actual schedule growth and the growth predicted by the other factors, and
- ε is a series of independent and identically distributed (*i.i.d.*) samples from a normal distribution with zero mean (i.e., Gaussian white noise).

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Table B-3 lists the coefficients c_i for the statistically significant factors in the model of the 5-year moving average of annual schedule growth on major MDAP contracts reporting EV.

Table B-3. Model Coefficients and Statistics: 5-Year Moving Average of Annual Growth of Contract Schedules

Driver Type	Factor	MLE (OPG)	p-value MLE (OPG)
Linear declining trend	Coefficient for time trend (per year) (standard error)	−0.157%/year (0.000651)	0.014**
Self-Corrections	Autocorrelation coefficient: correction amount of actual-to-model difference in prior year (standard error)	0.766 (0.154)	0.000***
Base	Coefficient for constant (standard error)	3.21 (1.30)	0.016**

** statistically significant at the 5% level of significance

*** statistically significant at the 1% level of significance

NOTES: Annual 5-year moving average of schedule growth for executing contracts for major programs has a negative secular time trend over the last 31 years (i.e., schedule growth is declining). Each year's growth is the sum of all the changes in active contract schedules divided by the sum of all the original schedules. Thus, the portfolio percentage change will be closer in value to the percentage change of the longer contracts (similarly to how the growth in EV contract costs is affected by larger programs). The autocorrelation coefficient met stability conditions. After accounting for autocorrelation, the residual error was white noise.

For this model we employed ordinary least squares (OLS) and maximum likelihood estimation (MLE) estimation methods. For calculating the correct variance-covariance matrix we employed three different methods: Newey-West, observed information matrix (OIM), and sum of outer product of gradient vectors (OPG). The autocorrelation coefficient met stability conditions, and the residual error after accounting for autocorrelation was white noise.

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C. Analytic Details: Total Growth of MDAP Contract Costs Aligned to Milestone B

We analyzed the same EV data discussed in Appendix A above in the annual growth study. These data used summary EV data on 1,123 major contracts from FY 1981 to 2015 for 239 MDAPs. These included the combined results from 9,680 EMD reports and 8,790 early production reports. Table C-1 lists the actual 5-year moving average of total growth of EV contract costs aligned to MS B as calculated using the equations below.

These results are robust to different estimation methods and different ways of calculating the variance-covariance matrix. The autocorrelation coefficients met stability conditions. The residual error after accounting for autocorrelations was white noise.

Table C-1. Five-Year Moving Average of Total Growth of MDAP Contracted Costs Aligned to MS B Date (FY 1985–2012)

FY	Growth (actual)		FY	Growth (actual)
1985	36.3%		1999	63.8%
1986	35.5%		2000	63.9%
1987	50.3%		2001	72.6%
1988	58.9%		2002	54.0%
1989	84.2%		2003	52.4%
1990	77.1%		2004	47.4%
1991	73.0%		2005	47.2%
1992	58.7%		2006	40.5%
1993	66.0%		2007	36.5%
1994	40.1%		2008	46.1%
1995	37.7%		2009	42.8%
1996	38.1%		2010	46.3%
1997	61.5%		2011	44.8%
1998	51.1%		2012	42.8%

NOTE: Results reflect 18,470 earned-value reports on 1,123 major contracts for 239 major defense programs, including work-content growth (which dominates EV cost growth generally) and cost-over-target (i.e., overruns relative to the contract target). Because these are five-year moving averages, the values for 1985–1988 include data before 1985. Also, there was no MS B date after 2012 for the MDAPS that these contracts supported, but the dates up to 2012 include cost data through 2015.

These growths are calculated across all contracts together by totaling for each year the latest changes of the PM EAC for all contracts for the MDAP that had an MS B in that year, then dividing by the sum of all the initial contract cost targets for those contracts:

$$g(t) = \frac{\sum_{r=1}^{m} \Delta PMEAC_r(t)}{\sum_{i=1}^{n} CBB_i(original)}$$

for *m* reports on *n* contracts for MDAPs that passed MS B in year *t*

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where:

$g(t)$ is the total growth (adjusted for inflation) of contracted costs across all active EV contracts for MDAPs with MS B in year *t*,

$\Delta PMEAC_r(t)$ is the change in contract cost as reported by the PMEAC for EV report *r* for all contracts for MDAPs with MS B in year *t*, after adjusting for inflation,

$CBB_i(original)$ is the original negotiated cost target[49] at contract award for contract *i* in common base-year dollars, and

t is the fiscal year in which the MDAPs passed MS B.

Given g_t, the 5-year moving average growth G_t of EV contract costs for year *t* is simply:

$$G_t = \frac{\sum_{i=0}^{4} g(t-i)}{5}$$

for $t \in [FY1985, FY2012]$.

Model of Total Growth of Contract Costs Aligned to MDAP MS B Date

The following equations show our statistical model of the 5-year moving average of annual growth of EV contract costs on major MDAP contracts:

$$G_t = c_0 + c_2 \Delta B_t + u_t$$
$$u_t = c_1 u_{t-1} + c_4 u_{t-4} + c_5 u_{t-5} + \varepsilon$$
$$\varepsilon \sim i.i.d.\ N(0, \sigma^2)$$

for $t \in [FY1985, FY2012]$.

where

G_t is the 5-year moving average of annual growth of EV contract costs at time *t*,

c_i are coefficient constants,

$\Delta B_t = B_t - B_{t-1}$ is the change in the 5-year moving average of the budget from time *t-1* to time *t*,

u_t is an autoregressive factor for the difference between the actual growth and the growth predicted by the other factors 1, 4, and 5 years earlier, and

ε is a series of independent and identically distributed (*i.i.d.*) samples from a normal distribution with zero mean (i.e., Gaussian white noise).

[49] In EV reports, the CBB is the sum of the Negotiated Contract Cost (NCC) and the Authorized Unpriced Work (AUW).

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Table C-2 lists the coefficients c_i for the statistically significant factors in the model of the 5-year moving average of total growth of MDAP contracted costs aligned to MS B date.

Table C-2. Model Coefficients and Statistics: 5-Year Moving Average of Total Growth of MDAP Contracted Costs Aligned to MS B Date

Driver Type	Factor	OLS (Newey-West)	MLE (OIM)	MLE (OPG)	p-value OLS	p-value MLE (OIM)	p-value MLE (OPG)
Budget Effects	c_2 coefficient for each $10B change in 5-year moving average of prior DoD TOAs from last year	−2.95%	−2.31%	−2.31%	0.045**	0.012**	0.031**
	(standard error)	*(0.00141)*	*(0.000923)*	*(0.00107)*			
Self-Correction	c_1 autocorrelation coefficient: correction amount of actual-to-model difference in prior year	0.638	0.539	0.539	0.000***	0.000***	0.000***
	(standard error)	*(0.130)*	*(0.0932)*	*(0.0956)*			
	c_4 autocorrelation coefficient: correction amount of actual-to-model difference 4 years prior	*N/A*	0.280	0.280	N/A	0.016**	0.083*
	(standard error)		*(0.116)*	*(0.162)*			
	c_5 autocorrelation coefficient: correction amount of actual-to-model difference 5 years prior	*N/A*	−0.724	−0.724	N/A	0.000***	0.000***
	(standard error)		*(0.111)*	*(0.129)*			
Partial constant	c_0 coefficient for constant	52.4%	52.9%	52.9%	0.000***	0.000***	0.000***
	(standard error)	*(0.0410)*	*(0.0163)*	*(0.0174)*			

* statistically significant at the 10% level of significance.
** statistically significant at the 5% level of significance
*** statistically significant at the 1% level of significance.
NOTES: These results are robust to the different estimation methods shown and to different ways of calculating the variance covariance matrix. The autocorrelation coefficients met stability conditions. After accounting for autocorrelations, the residual error was white noise.

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D. Analytic Details: Correlates of O&S Cost Estimates

To model the correlates of O&S cost estimates, we examined the SARs from CY 2001 to 2014 (FY 2002–2015) and identified 161 MDAPs that provide O&S cost estimates. We then used multivariate regression to test a range of variables for correlation with the changes over time in O&S cost estimates during acquisition. The following proxy variables were used for wages, fuel prices, and health-care costs:

- Annual average wage per worker (from Social Security Administration)
- Fuel prices (price of a barrel of crude) (from Energy Information Administration)
- Personal health consumption (from Centers for Medicaid/Medicare Services)

All data was adjusted for inflation by converting 2016-dollars using Comptroller's Green Book (USD(C), 2016c). There were no O&S estimates in the Defense Acquisition Management Information Retrieval system before December 2001.

Defense-Wide

The following equation shows our statistical model of growth on O&S cost estimates across all MDAPs in the sample:

$$y_t = c_0 + c_1 x_{1t} + c_2 w_{t-2} + c_3 wg_{t-3} + c_4 hcg_{t-5} + c_5 fp_{t-5} + \varepsilon_t$$

$$\varepsilon_t \sim i.i.d.\ N(0, \sigma^2) \text{ (i.e., white noise)}$$

$$\text{for } t \in [FY2002, FY2015].$$

where:

y_t is the real annual change in O&S cost estimates for the MDAPs reporting in year t,
c_i are coefficient constants,
x_{1t} is the annual change in the portfolio maintenance estimate,
w_{t-2} is the annual average wage per worker, lagged 2 years,
wg_{t-3} is annual year-on-year change in the annual median wage per worker, lagged 3 years,
hcg_{t-5} is the annual year-on-year change in the annual per capita health care consumption, lagged 5 years.
fp_{t-5} is the annual average price of a barrel of crude, lagged 5 years, and
ε is a series of independent and identically distributed (*i.i.d.*) samples from a normal distribution with zero mean (i.e., Gaussian white noise).

Table D-1 lists the coefficients c_i for the statistically significant factors in the model of the annual change in O&S cost estimates. Recall that Figure 3-9 on p. 96 shows how closely this statistical model matches the actual growth in annual O&S cost estimates over this period.

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Table D-1. Model Coefficients and Statistics: Annual Change in O&S Cost Estimates for MDAPs: Defense-Wide (CY 2001–2014)

Driver Type	Factor	OLS Newey-West *(standard error)*	p-value OLS
Maintenance	c_1 coefficient for annual change in portfolio maintenance estimate	0.0913 *(0.0309)*	0.018**
Wage	c_2 coefficient for average annual wage per worker ($, real), lagged 2 years	0.0000591 *(0.0000147)*	0.004***
	c_3 coefficient for change in annual median wage per worker, lagged 3 years	2.27 *(0.493)*	0.002***
Health care	c_4 coefficient for change in annual per capita health consumption, lagged 5 years	2.64 *(0.684)*	0.005***
Fuel	c_5 coefficient for fuel price ($, real), lagged 5 years	−0.0000891 *(0.0000295)*	0.016**
Partial constant	c_0 coefficient for constant	−2.59 *(0.639)*	0.004***

* statistically significant at the 10% level of significance.
** statistically significant at the 5% level of significance
*** statistically significant at the 1% level of significance.

NOTES: n = 161 MDAPs. R-squared = 81 percent. The p-value for the model is 0.0000***. The residual error was white noise.

The Ramsey regression equation specification error test (RESET) indicates there are no omitted variables in this model. The Breusch-Pagan/Cook-Weisberg test indicates the errors have a constant variance. The Shapiro-Wilk and the skewness/kurtosis tests both indicate the error term is distributed normal. The sample of residuals, used to estimate the error term, has a sample mean of 0.00 and a constant variance of 0.0397. The variable inflation factor test suggests that multicollinearity among the independent variables is not a problem. Spearman's test for correlation indicates that all the independent variables are mutually independent (at the 5% level of significance). The linktest indicates the model is properly specified. Both the Portmanteau and Bartlett tests indicate the error term is white noise.

A similar approach was used in our analysis of correlates for MDAPs by Commodity (Army, Navy, Air Force, and other DoD) and commodities.

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E. Further Statistical Analysis Details

Generally, statistical analyses conducted for this report involved both parametric and nonparametric tests, as discussed below.

Supporting Sample Analysis for Regressions

In our linear multivariate regression analyses, we conducted supporting sample analysis tests for normality of residuals (Smirnov-Kolmogorov and Shapiro-Wilk tests), heteroskedasticity (Cook-Weisberg test), multicollinearity (variance inflation factor test), omitted variables (Ramsey RESET), and correct model specification (linktest). We also used bootstrap simulations to obtain unbiased coefficient estimates, correct standard errors, and correct confidence intervals.

Single Variable Analysis Tests

Single variable analyses allowed us to focus on differences by a single factor (e.g., phase, contract type, cost or price growth, schedule growth, or final margin). Nonparametric tests (Wilcoxon rank-sum and Kolmogorov-Smirnov) were used to test for statistical significance between populations, and the median was used as the measure of central tendency because the distributions were skewed. The chi-squared test was used to determine statistical significance for categorical variables.

Interpreting Box-and-Whisker Diagrams and Percentile Plots

Throughout this report, the so-called "box and whisker" charts (described in Figure E-1) help visualize the distribution of a particular variable. The gray boxes show the second and third quartiles (i.e., the 25th to the 50th percentile, and the 50th to the 75th percentile). The minimum and maximum are shown with a small bar at the end of the vertical line (or may run off the chart in some instances). The median (50th percentile, where half of the occurrences are above it and half below) is the *best measure of central tendency* in the data because the distributions are skewed. Note that the quartiles do not convey the actual distributions within the quartiles. As seen by the illustrations on the left of the figure, these distributions can be "lumpy" or nonuniform, but the charts do provide a quick visual for comparing two distributions. The charts also convey a sense of how much of the distribution is, say, negative or larger than a value of interest.

Next to some box-and-whisker charts we show the actual distributions so that we can see the distributions within each quartile. Figure E-2 shows how these percentile charts compare to the

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box-and-whisker charts, providing not only the quartiles but the whole distribution for each percentage. In this case, we show the box-and-whisker for the black line.

Figure E-1. Key to Reading the "Box and Whisker" Charts

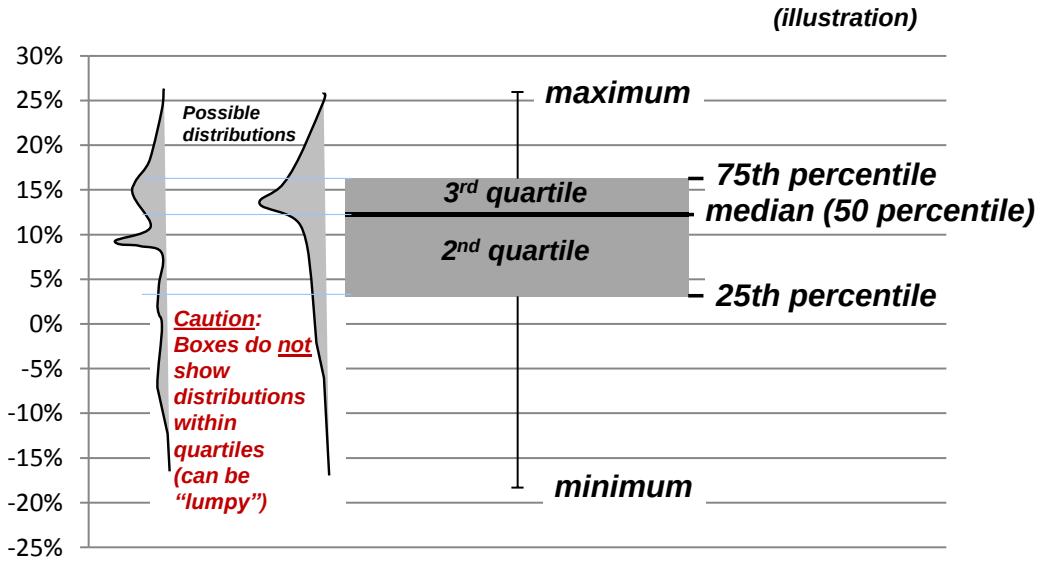
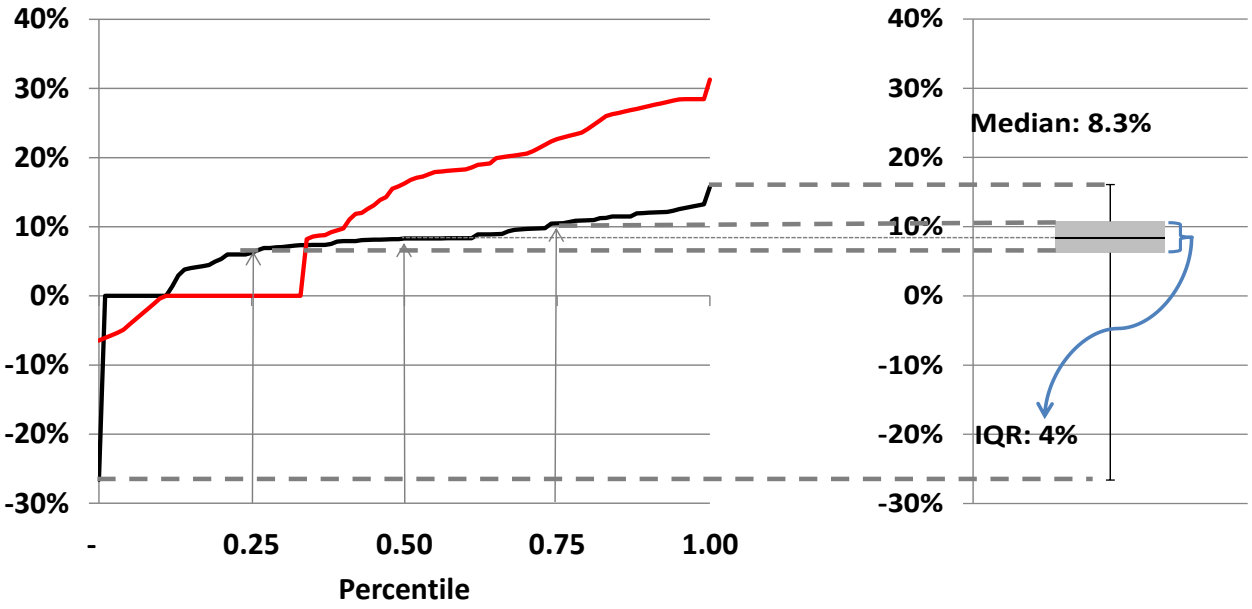


Figure E-2. Comparing Percentile and "Box and Whisker" Charts



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F. Program Name Acronyms

Program Acronym	Definition	Component
AAG	Advanced Arresting Gear	Navy
ABRAMS UPGRADE	M1A2 Abrams Tank Upgrade	Army
ACS	Aerial Common Sensor	Army
ADS (AN/WQR-3)	Advanced Deployable System	Navy
AEHF	Advanced Extremely High Frequency Satellite	Air Force
AGM-88E AARGM	Advanced Anti-Radiation Guided Missile	Navy
AH-64E New Build	Apache New Build	Army
AH-64E Reman	Apache Remanufacture	Army
AIM-9X Blk II	Air Intercept Missile, Block II (Sidewinder)	Navy
AIM-9X BLOCK I	Air Intercept Missile, Block I (Sidewinder)	Navy
AMDR	Air and Missile Defense Radar	Navy
AMF JTRS	Airborne & Maritime/Fixed Station Joint Tactical Radio System	Army
AMF JTRS SALT	Small Airborne Link 16 Terminal	Army
AMF JTRS SANR	Small Airborne Networking Radio	Army
AMPV	Armored Multi-Purpose Vehicle	Army
AMRAAM	AIM-120 Advanced Medium Range Air-to-Air Missile	Air Force
ARH	Armed Reconnaissance Helicopter	Army
ASDS	Advanced Seal Delivery System	Navy
ASIP	Airborne Signals Intelligence Payload	Air Force
ATACMS-APAM	Army Tactical Missile System-Anti-Personnel Anti-Materiel	Army
ATACMS-BAT	Army Tactical Missile System-Brilliant Anti-Tank	Army
ATIRCM/CMWS	Advanced Threat Infrared Countermeasure/Common Missile Warning System	Army
ATIRCM/CMWS QRC	Quick Reaction Capability	Army
AV-8B REMANUFACTURE	Harrier II Remanufacture	Navy
AWACS Blk 40/45 Upgrade	Airborne Warning and Control System Block 40/45 Upgrade	Air Force
AWACS RSIP (E-3)	Radar System Improvement Program	Air Force
B-1B CMUP	Conventional Mission Upgrade Program	Air Force
B-1B CMUP DSUP	Defensive Systems Upgrade	Air Force
B-1B CMUP JDAM	Joint Direct Attack Munition	Air Force
B-2 EHF Inc 1	Extremely High Frequency SATCOM and Computer Increment 1	Air Force
B-2 RMP	Radar Modernization Program	Air Force
B61 Mod 12 LEP TKA	Mod 12 Life Extension Program Tailkit Assembly	Air Force
BLACK HAWK (UH-60A/L)	Black Hawk Utility Helicopter	Army
BFVS A3 Upgrade	Bradley Fighting Vehicle Systems A3 Upgrade	Army
C-130 AMP	Avionics Modernization Program	Air Force
C-130J	Hercules Transport Aircraft	Air Force
C-17A	Globemaster III	Air Force
C-27J	Joint Cargo Aircraft	Air Force
C-5 AMP	Avionics Modernization Program	Air Force
C-5 RERP	Reliability Enhancement and Re-engining Program	Air Force
CANES	Consolidated Afloat Networks and Enterprise Services	Navy
CEC	Cooperative Engagement Capability	Navy
CGS (JSTARS GSM)	Common Ground Station (Formerly JSTARS CGS)	Army
CH-47F	Improved Cargo Helicopter	Army
CH-53K	Heavy-Lift Replacement Helicopter	Navy

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Program Acronym	Definition	Component
Chem Demil-ACWA	Chemical Demilitarization, Assembled Chemical Weapons Alternatives	DoD
Chem Demil-CMA	Chemical Materials Agency	DoD
Chem Demil-CMA Newport	Chemical Materials Agency Newport	DoD
Chem Demil-CMA/CSD	Chemical Stockpile Disposal	DoD
Chem Demil-Legacy/NSCMP	Legacy/Non-Stockpile Chemical Materiel Project	DoD
COBRA JUDY REPLACEMENT	Cobra Judy Replacement	Navy
Comanche	Comanche Helicopter	Army
CRH	Combat Rescue Helicopter	Air Force
CVN 68	Nimitz Class Nuclear Aircraft Carrier	Navy
CVN 78	Gerald R. Ford Class Nuclear Aircraft Carrier	Navy
CVN 78/EMALS	Electromagnetic Aircraft Launching System	Navy
DCGS, Inc. 1	Distributed Common Ground System, Increment 1	Army
DDG 1000	destroyer, guided-missile, Zumwalt class	Navy
DDG 51	destroyer, guided-missile, Arleigh Burke class	Navy
DEAMS	Defense Enterprise Accounting and Management System	Air Force
E-2C REPRODUCTION	E-2C Reproduction	Navy
E-2D AHE	Advanced Hawkeye Aircraft	Navy
EA-18G	Growler Aircraft	Navy
EA-6B ICAP III	Improved Capability III	Navy
EELV	Evolved Expendable Launch Vehicle	Air Force
EFV	Expeditionary Fighting Vehicle	Navy
EPS	Enhanced Polar System	Air Force
ERM	Extended Range Munition	Navy
Excalibur	Excalibur Precision 155mm Projectiles	Army
F/A-18E/F	Super Hornet Aircraft, E/F variant	Navy
F-15 EPAWSS	Eagle Passive Active Warning Survivability System	Air Force
F-22	Raptor Advanced Tactical Fighter Aircraft	Air Force
F-22 Inc 3.2B Mod	Increment 3.2B Modernization	Air Force
F-35	Lightning II Joint Strike Fighter (JSF) Program	DoD
FAB-T	Family of Advanced Beyond Line-of-Sight Terminals	Air Force
FAB-T CPT	Command Post Terminal	Air Force
FAB-T FET	Force Element Terminal	Air Force
FBCB2	Force XXI Battle Command Brigade and Below Program	Army
FCS	Future Combat System	Army
FMTV	Family of Medium Tactical Vehicles	Army
G/ATOR	Ground/Air Task Oriented Radar	Navy
GBS	Global Broadcast Service	Air Force
GBSD	Ground Based Strategic Deterrent	Air Force
GCSS-A	Global Combat Support System, Army	Army
GMLRS/GMLRS AW	Guided Multiple Launch Rocket System/Guided Multiple Launch Rocket System Alternative Warhead	Army
GPS III	Global Positioning System III	Air Force
H-1 Upgrades	Upgrades (4BW/4BN)	Navy
HC/MC-130 Recap	Recapitalization Aircraft	Air Force
HIMARS	High-Mobility Artillery Rocket System	Army
IAMD	Integrated Air and Missile Defense	Army
ICBM Fuze Mod	Intercontinental Ballistic Missile Fuze Modernization	Air Force
IDECM	Integrated Defensive Electronic Countermeasures	Navy
IFPC Inc 2-I Block 1	Indirect Fire Protection Capability, Increment 2, Intercept Block 1	Army
INCREMENT 1 E-IBCT	Increment 1 Early Infantry Brigade Combat Team	Army
IPPS-A	Integrated Personnel and Pay System, Army	Army
JAGM	Joint Air-to-Ground Missile	Army

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Program Acronym	Definition	Component
JASSM	Joint Air-to-Surface Standoff Missile	Air Force
JASSM-ER	Extended Range	Air Force
JAVELIN	Advanced Anti-Tank Weapon System, Medium	Army
JDAM	Joint Direct Attack Munition	Air Force
JHSV	Joint High-Speed Vessel	Navy
JLENS	Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System	Army
JLTV	Joint Light Tactical Vehicle	DoD
JOINT COMMON MISSILE	Joint Common Missile	Army
JOINT MRAP	Joint Mine Resistant Ambush Protected Vehicle	Navy
JPALS	Joint Precision Approach and Landing System	Navy
JPATS	Joint Primary Aircraft Training System	Air Force
JSF	F-35 Joint Strike Fighter	Air Force / Navy
JSOW	Joint Standoff Weapon	Navy
JTN	Joint Tactical Network	Army
JTRS GMR	Joint Tactical Radio System: Ground Mobile Radios	DoD
JTRS HMS	Joint Tactical Radio System: Handheld, Manpack, and Small Form-Fit Radios	Army
KC-130J	Transport Aircraft	Navy
KC-46A	Tanker Modernization	Air Force
Land Warrior	Land Warrior	Army
LCS	Littoral Combat Ship	Navy
LCS MM	Littoral Combat Ship Mission Modules	Navy
LHA 6	America Class Amphibious Assault Ship	Navy
LHD 1 [LHD]	Wasp Class Amphibious Assault Ship	Navy
LONGBOW APACHE	Longbow Apache AH-64D Helicopter	Army
LONGBOW HELLFIRE	Longbow Apache Precision Strike Missile System	Army
LMP	Logistics Modernization Program	Army
LPD 17	San Antonio Class Amphibious Transport Dock	Navy
LUH	Light Utility Helicopter	Army
MH-60R	Multi-Mission Helicopter	Navy
MH-60S	Fleet Combat Support Helicopter	Navy
MHC 51	Coastal Mine Hunter	Navy
MIDS	Multifunctional Information Distribution System	Navy
MINUTEMAN III GRP [MMIII GRP]	Minuteman III Guidance Replacement Program (GRP)	Air Force
MINUTEMAN III PRP	Minuteman III Propulsion Replacement Program (PRP)	Air Force
MOP GBU-57A/B	Massive Ordnance Penetrator Guided Bomb Unit	Air Force
MP-RTIP	Multi-Platform Radar Technology Insertion Program	Air Force
MPS	Mission Planning System	Air Force
MQ-1B UAS PREDATOR	Predator Unmanned Aircraft System	Air Force
MQ-1C Gray Eagle	Gray Eagle Unmanned Aircraft System	Army
MQ-4C Triton	Triton Unmanned Aircraft System	Navy
MQ-8 Fire Scout	Fire Scout Unmanned Aircraft System	Navy
MQ-9 Reaper	Reaper Unmanned Aircraft System	Air Force
MUOS	Mobile User Objective System	Navy
NAS	National Airspace System	Air Force
NAVSTAR GPS	NAVSTAR Global Positioning System	Air Force
Navy Area TBMD	Navy Area Theater Ballistic Missile Defense	DoD
NMT	Navy Multiband Terminal	Navy
NPOESS	National Polar-orbiting Operational Environmental Satellite System	Air Force
OCX	Next-Generation Operational Control System	Air Force

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Program Acronym	Definition	Component
P-8A	Poseidon Multi-Mission Maritime Aircraft	Navy
PAC-3	Patriot Advanced Capability, variant 3	Army
PAC-3 MSE	Missile Segment Enhancement	Army
Patriot/MEADS CAP	Patriot/Medium Extended Air Defense System Combined Aggregate Program	Army
PIM	Paladin Integrated Management	Army
RMS	Remote Minehunting System	Navy
RQ-4A/B Global Hawk	Global Hawk Unmanned Aircraft System	Air Force
SADARM	Sense and Destroy Armor	Army
SBIRS Follow-On	Space-Based Infrared System Follow-On	Air Force
SBIRS High	Space-Based Infrared System High	Air Force
SBSS BLOCK 10	Space Based Space Surveillance Block 10	Air Force
SDB I	Small Diameter Bomb, Increment I	Air Force
SDB II	Small Diameter Bomb, Increment II	Air Force
SM 2	Standard Missile-2	Navy
SM-6	Standard Missile-6	Navy
Space Fence Inc 1	Space Fence Ground-Based Radar System, Increment 1	Air Force
SSC	Ship-to-Shore Connector Amphibious Craft	Navy
SSDS	Ship Self-Defense System	Navy
SSGN	SSGN Ohio Class Conversion	Navy
SSN 21 / AN/BSY-2	SEAWOLF Class Nuclear Attack Submarine/Combat System	Navy
SSN 774	Virginia Class Submarine	Navy
STRATEGIC SEALIFT	Naval Transport Ship	Navy
STRYKER	Stryker Family of Vehicles	Army
T-45TS	Naval Undergraduate Jet Flight Training System (GOSHAWK)	Navy
TACTOM	Tactical Tomahawk RGM-109E/UGM-109E Missile	Navy
T-AKE	LEWIS and CLARK Class Dry Cargo/Ammunition Ship	Navy
T-AO 205 Class, T-AO(X)	John Lewis Class Fleet Oiler	Navy
TITAN IV	Space Booster	Air Force
TMIP-J	Theater Medical Information Program, Joint	DHA
Trident II Missile	Trident II (D-5) Sea-Launched Ballistic Missile UGM 133A	Navy
TSAT	Transformational Satellite Communications System	Air Force
TWS	Thermal Weapon Sight	Army
UH-60M Black Hawk	Black Hawk Helicopter	Army
V-22	Osprey Joint Services Advanced Vertical Lift Aircraft	Navy
VH-71	Presidential Helicopter Fleet Replacement	Navy
VH-92A	Presidential Helicopter	Navy
VTUAV	Vertical-Takeoff-and-Landing Tactical Unmanned Aerial Vehicle (Fire Scout)	Navy
WAS	Wide-Area Surveillance	Air Force
WGS	Wideband Global SATCOM	Air Force
WIN-T	Warfighter Information Network, Tactical	Army
WIN-T Inc 1	Increment 1	Army
WIN-T Inc 2	Increment 2	Army
WIN-T Inc 3	Increment 3	Army

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G. Abbreviations

(See also the program names defined starting on p. 159)

ACAT—Acquisition Category

APB—Acquisition Program Baseline

APUC—Average Procurement Unit Cost

AT&L—Acquisition, Technology, and Logistics

BA—budget activity

BBP—Better Buying Power

BLRIP—beyond low-rate initial production

BY—base year

C4ISR—Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance

CBB—Contract Budget Base

COTS—Commercial Off the Shelf

CPARS—Contractor Performance Assessment Reporting System

CY—calendar year

DAE—Defense Acquisition Executive

DAWDF—Defense Acquisition Workforce Development Fund

DCAA—Defense Contract Audit Agency

DHA—Defense Health Agency

DLA—Defense Logistics Agency

DoD—Department of Defense

DoDI—Department of Defense Instruction

DOT&E—Director, Operational Test and Evaluation

DPARCA—Director, Performance Assessments and Root Cause Analyses

EAC—estimate at completion

EMD—Engineering, Manufacturing and Development

EV—earned value

FAR—Federal Acquisition Regulation

FDD—Full-Deployment Decision

FFO—(date) funds first obligated

FPDS-NG—Federal Procurement Data System-Next Generation

FPIF—fixed-price incentive firm

FY—fiscal year

FYDP—Future-Years Defense Program

GAO—Government Accountability Office

HUBZone—Historically Underutilized Business Zone

IOC—Initial Operational Capability

IPT—integrated product team

IQR—interquartile range

IR&D—Independent Research & Development

IT—information technology

JCIDS—Joint Capabilities Integration and Development System

KSA—Key System Attributes

KPP—Key Performance Parameter

LFT&E— Live-Fire Test and Evaluation

LRIP—Low-Rate Initial Production

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MAIS—Major Automated Information Systems

MAR—MAIS Annual Report

MDA—Milestone Decision Authority

MDAP—Major Defense Acquisition Program

MDD—Materiel Development Decision

MOE—MAR original estimate

MPS—Mission Planning System

MS—Milestone

NDAA—National Defense Authorization Act

O&M—Operations and Maintenance

O&S—Operating and Support

OCO—Overseas Contingency Operations

OSD—Office of the Secretary of Defense

OT&E—operational test and evaluation

PARCA—Performance Assessments and Root Cause Analyses

PAUC—Program Acquisition Unit Cost

PB—President's budget (request)

PBL—performance-based logistics

PEO—Program Executive Officer

PM—program manager

PM EAC—Program manager's estimate at completion

PSC—product service code

Q—quarter

R&D—research and development

RDT&E—Research Development Test and Evaluation

RESET—Ramsey regression equation specification error test

SAE—Service Acquisition Executive

SAIC—Science Applications International Corp.

SAR—Selected Acquisition Report

SSIP—Superior Supplier Incentive Program

TMRR—Technology Maturation and Risk Reduction

TOA—Total Obligation Authority

TSPR—Total System Performance Responsibility

TY—then year (not adjusted for inflation)

UAV—unmanned aerial vehicle

UCA—undefinitized contract action

ULA—United Launch Alliance

ULS—United Launch Services

USD—Under Secretary of Defense

U.S.C.—United States Code

USD(AT&L)—Under Secretary of Defense, Acquisition, Technology, and Logistics

WSARA—Weapon System Acquisition Reform Act (of 2009)

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H. INDICES

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Army Aviation's Pacific Rebalance: Evolution towards Maritime Operations

A Monograph

by

MAJ John M. McLean II
US Army



School of Advanced Military Studies
United States Army Command and General Staff College
Fort Leavenworth, Kansas

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US Army Aviation provides essential movement capabilities to maneuver and joint force commanders. Transitioning from exclusively land-based operations to potential maritime operations in the Pacific command area of responsibility, Army Aviation faces increased demands to overcome geographical complexities to support joint operations. This monograph examines historical maritime operations where Army Aviation's maritime applications provided commanders with increased options to achieve mission success. Army Aviation operations in the maritime domain pose unique challenges which require innovative adaptations of doctrine, organization, and training to overcome these operational challenges. Through continued doctrinal development and joint, multinational training exercises Army Aviation can augment existing maritime capabilities to increase the US military's operational capacity in the Pacific command area of responsibility.

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Abstract

Army Aviation's Pacific Rebalance: Evolution towards Maritime Operations, by MAJ John M. McLean II, US Army, 59 pages.

US Army Aviation provides essential movement capabilities to maneuver and joint force commanders. Transitioning from exclusively land-based operations to potential maritime operations in the US Pacific command area of responsibility, Army Aviation faces increased demands to overcome geographical complexities to support joint operations. This monograph examines historical maritime operations where Army Aviation's maritime applications provided commanders with increased options to achieve mission success. Army Aviation operations in the maritime domain pose unique challenges which require innovative adaptations of doctrine, organization, and training to overcome these operational challenges. Through continued doctrinal development and joint, multinational training exercises Army Aviation can augment existing maritime capabilities to increase the US military's operational capacity in the US Pacific command area of responsibility.

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Acronyms

AOR	Area of Responsibility
ARG	Amphibious Ready Group
ATP	Army Training Publication
CAB	Combat Aviation Brigade
CV	Aircraft Carrier
CVN	Aircraft Carrier, Nuclear
DDH	Destroyer, Helicopter (Japan)
FM	Field Manual
FVL	Future Vertical Lift
INTERFET	International Force in East Timor
JMSDF	Japan Maritime Self-Defense Force
JP	Joint Publication
JTF	Joint Task Force
LHA	Landing Helicopter Assault - Amphibious Assault Ship
LHD	Landing Helicopter Dock - Amphibious Assault Ship
MAGTF	Marine Air-Ground Task Force
MCWP	Marine Corps Warfighting Publication
MEDEVAC	Medical Evacuation
MEU	Marine Expeditionary Unit
NATOPS	Naval Air Training and Operating Procedures Standardization
NAVAIR	Naval Air Systems Command
TRADOC	Training and Doctrine Command
UAS	Unmanned Aerial System
USARPAC	United States Army Pacific Command
USPACOM	United States Pacific Command

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Introduction

> The strength of any Joint Force has always been the combining of unique Service capabilities into a coherent operational whole.
>
> —General Martin Dempsey, *Capstone Concept for Joint Operations*, 2012

In 2011, the United States government introduced the "Pivot to the Pacific" to rebalance its strategic focus following a decade of emphasis on the Middle East and Southwest Asia.[1] To do so, the United States intends to rebalance its diplomatic, economic, and military focus toward increased emphasis on Asia-Pacific regional threats and opportunities.[2] Militarily, the Pacific region's maritime-dominated environment requires reprioritization from the land-based competence earned in Iraq and Afghanistan.[3] The US Pacific Command's (USPACOM) expansive Area of Responsibility (AOR) ranges from dispersed islands to densely populated urban centers.[4] For United States Army Aviation, the Pacific rebalance requires a broadened approach to its core competencies to increase its interoperability between land and maritime environments. US Army Aviation proved its integral capability to project power throughout a land-based operational environment. To match this capability in the US Pacific Command's maritime area of responsibility, US Army Aviation must evolve to maintain its ability to support joint maneuver forces in maritime dominated environments.

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[1] Joseph Gerson, "Reinforcing Washington's Asia-Pacific Hegemony," *Foreign Policy in Focus*, 13 September 2012, accessed August 4, 2015,. http://www.fpif.org/reinforcing_ washingtons_asia-pacific_hegemony.

[2] US Department of Defense, *The 2014 Quadrennial Defense Review* (Washington, DC: Government Printing Office, 2014), 4.

[3] Office of the President of the United States, *National Security Strategy, February 2015* (Washington, DC: Government Printing Office, 2015), "Foreword."

[4] Thomas J. Bickford et al., "The Role of the U.S. Army in Asia," *CNA China Studies* (May 2015): 74-75, accessed August 8, 2015, http://www.dtic.mil/docs/citations/ADA618342.

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Operations Iraqi and Enduring Freedom's land-based theaters allowed combat aviation brigades (CABs) to maximize Army rotary wing capabilities via central location.[5] This placement enabled commanders' to project combat forces throughout the depth of the operational environment and maximize centralized support. In future operations, the USPACOM AOR's dispersion will likely impede centralized aviation support in maritime-dominated operational environments.[6] To overcome geographic impediments, the Army develop "innovative and collaborative" approaches to its doctrine, training, and ability to organize to fulfill its core competencies in support the US Pacific Command area of responsibility.[7]

US Army Aviation must evolve to remain viable in the USPACOM AOR. To identify Army Aviation's necessary changes, this monograph asks: What adaptation of the US Army's rotary wing aviation capabilities will lead to successful employment in the maritime regions of the US Pacific Command area of responsibility?[8] A critical consideration for this research question is the fact that the Army Aviation will not abandon its land-based proficiencies to increase maritime competency. Instead, Army Aviation must expand existing capabilities to enhance maritime application.

Fiscal constraints and general practicality limit this monograph's recommendations, which allows for near-term implementation. From an organization perspective, the combat aviation brigade remains the primary tactical aviation organization. Recommended organizational

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[5] James W. Williams, *A History of Army Aviation. From Its Beginnings to the War on Terror* (New York: iUniverse, Inc., 2005), 378.

[6] John A. Olsen, ed. *Global Air Power* (Washington, DC: Potomac Books, 2011), 295.

[7] US Joint Chiefs of Staff, *Capstone Concept for Joint Operations: Joint Force 2020 (*Washington, DC: Government Printing Office, 2012), accessed January 11, 2016, http://www.dtic.mil/doctrine/concepts/ccjo_jointforce2020.pdf, 12.

[8] Army Aviation includes both rotary wing, fixed wing, and unmanned airframes. For the purpose of this monograph, the term "Army Aviation" will focus on its rotary wing airframes assigned to combat aviation brigades unless otherwise specified.

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changes are limited to internal arrangement of current CAB compositions. Existing aircraft remain the baseline to recommend improvements to doctrine, organization, and materiel.[9] This monograph's recommendations remain economically feasible and implementable within three years by excluding new aircraft acquisition and CAB re-organization.

Consistent with the current Army Operating Concept, Army Aviation's incorporation into joint and multinational maritime operations increases the Army's operability across land and maritime domains, in support of joint and multinational partners.[10] Increased Army maritime capabilities will augment, not supersede, Marine Air-Ground Task Force (MAGTF) capabilities. As fiscal constraints limit the amount of US Marine Corps and US Navy assets, Army Aviation will fulfill supplementary roles to ensure operational commanders can tailor available assets toward the appropriate operational requirements.

This monograph focuses specifically on Army Aviation's core competencies that enable the movement, sustainment, and mission command capabilities of supported maneuver forces.[11] These competencies require the most difficult effort to integrate with joint and multinational operations and exemplify the operations Army Aviation is most likely to execute as opposed to a standing MAGTF. These competencies focus the case studies and recommendations on utility and cargo helicopter operations. Lastly, proposed recommendations consider all levels of war. In a

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[9] This monograph assumes no change to the ongoing OH-58D divestment plan. During this transition, AH-64D/Es and RQ-7 equipped Heavy Armed Reconnaissance Squadrons replace OH-58D equipped Armed Reconnaissance Squadrons.

[10] Training and Doctrine Command Pamphlet (TRADOC PAM) 525-3-1, *The US Army Operating Concept: Win in a Complex World 2020-2040* (Washington, DC: Government Printing Office, 2014), 7-10.

[11] Field Manual 3-04, *Army Aviation* (Washington, DC: Government Printing Office, 2015), 1-1 – 1-5. Army Aviation is founded in seven core competencies. This monograph focuses primarily on four: air assault ground maneuver forces; air movement of personnel, equipment, and supplies; evacuate wounded or recover isolated personnel; and enable mission command over extended ranges and complex terrain.

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maritime dominated operational environment, proximity to partner nations, conventional and irregular threats, and the unmatched distances that separate areas of operation from support areas provide unique and challenging military problems in the United States' strategic rebalance toward the Pacific.[12]

Modern Army Aviation is optimized for land-based application and must adapt its doctrine, organization, training, and materiel to support joint operations throughout a maritime dominated operational environment. To prepare for maritime geographical limitations, Army Aviation must be able to scale-down to task force and team echelons based vast distances between support areas and the potential for amphibious, ship-based operations. Despite the differences between continental and maritime operational environments, the Army expects rotary wing aviation to support its maneuver forces with timely and precise mobility, fires, sustainment, and intelligence. By enabling the rapid displacement and concentration of combat power throughout the operating environment, Army Aviation enables efficiency and agility in joint operations.[13] Efficiency increases enable military leaders to achieve mission objectives with less personnel or equipment. This efficiency is important given the growing attention on military expenditure and the political focus on troops strengths dedicated to contingency operations. Second, Army Aviation concentrates combat power at decisive points, in both time and space. Efficiency and concentration allow commanders to achieve relative and decisive advantages over their adversary.[14]

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[12] US Joint Chiefs of Staff, *The National Military Strategy of the United States of America 2015: The United States Military's Contribution to National Security (*Washington, DC: Government Printing Office, 2015), 15. The 2015 *National Military Strategy* outlines the requirement to accomplish strategic objectives in an innovative, efficient, and agile manner; focusing on joint, interagency, and international partnered operations.

[13] Ibid.

[14] FM 3-04, 4-7.

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Rebalancing its global priorities, the United States National Command Authority directed the Department of Defense to emphasize readiness and engagement in the USPACOM AOR in future military efforts.[15] USPACOM's predominately maritime geography differentiates it from the primarily land-based focus of other geographic combatant command areas of responsibility. Extending beyond the limits of the Pacific Ocean, the USPACOM AOR also includes Australia, China, India, and nearly 80% of the Indian Ocean. Portrayed in Figure 1. US Pacific Command Area of Responsibility, this area hosts over fifty percent of the world's population, which magnifies the AOR's security considerations stemming from ethnic tensions and population density.[16]

Due to USPACOM AOR's vast size, this monograph differentiates two amphibious regions for expected Army Aviation employment. Also depicted in Figure 1. US Pacific Command Area of Responsibility, the "Continental amphibious region" denotes areas where Army Aviation will most likely operate in a traditional manner from land bases. More importantly for this monograph, the depicted "Maritime amphibious region" includes fragmented land areas where traditional operations may not be feasible. This "maritime amphibious region" provides the greatest likelihood for amphibious or ship-based operational requirements for Army Aviation.[17]

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[15] Gerson, "Reinforcing Washington's Asia-Pacific Hegemony".

[16] US Pacific Command, "USPACOM Area of Responsibility," US Pacific Command Homepage, accessed February 3, 2016, http://www.pacom.mil/AboutUSPACOM/USPACOMAreaofResponsibility.aspx.

[17] In Figure 1, the depicted "continental amphibious region" and "maritime amphibious region" are author-created for this monograph and neither attributed nor endorsed by USPACOM.

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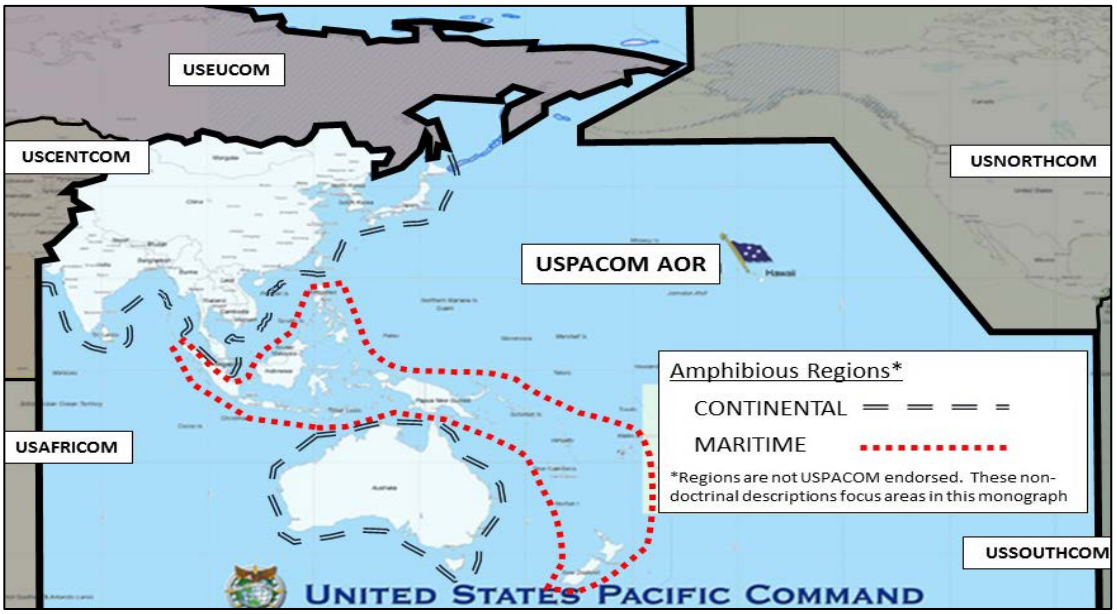


Figure 1. US Pacific Command Area of Responsibility and Amphibious Regions

Source: Adapted from "United States Pacific Command" (map), US Pacific Command website, accessed 3 February 2016, http://www.pacom.mil/portals/55/Images/USPACOM _map.png.

Economically, the United States' trade relations throughout the Asia-Pacific region provide credibility with its strategic Asia-Pacific partners.[18] By 2020, over half of the United States' international growth is expected to occur within the USPACOM AOR.[19] Military capabilities deter hostile action to maintain freedom of navigation in support of the United States' economic interests. A maritime-capable Army assures the United States' strategic partners in its ability to deter against adversarial aggression and economic impacts in the Asia-Pacific region.

Economic competition in the Asia-Pacific Region increases the potential for military conflict to guarantee access to resources and trade.[20] The expansion of the Army's maritime capabilities will ensure that the United States' largest military service remains a viable asset in

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[18] Mark Borthwick, *Pacific Century: The Emergence of Modern Pacific Asia*, 3rd ed. (Boulder, CO: Westview Press, 2007), 544.

[19] *US National Security Strategy*, *2015*, 24.

[20] Bruce Berkowitz, *Strategic Advantage. Challengers, Competitors, and Threats to America's Future* (Washington, DC: Georgetown University Press, 2008), 231.

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military operations in the USPACOM AOR. Aviation is a critical enabler for the Army; the development of amphibious aviation capabilities allows the US military to counter external influences and preserve its Asia-Pacific security and prosperity.

The Asia-Pacific region is one of the most complex global military landscapes, including seven of the world's largest militaries and five nuclear-capable nations.[21] Multilateral military partnerships are essential to strengthen the United States' regional security posture. China refutes the United States' future ability to maintain Pacific security and proposes that its People's Liberation Army assumes the primary role in Asia-Pacific security.[22] China's challenge requires increased US efforts to ensure national capabilities remain viable in the USPACOM AOR. This application of Nye's "smart power" will strengthen the United States' influence Asia-Pacific.[23] Adapting Army Aviation towards maritime capabilities provides a critical step to ensure that the United States' largest military service can conduct operations throughout the USPACOM AOR.

Army Aviation requires doctrinal and organizational adaptation to continue its joint efficiency and agility in maritime environments. This monograph examines the USPACOM AOR's unique geographic and operational requirements to determine the best opportunities for military employment. Army Aviation operations in the USPACOM AOR requires joint and multinational capabilities to improve interoperability and mission effectiveness to strengthen the United States' strategic deterrence throughout the USPACOM AOR.

This monograph uses current service doctrine and historical case studies as the lens to determine viable applications for Army Aviation in the maritime regions of the USPACOM

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[21] "USPACOM Area of Responsibility."

[22] David Capie, "The United States and Humanitarian Assistance and Disaster Relief (HADR) in East Asia: Connecting Coercive and Non-Coercive Uses of Military Power," *Journal of Strategic Studies* 38, no. 3 (March 11, 2015): 322.

[23] Joseph S. Nye, *The Future of Power* (New York: Public Affairs, US, 2011), 208-209.

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AOR. Service doctrine establishes the current frame of reference to establish a baseline assessment of Army Aviation's prospective capabilities. Following the capabilities assessment, three case studies provide contextual data to conduct a qualitative analysis of the potential for future Army Aviation applications in the USPACOM AOR. The current Army Aviation expectations and case studies identify the opportunities to recommend feasible modification to Army Aviation training, from unit-level drills to multinational Pacific training exercises.[24]

A cursory understanding of Army Aviation capabilities is required to anticipate future maritime requirements. An Army doctrine overview, specifically focusing on maritime, amphibious, and shipboard operations highlights existing capability and shortfalls as applied to operations in the USPACOM AOR. A similar review of US Joint and cross-service doctrine and equipment identifies existing aspects necessary to improve Army Aviation doctrine and increase maritime capability.

The first case study examines Army Aviation's ship-based execution of Operation Uphold Democracy, the 1994 operation to secure Haiti. This case examines the opportunity created by the unprecedented and innovative amphibious employment of Army rotary wing Aviation from two US Navy aircraft carriers.[25] This case exemplifies the effects of joint interoperability and planning considerations preceding operation. The scale of the operation and joint coordination complications highlight potential differences between anticipated Pacific operations and those exhibited in Operations Iraqi and Enduring Freedom.[26] Though it did not

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[24] Tyrone Marshall, "Pacific Pathways Increases Readiness through Partnership," *US Department of Defense Homepage,* October 15, 2014, accessed October 18, 2015, http://www. defense.gov/News-Article-View/Article/ 603461.

[25] Walter E. Kretchik, Robert F. Baumann, and John T. Fishel, *Invasion, Intervention, "Intervasion": A Concise History of the U.S. Army in Operation Uphold Democracy* (Fort Leavenworth, KS: US Army Command and General Staff College Press, 1998), 51-55.

[26] William B. Garrett, interview by Robert K. Wright, Donald Carter, and Cynthia L. Hayden, *JTF-180 Uphold Democracy: Oral History Interviews,* March 29, 1995. ed. Cynthia L. Hayden (Ft. Bragg, NC: XVIII Airborne Corps, 1996).

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occur in the USPACOM AOR, Operation Uphold Democracy's unprecedented air assault demonstrates the potential scale required of Army Aviation's amphibious combat power projection in a maritime environment.

The second case study, 1999's Operation Stabilise, examines a USPACOM scenario where amphibious Army Aviation employment could have led to operational success. This United Nations (UN) initiated this peacekeeping operation to safeguard an independence referendum and stop a humanitarian crisis between Indonesia and the seceding East Timor. Despite East Timor's pursuit for independence from Indonesia, Timor Island remained Indonesian sovereign territory. Vast geographical distances and geopolitical complications delayed peacekeepers until Indonesia granted its approval. Though the US military did not play a primary role in Operation Stabilise, this case's geographic and political aspects represent a likely future scenario where amphibious capabilities may afford a strategic advantage.[27] Furthermore, the multinational aspect of Operation Stabilise makes it a viable case to examine joint and multinational partner employment capabilities for amphibious Army Aviation.

The final case study examines a worst-case scenario, where ship-based Army Aviation could augment joint foreign humanitarian response operations. Operation Tomodachi examines the multinational response to Japan's destroyed nuclear power plant following a tsunami. The combined effects of the tsunami and nuclear meltdown warranted an immediate US military response. Led by a USMC Marine Expeditionary Unit (MEU), the US government led the massive foreign humanitarian assistance and disaster relief mission. Despite the mission's success, mission requirements nearly exceeded relief capability on several occasions.[28] In a future

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[27] John Crawford and Glyn Harper, *Operation East Timor: The New Zealand Defence Force in East Timor, 1999-2001* (Birkenhead, Auckland, NZ: Reed Books, 2001), 15.

[28] Rockie K Wilson, "Operation TOMODACHI: A Model for American Disaster Response Efforts and the Collective use of Military Forces Abroad" (research report, Harvard University, 2012), 8-9, accessed February 11, 2016, http:/www.dtic.mil/dtic/tr/fulltext/u2/a567991.pdf.

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scenario, amphibious Army Aviation could augment or relieve USMC units to increase operational capacity. Amphibious based employment alleviates the complications based upon potentially limited access. The counterpoint to Operation Stabilise's requirement for precise capabilities, operation tomodachi exemplifies the need to respond with massive operational capabilities in support response to crises in the USPACOM AOR.

The Pacific area of responsibility's vast array of population density (mega cities to desolate islands), infrastructural condition (modernity to squalor), and severe natural disasters (typhoons, earthquakes, volcanos) makes the region rife with plausible disaster scenarios. In these extreme scenarios, amphibious based or amphibiously introduced Army rotary wing operations provide an ideal augmentation to the primary, yet limited disaster response capabilities. In these case studies, rotary wing precision combined with reduced logistical requirements promote Army aviation assets as a viable option in large scale, Pacific disaster response.

The last decade's resurgence in Joint/Multinational partnership and exercises throughout the US Pacific Command area of responsibility provides the opportunities and resources required to develop Army Aviation's maritime capability. Implementing the Pacific Pathways construct, US Army Pacific Command conducts several multinational exercises to reduce training budgets and maximize training exposure with military allies and the US State Department.[29] These exercises provide the venue to incorporate Army Aviation to develop and improve Army Aviation's maritime competency in the Asia-Pacific region.[30]

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[29] Marshall, "Pacific Pathways Increases Readiness through Partnership."

[30] US Army Pacific, *Partnering in the Asia-Pacific Theater: The U.S. Army, Pacific Theater Engagement Strategy White Paper*, April 2012, accessed October 29, 2015, https://www.usarpac.army.mil/pdfs/Partnering%20in%20the%20Pacific%20Theater.pdf, 3-5.

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Army Aviation's re-organization into specialized task forces will employ smaller, agile units, capable of providing direct support to independent Brigade Combat Teams. Scalable aviation organizations can provide tailored support to maneuver elements in areas where physical separation prohibits centralized support.[31] Aviation missions executed from non-US Navy amphibious platforms provides a multinational opportunity to maximize Army Aviation's maritime potential in the Pacific. This monograph examines the feasibility of overcoming the Pacific expanse by conducting combined, joint operations with the Australian Defence Forces and Japanese Maritime Self Defence Forces.

The combination of historical examples and contemporary applications provides the method to assess whether the recommended aviation competencies yield increased joint and multinational capability. Examination of operational expectations, joint/multinational capabilities, and mission feasibility identifies recommended changes to doctrine, organization, training, and materiel for Army Aviation to succeed in the USPACOM AOR. This monograph recommends initial changes to training and doctrine that later enable opportunities to conduct combined and joint training as the method to optimize USPACOM employment. Additionally, this approach recognizes strategic and political advantages that maximize the United States' ability to increase its influence and deter opposition in the Pacific.

Three contentions shape what the recommended capabilities Army Aviation must develop to achieve mission success in the USPACOM AOR. First, Army Aviation must retain the capability to conduct a Brigade Combat Team sized air movement/air assault into semi-permissive environments.[32] Second, Army aviation must retain the capability to sustain battalion-sized or smaller, multipurpose aviation task forces in support of a Brigade Combat Team or smaller operations in an austere environment. These mission capabilities represent the most

[31] FM 3-04, 2-13 – 2-15.

[32] Bickford et al., "The Role of the U.S. Army in Asia," 51-53.

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demanding scenarios Army Aviation will likely face in the Asia-Pacific region. Third, aviation-capable amphibious platforms are limited in number and retain strategic importance; only strategically vital operations will warrant amphibious ship retask and reconfiguration to employ Army assets. These elements guide the recommendations for Army Aviation's joint capabilities in a maritime domain.

Aviation/Amphibious Capability: Doctrine, Organization, Training, and Equipment

A preliminary understanding of the applicable doctrine is required to recommend improvements for Army Aviation in the USPACOM AOR. This monograph considers applicable doctrine separated into three categories: Army service doctrine, US Joint doctrine, and US Naval doctrine. Army and Joint doctrine inform the capabilities, mission expectations, and limitations of aviation organizations specific to maritime operations. US Naval doctrine provides additional insight into the cross-service competencies that will aid Army Aviation's transition towards amphibious capabilities necessary in the USPACOM AOR.

Army Doctrine

Despite the Army's contemporary focus on land-based operations, its most recent doctrine incorporates maritime operations more than prior editions. The most notable additions are the release of Army Aviation's capstone document, Field Manual 3-04, *Army Aviation* and its technical companion Army Training Publication (ATP) 3-04.1, *Aviation Tactical Employment.* Integrating combat tactics, techniques, and procedures with new technology, FM 3-04 expands Army Aviation's doctrine to incorporate maritime capability and joint interoperability.[33]

[33] FM 3-04, vii, 1-4. Released in 2015 and 2016, FM 3-04, *Army Aviation* and ATP 3-04.1, *Aviation Tactical Employment* supersede multiple publications, including the 1997 publication, FM 1-100, *Army Aviation Operations* and 2007's FM 3-04.111, *Aviation Brigades*.

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Despite the integrated importance of Army Aviation's core competencies, rotary wing movement of personnel and equipment in joint, maritime environments requires the most integration with supported forces.[34] Rotary wing aircraft allow commanders to overcome anti-access and area denial environments to insert ground forces into the depth of an area of operations using speed and range of army aircraft.[35] Air assault and air movement operations differ in execution, but both increase its operational range and tempo a supported force can influence its operational environment.[36] In maritime environments, ground movement may be impractical or impossible. Army Aviation overcomes physical limitations by providing viable means for moving combat forces, humanitarian cargo, evacuate wounded persons, or enhance mission command capabilities across dispersed terrain.[37]

Army Aviation's rotary wing depth exceeds all other services. This ability to mass rotary wing aviation enables joint commanders to increase capacity in foreign humanitarian assistance operations. Whether deployed from naval vessels or between isolated landmasses, Army Aviation provides operational commanders with increased flexibility to achieve mission objectives or augment existing forces.

FM 3-04 and ATP 3-04.1 depict combat aviation brigade organization and serve two key purposes for maritime readiness: brigade organization and scalability. FM 3-04 outlines the

---

[34] Though the fires and intelligence capabilities are necessary in maritime environments, this monograph assumes other joint non-amphibious-based platforms can produce similar effects without requiring the use of amphibious-based aviation platforms.

[35] FM 3-04, 1-14 – 1-15.

[36] Ibid., 1-4 – 1-6. Air assaults intend to destroy enemy forces or seize key terrain. Air movements support offensive, defensive and stability operations including foreign humanitarian assistance, foreign disaster relief, and non-combatant evacuation operations.

[37] Ibid., 3-23 – 3-31.

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standard CAB organization beyond the aviation restructuring initiative.[38] These publications describe scaled-down forces packages at the battalion tasks force and company team level, to ensure the necessary maintenance, sustainment, and mission command capabilities accompany the airframes.[39] Due to space limitations for equipment and personnel aboard amphibious ships, mission configured force packages are essential to optimize Army Aviation capabilities in support of joint operations on amphibious vessels or in austere environments.

A significant limitation for Army Aviation in maritime environments is the increased maintenance consideration required in saltwater environments. Salt water's corrosive effects on Army aircraft increases routine maintenance requirements. Understanding the effects of salt water corrosion in shipboard operations is critical to ensure Army Aviation capabilities endure operational assignments in maritime environments.[40]

In preparation for contingency operations in the USPACOM AOR, FM 3-04 addresses Army Aviation's mission capability in "other environments": pandemic zones; post-disaster areas; and chemical, biological, radiological, and nuclear environments. Recent events in the Asia-Pacific region exhibits these environments: avian flu, typhoons and tsunamis near populated areas, and potential conflicts on the North Korean peninsula. [41] These environments exemplify the necessary conditions in which Army Aviation must prepare to operate.

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[38] FM 3-04, 2-1, 2-7– 2-9. The current CAB contains a headquarters and five subordinate battalions: an Attack Reconnaissance Battalion with twenty-four AH-64D/Es and twelve MQ-1C Gray Eagle Unmanned Aerial Systems (UAS); an Assault Helicopter Battalion with thirty UH-60M utility helicopters; a General Support Aviation Battalion (GSAB) with eight UH-60Ms, twelve CH-47F cargo helicopters, and fifteen MEDEVAC HH-60Ms; the thirty OH-58D Attack Reconnaissance Squadron is in transition to a Heavy Squadron with twenty-four AH-64D/Es and twelve RQ-7B UAS, an Aviation Support Battalion (ASB) provides maintenance and support.

[39] FM 3-04, 2-13 – 2-15; Army Training Publication 3-04.1, *Aviation Tactical Employment* (Washington, DC: Government Printing Office, 2016), A-1 – A-5.

[40] FM 3-04, 1-15 – 1-16.

[41] Ibid., 1-17 – 1-18; *US National Security Strategy, 2015*, 10-11.

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Commensurate with the Army's Doctrine 2015 initiative, the US Army Aviation Center of Excellence's top-down Army Aviation doctrine revisions started with FM 3-04 and will cascade down to subordinate doctrine. Last updated in 1997, FM 1-564 *Shipboard Operations* details are obsolete, but retains conceptual utility for joint planning, Navy flight deck procedures, and LHD flight deck dimensions and capacities.[42] Once updated and nested into the FM 3-04 series, FM 1-564 will provide a vital tool for planning joint operations amphibious operations.

Joint Doctrine

In preparation for maritime operations, Army Aviation doctrine must nest with Joint doctrine and incorporate US Navy and Marine Corps doctrine. In its capstone document, Joint Publication (JP) 3-0, *Joint Operations* instructs the Army to prepare to employ its rotary wing assets in support of military operations across the entire range of military operations and conflict continuum. Including combat operations, JP 3-0 specifically instructs the Army to prepare to employ rotary wing capabilities in support of peace operations, including foreign humanitarian assistance and reconstructions efforts. In the USPACOM AOR, Army Aviation can provide an unmatched capability supporting foreign humanitarian assistance operations.[43]

Joint Publication 3-04, *Joint Shipboard Helicopter and Tiltrotor Aircraft Operations*, describes the unique aspects of joint shipboard operations. The publication covers all facets of pre-deployment, embarkation, and debarkation planning for joint shipboard operations, and addresses shipboard command authorities, flight/hangar deck operations, and sustainment considerations. JP 3-04 also provides general guidance for integrating aircraft from all the

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[42] Field Manual 1-564, *Shipboard Operations* (Washington, DC: Government Printing Office, 1997), chapter 2, 4-6 – 4-7, Annex G.

[43] Joint Publication 3-0, *Joint Operations* (Washington, DC: Government Printing Office, 2011), V-22 – V-26.

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services aboard air-capable ships, amphibious assault ships, and aircraft carriers. It also examines historical complications of shipboard Army Aviation operations including space limitations, aircraft incompatibility issues, and ammunition and fuel considerations.[44]

JP 3-04 addresses "mission trade-off" as the most important consideration regarding joint amphibious operations at the operational level of warfare. Amphibious assault ships and aircraft carriers are limited in quantity and fulfill strategic roles. Operational commanders must consider that embarking Army Aviation onto Navy vessels incurs mission trade-off in the removal of Navy or USMC assets which are originally designed and optimized for shipboard operations.[45] Reconfiguring aircraft carriers for Army operations requires additional Navy ships to defend the aircraft carrier. USMC MAGTFs are optimized to operate from LHD and LHA class amphibious assault ships. Army Aviation's reduced compatibility requires additional mission trade-off as compared to USMC fixed and rotary wing aviation.[46] JP 3-04 provides the general insight for Army Aviation to incorporate joint concepts, additional publications provide additional utility for specific mission scenarios.

JP 3-04's accompanying manual, JP 3-04.1, Joint *Tactics, Techniques, and Procedures for Shipboard Helicopter Operations*, requires revision but remains useful at the tactical level.[47] Once revised, JP 3-04.1 will guide FM 1-564's revision to a 3-04 series *Shipboard Operations*.

Joint doctrine spans the conflict continuum, informing expectations for Army Aviation in both combat and support operations. Joint Publication 3-03, *Joint Interdiction* addresses the

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[44] Joint Publication 3-04, *Joint Shipboard Helicopter and Tiltrotor Aircraft Operations* (Washington, DC: Government Printing Office, 2013), II-39.

[45] JP 3-04, II-1. The US Navy currently operates ten aircraft carriers and nine amphibious assault ships, with one aircraft carrier and one amphibious assault ship near completion.

[46] Ibid., II-4.

[47] JP 3-04.1, *Joint Tactics, Techniques, and Procedures for Shipboard Helicopter Operations'* last revision was 1997, the same year as Army FM 1-564, *Shipboard Operations*.

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combat related end of the conflict continuum describing how Army Aviation's attack and air assault capabilities enable joint force commanders to overcome the prohibitive effects of terrain and enemy force activity to gain an advantage. Additionally, maritime interdiction can isolate enemy forces from external support, stop their actions, or enforce legal sanctions.[48] Army forces supported by Army Aviation greatly increase the available combat forces able to conduct maritime interdiction operations in the USPACOM AOR.

Addressing the peaceful end of the continuum, Joint Publication 3-29, *Foreign Humanitarian Assistance*, describes Army Aviation's unique contribution to humanitarian assistance operations. Amphibious-capable Army forces increase the overall joint force capability and throughput. JP 3-29 describes how massive international response can cripple logistics architecture, requiring military augmentation to support airfield operations and increase airlift support. Additionally, helicopters provide unmatched utility during disaster relief efforts as ground transportation infrastructure is often impaired.[49] Rotary wing casualty evacuation capabilities combined with ship-based medical capabilities greatly increase the ability to save lives in a crisis. Overall, ship-based aviation capabilities alleviate the strain on land based logistical nodes while providing critical assistance capabilities.

Joint doctrine provides conceptual information necessary to incorporate amphibious Army Aviation into joint force operations. To prepare the combat aviation brigades for tactical requirements, Marine Corps and Navy doctrine inform how its MAGTFs execute expeditionary shipboard aviation operations. Most important, Marine Corps Warfighting Publication (MCWP) 3-24, *Assault Support,* introduces Army Aviation to "Command and Control in Amphibious

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[48] Joint Publication 3-03, *Joint Interdiction* (Washington, DC: Government Printing Office, 2011), II-4 – II-8.

[49] Joint Publication 3-29, *Foreign Humanitarian Assistance* (Washington, DC: Government Printing Office, 2014), chapter III.

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Operations," detailing the authorities and procedures required to operate with the US Navy.[50] US Naval Air Systems Command (NAVAIR) published two essential Naval Air Training and Operating Procedures (NATOPS) manuals which provide CAB planners essential references for planning shipboard operations. NAVAIR 00-80T-106, *LHA/LHD NATOPS Manual* details all aspects of aviation operations from amphibious assault ships and NAVAIR 00-80T-105, *CV NATOPS Manual* describes operations aboard aircraft carriers (CV). These two comprehensive publications provide the essential details required to prepare Army Aviation units for amphibious operations.

Where doctrine guides Army Aviation's training requirements, equipment interoperability also affects joint employment in the USPACOM AOR. Previously discussed; Army Aviation cannot abandon existing competencies nor acquire airframes that achieve increased shipboard compatibility. This section examines the basics of the naval vessels Army Aviation can expect to operate from in the USPACOM AOR as well as the helicopter-specific capabilities and limitations in conducting shipboard operations.

US Navy Amphibious Ships

Amphibious based Army Aviation can operate primarily from three classes of US Navy ships. The Navy currently operates ten of the Nimitz-class nuclear aircraft carriers (CVNs) organized into multi-ship Carrier Strike Groups (CSGs). Additionally, the Navy operates one America class (LHA) and eight Wasp-class (LHD) and amphibious assault ships, which the Navy organizes into Amphibious Ready Groups to forward-deploy MEUs. Table 1 includes additional

[50] Marine Corps Warfighting Publication 3-24, *Assault Support* (Washington, DC: Government Printing Office, 2004), 1-4, 4-1 – 4-4.

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ship capabilities and comparison to allied assets. Though deployable to any geographic combatant command, eleven of these nineteen ships are Pacific based in the United States and Japan.[51]

Nimitz class aircraft carriers are the world's largest warships, and though optimized for Navy and Marine Corps fixed-wing aircraft, can accommodate Army helicopters. The flagship for Carrier Strike Groups, US aircraft carriers provide the United States with an unmatched strategic strike platform and deterrent capability. Fueled by nuclear reactors, US aircraft carriers have unlimited range and are the fastest amphibious ship. While CVNs are capable of amphibious operations, they are designed specifically for open-sea operations and long-range strike.[52] No other nation's aircraft carriers match number or capability of the Nimitz class'. Embarked Army Aviation incur significant mission trade-off as the carrier must operate closer to shore with fewer fixed wing capabilities. See Table 1 for additional aircraft carrier capabilities.

Table 1. Amphibious Ship Capability Comparison

Class-Type	# Ships	# Pacific Based	Displacement (tons)	Flight Deck length	Max Helos	Well Deck	Speed	Range	Embark Troops
Nimitz - CVN	10[A]	6	101,000	1100'	50+	N	31 kts	unlimited	3000+
Wasp - LHD	8	5	41,000	818'	28	Y	24 kts	9500nm	1687
America - LHA	1[B]	1	45,000	818'	28	N	24 kts	9500nm	1687
Canberra - LHD (AUS)	2	2	28,000	757'	18	Y	20 kts	8000nm	1100
Hyuga-DDH (JPN)	2	2	20,000	646'	15	N	30 kts	6000nm	n/a
Izumo - DDH (JPN)	1[C]	1	24,000	810'	~22	N	30 kts	6000nm	400

[A] USS *Ford, Kennedy* in production (CVN) [B] USS *Tripoli* in production (LHA) [C] DDH *Kaga* in production (DDH)

Source: Adapted from Military Periscope Equipment Databases: America LHA-6 and Wasp LHD Class, Canberra Class LHD, Hyuga and Izumo Class DDH, and Nimitz Class CVN, accessed December 30, 2015, https://www.military periscope.com/weapons/ships/amphib/w0007824.html.

[51] US Navy, "Pacific Fleet Ships by Class," accessed August 20, 2015, http://www. public.navy.mil/surfor/Pages/USNavyPacificFleetShipsbyClass.aspx#.VtufnY-cHcc.

[52] Military Periscope, "NIMITZ (CVN-68) Class," Military Equipment Database, accessed December 30, 2015, https://www.militaryperiscope.com/ weapons/ships/carriers/ w0002877.html.

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Half the size of Nimitz-class aircraft carriers, amphibious assault ships are tailored for amphibious rotary wing operations and are the best-suited ship class to facilitate amphibious based Army Aviation operations. The United States currently employs nine amphibious assault ships in two ship classes. Wasp class LHDs conduct aviation and surface amphibious operations from its flight deck and well deck, whereas America class LHAs are exclusively aviation platforms without well decks.[53] These two classes comprise the Navy's nine amphibious assault ships which serve as the primary aviation platform and flagship for Amphibious Readiness Groups (ARG).[54] The ARG supports the MAGTF ability to conduct amphibious operations near maritime littorals.

Amphibious assault ships' aviation capabilities are designed to support rotary wing operations and vertical takeoff and land fixed wing operations (AV-8B Harrier and USMC variant F-35 Joint Strike Fighters). With nine deck landing positions and storage capacity for up to twenty-eight aircraft, LHD/As can simultaneously launch or recover an Army Aviation company and embark a partial Army Aviation battalion task force.[55] Below the flight deck, LHD/As have large hangar bays to conduct aviation maintenance and vehicle and cargo storage areas. During crisis response, amphibious assault ships can expand patient treatment facilities to six hundred hospital beds, forty-six inpatient beds, and a fourteen patient intensive care unit.[56]

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[53] US Navy, "SURFPAC's Amphibious Assault Ship (LHD/LHA) Info Page," accessed August 20, 2015, http://www.public.navy.mil/surfor/Pages/AmphibiousAssualtShip.aspx.

[54] US Navy. "The Amphibious Ready Group." accessed March 29, 2016, http://www.navy.mil/navydata/nav_legacy.asp?id=148. Though MEU-ARG scalable and tailorable to each mission, the traditional MEU-ARG configuration is one LHD with two smaller support ships.

[55] US Navy, "Pacific Fleet Ships by Class." USMC aircraft are designed to minimize space requirements on ships. Army rotary wing aircraft must anticipate a reduced shipboard capacity based upon airframe design.

[56] US Navy, "Essex ARG Ready to Provide Assistance to Japan," October 3, 2011, accessed February 29, 2016, http://www.navy.mil/submit/display.asp?story_id=59091.

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Amphibious assault ships habitually support expeditionary MAGTF operations and their availability to support Army Aviation is subject to mission trade-off and asset reallocation.

Allied Amphibious Ships

Australia's recent acquisition of two amphibious assault ships increased the potential bilateral for rotary wing aviation operations in the USPACOM AOR. Since 2014, the Australian Defense Forces (ADF) commissioned two Canberra class LHDs, the HMAS *Adelaide* and HMAS *Canberra*. This procurement indicates Australia's long-term commitment to Indo-Pacific security and will strengthen its military partnership with the United States.

Regarding general capabilities and capacities, Canberra LHDs provide a two-thirds scale of a US Wasp class. Notably, the Canberra class is compatible with US Army aircraft and able to launch or recover six UH-60s or four CH-47s simultaneously.[57] Despite the Canberra class smaller stature, the addition of two additional allied LHDs to the Pacific increases the multinational amphibious presence, reducing the appearance of United States amphibious unilateralism. For Army Aviation, partnered operations provide the opportunity to conduct combined amphibious operations with the ADF.

The Japanese Maritime Self-Defense Force (JMSDF) currently operates three helicopter carriers (DDHs) as anti-submarine warfare vessels.[58] Japan's two Hyuga-class and one Izumo class DDH are similar in size and capability to the Canberra Class LHDs. IN addition to anti-

[57] Royal Australian Navy Homepage, "Amphibious Assault Ship (LHD)," Fleet ship/boat/craft information page, accessed November 3, 2015, http://www.navy.gov.au/fleet/ships-boats-craft/lhd. The ADF currently operates CH-47 and UH-60 variants, but is transitioning to european MRH-90 helicopters which are better suited for shipboard operations.

[58] Military Periscope, "HYUGA (DDH-181) Class," Military Equipment Database, accessed January 16, 2016, https://www.militaryperiscope.com/weapons/ships/destroyr/w0007432.html. Japan's constitution prevents the acquisition and operations of offensive aircraft carriers, so their helicopter capable ships' primary role is defensive anti-submarine warfare.

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submarine warfare, these ships conduct humanitarian support and logistical operations in the USPACOM AOR.[59] Though originally forecasted to acquire four Hyuga class DDHs, China's increased maritime presence prompted the Japanese Navy to halt production of the smaller Hyuga class in favor for the larger and more capable Izumo class DDH.[60]

Like the Canberra LHDs, Japanese DDHs are compatible with American helicopters and can simultaneously launch or recover four helicopters and store approximately ten to fifteen more on its flight deck and in the hangar. DDHs can launch an Army Aviation platoon and the embark approximately two aviation company teams. The Izumo-class DDH can accommodate up to four hundred embarked troops; a decreased capacity as compared to comparable sized United States and Australian LHDs.[61] Japan's DDH fleet provides more options to conduct multinational, Army Aviation shipboard operations in the USPACOM AOR.

By including Australian and Japanese helicopter-capable ships in addition to US platforms, the number of US-allied amphibious assault ships in the USPACOM AOR increases from six to eleven. Partnered operations provide an opportunity to increase platform availability for Army Aviation to conduct shipboard operations by overcoming mission trade-off for Navy assets that primarily support MAGTFs. Additionally, multinational shipboard operations allow Army Aviation deploy via strategic airlift to the western Pacific and embark closer to the required area of operation.

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[59] Ibid.

[60] Military Periscope, "IZUMO-Class Helicopter Carrier," Military Equipment Database, accessed January 16, 2016, https://www.militaryperiscope.com/weapons/ships/carriers/w0008535.html.

[61] Ibid.

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US Army Helicopters

Inherent incompatibilities between Army aircraft and amphibious assault ships reduce the efficiency that Army Aviation can conduct amphibious operations. In contrast, USMC aircraft are designed to operate from amphibious assault ships. The most significant Army aircraft inefficiency is the inability to transform automatically from an operational profile to a storage profile on the flight deck. Compact landing gear and automated blade folding systems improve USMC aircraft deck capacity and preparation time.[62] Army CH-47's size and tandem rotor design inhibit its maintenance capability as crew chief must remove its rotor blades for the aircraft to fit on LHD/A elevators. Despite these constraints, Army Aviation can conduct shipboard operations, but inform planners must account for the inefficiencies as compared to MAGTF airframes.

These Army Aviation characteristics decrease the efficiency and capacity of flight deck storage, maintenance operations, and launch and recovery.[63] Due to its degraded shipboard compatibility and efficiency, Army Aviation shipboard operations must be deliberate and limited in duration. Joint planning between the Army and Navy will resolve many of these mission impediments before operations commence. This section provided the basic doctrinal and equipment fundamental necessary for Army Aviation to conduct joint and multinational operations in maritime environments. The subsequent three case studies focus on historical military instances which contribute towards the application of Army Aviation operations in the USPACOM AOR.

Case Study #1: Operation Uphold Democracy: Haitian Liberation 1994

In 1994, Operation Uphold Democracy ushered Army Aviation into a new era of joint operations. During this mission to reinstate the exiled Haitian President, Jean-Bertrand Aristide,

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[62] Geoffrey C. Lambert and Mark M. Huber, "Joint Shipboard Helicopter Operations." *Joint Forces Quarterly*, Winter 2000–01 (2001), 85.

[63] JP 3-04, II-5.

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the Army executed the largest amphibious, rotary wing air assault in history. Operation Uphold Democracy's distinguishing contribution to this monograph is the parallel planning effort to prepare for both an opposed airborne invasion and an unopposed/semi-opposed brigade combat team air assault using Army helicopters from a US Navy aircraft carrier. This innovative operation marked the first time Army Aviation operation of this size deployed from a Navy aircraft carrier since Doolittle's Tokyo raid in 1942.[64]

In 1990, Haiti elected Jean-Bertrand Aristide, a priest and outspoken critic of previous regimes, as president. Passionate but inexperienced, Aristide failed to bring effective change to the Haitian people. In September 1991, Lieutenant General Raoul Cedras prepared a military coup, to which President Aristide ceded power and fled to Venezuela. In response, the United States initiated diplomatic and military plans to remove Cedras' coup and re-install Aristide to power, but the collapse of the Soviet Union postponed the plans for two years.[65]

In October 1993, a United Nations envoy aboard the USS *Harlan County* arrived in Port-au-Prince to assess humanitarian conditions under Cedras' regime. To demonstrate his power to the international community, General Cedras unexpectedly employed armed naval craft and a hostile mob in the port, denying the UN team's debarkation. In response, President Clinton's administration initiated military planning to remove Cedras from power under a wide array of contingencies, from a peaceful transfer of power to full military invasion.[66]

In the spring of 1994, chief of the US Atlantic Command instructed the 18th Airborne Corps commander, then LTG Hugh Shelton, to establish Joint Task Force (JTF)-180 and commence planning the forcible entry into Haiti, OPLAN 2370. In July 1994, the US Army

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[64] Williams, *A History of Army Aviation*, 373.

[65] Kretchik, Baumann, and Fishel, *Invasion, Intervention, "Intervasion"*, 19-20.

[66] Garrett, *JTF-180 Uphold Democracy: Oral History Interviews,* 43.

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Forces Commander, General Dennis Reimer, activated Major General Meade's 10th Mountain Division as JTF-190, tasked to develop OPLAN 2380, as a non-invasion branch plan to seize key Haitian infrastructure, evacuate US citizens, and stabilize the Haitian population through the transition of national power.[67] Unique to this plan was the concept of embarking elements of the 10th Mountain Division's Aviation Brigade and 1st Brigade Combat Team aboard the aircraft carrier, USS *Eisenhower*. Opting to preposition air assault forces within the Joint Operations Area provided strategic leaders the option to execute an amphibious air assault/air movement into Port-au-Prince with fewer complications due joint coordination and national approval authorities.

On short notice, the 10th Aviation Brigade transitioned from planning to training for operations aboard the USS *Eisenhower*. The 10th Aviation Brigade received their warning order on 1 August 1994 and without precedent, created a training program to simulate carrier deck landings within the week. By 8 August 1994, aircrews conducted mock deck qualifications on replica aircraft carriers painted on airfield taxiways.[68] The following week, 10th Aviation Brigade deployed its aircrews to Norfolk, VA and in just four days, conducted over twelve hundred day and night deck landings aboard the USS *Roosevelt*. More importantly, the Army and Navy maintainers and armament personnel cross-trained each other on helicopter characteristics and aircraft carrier deck procedures.[69] Through live training and shared knowledge, the 10th Aviation Brigade identified key training objectives, synchronized their embarkation and deployment plans, and qualified the requisite number of aircrews within two weeks of mission notification. Through the joint exchange in Norfolk, the aircrews gained tactical repetition, but more importantly, the

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[67] Cynthia L. Hayden, *JTF-180 Operation Uphold Democracy: Oral History Interviews* (Fort Bragg, NC: XVIII Airborne Corps & Fort Bragg Training Support Center, 1995), 1-5.

[68] Lawrence Casper, interview by Dennis Mroczkoswki, *JTF-190 Uphold Democracy: Oral History Interviews,* October 19, 1994, ed. Cynthia L. Hayden (Ft. Bragg, NC: XVIII Airborne Corps, 1996), 391.

[69] Ibid.

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maintainers learned the nuances of amphibious based maintenance and the leaders gained an appreciation for the risks associated with amphibious flight operations.

On the 14th of September 1994, the USS *Eisenhower* and USS *America* departed Norfolk embarked with Army forces on the twelve-hundred-mile voyage to Haiti (depicted in Figure 2).[70] On 18 September 1994, with the invasion force en route to Haiti, General Cedras agreed to the peaceful terms set forth by former President Carter's diplomatic envoy.[71] Facing the reality of a US military invasion, General Cedras ceded Haitian authority and granted US military peacekeepers unopposed Haitian entry.[72]

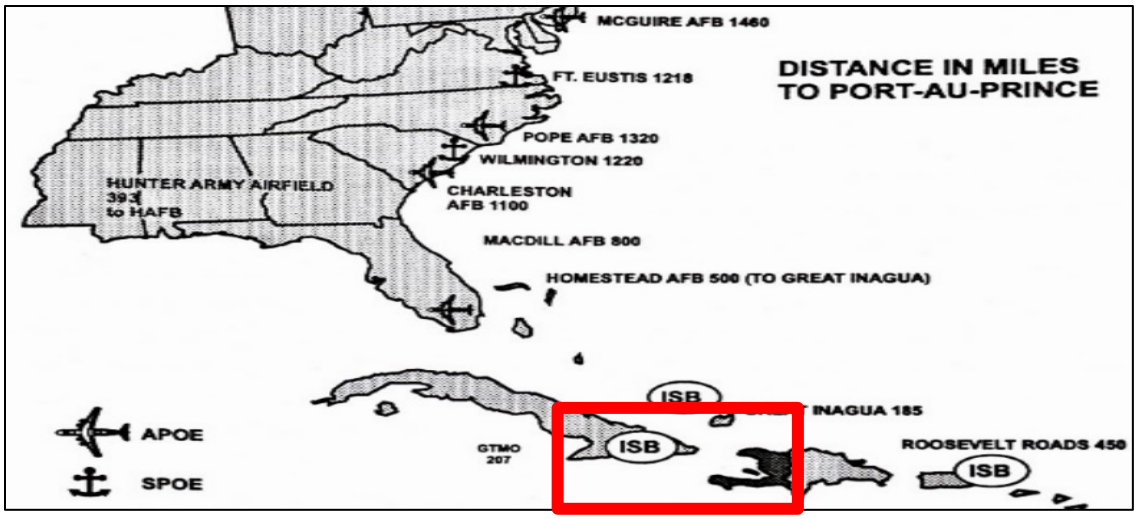


Figure 2. Map of Operation Uphold Democracy Operational Environment

Source: "Map 8: Force deployment scheme" (map), *Invasion, Intervention, "Intervasion", A Concise History of the U.S. Army in Operation Uphold Democracy* (Ft. Leavenworth, KS: US Army Command and General Staff College Press, 1998), 55.

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[70] E.D. McGrady and Robert E. Sullivan, *Operation Uphold Democracy: Observations on Joint Assault Forces Operated From a CV* (Alexandria, VA: Center for Naval Analysis, 1996), 1-6. In addition to the USS *Eisenhower*, the USS *America* departed Norfolk for Haiti with Army Special Operations Aviation and Special Operations Forces embarked.

[71] John R. Ballard, *Upholding Democracy: The United States Military Campaign in Haiti, 1994-1997* (Westport, Conn.: Praeger Publishers, 1998), 96-100; Kretchik, Baumann, and Fishel, *Invasion, Intervention, "Intervasion"*, 74-76.

[72] Joe Truelove, interview by Robert K. Wright, *JTF-180 Uphold Democracy: Oral History Interviews*, March 30, 1995, ed. Cynthia L. Hayden. Ft. Bragg, NC: XVIII Airborne Corps, 1996.

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Within hours, planners hastily adapted JTF-190's semi-permissive entry into Operation Uphold Democracy's main effort. Labeled OPLAN 2380 Plus, the brigade level amphibious air assault sought to seize key Port-au-Prince infrastructure to facilitate follow-on peacekeeping forces.[73] On 19 September 1994, 10th Aviation Brigade executed a fifty-helicopter air assault, transporting over two thousand Army soldiers from the USS *Eisenhower* to seize the Port-au-Prince airport and deter opportunist aggression by Cedras loyalists.[74]

Available shipboard Army Aviation created operational and strategic leverage. Strategically, the depth of military capabilities strengthened President Carter's negotiations and forced Cedras' surrender. Operationally, the ability to rapidly transition from a combat airborne invasion to a semi-opposed air assault gave General Shelton a variety of options to seize/secure key Haitian infrastructure without delay. One of the 18th Airborne Corps' planners explained Army Aviation's amphibious value, stating: "having the 10th mountain division's 1st brigade combat team aboard the USS *Eisenhower* gave the plan and the planners the flexibility to adapt to the last minute change in plan and the ability to adapt and meet operational requirements."[75]

As a case study, Operation Uphold Democracy demonstrated an innovative application of joint interoperability and established the maximum scale for amphibious Army Aviation operations. Tactical mission preparation for non-standard Army Aviation missions will provide operational commanders the necessary flexibility to employ Army Aviation in the USPACOM AOR to respond to emergent problems in a complex environment.[76] Additionally, the credible threat JTF-190 posed upon the Cedras regime helped used the United States' military capabilities

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[73] Kretchik, Baumann, and Fishel, *Invasion, Intervention, "Intervasion"*, 78.

[74] Casper, *JTF-190 Uphold Democracy: Oral History Interviews*, 393.

[75] Garrett, *JTF-180 Uphold Democracy: Oral History Interviews*, 55.

[76] Frans P.B. Osinga, *Science, Strategy and War: The Strategic Theory of John Boyd* (New York: Routledge, 2007), 95.

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to reinforce diplomatic power. Exhibiting Joseph Nye's concept of "Smart Power," the next case study demonstrates Army Aviation's amphibious potential in as a missed negotiation opportunity.[77]

A counterpoint to Operation Uphold Democracy's application towards operations in the USPACOM AOR is the vast differences in the distance and security requirements between the operations in the Caribbean Sea and the Pacific or Indian Oceans. The disparate times and distances required to execute a multi-day, twelve hundred mile operation in the Caribbean pale in comparison to the multi-week or multi-month operations, six to eight thousand miles from the continental United States.[78] This case study demonstrates a feasible scenario for operational employment of amphibious Army Aviation, but it is doubtful whether the US Navy would risk the long-term mission trade-off of an entire carrier strike group to employ Army Aviation loaded aircraft carrier on the far side of the USPACOM AOR.

A significant takeaway from Operation Uphold Democracy is the importance of personnel integration over tactical training. While aircrews had to conduct hasty deck qualifications, the training was accomplished relatively quickly with minimal preparation. The most important learning point was the Army to Navy exchange that occurred in Norfolk, as this allowed subject matter experts to coordinate and identify equipment and procedural incompatibilities before they impacted mission readiness. This exchange highlights the importance of updated doctrine to identify incompatibilities and recommend operational solutions. In doing so, Army Aviation can facilitate efficient training opportunities and overcome equipment incompatibilities to help to employ Army Aviation assets from naval platforms in any maritime environment.

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[77] Nye, *The Future of Power*, 208-209.

[78] Bruce Berkowitz, *The New Face of War. How War Will Be Fought in the 21st Century* (New York: The Free Press, 2003), 181.

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Operation Uphold Democracy described Army Aviation's most significant contemporary maritime operation, the execution of a brigade-level air assault from a US Navy aircraft carrier. Despite its significance demonstrating Army Aviation's shipboard capabilities, the geostrategic implications of the Caribbean pale in comparison to those encountered across the Pacific Ocean. The next case study examines a contemporary peacekeeping operation in the USPACOM AOR where geographic limitations warrant amphibious Army Aviation capability.

Case Study #2: Operation Stabilise: East Timor Crisis 1999

Operation Stabilise, the 1999 United Nations peacekeeping mission in East Timor examines the anticipated operational requirements for amphibious Army Aviation with specific emphasis on the USPACOM AOR's geography.[79] East Timor's geography exemplifies the remote location within the maritime amphibious region where joint commanders can utilize shipboard Army Aviation to introduce forces into a low-intensity, permissive environments. These operations represent Army Aviation's expected contribution to multinational foreign humanitarian assistance operations. Operation Stabilise depicts the likely future scenario in which shipboard Army Aviation capabilities can achieve a strategic advantage to deter or compel hostile foreign activities.

Gaining its independence in 2002, East Timor is one of Southeast Asia's youngest and poorest states.[80] Located in the southern Indonesian archipelago and roughly the size of Connecticut, Timor Island is divided between western Indonesian territory and East Timor occupying the remainder. Exhibiting the physical and diplomatic isolation, East Timor lacks access to natural resources and is virtually isolated from all states except Indonesia. This lack of

[79] Since Operation Stabilise, East Timor's official title changed to "Timor-Leste". This monograph uses the outdated "East Timor" to maintain continuity with reference material.

[80] Simon Chesterman, "East Timor," in *United Nations Interventionism, 1991-2004*, ed. Mats Berdal and Spyros Economides (New York: Cambridge University Press, 2007), 192.

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resources limits economic trade and the development of economic partners. Depicted in Figure 3, East Timor is encircled by Indonesian territory. With 275 nautical miles between East Timor and its next closest state, East Timor remains subject to Indonesian influence.[81]



Figure 3. East Timor in the South Indian Ocean

Source: "Indonesia" (map), CIA World Factbook, accessed 2 March 2016, https://www.cia.gov/library/publications/resources/the-world-factbook/geos/id.html.

In 1975, Indonesia invaded and annexed the Portuguese colony, Timor Island, initiating an era of coercive governance.[82] Australia, In an attempt to strengthen its strategic relationship with Indonesia, was one of the only world governments that recognized Timor Island's annexation.[83] Though 1980, Indonesia enforced its authority through military aggression as the Indonesian Army was the only national institution capable of imposing national control

[81] CIA World Factbook, "Timor-Leste," US Central Intelligence Agency Homepage, last modified January 7, 2016, accessed February 2, 2016, https://www.cia.gov/library/publications/the-world-factbook/geos/tt.html.

[82] Borthwick, *Pacific Century*, 338; Chesterman, "East Timor," 194.

[83] Chesterman, "East Timor," 193-194.

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throughout its dispersed territory.[84] Throughout the 1980s and 1990s, military conflict ceased, but coercion and brutality continued, inciting East Timor's secession movement during the mid-1990s. Physically isolated and lacking economic means to forge strategic partnerships, East Timor was subject to Indonesian coercion and brutality. The matter complicated regional relations as South Pacific nations wanted to end East Timor's humanitarian crisis, but feared disrupting their strategic relations with Indonesia.[85] In 1998, Indonesian President Suharto left office which increased East Timor's secession movement.[86] In 1999, the United Nations internationally recognized East Timor's desire for independence by sponsoring a 1999 independence referendum and promised to provide a peacekeeping mission to police the fall 1999 referendum.

Early 1999, despite the auspice of an unobstructed referendum, continued Indonesian coercion attempted to influence East Timor's population to remain under Indonesian sovereignty. The Indonesian military and militia inflicted widespread violence in pro-independence areas. Throughout 1999, Indonesia's coercive practices intensified as violence spiraled into localized genocide, fostering increased tension and animosity that endured since Indonesia's 1975 occupation.[87]

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[84] Ben Kiernan, "War, Genocide, and Resistance in East Timor, 1975-1999: Comparative Reflections on Cambodia," in *War & State Terrorism. The United States, Japan, & the Asia-Pacific in the Long Twentieth Century*, ed. Mark Selden and Alvin Y. So (Lanham, MD: Rowman & Littlefield Publishers, 2004), 203; Alan Stephens, "The Asia Pacific Region," in *Global Air Power*, ed. John A. Olsen (Washington, DC: Potomac Books, 2011), 300, 323.

[85] John Sanderson, "The Cambodian Experience: A Success Story Still?" in *United Nations Peacekeeping Operations: Ad Hoc Missions, Permanent Engagement*, ed. Ramesh Thakur and Albrecht Schnabel, (New York: United Nations University Press, 2001), 159.

[86] Kiernan, "War, Genocide, and Resistance in East Timor," 222-226.

[87] Ibid., 224-226.

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The key aspect of this case study is the conflict between geo-political relations and support of humanitarian rights in poor, remote locations that inhibit neutral base access. In response to Indonesia's violence, Australia offered five thousand troops to lead the International Force in East Timor (INTERFET), a multinational UN peacekeeping coalition consisting of ten thousand troops from twenty-two nations.[88] Despite INTERFET's creation, neither Australia nor any other contributing nation authorized their forces to deploy without Indonesia's formal acceptance. Inaccessible from neutral areas, East Timor remained Indonesian sovereign territory and subject to maritime isolation; the closest neutral territory was 275 nautical miles away.[89] The inability for INTERFET to reach East Timor from neutral territory emboldened the Indonesian government's continued coercion and refusal of UN peacekeepers.

Subject to limited options, the INTERFET could either invade Indonesia or await diplomatic resolution. Unwilling to endure diplomatic and economic damage to its relationship with Indonesia, Australia awaited Indonesian approval. Despite the UN Security Force assessment that a continued Indonesian terror and destruction would precede and follow the referendum, INTERFET did not intervene.[90] This continued UN inactivity further emboldening the Indonesian military and militia to continue their violent campaign in East Timor.

Despite continued Indonesian violence, the East Timor populace overwhelmingly voted for independence on 30 August 1999.[91] Following the results, Indonesian forces killed nearly one thousand citizens and destroyed eighty percent of their dwellings.[92] This abject act of retaliatory

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[88] Chesterman, "East Timor," 196.

[89] Joseph Nevins, *A Not-So-Distant Horror: Mass Violence in East Timor* (Ithaca, NY: Cornell University Press, 2005), 118-119.

[90] Ibid., 120-121.

[91] CIA World Factbook, "Timor-Leste."

[92] Borthwick, *Pacific Century*, 500.

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violence finally swayed the international community to pressure Indonesia to cease hostilities and permit the entry of the UN peacekeeping force.[93] On 12 September 1999, the Indonesian government authorized UN entry and on 15 September, the UN Security Council authorized Operation Stabilise, the Australian-led peacekeeping mission to East Timor.

Once the INTERFET arrived in East Timor, Indonesian violence subsided, but the true damage had occurred as the UN failed to interdict the violence the spring of 1999 as INTERFET reconnaissance of former Indonesian military compounds discovered evidence of execution and torture sites which exceeded prior estimates.[94] The Indonesian military was never deterred from violence because East Timor's geographic isolation and the regional strategic relationships with Indonesia prevented external intervention.

Operation Stablise demonstrates the important concept of geographic access as a necessary means to deter coercive violence in the USPACOM AOR. Without access, the INTERFET could not provide a credible deterrent to Indonesian aggression, which emboldened the Indonesian military to commit unchecked acts of violence in East Timor. Through the introduction of amphibious based aviation, the INTERFET would have gained a viable third option to intervene in East Timor. Shipboard Army Aviation capabilities may have theoretically provided UN forces with the ability seize the strategic initiative and compel the Indonesian military to cease violence.

Though it is impossible to prove whether amphibious capabilities would have prevented the stopped violence in East Timor, this case validated the utility amphibious aviation access remote objectives in the USPACOM AOR.[95] Furthermore, amphibious assault ships not only

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[93] Kiernan, "War, Genocide, and Resistance in East Timor," 203.

[94] David Dickens, "The United Nations in East Timor: Intervention at the Military Operational Level," *Contemporary Southeast Asia 23,* no. 2 (August 2001): 221, accessed December 11, 2015, http://www.jstor.org/stable/25798543.

[95] Berkowitz, *The New Face of War,* 182. Berkowitz references A.T. Mahan's concepts as enduring precepts in US Naval doctrine regarding the benefit of aircraft carriers.

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overcome the requirement to gain access, provide a neutral location from which to project foreign humanitarian assistance capabilities. In this case, amphibious based aviation would negate the requirement to create forward operating bases as LHD/A based Army Aviation combine amphibious maintenance and medical capabilities with the Army's aerial medical evacuation (MEDEVAC) and sustainment capacity in support of foreign humanitarian assistance and disaster response operations.

Conversely, Indonesia was emboldened by their physical realities surrounding their area of operations. Conventional responses limit the prospective solution sets to the geographic constraints placed upon the problem. Additionally, extended MEU operations to facilitate long-term deterrence may work, but remain a comparatively low priority based potential mission sets required by this capable formation. Essentially, Army Aviation mere ability to execute shipboard operations can deter the opposition's military commanders or political leaders. In the East Timor case, continued shipboard operations were not required. Instead, Army Aviation could conduct a one-time air movement from ship to shore to establish a rapid buildup of humanitarian assistance capabilities ashore within hours, not days from notification.

Operation Stabilise stressed the importance of multilateral operations. In this scenario, the Australian government risked future diplomatic and economic relationship with Indonesia by supporting an Indonesian colony's secession. Though Australia's intervention prioritized ending humanitarian atrocities over political aims, their intervention strained Australia-Indonesian relations following Operation Stabilise. Australia's overwhelming contribution to the INTERFET created the perception of Australian unilateral action as opposed to a multinational UN effort. Traditional amphibious operations are most often unilateral actions. This case study highlights the need for Army Aviation to continue multinational training exercises to ensure multinational contribute to forces can gain access locations that require foreign humanitarian assistance. This application of the US smart power increases its regional credibility to reassure its regional allies

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and deter its adversaries.[96] Army Aviation in partnership with Australian Defense Forces provides the United States and the international community with an additional economy of force capability to exert deterrence and truly exert smart power through the "skillful combination" of military presence and diplomacy.[97]

Though a MEU served as an operational reserve during the execution of Operation Stabilise, its capabilities were needed months before mission execution to deter Indonesia's continued violence. Another example of mission trade-off, the US military cannot dedicate its MAGTFs for multiple months in support of stability operations. Expeditionary in nature, MAGTFs are forward deployed to react to any contingency operation in its assigned AOR. Army Aviation could augment the MEU to support the UN operation and free the MEU for higher priority missions. Future conflict is most likely as states compete for access and influence in the vicinity of the major shipping lanes in the USPACOM AOR. Figure 4's depiction of the major Indo-Pacific shipping lanes emphasizes the South China Sea and Strait of Malacca, areas which bisect the "maritime amphibious region" and "continental amphibious region" previously discussed in Figure 1. These major shipping routes border areas that will likely require increased US Navy and MAGTF presence.[98] Maritime Army Aviation capabilities can focus on peripheral operations in less-essential areas or augment MAGTF operations. Army augmentation would enable MAGTF presence in strategically vital and conflict-prone areas of the USPACOM AOR.[99]

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[96] Capie, "The United States and HADR in East Asia," 325; Nye, *The Future of Power*, 213-214.

[97] Nye, *The Future of Power*, 208-209.

[98] Crawford and Harper, *Operation East Timor*, 15.

[99] A counterpoint to Army Aviation's utility in future scenarios similar to Operation Stabilise is the limited duration in which Army Aviation can conduct shipboard and maritime operations based on the materiel damage incurred in saltwater environments. While this precludes

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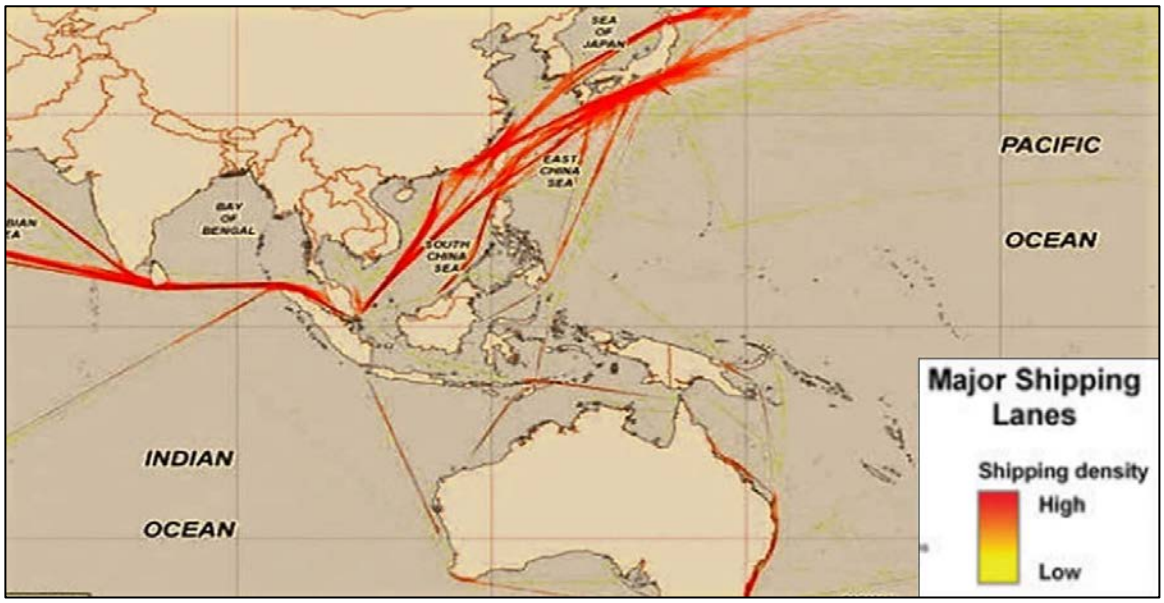


Figure 4. USPACOM Major Shipping Lanes

Source: Australian Department of Defence, *Defence White Paper 2013. Defending Australia and Its National Interests*, accessed November 3, 2015, http://www.defence.gov.au/whitepaper/2013/docs/WP_2013_web.pdf, 13.

East Timor represents one instance where internal turmoil and bids for independence spur humanitarian crises that the international community must mediate in the Asia-Pacific region. West Papua, the Moluccas, Papua New Guinea, and the Solomon Islands all represent a short list of states in the maritime dominated South Pacific that exhibit the potential for international assistance.[100] Additionally, violent extremist organizations traditionally associated with the middle east are attempting to spread their influence to the Pacific region with its vast Islamic

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enduring shipboard operations, Army Aviation's utility in one-time ship to shore operations and demonstrated deterrence mitigates the effects of salt water corrosion by limiting flight hours, thus reducing the corrosive effects and increasing the ability to conduct preventative maintenance.

[100] John McFarlane and William Maley, "Civilian Police in United Nations Peace Operations: Some Lessons from Recent Australian Experience," in *United Nations Peacekeeping Operations: Ad Hoc Missions, Permanent Engagement*, ed. Ramesh Thakur and Albrecht Schnabel (New York: United Nations University Press, 2001), 182-183.

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populace.[101] US, allied, and UN presence and engagement can counter the coercive environments where violent extremist organizations recruit and operate in the USPACOM AOR.[102]

Operation Stabilise provides a scenario where Army Aviation capabilities can contribute key amphibious capabilities in permissive, joint force operations. This case exemplifies by a "most likely" scenario that necessitates Army Aviation's scalable shipboard employment to execute the USPACOM AOR's most likely and frequent missions, foreign humanitarian assistance operation. The next case study examines a "worst case" scenario which would require a large scale requirement for shipboard Army Aviation employment in the USPACOM AOR.

Case Study #3: Operation Tomodachi: Fukushima Nuclear Disaster 2011

The previous case study demonstrated Army Aviation's contribution to maritime operations to overcome increased distances between land-based support bases and operational areas. The next case study examines a historical situation where Army Aviation's shipboard capabilities would increase the aviation lift capability and throughput in response to large-scale maritime operations demands. Operation Tomodachi examines a scenario where the response to a catastrophic event warrants Army Aviation to augment traditional amphibious capabilities in the USPACOM AOR.[103]

Combining maritime, post-disaster, and radiological factors, Operation Tomodachi simultaneously incorporates three demanding environments in which Army Aviation doctrinally operates.[104] Operation Tomodachi exemplifies Army Aviation's ability to augment a large-scale

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[101] US Army Pacific, *Partnering in the Asia-Pacific Theater*, 4-5.

[102] *US National Security Strategy, 2015*, 9-11.

[103] Moroney et al., *Lessons from Department of Defense Disaster Relief Efforts in the Asia-Pacific Region* (Santa Monica, CA: RAND, 2013), 90. "Operation Tomodachi" translated to English means "Operation Friends."

[104] FM 3-04, 1-14 – 1-18. FM 3-04 specifically defines operations in the maritime environments and other environments including post-disaster zones and in Chemical, Biological, Radiological, and Nuclear environments.

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foreign humanitarian assistance operation. This case study represents Army Aviation's maximum anticipated requirement in response to crises in the USPACOM AOR.

Midafternoon, on March 11th, 2011, a magnitude-nine earthquake erupted on the Pacific Ocean floor, eighty miles east of the Japanese coast (as depicted in Figure 5). Fifty-five minutes later, a fifty-foot tall tsunami inflicted extraordinary destruction upon Japan's coastal infrastructure and catastrophic damage to the nuclear reactors at the Fukushima Daiichi power plant.[105] The combined effects of the tsunami's infrastructural damage and mounting nuclear crisis exceeded Japan's emergency response capability.[106] Though the event occurred only one hundred miles north of Tokyo, the extensive infrastructural damage (highways, airfields, rail

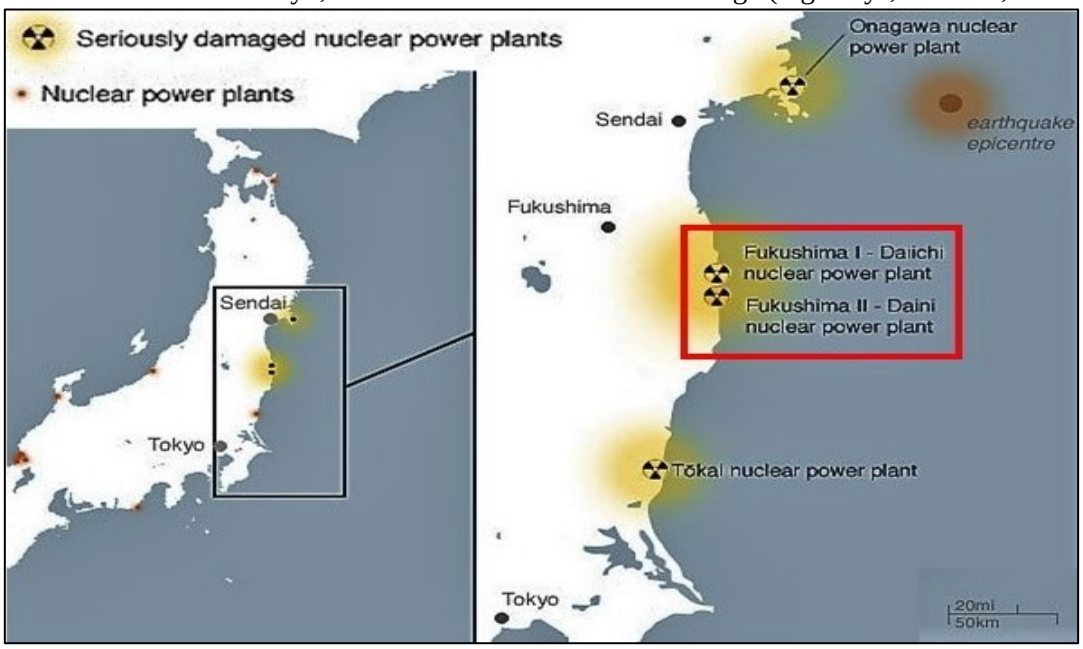


Figure 5. Fukushima Daiichi Nuclear Reactor and Earthquake locations.

Source: "Location of the Fukushima nuclear disaster" (map), Greenpeace website, accessed 10 February 2016, http://www.greenpeace.org/new-zealand/en/Multimedia/photos/2011/ March/ Japan-map---Fukushima-/.

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[105] David Lochbaum et al., *Fukushima: The Story of a Nuclear Disaster* (New York: The New Press, 2014), 4-12.

[106] Capie, "The United States and HADR in East Asia," 318.

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lines, electric, telecommunication) prevented Japan's Nuclear and Industrial Safety Agency from assisting with a national response.[107] Additionally, the proximity to the capital's vast population raised the concerns of unmitigated radioactive fallout on populated areas.[108] By the end of 11 March 2011, the Japanese government, one of the best prepared in the world, required international assistance to counter this catastrophe.

By 12 March 2011, the Government of Japan's declared a state of emergency. Forty-five countries offered assistance, but the Japanese government declined aid from all but four allies to avoid over complication. Based on established diplomatic and military partnership, the United States, Australia, New Zealand, and South Korea commenced Operation Tomodachi, the international disaster response to the Japan.[109] In all, the tsunami's effects forced the evacuation of over two hundred thousand Japanese civilians, over one hundred billion dollars in damages, and resulted in over twenty-six thousand fatalities.[110]

The United States response to the incident had domestic and coalition objectives. First, the US government retains the responsibility to safeguard its citizens abroad. Second, the United States provided nuclear expertise and foreign humanitarian assistance to its longtime ally. By March 16, 2011, the US Secretary of Defense committed over twenty-four thousand US forces, twenty-four naval vessels, and 140 military aircraft in a three-phased response.[111] The initial priority, save civilian lives and prepare to evacuate American citizens. The second priority, deliver basic human needs and restore essential civil services. The third priority, restore Japan to

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[107] Lochbaum et al., *Fukushima: The Story of a Nuclear Disaster,* 17.

[108] Capie, "The United States and HADR in East Asia," 318-320.

[109] Moroney et al., *Lessons from DoD Disaster Relief Efforts*, 89-90.

[110] Capie, "The United States and HADR in East Asia," 318.

[111] Ibid., 319; Moroney et al., *Lessons from DoD Disaster Relief Efforts*, 91-92.

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pre-disaster conditions.[112] Despite the global effort to coordinate and deliver disaster response materiel to the region, the USMC 31 MEU's rotary wing and tiltrotor aircraft provided the critical capability to deliver these necessities to the affected disaster areas.

Immediately following the disaster, the Okinawa-based 31 MEU provided the most useful capabilities during Operation Tomodachi. Aboard the USS *Essex's* amphibious readiness group, 31 MEU arrived at the disaster area ready to evacuate American citizens and provide amphibious based foreign humanitarian assistance operations off the Pacific coast.[113] Though the MEU fulfilled its mission requirements, two minor variations to the operating environment may have required augmentation by Army Aviation: increased demand for personnel evacuation and decreased available MEU aircrews due to radiation exposure.

In the initial response to the meltdown of the Fukushima Daiichi reactors, the Japanese government established a twelve-mile evacuation radius based upon fallout assessments.[114] 31 MEU possessed the necessary lift capabilities to evacuate the affected zone. Days later, the evacuation radius expanded drastically, from twelve to fifty miles based upon deteriorating meteorological conditions. The increased the evacuation area nearly tenfold and threaten radiological exposure in Tokyo, increasing assessed exposure levels at the US embassy to evacuation thresholds in only four days.[115] Though the government rescinded the fifty-mile evacuation radius, the American and Japanese evacuation requirements would have exceeded 31 MEU's lift capabilities. Tokyo's increased exposure would re-prioritize the US military mission

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[112] Capie, "The United States and HADR in East Asia," 318-319.

[113] Lochbaum et al., *Fukushima: The Story of a Nuclear Disaster,* 132.

[114] Lochbaum et al., *Fukushima: The Story of a Nuclear Disaster,* 119.

[115] Ibid., 131-132.

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from foreign humanitarian assistance to American citizen evacuation.[116] Army Aviation assets could augment MAGTF aviation to fulfill foreign humanitarian assistance obligations and allow the operations to allow the MAGTF to accomplish its higher priority missions.

During Foreign Humanitarian Assistance operations, helicopters provide critical lifesaving capabilities to operational commanders.[117] Amphibious assault ships possess vast medical capabilities, second only to the Navy's hospital ships. In response to a crisis, LHD crews can expand their patient treatment facilities to upwards of six hundred hospital beds, complimented by a fourteen patient intensive care capacity and a forty-six-bed inpatient ward.[118] By pairing US Army MEDEVAC with an LHD's medical facilities provides immediate medical capacity well before comparable medical facilities can be established ashore.

Increased operational requirements are one factor which necessitates increased rotary wing augmentation; another is the degradation of available rotary wing assets. During Operation Tomodachi, aircrew and airframe cumulative radiation exposure directly limited 31 MEU's ability to conduct enduring operations. The radiological environment in the immediate disaster vicinity prevented the establishment of local support areas. Naval platforms maneuvered closer and farther away from the contaminated area based upon prevailing meteorological conditions. This ability to move the amphibious ship's location to suitable areas decreased the crew's exposure and increased their ability to support operations.

Though aerial radiological exposure is minimal compared to ground exposure, the cumulative effects degrade enduring operational capabilities. During Operation Tomodachi,

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[116] Wilson, "Operation TOMODACHI", 8-9. Traditional American evacuation operations employ commercially contracted means that cannot operate in radiological environments.

[117] JP 3-29, III-14.

[118] US Navy, "Essex ARG Ready to Provide Assistance to Japan."

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routine radiological tests aboard the USS *Essex* and USS *Ronald Reagan* identified radiation on at least three aircraft and seventeen aircrew members.[119] Though decontamination proved successful, the time-intensive decontamination process degraded operational readiness. Furthermore, cumulative radiological exposure limitations establish maximum safe exposure levels crewmembers can endure before risking permanent health complications. During Operation Tomodachi aircrews did not exceed exposure thresholds. However, in future scenarios, aircrews may surpass exposure limitations, requiring augmentation forces to continue the mission.

Operation Tomodachi was an operational success without the use of Army Aviation. However, future operations may require increased aviation capabilities to meet the objectives. Though the combined tsunami and radiological effects are unlikely, worst-case scenario, overpopulation, frequent natural disasters are representative of the region and require preparation for future assistance operations in the USPACOM AOR. Furthermore, Operation Tomodachi also demonstrates how foreign humanitarian response operations are not limited to impoverished states, but also occur in states with modern governments and militaries. Army Aviation's ability to augment these operations will strengthen US Pacific alliances and uphold their ability to respond to regional challenges.[120]

Following the tsunami's destruction, essential civil services were either inoperable due to the tsunami or located in the radiation fallout zone. These factors negated ground response assets, making helicopters the primary means to support the operational area, emphasizing amphibious rotary wing aviation as a critical capability in the operation.[121] Army Aviation's ability to conduct Brigade or Battalion sized operations aboard naval ships provides operational commanders and

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[119] US Navy, "Seventh Fleet Repositions Ships after Contamination Detected," Seventh Fleet Public Affairs Office, March 19, 2011, accessed February 29, 2016, http://www.navy.mil/submit/display .asp?story_id=59065.

[120] *US National Security Strategy*, *2015*, 24.

[121] JP 3-29, III-13 – III-14.

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political leaders with an increased capacity to conduct large-scale amphibious rotary wing operations to facilitate foreign humanitarian assistance and disaster response operations.

With its increased population density and location around the Pacific rim, the USPACOM AOR's nations are subject to many crises which require a unique US response. Army Aviation's increased maritime capabilities will facilitate increased United States ability to conduct foreign humanitarian assistance operations. This capability will increase US international influence. Pandemic outbreaks, volcanic eruptions, earthquakes, and tsunamis represent the common occurrences which may require international assistance in the USPACOM AOR's maritime regions.[122]

In contrast to Operation Stabilise's requirement for limited aviation capabilities, Operation Tomodachi exemplifies the need for large-scale aviation capacity. This case study examined a scenario which may require the maximum US crisis response in the USPACOM AOR, requiring the need for a combat aviation brigade complement of utility and cargo aircraft. Environmental exposure rates in future operations could require an Army Aviation to augment or relieve a MAGTF to continue foreign humanitarian assistance operations in affected maritime areas.[123]

As a counterpoint to Army Aviation's ability to augment MAGTF crisis response capabilities again revolves around the joint concept of mission trade-off and limited availability of helicopter-capable ships. While US Navy assets may not be available, this increases the requirement for Army Aviation to maximize its unmatched rotary wing depth with available ADF LHDs or JMSDF DDHs ships.

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[122] Borthwick, *Pacific Century*, 498; CIA World Factbook, "Indonesia," US Central Intelligence Agency Homepage, last modified February 25, 2016, accessed March 2, 2016, https://www.cia.gov/library/publications/ resources/the-world-factbook/geos/id.html.

[123] JP 3-29, III-13.

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Overall, these three case studies provided historical examples where actual, or potential Army Aviation capabilities provided utility towards accomplishing mission objectives in maritime environments. The increased trend in joint and multinational training exercises throughout the USPACOM AOR highlights the increased opportunities to train and employ shipboard Army Aviation capabilities.

Contemporary Multinational Operations: US Army Aviation with Pacific Partners

In accordance with the 2015 National Security Strategy, the United States will increase its multinational partnerships and military operations with its Pacific allies. This effort to modernize its military alliance seeks collaborative relationships to diversify the United States' "posture and presence" and demonstrate its resolve to America's Pacific partners and adversaries.[124] Maritime-capable Army Aviation reassures US allies of America's regional commitment and ability to increase multilateral partnership with Australian Defence and Japanese Self-Defence Forces. Applying America's military strengths in unilateral and multinational operations preserve the ability to exert US influence throughout the USPACOM AOR.[125]

Maritime aviation capability is essential for the Army to secure its national interests and is best achieved through joint and multinational interoperability.[126] Consistent with the Army Operating Concept, enhanced Army Aviation increases the joint force commander's employment options in maritime environments across the continuum of conflict.[127] The government's desire

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[124] *US National Security Strategy, 2015*, 24; TRADOC PAM 525-3-1, iv.

[125] Berkowitz, *Strategic Advantage*, 230-231.

[126] Ibid., 223.

[127] *The US Army Operating Concept,* iv.

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for soft power aligns with military commanders' desire for an Army capable of rapid response to isolated aggression, small conflicts, and natural disasters in the USPACOM AOR.[128]

The US government leverages Army Aviation to increase "soft power" in the Pacific by increasing partnership with low-intensity, foreign humanitarian assistance operations.[129] This "capability dividend" increases military presence without decreasing deterrence by over-tasking US expeditionary forces in the USPACOM AOR.

Strategically, bilateral foreign humanitarian assistance operations demonstrate the combined capabilities which allow the United States, Australia, and Japan to reinforce alliances and deter adversaries.[130] Operationally, partnered Army Aviation operations, when available, benefit the US military by utilizing foreign military capabilities to circumvent LHD/A utilization trade-off. The ADF and JMSDF benefit via increased access to amphibious-capable Army Aviation. Furthermore, using US strategic airlift to embark Army Aviation in Australia or Japan reduces Pacific transit delays.

Australia's Canberra-class LHDs increase ADF's ability to influence the Indo-Pacific region via foreign humanitarian assistance and multilateral training exercises.[131] These ships also provide Army Aviation its greatest opportunity for partnered amphibious operations in the USPACOM AOR. Army Aviation must continue allied amphibious exercises with ADF to increase partnered interoperability and regional multilateralism. The US-Australian alliance must

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[128] Rajiv Chandrasekaran, "Army's 'Pacific Pathways' Initiative Sets up Turf Battle with Marines," *Washington Post*, December 29, 2013, accessed March 1, 2016, https://www. Washingtonpost.com/world/national-security/armys-pacific-pathways-initiative-sets-up-turf-battle-with-marines/2013/12/29/11c948c8-69b1-11e3-a0b9-249bbb34602c_ story.html.

[129] Capie, "The United States and HADR in East Asia," 328.

[130] Ibid., 325.

[131] Australian Department of Defence, *Defence White Paper 2013. Defending Australia and Its National Interests,* accessed November 3, 2015, http://www.defence.gov.au/whitepaper/ 2013/docs/WP_2013_web.pdf, 77, 84.

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prevent the rise of terrorism and violent extremist organizations in the weakly governed and impoverished Southeast Asian maritime region.[132] These opportunities for Army Aviation to partner with ADF increases Australia's capabilities and US presence in the USPACOM AOR.

Though Army Aviation applications in the USPACOM AOR will support regional deterrence, increased trilateral partnerships between the United States, Japan, and Australia potentially provoke an unintended response by threatening their adversary's influence.[133] To avoid provocation, Army Aviation must start maritime applications with low-intensity operations establish the Army's image without excessive provocation. Multinational forces must overcome strategic and operational incompatibilities by developing common understanding via basic military principles: communications protocols, common logistics, and information/intelligence sharing methods.[134] Routine military engagement and regular training exercises are the most effective and affordable methods to achieve maritime military commonality and interoperability in USPACOM's complex AOR.

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[132] Michael Evans, *The Tyranny of Dissonance. Australia's Strategic Culture and Way of War 1901-2005* (Duntroon, Australia: Land Warfare Studies Centre, 2005), 101.

[133] Tetsuo Kotani, "Japan's Interest in Non-Traditional Security Issues," in *Enhancing Trilateral Disaster Preparedness and Relief Cooperation between Japan, U.S. and Australia. Approaches from Various Civil-Military Perspectives*, ed. Lauren Richardson (A Joint Research Project by: The Association for Cooperation between Japan, US and Australia; The Asia-Pacific Center for Security Studies; and the Queensland University of Technology, 2013), 20.

[134] David Fouse, "U.S. Interest in Non-Traditional and Transnational Security Threats," in *Enhancing Trilateral Disaster Preparedness and Relief Cooperation between Japan, U.S. and Australia. Approaches from Various Civil-Military Perspectives*, ed. Lauren Richardson (A Joint Research Project by: The Association for Cooperation between Japan, US and Australia; The Asia-Pacific Center for Security Studies; and the Queensland University of Technology, 2013), 28; William J. Lahneman, "Military Intervention: Lessons for the Twenty-First Century," in *Military Intervention: Cases in Context for the Twenty-First Century* (Lanham, MD: Rowman & Littlefield Publishers, 2004), 184.

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Exercises: Pacific Pathways

Despite the benefits of multilateral operations, practical applications prove difficult to support due to fiscal shortfalls and amphibious ship unavailability. Recently the Army has led an initiative meant to reduce the budget constraints and asset unavailability by replacing individual bilateral training exercises with successive, multilateral exercises throughout the USPACOM AOR. The development of Pacific Pathways transformed separate bilateral exercises into a collective, multi-month operation to enhance military interaction with Pacific allies.[135]

Two of the most prominent Pacific exercises, Talisman Saber and Yama Sakura, incorporate consistency with the United States' two most significant Pacific allies: Australia and Japan. Biannually, Talisman Saber exercises ADF and US Forces in joint operations ranging from combat operations to foreign humanitarian assistance.[136] Annually, Yama Sakura exercises Japan's Self-Defense Forces with US Forces in a two-week event to strengthen regional stability and improve US-Japanese interoperability.[137] Talisman Saber and Yama Sakura provide Army Aviation the opportunity to improve its amphibious capabilities aboard the ADF's Canberra LHDs and JMSDF's Hyuga and Izumo-class helicopter carriers. Together these two exercises

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[135] Cheryl Pellerin, "Army's I Corps Supports DoD Asia-Pacific Rebalance," *US Department of Defense Homepage*, August 21, 2015, accessed October 18, 2015, http://www.defense.gov/News- Article-View/Article/614372/armys-i-corps-supports-dod-asia-pacific-rebalance.

[136] Paul Barnes, "Potential for Growth in Collaboration on Non-Traditional Security Responses," in *Enhancing Trilateral Disaster Preparedness and Relief Cooperation between Japan, U.S. and Australia. Approaches from Various Civil-Military Perspectives*, ed. Lauren Richardson (A Joint Research Project by: The Association for Cooperation between Japan, US and Australia; The Asia-Pacific Center for Security Studies; and the Queensland University of Technology, 2013), 34-35.

[137] Eliverto Larios, "Yama Sakura 69 Kicks Off with Ceremony in Japan," *US Pacific Command Homepage*, December 7, 2015, accessed January 13, 2016, http://www.pacom.mil/Media/News/tabid/5693/Article/633214/yama-sakura-69-kicks-off-with-ceremony-in-japan.aspx.

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present Army Aviation with rare opportunities to exercise bilateral, shipboard aviation operations in the USPACOM AOR.

Pacific Pathways' vital contribution to Army Aviation is the employment of reduced-scale Army Aviation elements in maritime operations. Unlike Operation Uphold Democracy's massive CAB operation, smaller-scale employment provides two advantages. First, smaller elements reduce embarkation requirement. Less embarked assets increases Army access to scarce US and allied nation naval assets. [138] Second, employing company-sized aviation teams facilitates operational innovation and experimentation. This innovation advances mission command, maintenance, and tactical procedures necessary to develop functional maritime doctrine. Despite its advantages, scaled-down aviation operations cannot replicate the staff tempo or support requirements associated with larger operations like Operation Tomodachi or Uphold Democracy. Ultimately, Pacific Pathways provides Army Aviation with the opportunity to integrate aviation and naval capabilities to increase the speed and agility of ground combat forces to prevent, shape, and win in the USPACOM AOR.[139]

Despite Pacific Pathways' utility, critics assert that Army-Pacific engagement duplicates the US Marine Corps' expeditionary mission, effort, and budget.[140] Though correct that the Marine Corps' training and equipment are ideal for Pacific operations, increased Army maritime capabilities will enable USMC expeditionary forces to remain ready and available to respond to immediate contingencies and decisive action. Maritime Army units will not replace MAGTFs. Instead, Army Units will augment USMC capabilities to increase US presence and capabilities in the USPACOM AOR.

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[138] Lambert and Huber, "Joint Shipboard Helicopter Operations," 84-87.

[139] Chandrasekaran, "'Pacific Pathways' Turf Battle."

[140] Ibid.

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Future Considerations and Research

A specific area for future research is Army Aviation's continued maritime application of its future aviation platforms and capabilities in the USPACOM AOR. Two current acquisition priorities outline Army Aviation's continued maritime capabilities: the Future Vertical Lift initiative and rotary wing Manned-Unmanned Teaming.

Through 2030, Army Aviation forecasts no new rotary wing acquisitions which leaves fifteen to twenty years of aircraft continuity to improve existing shipboard interoperability.[141] Despite the Army's airframe continuity, US Marine Corps aviation continues its transition to next-generation aircraft including V-22 Osprey tiltrotor and F-35 aircraft. As the primary user of LHD/A ships, the Marine Corps' transition will likely incorporate Navy procedural changes, requiring Army Aviation to remain up-to-date. This timeframe also includes a three ship increase in aviation-capable amphibious ships with the scheduled commissioning of one additional America class LHA and two Ford class CVNs.[142] Through 2030, no significant detractions exist that would weaken Army Aviation's commitment to maritime proficiency.

The US Department of Defense future vertical lift (FVL) initiative's goal is to achieve cross-service rotary and tiltrotor interoperability and reduce sustainment costs through development and acquisition of common future airframes.[143] The Army recently approved two

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[141] Keith Brown, "Q&A with Army Aviation Program Executive Officer Tim Crosby," *Rotor & Wing Magazine*, July 2012, accessed August 21, 2015, http://accessintelligence.imirus.com/Mpowered/book/vrw12/i7/p56.

[142] Military Periscope, "AMERICA (LHA-6) Class," Military Equipment Database, accessed December 29, 2015, https://www.militaryperiscope.com/weapons/ships/amphib/w0005789.html; Military Periscope, "GERALD R. FORD (CVN-78) Class," Military Equipment Database, accessed December 30, 2015, https://www.militaryperiscope.com/weapons/ships/carriers/ w0007233.html. LHA-7: USS *Tripoli;* CVN-78: USS *Ford*; CVN 79: USS *Kennedy*.

[143] Walter J. Boyne, *How the Helicopter Changed Modern Warfare* (Gretna, LA: Pelican Publishing Company, 2011), 276.

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aircraft designs FVL prototype development: one modified tiltrotor and a coaxial-rear thrust variant.[144] The tiltrotor variant benefits from increased maximum speed and longer range, but also occupy more flight deck space than existing Army aircraft. The benefits of the coaxial variant's reduced space requirement is countered by its lack of speed and range due to its fixed main rotor aerodynamic limitations.[145]

Army rotary wing operations will become increasingly interoperable with its organic unmanned aerial systems. Current UAS configurations prevent shipboard operation. The RQ-7B Shadow requires no runway to launch, but the likelihood of a shipboard recovery is unlikely and prevents launch and recover operations afloat. The MQ-1C Gray Eagle cannot conduct shipboard operations, but its extended range allows for manned-unmanned-teaming near maritime objectives. This ability to implement Gray Eagle UAS into maritime intelligence, surveillance, and reconnaissance roles will offset the number of required attack and reconnaissance aircraft from embarked requirement and increasing overall economy of force.

Conclusion

Army Aviation's future application in the USPACOM AOR requires the identification of optimal maritime missions for Army employment and the corresponding emphasis on the development of maritime capabilities. Historical events, current military and political trends, and opportunities for multinational military partnership all define how Army Aviation must evolve to increase its utility in the USPACOM AOR. Despite Army Aviation's capabilities, limited amphibious ship availability poses the principal limitation which constrains Army Aviation maritime applicability. Army Aviation doctrine, organization, and training must incorporate three

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[144] Marina Malenic, "Commonality is Key to Controlling FVL Costs, Officials Say," July 22, 2015, accessed September 12, 2015, http://www.janes.com/article/53161/commonality-is-key-to-controlling-fvl-costs-officials-say. Tiltrotor design resembles the V-22 Osprey, while coaxial design features two counter-rotating main rotor blades with a forward propulsion prop.

[145] Boyne, *How the Helicopter Changed Modern Warfare*, 280-281.

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recommendations to develop and improve future maritime capabilities: immediate doctrine revision to incorporate maritime capabilities, aviation training focused on company-sized shipboard operations, and the prioritization of low-intensity and multinational operations.

As defined in JP 3-04, mission trade-off remains the most significant impediment to Army Aviation's shipboard employment. Employing scarce US Navy amphibious ships in non-standard configurations incurs such a high opportunity cost that only strategically important missions necessitate shipboard Army Aviation. Contemporary Pacific Rim operations incur greater risk than exhibited in Operation Uphold Democracy as increased proximity to anti-access, area-denial threats and extended sea lines of communication decrease Army Aviation's maritime utility. Mission trade-off refutes the first stated contention that Army Aviation must retain the ability to transport Brigade Combat Teams in maritime environments. Though applicable in the land domain, this contention is infeasible for general shipboard application. Army Aviation must retain the ability to support Brigade Combat Team-sized operations in the USPACOM AOR where land basing is suitable to support the depth of the operational environment. Also, mission trade off validates contentions two and three, confirming amphibious Army Aviation must support Brigade Combat Team and smaller operations must support strategic importance.

To increase its maritime applicability in the USPACOM AOR, Army Aviation must first codify and disseminate the baseline doctrine required to execute joint and multinational shipboard operations. As proven in Operation Uphold Democracy, cross-service communication founded in doctrine and professional expertise allowed 10th Aviation Brigade to overcome aircrew-training deficiencies in preparation for an unprecedented mission. As Army Aviation prepares to conduct joint and multinational operations with the United States, Australian, and Japanese amphibious navies, improved doctrine will enable Army planners to anticipate requirements, identify opportunities, and mitigate risks. The doctrine priority is to update FM 1-564 *Shipboard Operations'* in accordance with FM 3-04, *Army Aviation* and JP 3-04.1 *Joint Tactics, Techniques, and Procedures for Shipboard Helicopter Operations.* Updated doctrine will allow combat

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aviation brigades to incorporate basic maneuvers and academics into home station aircrew training programs to exercise shipboard operations in simulators and training areas to increase deck qualification proficiency in the absence of naval vessels.

Army Aviation must focus on small-scale, limited-duration maritime operations. Though effective in Operation Uphold Democracy, mission trade-off eliminates the likelihood of large-scale application in the USPACOM AOR. The focus on one-time ship to land missions and limited duration amphibious operations minimizes interoperability complications and reduces aircraft exposure to corrosive environments. This combines Uphold Democracy's method to introduce Army rotary wing assets from a maritime environment proved essential in Operations Tomodachi and Stablise to overcome geographic or diplomatic constraints. Deploying company-sized elements optimizes embarked task organization to ensure the necessary operational, maintenance, and support personnel and equipment accompany each unit. Reduced-scale operations increase the access and availability of suitable US Navy, Australian Defense Force, and Japan's Maritime Self-Defense Force ships and expand US military presence throughout the USPACOM AOR.

Multinational-partnered shipboard operations provide a dual benefit. First, these operations overcome US Navy mission trade-off required of its limited number of ships. Second, and shortens the distance and transit required to deploy Army forces by forward deploying helicopters via more efficient methods (strategic airlift or cargo shipping). In-theater embarkation decreases airframe exposure and decreases transit time to joint operations areas. Operation Stabilise identified an opportunity to partner US Army capabilities with Australian assets to increase the multinational UN presence. The Australian Navy's amphibious platforms offer an ideal opportunity to merge regional amphibious capabilities with the US military's depth of rotary wing capabilities. The Australian Defense Force's relative lack of utility and cargo helicopters exemplifies the mutual benefit of US combat aviation capacity paired with allied amphibious

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capabilities. Despite the advantages of allied operations, multinational employment does incur the increased risks associated with cultural, professional, and procedural differences between allies.

By implementing these recommendations, Army Aviation will increase its utility at all levels of war. Maritime-capable Army Aviation will not only increase military efficiency at the tactical and operational levels of war, but also increase the US military's strategic deterrence by broadening its ability to project combat power ashore. Exhibited during Operation Uphold Democracy and suggested for Operation Stabilise, integrated maritime capabilities enhance the United States' ability to deter conflict and aggression alongside its allies in the USPACOM AOR.

In Operation Uphold Democracy, the adversary's political leadership lost its strategic leverage when faced amphibious, air-capable forces which allowed the United States to avoid a military invasion and seize control by less hostile means. Preceding Operation Stabilise, the creation of a multinational United Nations amphibious-capable task force may have provided a decisive option to introduce peacekeepers into East Timor without risking invasion. Army Aviation's increased operational capability will allow the United States to prioritize its maritime assets to strengthen regional deterrence. Best suited to execute foreign humanitarian assistance missions, maritime-capable Army Aviation will allow the United States to focus its more-capable maritime assets, Navy Carrier Strike Groups and Marine Air-Ground Task Forces, towards more complex operational environments: the South China Sea, Strait of Malacca, or emergent threats from regional violent extremist organizations. Army Aviation's increased maritime competence will strengthen the US strategic advantage in the USPACOM AOR.

Overall, Army Aviation allows the US military to expand its capacity to conduct joint operations in maritime environments. By focusing on operations at the battalion and company level, Army Aviation will increase the US military's ability to conduct amphibious operations in maritime environments. Simultaneously, Army Aviation must remain balanced to train and deploy combat aviation brigades to provide integrated aerial support to combined, joint, and multinational operations throughout any land or maritime operational environment.

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THESIS

OPTIMIZATION CASE STUDY: ISR ALLOCATION IN THE GLOBAL FORCE MANAGEMENT PROCESS

by

Guillermo I. Carrillo

September 2016

Thesis Advisor: Walter E. Owen
Co-Advisor: Paul Ewing

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13. ABSTRACT (maximum 200 words)

Global Force Management (GFM) is a force-allocation process-driven system that distributes military forces across the globe to meet Combatant Commander objectives. The goal is to match military capabilities provided by the military services to Geographic Combatant Commander requirements. This thesis is a proof of concept for an optimization model that maximizes the distribution of a finite number of full motion video intelligence, surveillance, and reconnaissance (ISR) assets to a prioritized list of requirements to meet national security objectives.

This thesis examines the ISR GFM process. With the insight gained to the process, the model applies a mixed integer linear programming formulation to provide an optimized force allocation recommendation The model's objective function managed the trade-off between FADM priority and platform consideration, which optimized the allocation 902 hours per day of full motion video to meet 1902 hours per day of 20 CCDR requirements.

The research, methodology, and analyses presented in this thesis is a successful proof of concept proving that this optimization model will objectively inform senior decision makers in the Department of Defense for intelligence surveillance reconnaissance Global Force Management allocation.

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OPTIMIZATION CASE STUDY: ISR ALLOCATION IN THE GLOBAL FORCE MANAGEMENT PROCESS

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Global Force Management (GFM) is a force-allocation process-driven system that distributes military forces across the globe to meet Combatant Commander objectives. The goal is to match military capabilities provided by the military services to Geographic Combatant Commander requirements. This thesis is a proof of concept for an optimization model that maximizes the distribution of a finite number of full motion video intelligence, surveillance, and reconnaissance (ISR) assets to a prioritized list of requirements to meet national security objectives.

This thesis examines the ISR GFM process. With the insight gained to the process, the model applies a mixed integer linear programming formulation to provide an optimized force allocation recommendation The model's objective function managed the trade-off between FADM priority and platform consideration, which optimized the allocation 902 hours per day of full motion video to meet 1902 hours per day of 20 CCDR requirements.

The research, methodology, and analyses presented in this thesis is a successful proof of concept proving that this optimization model will objectively inform senior decision makers in the Department of Defense for intelligence surveillance reconnaissance Global Force Management allocation.

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LIST OF ACRONYMS AND ABBREVIATIONS

AOR	area of responsibility
CCDR	Combatant Commander
CONOPS	concept of operations
DEPORD	deployment order
DOD	Department of Defense
EMARSS	Enhanced Medium Altitude Reconnaissance and Surveillance System
FADM	force allocation decision matrix
FMV	full motion video
FP	force provider
GEF	Global Employment of the Force
GFM	global force management
GFMAP	Global Force Management Allocation Plan
GFMIG	Global Force Management Implementation Guidance
ISR	intelligence surveillance reconnaissance
JFC	Joint Force Coordinator
JFP	Joint Force Provider
LRE	launch and recovery element
NATO	North Atlantic Treaty Organization
NSC	National Security Council
OPLAN	operation plan
POTUS	President of the United States
SDOB	Secretary of Defense Orders Book
SECDEF	Secretary of Defense
SIGINT	signals intelligence
SOF	special operations forces
SVTC	secure video teleconference
USAFRICOM	United States Africa Command
USCENTCOM	United States Central Command
USEUCOM	United States European Command

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USNORTHCOM	United States Northern Command
USPACOM	United States Pacific Command
USSOUTHCOM	United States Southern Command
USSTRATCOM	United States Strategic Command

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EXECUTIVE SUMMARY

Global Force Management (GFM) is a force-allocation process-driven system that distributes military forces across the globe to meet Combatant Commander objectives. The goal of GFM is to match military capabilities provided by the Services to Geographic Combatant Commander requirements. This thesis is a proof of concept for an optimization model that maximizes the distribution of finite number of assets to a prioritized list of requirements.

The Secretary of Defense (SECDEF) directs the Global Force Management (GFM) allocation process in the Dissemination and Guidance for the Employment of the Force. The National Strategic Strategy, the National Defense Strategy, and the National Military Strategy direct, guide, and inform the GFM process. The National Strategic Strategy establishes national priorities; the National Defense Strategy guides the Department of Defense (DOD), which along with the National Military Strategy, provides strategic direction.

The GFM process organizes and distributes military forces to meet Geographic Combatant Commanders (CCDRs) requirements. The allocation process looks across the entire DOD to identify and recommend the most appropriate and responsive force that can meet CCDR requirements. Each force request culminates in a Secretary of Defense (SECDEF) decision and subsequent deployment order to allocate a force. The forces come from several sources, including: a Service Secretary such as the Army, Navy, Marine Corps, or Air Force; a CCDR's assigned forces; or forces from other DOD Agencies. The SECDEF allocates the forces to the requesting CCDR based on informed recommendations from the Joint Staff. The design of the entire global force management process allows the SECDEF to make prioritized decisions for the employment of the force. The product of the GFM process is deployed military forces to the Geographic Combatant Commanders (CCDR).

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1. Secretary of Defense. 2015. (U) *Dissemination of the Guidance for the Employment of the Force.* Washington, DC: Department of Defense. This document is classifed SECRET.

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This thesis focuses on the intelligence, surveillance, and reconnaissance capabilities within the GFM process. Typically, ISR capabilities such as full motion video (FMV) are in high demand by CCDRs. However, the availability of ISR platforms is severely limited. ISR capability is described as high demand and low density. Because of the ability of ISR platforms potentially to provide capability to multiple CCDRs from a common operating location and competing demands for mission critical requirements, the allocation of ISR forces includes close coordination between the Joint Staff, CCDRs, force providers, and the Joint Functional Component Command for Intelligence, Surveillance, and Reconnaissance (JFCC ISR).

The challenge with the current ISR allocation process is objectively quantifying the reason behind a recommended sourcing solution for ISR global allocation. Current military operations across the globe experience more demand from the Geographic Combatant Commanders (GCC) than the Force Providers have assets available to meet the GCC requirements. The Joint Staff, in concert with USSTRATCOM, use many factors to prioritize allocation of assets to include determining which GCC gets the assets and for how long. The decision influencers recommend a resource allocation solution based on experience, force capacity, GCC demand, and the strategic environment provided by guidance from the National Security Council (NSC).

The ISR allocation optimization model applies to any of the ISR requirement capabilities, including but not limited to Full Motion Video (FMV), Signals Intelligence (SIGINT), Communications Intelligence (COMINT), and other intelligence collection capabilities. The complexity of FMV force allocation makes FMV the ideal capability to use for a proof of concept.

Hypothetical data is used to keep this thesis unclassified. The platform capabilities come from a small sampling of ISR FMV platforms that have sufficient open-source information to make the model relevant. The hypothetical CCDR requirements are derived from and loosely based on historical data from GFMAP force allocations. Actual CCDR requirements, force capacities, and FADM priorities are classified. The model uses a methodical approach using known data and informed assumptions to develop reasonable scenarios to implement in the model.

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This optimization model and its methodology uses full motion video capability and notional requirements to model the applicably of optimization in the Global Force Management allocation process. The model uses an objective function that to maximize the hours of FMV allocated to each CCDR to meet the prioritized mission requirements. The objective function manages the trade-off between ISR platform constraints and CCDR requirements constraints.

Results from the base model, which only considered FADM for allocation prioritization, shows that with only 902 hours per day of FMV capacity to meet 1902 hours per day of requirements, the optimized solution provided 100 percent of the requirement capability to 12 of the 20 CCDR requirements and a partial allocation of 39 hours per day or nine percent of the requirement to the single next lowest FADM priority requirement. These results are useful to inform senior decision makers within the DOD of which requirements will not receive a capability allocation. The results can be compared against the actual Global Force Management Allocation Plans to highlight which lower FADM priorities are actually receiving a force allocation. The reasons for the differences can inform decision makers that the strategic priorities do not align to how the allocation is being allocated. For force providers and DOD budget personnel, the gaps highlight areas where additional resources can be committed to meet strategic objectives.

Combining and balancing FADM and platform consideration into the optimization model allows decision makers a model that more closely resembles current allocation methods. The results of the combined model change if we modify the $value_{ij}$ parameter for a particular platform. This change may represent where the platform consideration is modified based on new information or just to examine model sensitivity. This is the expected result because the model is using the product of platform consideration times the FADM priority to define $value_{ij}$ in the objective function. The objective function manages the trade-off between FADM priority and platform consideration. The combined model more closely simulates how the force allocations recommendations are made because it takes into account regional geographic realities while managing global strategic priorities.

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The current GFM process method cannot quantify and objectively compare the specifics of platform considerations and strategic priority. This model highlights the areas where there may be trade-space for additional allocation opportunities. For example, if the only means to provide capability to a specific ISR requirement is allocating manned aircraft, the model will show what requirements will be affected to meet that limitation. Additionally, by interpreting the results, the CCDR can assess where their requirement priorities are evaluated globally across all of the CCDR's requirements. The Joint Staff can evaluate the data to verify that the results support the military objectives of the National Military Strategy. If the results do not support the strategic objectives then the CCDR priorities and the force provider capacity must be scrutinized to mitigate the capability and requirement gaps. The impact implications are important to the Combatant Commanders for mitigation options and important to the SECDEF for accepting the risk associated with the recommendation.

Combining the optimization model described throughout this thesis with a risk informed model that can be implemented for the force allocation of all ISR capabilities is a logical evolution that optimizes the force allocation decision process that informs the SECDEF for force decisions and responsibility. This thesis critically examines the GFM ISR allocation process and the factors that influence it. With the insight gained about the process, the proof of concept applied a methodical optimization formulation to a complex ISR force allocation problem that is complicated further by significantly less capacity than demand. The research, methodology, and analyses presented successfully prove that this optimization model will objectively inform senior decision makers in the Department of Defense for intelligence surveillance reconnaissance Global Force Management allocation.

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I. INTRODUCTION

A. BACKGROUND

Global Force Management (GFM) is a force-allocation process-driven system that distributes military forces across the globe to meet Combatant Commander objectives. The goal is to match military capabilities provided by the Services to Geographic Combatant Commander requirements. This thesis is a proof of concept for an optimization model that maximizes the distribution of finite number of assets to a prioritized list of requirements.

Chapter I begins with a broad description of GFM and the documents that direct and guide the process. It introduces how GFM addresses and balances risk to both the Services and the Combatant Commanders. This chapter asks the question, "What can be added to the GFM process to objectively inform senior decision makers in the Department of Defense for intelligence surveillance reconnaissance (ISR) Global Force Management allocation?" Although GFM addresses the allocation of all military capabilities, this thesis focuses on intelligence, reconnaissance, and surveillance capabilities; specifically full motion video. The requirements demand for ISR and full motion video significantly exceeds global capacity of assets available. This makes ISR full motion video capability an ideal candidate for optimization.

The methodology outlined in Chapter II breaks down the GFM process into decisional process steps. It identifies who the decision makers and influencers are in each step. The purpose of Chapter II is to develop an understanding of the GFM process as it exists today and to get a sense its complexity. With this foundational understanding, the paper describes the specifics of the ISR allocation process. ISR allocation recommendations are based on a combination of objective and heuristic data and variables.

Chapter III introduces the objective function which maximizes the number of hours of ISR capability provided to the Geographic Combatant Commanders in to meet

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prioritized mission objectives. It introduces the indices, parameters, and constraints that shape the implementation of the model.

Chapter IV describes in detail, the indices, parameters, and constraints introduced in Chapter III using notional data. It describes the assumptions made in the model development. The model applies a methodical approach using known data and informed assumptions to develop reasonable notional scenarios for implementation in the model. This chapter describes the analyses of the results.

Chapter V summarizes the success of the optimization model and recommends continued development of the model to include all ISR capabilities. It also recommends a model that takes into account risk informed factors. Building on both models, we can apply the next iteration to the emergent allocation process.

1. Global Force Management System Process

The Secretary of Defense (SECDEF) directs the Global Force Management (GFM) allocation process in the Dissemination and Guidance for the Employment of the Force.[1] The GFM process organizes and distributes military forces to meet Geographic Combatant Commanders (CCDRs) requirements.

The National Strategic Strategy, the National Defense Strategy, and the National Military Strategy direct, guide, and inform the GFM process. The National Strategic Strategy establishes national priorities; the National Defense Strategy guides the Department of Defense, and the National Military Strategy provides strategic direction. The following strategic planning documents guide GFM:

- Unified Command Plan signed by the President of the United States (POTUS)

  Unified Command Plan (UCP) establishes the combatant commands, identifies geographic areas of responsibility, assigns primary tasks, defines authority of the commanders, establishes command relationships, and

[1] Secretary of Defense. 2015. (U) *"Dissemination of the Guidance for the Employment of the Force."* Washington, DC: Department of Defense. This document is classifed SECRET.

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gives guidance on the exercise of combatant command. The President of the United States approves the UCP. The CJCS publishes the UCP for the commanders of combatant commands.

- Joint Strategic Capabilities Plan

  The Joint Strategic Capabilities Plan (JSCP) carries out the Chairman of the Joint Chiefs of Staff National Military Strategy and provides guidance to combatant commander and the JCS to accomplish tasks and missions based on current military capabilities.

- Global Force Management Implementation Guidance

  The Global Force Management Implementation Guidance (GFMIG) establishes procedures for assignment, allocation, and apportionment of U.S. military forces. The GFMIG includes a military risk matrix.

  The Secretary of Defense (SECDEF) approves the GFMIG.

- Guidance for Employment of the Force

  The Guidance for Employment of the Force (GEF) provides both the president's guidance for contingency planning and conveys the SECDEF's guidance to focus on the use of existing Department of Defense forces to accomplish near-term objectives.

  The GEF establishes the defense posture for a 2–15-year timeframe

  The GEF inherently accepts risk and informs decision makers across the DOD to make risk-informed decisions. The GEF prioritizes greatest national security risks and highest consequence issues.

The allocation process looks across the entire DOD to identify and recommend the most appropriate and responsive force that can meet CCDR requirements. Each force request culminates in a Secretary of Defense (SECDEF) decision and subsequent deployment order to allocate a force. The forces come from several sources, including: a Service Secretary such as the Army, Navy, Marine Corps, or Air Force; a CCDR's assigned forces; or forces from other DOD agencies. The SECDEF allocates the forces to the requesting CCDR based on informed recommendations from the Joint Staff.

The allocation process illustrated in Figure 1 is the OV-1 diagram from the Joint Staff Global Force Management Enterprise Integration Architecture document (Joint Staff 2014). The Global Force Management process provides feasible sourcing options to the SECDEF with the decision support process to assess quickly and accurately current and future impact and risks associated with proposed force changes. Each allocation

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recommendation balances force provider risk to force with CCDR risk to mission. Assessing force allocation risk is complex. A CCDR must assess risk to current operations while at the same time predicting risk to strategic operational plans.

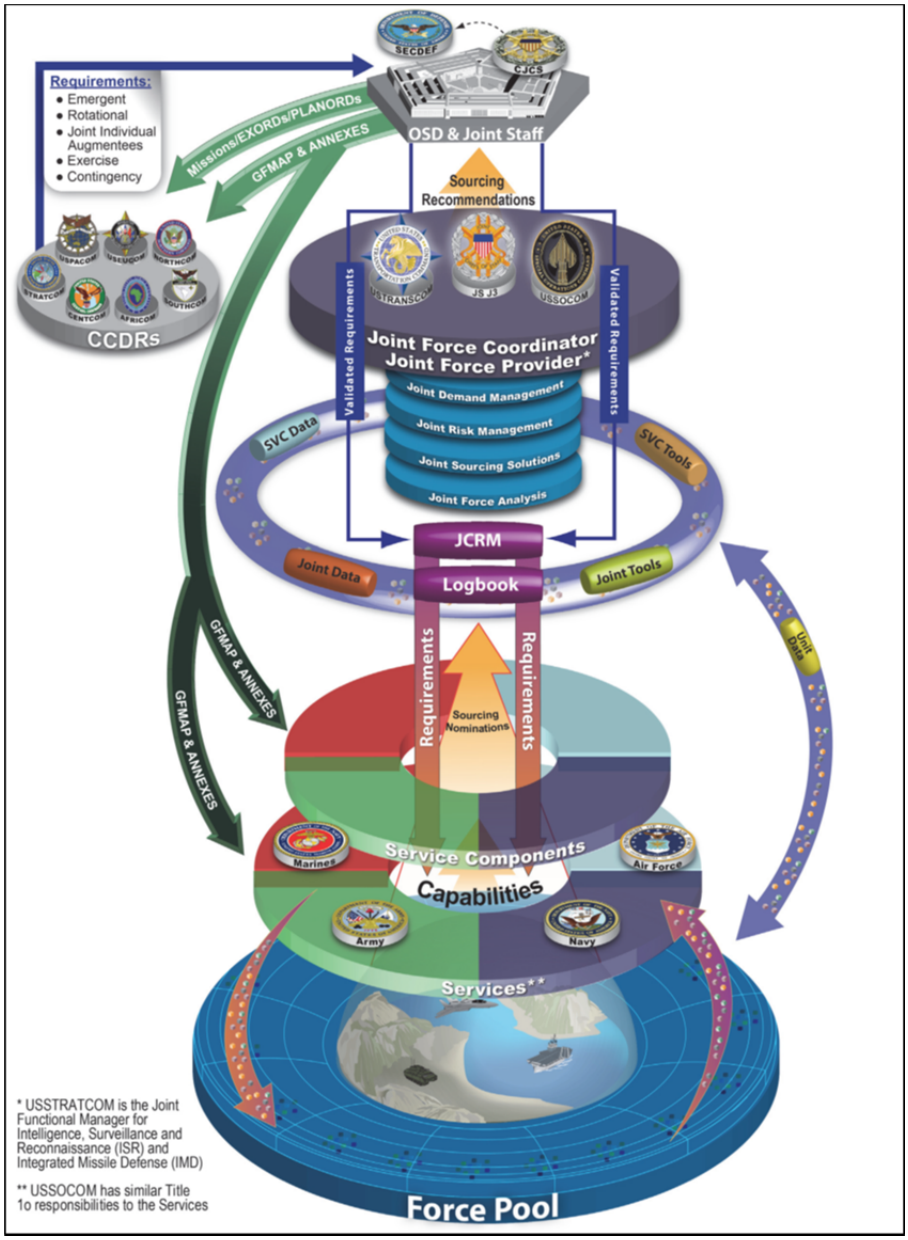


Figure 1. OV-1 Allocation Operational Concept Graphic. Source: Joint Staff (2014).

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This chapter will step through the GFM allocation process and develop an understanding of the GFM process depicted in Figure 1. The allocation process begins when the SECDEF assigns missions and operations to CCDRs. To meet the mission and operations objectives, CCDRs request forces with the capabilities required to achieve mission objectives. For example if a CCDR is required to conduct a strike into a particular area, the CCDR needs to know what and where the targets are. To do that, the CCDR may require an ISR capability such as full motion video to build situational awareness of the battle space. The CCDR will request full motion video as the force requirement.

The GFM process supports both rotational requirements and emergent requirements. Rotational requirements are those operations and missions that CCDRs and Force Providers are able to plan for from fiscal year to fiscal year. For example, to conduct Operation IRAQI FREEDOM (OIF), Commander United States Central Command's (USCENTCOM) strategy requires forces to continue from one fiscal year into the next. USCENTCOM will continue to require ISR capabilities to monitor the situation in Iraq. This plan informs the demand for USCENTCOM's rotational requirements. Emergent requirements are force capabilities needed in addition to the rotational requirements. Emergent requirements happen during the current fiscal year. For example, during the Ebola Crisis in the Commander United States Africa Command (USAFRICOM) Area of Responsibility (AOR), USAFRICOM requested additional medical support capabilities to augment the forces allocated in fiscal year 2014. Emergent requirements typically address the "what's changed?" in a CCDR's AOR within the fiscal year.

The Joint Staff will validate each CCDR's force requirement. Validation includes verifying requirements, assigning a priority, and ensuring the CCDR has the proper authorities to conduct the operation with the requested capability. The Joint Staff as the Joint Force Coordinator (JFC) will assign the Joint Force Provider (JFP) for conventional forces, Special Operations Forces (SOF), or mobility. The JFC and JFP will coordinate with the Air Force, Army, Marines, and Navy, who are the Force Providers (FP) to determine sourcing options to meet the CCDR's requirements. Force providers look

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across the complete spectrum of their Service capabilities and balance the need to meet the requirement with the risk to the impact to Service force readiness. With the high demand for combat forces across the globe continuing since 2011, the risk to Service and Force readiness is the most significant factor in force allocation recommendations to the SECDEF. In many force capabilities, there is no additional capacity to meet all of the CCDR's rotational requirements and emergent requirements without a reallocation of forces. This is the case with intelligence, surveillance, and reconnaissance (ISR) capabilities.

The JFC and JFPs critically review the FP nominations including analyzing risk to develop a recommended joint sourcing solution. The Joint Staff will socialize the recommended sourcing solution to the CCDRs and FPs to accurately address both risk to mission and risk to force impacts in order to inform the SECDEF for force allocation decision. When the FP and/or the CCDR do not agree with a recommendation, the issue becomes contentious. The contentious issue will go through a resolution process consisting of action officer and General Officer/Flag Officer (GOFO) level forums. A requirement becomes contentious for several reasons:

1. The FP does not have the capacity to meet a CCDR's requirement to a satisfactory level.

2. The proposed solution meets the requirement, but it is missing the specific unit type wanted by the CCDR.

3. The CCDR has a valid requirement yet there is no capacity to meet the requirement without reallocation from another CCDR.

4. The recommended solution reallocates existing forces in one CCDR's AOR to a different CCDR.

Situation (4) causes many contentious issues for ISR requirements. ISR capability demand far exceeds ISR capacity. When the force providers have all available forces allocated and there is no additional capacity for emergent requirements, it may be necessary to reallocate forces from one CCDR to another. The Joint Staff makes the recommendation to reallocate the assets, and the SECDEF is the approval authority to reallocate assets from one CCDR.

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The Joint Staff will staff all resource allocation recommendations. Once staffed, the recommendations become part of the draft Global Force Management Allocation Plan (GFMAP). The Joint Staff will staff the GFMAP to the FPs and CCDRs prior to submitting the sourcing recommendations to the SECDEF. The Joint Staff briefs the draft order through the Joint Staff Directorates and the Office of the Secretary of Defense (OSD) to the Chairman of the Joint Chiefs of Staff (CJCS), OSD leadership. When the SECDEF approves the GFMAP, the Joint Staff publishes the GFMAP. The GFMAP is the SECDEF Deployment Order (DEPORD) for all allocated forces.

2. Risk Assessment

The GFM process takes into account military risk and strategic risk. Strategic risk evaluates and judges both the probability and consequence of threats to the nation. The GFMIG defines military risk as risk to mission and risk to force; it uses the terms to express the overall risk associated with fiscal year requirements. Title 10, U.S.C., section 153 requires CJCS annually to "assess the nature and magnitude of the strategic and military risks with executing" National Military Strategy missions.

Risk to mission is the CCDR's ability to execute assigned missions at acceptable human, material, financial and strategic costs. Risk to mission should include the CCDR's assessment of what aspects of the mission will assume risk and for how long. Effective risk to mission assessments includes risk mitigation measures and the impact of those mitigation measures to the mission. In other words, what requirements will not be met and how will that affect meeting mission objectives? This thesis will identify what requirements will not be met.

B. PRIMARY RESEARCH THESIS QUESTION

How do we quantify the tradeoff necessary to reduce contentious decision-making in the Global Force Management allocation process?

This thesis is a proof of concept of an optimization model for ISR allocation within the Global Force Management process. The challenge with the current ISR allocation process is objectively quantifying the reason behind a recommended sourcing solution for ISR global allocation. Current military operations across the globe

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experience more demand from the Geographic Combatant Commanders (GCC) than the Force Providers have assets available to meet the GCC requirements. The Joint Staff, in concert with USSTRATCOM, use many factors to prioritize allocation of assets to include determining which GCC gets the assets and for how long. The decision influencers recommend a resource allocation solution based on experience, force capacity, GCC demand, and the strategic environment provided by guidance from the National Security Council (NSC).

C. BENEFIT OF STUDY

This ISR capability optimization proof of concept will take an ISR capability that the GCCs require such as full-motion video (FMV), and show how the allocation can be optimized to meet requirements across the GCCs. To do understand the complexities of the ISR force allocation, the next chapter will describe the allocation process.

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II. METHODOLOGY

This chapter describes how a Combatant Commander's capability requirement receives a force allocation. The Global Force Management process is explained step-by-step starting with the CCDR's requirement identified. It ends with a force deployed to meet that requirement and it identifies critical decision points. This chapter also describes the additional steps of the ISR allocation process.

A. GFM PROCESS DESCRIPTION

The design of the entire global force management process allows the SECDEF to make risk informed and prioritized decisions for the employment of the force. The product of the GFM process is deployed military forces to the Geographic Combatant Commanders (CCDR). The GFM process in Figure 2 describes how the CCDRs request forces through a request for forces (RFF) through the validation process, and receives force allocation as ordered by the SECDEF. For the purpose of this report, the scope and specifics of the process is unclassified. For ISR requirements, it is common for the issue to become contentious during the resource allocation process. There are not enough ISR assets to meet CCDR requirements (Secretary of Defense 2016). The entire process is to allow the SECDEF to make risk informed decisions for the employment of the force.

1. The GFM process begins with a RFF from the Geographic Combatant Commander. The request is for a capability needed in that GCC's area of operations that does not already exist.[2] An example of a capability request is for ISR full motion video from USEUCOM to monitor the refugee crisis of people leaving Syria across the Mediterranean Sea. The Joint Staff receives the RFF via an electronic message.

2. The Joint Staff verifies that the GCC has the authority for the capability of the RFF requested and the force meets the guidance of provided in Chapter I. When the RFF meets validation requirements, it moves to

[2] Secretary of Defense. 2015. (U) *"Dissemination of the Guidance for the Employment of the Force."* Washington, DC: Department of Defense. This document is classifed SECRET.

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validation. If the RFF does not meet the validation requirements, it returns to the CCDR with requests for more information in order to meet the validation requirements.

3. Decision Point. In validation, the J31 Deputy Director approves or denies the validation of the RFF. Validated RFFs proceed to the resource allocation process. Not validated RFFs return to the CCDR. Some of the reasons for not validating an RFF include but not limited to the following:

   a. The RFF is asking for a validated requirement that already exists.

   b. The RFF is asking for a requirement that does not meet the SECDEF's strategic direction.

   c. The RFF is requesting a relook at sourcing without a significant change in the CCDR strategic situation.

   Validation simply determines if the CCDR has valid SECDEF approved mission with fiscal authority, legal, and that there is not an existing requirement for the same capability (Joint Staff, 2014). Validation does not consider whether the Force Providers have the capacity to source the request. Validated RFFs may or may not have forces allocated. The SECDEF assumes all of the risk to the CCDR for not providing resources to meet the demand when a validated capability lacks resources. This happens when there are not enough forces to meet all of the requests from all of the COCOMs without breaking the force providers' ability to reconstitute forces from year to year and surge capacity to meet emergent requirements. Many ISR RFFs are validated yet do not receive the required resources.

4. The validated RFF is assigned a GEF priority and a request is sent to the Force Providers for force allocation feasibility. With some requirements, multiple services can source the requested capability. For example, the Navy and the Air Force can source ISR—Signals Intelligence (SIGINT) capabilities with the EP-3 Aries and the RC-135 V/W Rivet Joint. A single Service can only source other capabilities. For example, the Navy is obviously the only Service that can provide a maritime presence with a Carrier Strike Group. The Joint Staff as the Joint Force Coordinator, will use the Force Allocation Decision Model (FADM) to prioritize fulfillment

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of requirements.[3] The FADM is guidance that provides a flexibility for making force allocation recommendations among competing requests (Joint Staff, 2014). The details of the FADM are classified. However, the intent of the FADM is to align GFM allocation recommendations with Department of Defense priorities. It is a tiered framework where the higher the FADM priority, the more critical the requirement is to strategic end-states and top priority planning efforts (Joint Staff 2014).

5. Decision Point. The Joint Staff sends the RFF to the appropriate service or services for force allocation recommendations. If the service can meet the request, the service accepts the responsibility to the provide resources to the RFF. If the service cannot meet the requirement, the service must provide the reason including the risk assessment as to why it cannot meet the request. In some cases, the services will agree to provide resources with the capability with some exceptions or comments, which may outline a different unit to meet the same capability.

    a. For ISR requirements, there is an additional step in the process. JFCC-ISR will review the ISR RFF and provide force allocation recommendations to the force providers and the CCDRs through the Joint Staff. JFCC-ISR recommendations use trend analysis of requirements from year to year, service capacity to process the collection, and operational constraints such as basing options, over flight permissions, and command and control architecture limitations (Joint Staff 2014).

6. If the Force Provider has the capacity to meet the requirement, the FP sends the resource allocation recommendation to the Joint Staff. If the force provider cannot meet the requirement, the request returns to the Joint Staff for additional staffing, and the recommended solution is contentious between the Force Provider, the CCDR, and the Joint Staff.

7. The Joint Staff will work with both the force provider and the CCDRs to agree on an acceptable resource allocation solution. During the resolution process, force providers provide force availability data and answer questions to give decision makers a better understanding of why the

[3] Secretary of Defense. 2015. (U) *"Dissemination of the Guidance for the Employment of the Force."* Washington, DC: Department of Defense. This document is classifed SECRET.

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request is not feasible. Additionally, for many RFFs, the questions go back to the CCDRs for amplifying information. The purpose of this step is to resolve the issues with an acceptable solution from the CCDR and the Force Providers at the lowest decision maker level.[4]

7a. Decision Point. The first step in the adjudication process of a contentious issue is at the Action Officer level via a Secure Video Teleconference (SVTC). The required participants include the action officers from the Joint Staff, the GCCs, and the Services. The SVTC is an opportunity for each stakeholder to make the case why the RFF does not have the resource allocation as required by the CCDR. The Joint Staff is the broker of this step in the process. In some cases, the issue is resolved at this level with a negotiated resource allocation for or a formal withdrawal of the RFF from the CCDRs, removing the RFF. If the issue is not resolved and remains a contentious, it is elevated to the One-Star General Officer Flag Officer (GOFO) level.

7b. Decision Point. If unresolved after the action-officer level process, the contentious issue proceeds to a one-star GOFO level SVTC. The required participants include the one-star GOFO from the Joint Staff, each CCDR, and each Service force provider. This SVTC is an opportunity for each stakeholder to make the case why the recommendation does not meet the CCDR requirement. The Joint Staff is the broker of this step in the process. In some cases, the issue is resolved at this level with a negotiated resource allocation recommendation or a formal withdrawal of the RFF from the GCCs, removing the RFF. If the issue is not resolved and remains a contentious, the issue is elevated to the Three-Star GOFO Operations Deputies (OPSDEP) tank.

7c. Decision Point. If there is no resolution by this stage in the process, the contentious issue proceeds to a three-star GOFO Operations Deputies (OPSDEP) tank for resolution. The required participants include the three-star Operations Deputy GOFO from the Joint Staff, each GCC, and each Service force provider. This meeting is an opportunity for each stakeholder to make the case why the recommendation does not meet the

[4] Secretary of Defense. 2015. (U) *Dissemination of the Guidance for the Employment of the Force.* Department of Defense, Washington, DC. This document is classifed SECRET.

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CCDR requirement The Joint Staff is the broker of this step in the process. In some cases, the issue is resolved at this level with a negotiated resource allocation recommendation or a formal withdrawal of the RFF from the GCCs, removing the RFF.

7d. The unresolved issue remains contentious and is elevated to the Four-Star JCS tank. The JCS Tank adjudicates very few RFFs. For example, in fiscal year 2015, one ISR contentious issue went to the JCS for resolution. The specifics of the issue are classified; however, the context of the issue affected the overall force health of the Air Force remote piloted aircraft capability and required the attention and strategic prioritization of the Joint Chiefs of Staff. With a resource allocation decision made for the RFF, a risk to force assessment by the Service and a risk to mission assessment by the CCDR is included in the sourcing recommendation.

8. The Joint Staff compiles the RFFs and the sourcing solutions for SECDEF approval to deploy forces via the Global Force Management Allocation Plan (GFMAP) (Secretary of Defense 2016). The GFMAP authorizes the transfer of and attachment of forces from supporting CCDRs and Secretaries of the Military Departments and attachment to a supported CCDR. If a force allocated to one CCDR is shifted as a force sourcing solution to another CCDR, the CCDR from whom the force is reallocated is not a Force Provider, but must be consulted prior to reallocation.[5] Emergent ISR sourcing solutions often require reallocation across CCDRs due to the lack of overall ISR capacity. Prioritization on which CCDR will lose capability at the expense of another CCDR is an experienced-based subjective decision that would benefit by the implementation of an objective optimization tool set.

9. Decision Point. The Joint Staff briefs the details and the reason for the recommendation to the SECDEF on contentious issues for decision in GFMAP. The brief includes risk to mission and risk to force impacts. The SECDEF will make a risk informed decision to approve or deny each

[5] Secretary of Defense. 2016. (U) *"Global Force Management Implementation Guidance FY2016-2017."* Department of Defense, Washington, DC. This document is classifed SECRET.

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force recommendation in the GFMAP. The SECDEF assumes the risk to the CCDR mission when the allocation solution does not meet the CCDR requirements. The SECDEF assumes the risk to the force when the force allocation is at the expense of the force provider's force readiness.

10. The SECDEF approves the GFMAP and orders the force via the Global Force Management Allocation Plan (GFMAP) (Secretary of Defense 2016).

11. The process ends when the forces sourced deploy to the CCDR's AOR.

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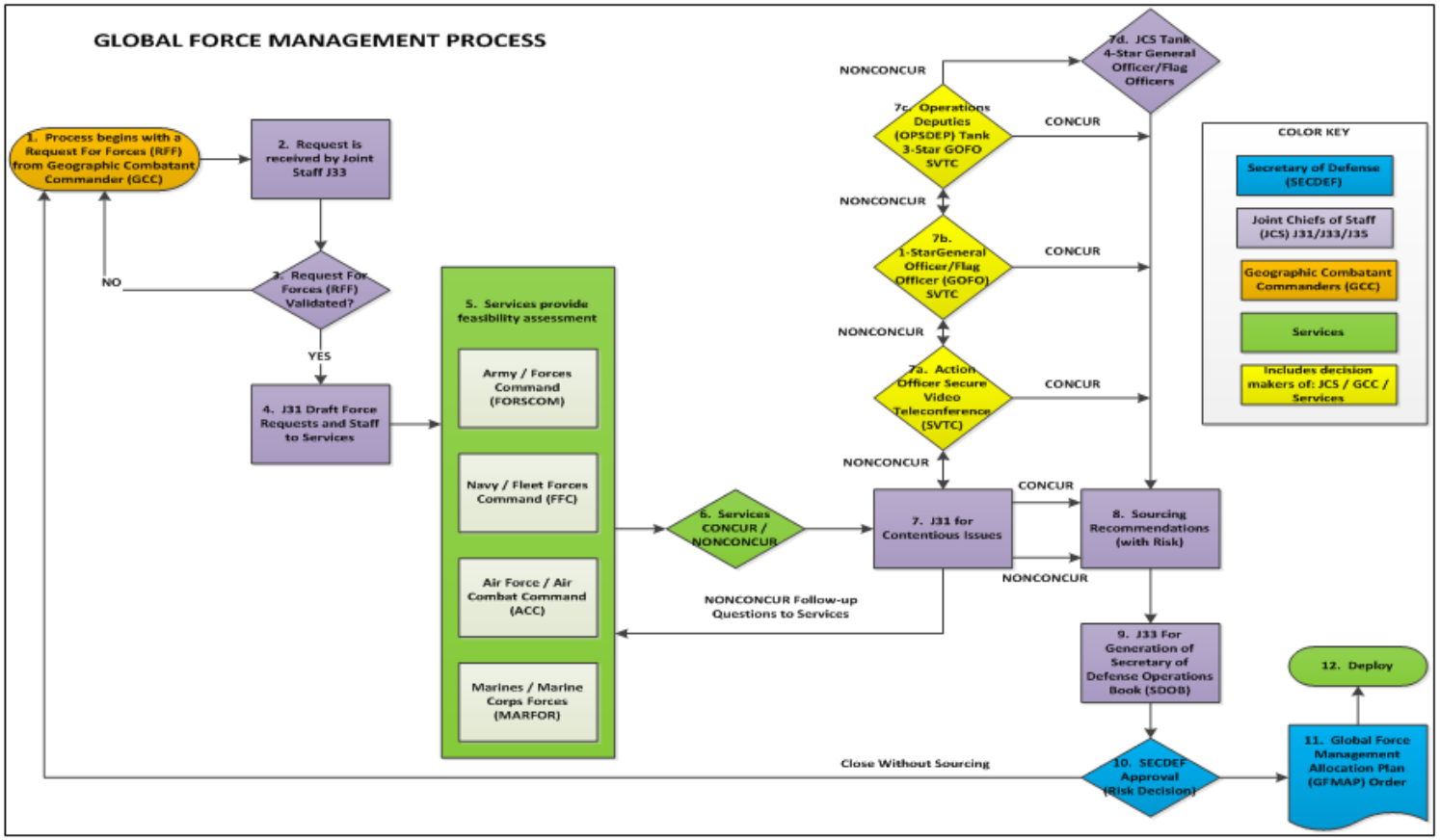


Figure 2. GFM Process Diagram Shows how the CCDRs Request Forces, the Requirement is Validated, and ultimately the SECDEF Orders the Forces.

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B. CURRENT ISR ALLOCATION PROCESS DISCUSSION

The intelligence, surveillance, and reconnaissance force allocation process includes additional steps in the force allocation process. Typically, ISR capabilities such as full motion video (FMV) are in high demand by CCDRs. However, the availability of ISR platforms is severely limited. ISR capability is described as high demand and low density. Because of the ability of ISR platforms to potentially service multiple CCDRs from a common operating location and competing demands for mission critical requirements, the allocation of ISR forces includes close coordination between the Joint Staff, CCDRs, force providers, and the Joint Functional Component Command for Intelligence, Surveillance, and Reconnaissance (JFCC ISR).

JFCC ISR is responsible to the Joint Staff and the Secretary of Defense to recommend the most effective use of the limited number of ISR platforms in support of CCDR objectives. For CCDR ISR requirements, the CCDR develops Concept of Collection Operations (CONOPS). The Global Force Management Allocation Policies and Procedures, CJCSM 3130.06A, direct JFCC ISR to evaluate CCDR ISR CONOPS to establish collection priorities to support of Operations Plans (OPLAN) and Concept Plans (CONPLAN). JFCC ISR analyzes the CONOP and accounts for all ISR requirements against categorized FAM priorities and operations areas. The ISR CONOP includes descriptions that address how all ISR collection assets including CCDR theater assets, national technical means (space-based), and Coalition partner capabilities are integrated to meet intelligence collection requirements.

JFCC ISR's assessment of the ISR CONOPS includes assumptions, operational constraints such as but not limited to aircraft basing options, over flight restrictions, collection processing limitations, C4I architecture limitations, and aircraft availability. The CCDR's ISR CONOPS should include a "what cannot be accomplished" risk statement if the requirements are not sourced or partially sourced. JFCC ISR's force allocation recommendations balance ISR gaps and shortfalls with CCDR priorities and force availability. Additionally, JFCC ISR uses trend analysis for comparing (increasing, decreasing, or steady) the previous fiscal year requirements with the proposed

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requirements for the current fiscal year. The analysis informs force allocation recommendations.

JFCC ISR makes the force allocation recommendation to the Joint Staff after the CCDR have submitted their ISR requirements to the Joint Staff and after the force providers have offered the available assets for allocation. The strategic priority of the FADM and previously described heuristics inform the recommendation. The proof of concept of the ISR allocation optimization model will apply similar heuristics and prioritization factors to inform both the Joint Staff and JFCC ISR in order to provide optimized recommendations to the SECDEF for the allocation of forces. Chapter III will introduce the model's objective function, which is to maximize the number of ISR capability hours provided to meet prioritized Geographic Combatant Commanders requirements.

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III. DATA PRESENTATION AND ANALYSIS

This chapter introduces the Global Force Management intelligence, surveillance, and reconnaissance allocation model. This model attempts to maximize the number of hours of ISR capability provided to the Geographic Combatant Commanders in a fiscal year to meet mission objectives. The optimization model uses a mixed integer linear programming formulation.

A. GLOBAL FORCE MANAGEMENT INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE ALLOCATION MODEL FORMULATION

1. Indices

i Full Motion Video (FMV) ISR platform type. For the purpose of this model, the following platforms will provide FMV capability to meet CCDR requirements:

- MQ-1B Predator
- MQ-1C Grey Eagle
- MQ-9 Reaper
- P-3C Orion
- Enhanced Medium Altitude Reconnaissance and Surveillance System (EMARSS)

j Combatant Commander with FMV requirements

- United States Africa Command (UAFRICOM)
- United States Central Command (USCENTCOM)
- United States European Command (USEUCOM)
- United States Northern Command (USNORTHCOM)
- United States Pacific Command (USPACOM)
- United Southern Command (USSOUTHCOM)

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2. Parameters and Data

$value_{ij}$ The FADM weighted platform consideration for ISR type *i* provided to CCDR *j*

$capacity_i$ Number of ISR hours available from force provider for platform *i* $\left[\text{hours/day}\right]$

req_j Number of total ISR hours required by CCDR *j* $\left[\text{hours/day}\right]$

lre_i Number of LRE sorties of ISR type *i* available from force provider $\left[\text{sorties/day}\right]$

$lre\_sorties_i$ Number of LRE sorties required to support one ISR type *i* sortie $\left[\text{hours/sortie}\right]$

3. Decision Variables

X_{ij} Number of ISR FMV hours from platform *i*, allocated to CCDR *j* $\left[\text{hours/day}\right]$

Y_{ij} Number of LRE sorties of type *i* allocated to CCDR *j* $\left[\text{sorties/day}\right]$

4. Objective Function

The goal of the ISR FMV allocation optimization model is to maximize the hours of FMV allocated to each CCDR to meet the prioritized mission requirements.

$$MAX\ Z = \sum_{ij} value_{ij} X_{ij} \qquad (1)$$

5. Constraints

$$\sum_{j} X_{ij} \le capacity_i \quad \forall i \qquad (2)$$

Constraint (2) ensures that the ISR sorties allocated to all CDDRs do not exceed force provider's capacity.

$$\sum_{i} X_{ij} \doteq req_j \quad \forall j \qquad (3)$$

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Elastic constraint (3) ensures CCDR each type ISR platform requirements are met if possible.

$$X_{ij} \leq lre\_sorties_i Y_{ij} \quad \forall i, j \qquad (4)$$

Constraint (4) ensures that LRE are allocated to support ISR platform sorties when required.

$$\sum_j Y_{ij} \leq lre_i \quad \forall i \qquad (5)$$

Constraint (5) requires that LRE sorties allocated to all CCDRs do not exceed the force provider's capacity.

$$X_{ij} \geq 0 \quad \forall ij \qquad (6)$$

Constraint (6) states that ISR FMV allocation hours must be non-negative.

$$Y_{ij} \equiv \text{integer} \quad \forall ij \qquad (7)$$

Constraint (7) enforces integer restrictions on all LRE platform decision variables.

This chapter introduced the equations that build the model. Chapter III goes into detail about the indices, parameters, and constraints that influence the objective function. It describes how the model is developed and discussions the assumptions used.

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IV. DATA, RESULTS, AND ANALYSES

This chapter describes in detail the indices, parameters, and constraints introduced in Chapter III using notional data and the assumptions made in the model development. The notional data provides results and informs the analysis of the model influenced by FADM and platform type. This chapter describes the analyses of the results. The model was solved using Microsoft Excel with Solver add-in.

A. HYPOTHETICAL DATA AND DEVELOPMENT

The ISR allocation optimization model applies to any of the ISR requirement capabilities, including but not limited to Full Motion Video (FMV), Signals Intelligence (SIGINT), Communications Intelligence (COMINT), and other intelligence collection capabilities. The complexity of FMV force allocation makes FMV the ideal capability to use for a proof of concept. FMV is real-time video imagery used for intelligence collection (Lockheed Martin 2016). For the purpose and scope of this thesis, FMV will be limited to airborne platforms. It does not include space-based imagery systems.

FMV is critical to the war fighter. It provides CCDRs real-time pattern of life of the battle space. It is one piece of the intelligence information puzzle. FMV combined with satellite imagery such as Google Earth and electronic warfare data provides decision makers the situational awareness required to meet mission objectives (C4ISRNET 2016). Figure 3 is a snapshot of one image of FMV. As a still image, it shows three vehicles in a single-file line along a road. Using FMV as a stream of video imagery over time, it provides point of origin of this group of vehicles and ultimate destination of these vehicles. Knowing where the trucks came from helps decision makers to distinguish if the vehicles are friendly, hostile, or potentially hostile forces on the move. This is an oversimplified example of the potential of FMV that illustrates how critical maintaining awareness of the operating area is to CCDRs. FMV combined with an armed platform allows for the rapid engagement of a time-critical target. FMW is a critical requirement to meet CCDR objectives and strategic priorities.

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Hypothetical data is used to keep this thesis unclassified. The platform capabilities come from a small sampling of ISR FMV platforms that have sufficient open-source information to make the model relevant. The hypothetical CCDR requirements are derived from and loosely based on historical data from GFMAP force allocations. Actual CCDR requirements, force capacities, and FADM priorities are classified. The model uses a methodical approach using known data and informed assumptions to develop reasonable scenarios to implement in the model.

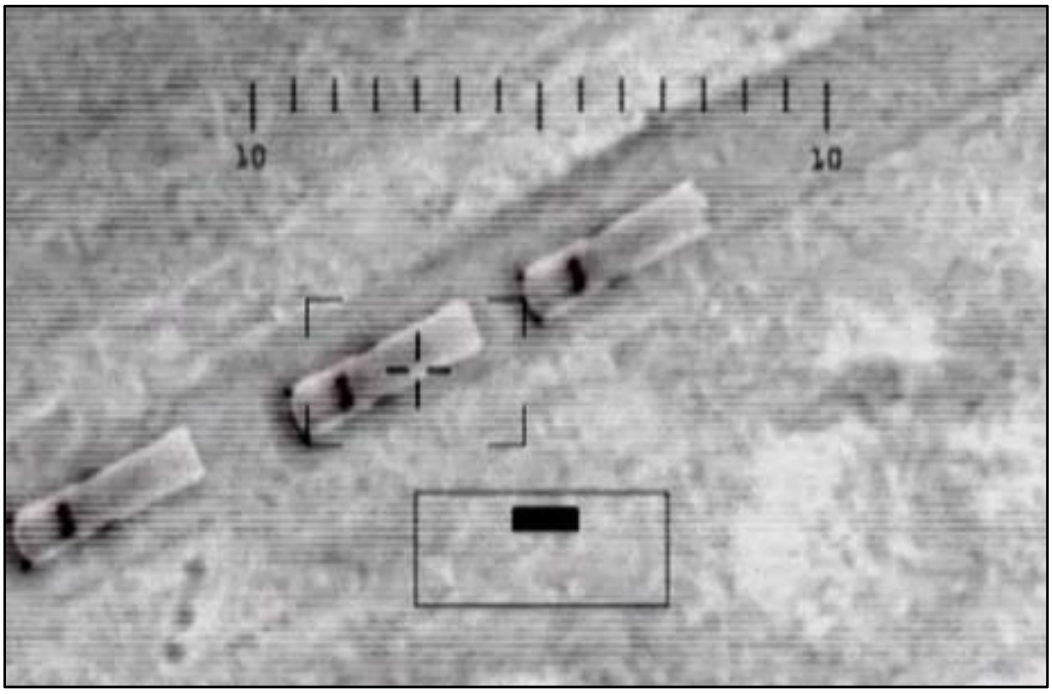


Figure 3. Full Motion Video (FMV) Example.
Source: Lockheed Martin (2016).

B. FORCE ALLOCATION MODEL DISCUSSION

This section describes in detail the formulation of the optimization model. It describes the indices of ISR platform types and CCDR requirements. The key to the understanding the optimization formulation is in the understanding of how the parameters are defined. The parameters are a combination of known objective data such as the force provider capacity of a specific platform, and an attempt to quantify heuristic data such as the importance of a particular platform type to a specific CDDR requirement.

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Understanding how the parameters effect the optimized solution informs the decision influencers to which parameters influence the formulation the most. The impact is useful to the force provider, the CDDR, and the Joint Staff. The force provider may use the data to apply additional funding to the area that has the most significant gains. The force provider can also use the data to identify areas that present a risk to force and inform the decision to determine if there are significant gains to meeting CCDR requirements while accepting additional risk to force. For CCDRs, this shows objectively where the CCDR has determined how important a requirement is and how that same importance influenced the resource allocation. By looking at the results, the CCDR can see where their requirement priorities are evaluated globally across all of the CCDR's requirements. The Joint Staff can evaluate the data to verify that the results support the military objectives of the National Military Strategy. The Joint Staff can use the formulation to run recommendation scenarios to model where largest gains from risk to force and risk to mission can be made. The information can influence recommendation to the SECDEF to order a force provider to provide additional assets at the expense of long-term force readiness. This optimization model provides transparency that is not easily interpreted or understood in the current ISR force allocation process.

1. Indices

a. Full Motion Video Platform Types

The optimization model uses a sampling of FMV capable aircraft to prove the concept. Although there are many FMV capable aircraft, the aircraft types selected include platforms from each Service that have allocable ISR aircraft. The selection includes manned and remotely piloted aircraft to show that the optimization model reflects current capabilities and that it can adapt to reflect future capabilities.

(1) MQ-1B Predator

The MQ-1B Predator is a remotely piloted reconnaissance aircraft built by General Atomics Aeronautical System Inc. The United States Air Force is the force provider for USAF MQ-1B Predators. A Predator system includes four aircraft, a ground

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control station, operators, and maintenance to support 24-hour missions anywhere in the world (Air Combat Command 2015). Pilots at the ground control stations fly the aircraft using data-link.

An MQ-1B carries a full motion video imaging sensor. It can either armed or unarmed with two laser-guided air to ground AGM-114 Hellfire missiles (Air Combat Command 2015). The aircraft has a range of 770 miles (Air Combat Command 2105). The combination of persistent FMV and air to ground armament allow the CCDR capability to engage time critical targets.



Figure 4. MQ-1B Predator (U.S. Air Force photo/Staff Sgt. Brian Ferguson). Source: Air Combat Command (2015).

(2) MQ-1C Gray Eagle

The MQ-1C Gray Eagle is an unmanned aircraft system built by General Atomics Aeronautical System Inc. The United States Army is the force provider for USA MQ-1C Grey Eagles. The Army deploys the Grey Eagle platoon as part of the Combat Aviation Brigade. Four aircraft, two ground control stations and terminals, one portable ground

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control station, communication equipment, ground support equipment, and 127 people make up one Gray Eagle platoon (United States Army 2016).

The Gray Eagle can carry an electro-optical sensor and up to four AGM-114 Hellfire missiles that provide FMV and strike capability to the CCDR (General Atomics Aeronautical 2016). The MQ-1C has a 2,500 miles range and an endurance profile of 27 hours (United States Army 2016). Q-1C Grey Eagle (General Atomic photo). Source: (General Atomics Aeronautical 2016)



Figure 5. MQ-1C Grey Eagle. Source: United States Army (2016)

(3) MQ-9 Reaper

The MQ-9 Reaper is a remote-piloted aircraft built by General Atomics Aeronautical Systems. The United States Air Force is the MQ-9 force provider. The MQ-9 Reaper provides combined FMV and strike capability against time-sensitive targets (Air Combat Command 2015). Reaper aircraft use multiple types of imaging sensors to provide full motion video capability (United States Air Force 2015). Like the MQ-1C, the MQ-9 can carry up to four AGM-114 Hellfire in addition to the FMV sensors.

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The MQ-9 units have four aircraft, a ground control station, and communication equipment. The 1,150 miles aircraft range is significantly more than the range MQ-1B Predator (United States Air Force 2015). In some cases, CCDR prefer the MQ-9 Reaper to the MQ-1B Predator due to the additional range and armament capacity of the Reaper platform.



Figure 6. Armed MQ-9 Reaper (U.S. Air Force Photo / Lt. Col. Leslie Pratt). Source: Air Combat Command (2015).

(4) P-3C Orion

The P-3C Orion is a U.S. Navy full motion video capable patrol aircraft built by Lockheed Martin (Lockheed Martin 2016). The P-3C Orion is a manned aircraft with multiple sensors including surface search radar and electro-optical real time video cameras. The P-3C Orion can be armed with AGM-84 Harpoon, AGM-84K SLAM-ER, AGM-65F Maverick missiles, Mk46/50/54 torpedoes, rockets, and mines (United States Navy 2016). The Orion has a range of 1,548 miles and an endurance of more than 12 hours (Janes IHS 2016). Unlike the remote piloted MQ-1B, MQ-1C, and the MQ-9 aircraft, the P-3C is a manned aircraft that can use on board real time video processing of

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FMV to prosecute targets on the ground (Lockheed Martin 2016) . Additionally the P-3C Orion has the capability to deliver anti-ship and anti-submarine ordnance to meet specific over water CCDR requirements.



Figure 7. P-3C Orion, captured by U.S. Navy Photo/Photographers Mate 2nd Class Elizabeth L. Burke. Source: United States Navy (2016).

(5) Enhanced Medium Altitude Reconnaissance and Surveillance System

The Enhanced Medium Altitude Reconnaissance and Surveillance System (EMARSS) is an United States Army ISR aircraft capable of providing FMV. EMARSS is an example of a successful Army program of record program that is taking former U.S. Air Force Liberty C-12 aircraft and integrating them into the Army EMARSS program (United States Army 2016). EMARSS and programs like it, are getting ISR capabilities to the warfighter through rapoid acquisition authority (United States Army 2016). The number and types of platforms in the optimization model can expand and include new or adpated technologies such as EMARSS.

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Figure 8. U.S. Army Enhanced Medium Altitude Reconnaissance and Surveillance System. Source: United States Army (2016).

b. Combatant Commanders

The Unified Command Plan of the United States divides the world into geographic regions and assigns responsibilities to geographic combatant commanders. Figure 3 illustrates the geographic division by CCDR.

(1) United States Africa Command

United States Africa Command (USAFRICOM) is responsible for the Unites States interests in Africa. It builds and strengthens military relations with African countries and the African Union to increase security and counter transnational threats (U.S. Department of Defense 2011).

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(2) United States Central Command

United States Central Command (USCENTCOM) is responsible for United States military operations in 20 countries including Afghanistan, Bahrain, Egypt, Iran, Iraq, Jordan, Kazakhstan, Kuwait, Kyrgyzstan, Lebanon, Oman, Pakistan, Qatar, Saudi Arabia, Syria, Tajikistan, Turkmenistan, United Arab Emirates, Uzbekistan and Yemen. The mission of USCENTCOM is increasing stability in the region through international partnerships (U.S. Department of Defense 2011).

(3) United States European Command

United States European Command (USEUCOM) is responsible for building and maintaining military partnerships with European, Middle Eastern, and Eurasian nations, including the North Atlantic Treaty Organization (NATO) to increase the security in EUCOM's area of responsibility (U.S. Department of Defense 2011).

(4) United States Northern Command

United States Northern Command (USNORTHCOM) is responsible for continental United States, Alaska, Mexico, Canada, portions of the Caribbean and surrounding waters. It also oversees the North American Aerospace Defense Command (NORAD).

(5) United States Pacific Command

United States Pacific Command (USPACOM) has the largest geographic area of responsibility including 36 nations and the waters of the United States west coast extending to the western border of India, and from Antarctica to the North Pole (U.S. Department of Defense 2011). USPACOM builds and fosters military partnerships to enhance security in the region.

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(6) United States Southern Command

United States Southern Command (USSOUTHCOM) is responsible for an area of 31 nations in Latin America, Central America, South America, and the Caribbean Sea. USSOUTHCOM's security efforts include promoting human rights, to deter illegal illicit trafficking and conducting multinational military exercises that build and foster partnerships (U.S. Department of Defense 2011).



Figure 9. Commander's Area of Responsibility.
Source: U.S. Department of Defense (2011).

(7) Combatant Commander Prioritization Factor Discussion

When implementing the optimization model, it is important for decision influencers to distinguish when force allocations are exclusively weighted and factored to FADM priority. For example: NORTHCOM has the responsibility to defend the United States (U.S.) against attacks to the U.S. homeland. Due to the consequences of the effects

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if the U.S. is attacked, USNORTHCOM may have the highest FADM priorities for many of its requirements. However, the resource allocation may need to be balanced to provide ISR assets to a CCDR that is actively engaged in combat operations. At the time of writing this thesis, the U.S. is involved in large-scale combat operations in USCENTCOM and USAFRICOM areas of responsibility.

In further development of this model and refining the factors that influence the optimization, a refinement of how priority will factor into the risk to potential OPLANs, versus the risk to ongoing combat operations will make the optimization model more relevant.

2. Parameters

a. $value_{ij}$

The $value_{ij}$ parameter is a numerical value assigned to the priority for sourcing of each requirement of CCDR *j* by platform *i*. It is based on a prioritization derived from FADM and platform considerations. The higher the FADM priority assigned by the Joint Staff, the larger the value that will applied to the requirement in the model. The actual is FADM is classified. Table 1 is an unclassified notional example of how the FADM priority is weighted with a value. A FADM of 1.1.1 has the highest priority and weighted the most. Assigning a weight factor to FADM priority enables the objective formula to allocate FMV capability to CCDR requirements that have the highest priority. According to the fiscal years 2015 and 2016 Global Force Management Allocation Plan, this is not the case (Secretary of Defense 2015; 2016). CCDRs prioritize against what they want. Not necessarily optimized against the FADM priorities. In this model, the highest FADM must receive some sourcing before lower FADM requirements.

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Table 1. FADM Priority and Weight Factor

FADM	Weight Factor	FADM	Weight Factor	FADM	Weight Factor
1.1.1	100	2.1.1	60	3.1.1	30
1.1.2	99	2.1.2	59	3.1.2	29
1.1.3	98	2.1.3	58	3.1.3	28
1.1.4	97	2.1.4	57	3.1.4	27
1.1.5	96	2.1.5	56	3.1.5	26
1.1.6	95	2.1.6	55	3.1.6	25
1.1.7	94	2.1.7	54	3.1.7	24
1.2.1	93	2.2.1	53	3.2.1	23
1.2.2	92	2.2.2	52	3.2.2	22
1.2.3	91	2.2.3	51	3.2.3	21
1.2.4	90	2.2.4	50	3.2.4	20
1.2.5	89	2.2.5	49	3.2.5	19
1.2.6	88	2.2.6	48	3.2.6	18
1.2.7	87	2.2.7	47	3.2.7	17
1.3.1	86	2.3.1	46	3.3.1	16
1.3.2	85	2.3.2	45	3.3.2	15
1.3.3	84	2.3.3	44	3.3.3	14
1.3.4	83	2.3.4	43	3.3.4	13
1.3.5	82	2.3.5	42	3.3.5	12
1.3.6	81	2.3.6	41	3.3.6	11
1.3.7	80	2.3.7	40	3.3.7	10

This table is an example of how notional FADM priority assigns a weight factor used in the $value_{ij}$ parameter for each requirement. The FADM weight factor represents the "global" tradeoffs made between the competing CCDR requirements.

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FADM is not the only factor that influences $value_{ij}$. In this model, each CCDR requirement is further categorized into platform *i* to allow platform consideration to influence the objective function. Equation (8) shows that FADM weight factor is multiplied across each CCDR's platform considerations. The platform consideration factor for CCDR $_i$, $scale_i$, determines to what extent the objective function is influenced by specific platform preferences for each requirement. The Joint Staff and JFCC ISR with the CCDR determine the platform consideration factor for each requirement.

$$value_{ij} = \sum_i W_i(scale_i) \quad \forall j \qquad (8)$$

Where,

W_i = FADM weight factor

$Scale_i$ = platform consideration factor

Table 2 illustrates how notional CCDR requirements affect $value_{ij.}$ For example, USAFRICOM requirement number 118003 shows that any FMV platform is suitable by having a multiplier of 1 for each platform except MQ-9. The MQ-9 notional multiplier is 1.1, meaning the MQ-9 is preferred. As a result, the $value_{ij}$ for that requirement is influenced accordingly.

In another example, USCENTCOM requirement number 218003 has 0 as a multiplier to each platform except the P-3C AIP which is 1. This means that the preferred platform to provide capability to that requirement is the P-3C AIP.

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Table 2. Example of $value_{ij.}$ Table for Model Calculations

	USAFRICOM			USCENTCOM		
Requirement Tracking Number	118001	118002	118003	218001	218002	218003
Requirement Hours/Month	1100	200	300	4700	700	22100
Requirement Hours/Day	36	7	10	155	23	727
FADM	1.2.3	3.1.1	1.2.3	2.2.5	1.2.2	1.2.3
FADM Weight Factor	91	30	91	49	92	91
MQ-1B	1	1	1	1	1	0
MQ-1C	1	1	1	0	1	0
MQ-9	1	1	1.1	1	1	0
P-3 AIP	1	1	1	0	1	1
EMARSS	1	1	1	1	1	0
	USAFRICOM			USCENTCOM		
$Value_{ij}$	118001	118002	118003	218001	218002	218003
MQ-1B	**91**	**30**	**91**	**49**	**92**	**0**
MQ-1C	**91**	**30**	**91**	**0**	**92**	**0**
MQ-9	**91**	**30**	**100.1**	**49**	**92**	**0**
P-3 AIP	**91**	**30**	**91**	**0**	**92**	**91**
EMARSS	**91**	**30**	**91**	**49**	**92**	**0**

The columns contain the CCDR capability requirements. The grey rows contain the capability requirement. The light blue rows represent the FADM weight factor. The yellow rows beneath the weight factor contain the platform consideration factor. The dark blue rows represent $value_{ij}$ computed using Equation (8).

b. $capacity_i$

The $capacity_i$ parameter is the Number of ISR hours available from force provider for platform *i*. Provided by force provider in units of number of sorties per month for each platform type. The sorties per month are converted to sorties per day then the units are converted to hours per day for the model using the unclassified notional planning factors.

c. req_j

The req_i parameter is the numbers of ISR capability hours required by CCDR j. CCDRs provide requirements in units of hours per month of a specific capability. For this model, the unit of measurement of the capability converts from hours of FMV required per month to per day. The CCDR does not specify a particular platform such as MQ-9 or EMARSS. The requirement is for capability (Secretary of Defense 2016).

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d. lre_i

The lre_i parameter is the number of Launch and Recovery Elements (LRE) of ISR type *i* available from force provider for platform *i*. MQ-1B and MQ-9 each require a LRE to support the takeoff and landing of each sortie. An LRE is platform specific. For example, a MQ-1B LRE can only support MQ-1B sorties. It cannot support MQ-9 sorties. The force provider can only support a limited number of LREs. The number of LRE crews that can operate each LRE at the location combined with the number of systems that can control the aircraft set the LRE capacity limit. Additionally, each LRE has a maximum number of sorties that a single LRE can support. For the purpose of this model, the number of sorties each LRE can support is five sorties per day for each platform type. The LRE parameter in this model only applies to MQ-1B and MQ-9. The Air Force is the force provider for the LREs and sets the limit to both how may LREs are available for force allocation and how many sorties each LRE can support. The LREs deploy to the location from where the MQ-1B and MQ-9 sorties take off and land.

e. cap_lre_i

The cap_lre_i parameter is the number of sorties per day that each LRE of platform type *i* can support.

f. $lre\_sorties_i$

The $lre\_sorties_i$ parameter is the numbers of sorties per day that support ISR of type *I* available from force provider. The Force Provider sets the total number of sorties that flown each day in support of CCDR. The number of Remote Piloted Aircraft (RPA) pilots, RPA sensor operators, and the Process, Exploitation, and Dissemination (PED) capacity available limit the number of RPA sorties available for allocation. Each sortie requires aircraft, RPA pilot crew, RPA sensor operator crew, and PED crew.

g. $collect_i$

The $collect_i$ parameter is the number of hours of ISR type *i* collection per sortie. JFCC ISR and the force provider determine the sortie length for the number of collection hours each aircraft can support.

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3. Decision Variables

a. X_{ij}

X_{ij} is the number of ISR FMV hours from platform *i* allocated to CCDR *j*. The units convert from hours per month to hours per day to simplify conversion to sorties per day to align with the sortie per day limitation set by the force provider.

b. Y_{ij}

Y_{ij} is the number of LRE sorties of type *i* allocated to CCDR *j*. The units convert from hours per month to sorties per day to align with the sortie per day limitation set by the force provider.

4. Objective Function

The goal of the ISR FMV allocation optimization model is to maximize the hours of FMV allocated to each CCDR to meet the prioritized mission requirements. The optimization model uses a mixed integer linear program formulation.

$$MAX\ Z = \sum_{ij} value_{ij} X_{ij} \qquad (1)$$

C. CONSTRAINTS

1. Sourcing Capacity Constraints

To maximize the utilization of a limited number of assets, each CCDR's requirement is equal to or greater than the sourcing recommendation. The optimized solution will not provide a CCDR more allocation of resources than what the requirement demand is.

$$\sum_{j} X_{ij} \le capacity_{i} \quad \forall i \qquad (2)$$

Constraint (2) ensures that the ISR sorties allocated to all CDDRs do not exceed force provider's capacity. However, the goal of the model is to try and allocate resources to meet and satisfy each CCDR requirement. The requirements exceed capacity. This

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makes the model infeasible. To make the model feasible an elastic variable constraint (3) is applied.

$$\sum_i X_{ij} \doteq req_j \quad \forall j \qquad (3)$$

Elastic constraint (3) ensures CCDR each type ISR platform requirements are met if possible.

2. Launch and Recovery Element (LRE) Constraints

$$X_{ij} \le lre\_sorties_i Y_{ij} \quad \forall i, j \qquad (4)$$

Constraint (4) ensures that LREs are allocated to support ISR platform sorties when required.

$$\sum_j Y_{ij} \le lre_i \quad \forall i \qquad (5)$$

Constraint (5) requires that LRE sorties allocated to all CCDRs do not exceed the force provider's capacity.

3. Nonnegativity Constraint

$$X_{ij} \ge 0 \quad \forall ij \qquad (6)$$

Constraint (6) states that ISR FMV allocation hours must be non-negative.

4. Integrality Constraint Integrality Constraint

$$Y_{ij} \equiv \text{integer} \quad \forall ij \qquad (7)$$

Constraint (7) enforces integer restrictions on all LRE platform decision variables.

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D. MODEL RESULTS AND ANALYSIS

This section discusses the results of the Global Force Management Intelligence, Surveillance, and Reconnaissance Allocation model. The model allocates forces to meet the most requirements using the objective function. The first sub-section describes how penalties are applied to the objective function to manage the trade-off between LRE constraints and CCDR requirement constraints. The second sub-section describes the model results of keeping the $value_{ij}$ parameter constant across all of the CCDR requirements and only applying FADM as the priority. The third sub-section describes the results of the model after adding CCDR platform consideration to each requirement. Both scenarios use the same twenty CCDR requirements and same the force provider capacities. The requirements are notional. Seven of the requirements have the same FADM priority to simulate the complexity of c CCDR's competing priorities.

1. Objective Function

The objective function (1) shows how FADM and platform consideration influences the model solution.

$$MAX\ Z = \sum_{ij} value_{ij} X_{ij} - \sum_{ij} (LRE\_penalty) Y_{ij} - \sum_{ij} (value_{ij}\_penalty)(elastic\_variable)$$

Breaking down the objective function into its three parts shows how the LRE_penalty and the value_penalty affect the model.

$$\sum_{ij} value_{ij} X_{ij}$$

The sum of the product of $value_{ij}$ * X_{ij} in the objective function encourages the model to maximize the resource allocation to the requirements that give have the highest value. The $value_{ij}$, is influenced by FADM priority and platform consideration. The parameter $value_{ij}$ is the weight factor applied to the requirement. The higher the $value_{ij}$, the more the model will allocate forces to those requirements.

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$$-\sum_{ij}(LRE\_penalty)Y_{ij}$$

Subtracting the sum of the product of the LRE_penalty * Y_{ij} in the objective function ensures that an LRE is only allocated when necessary. A penalty factor influences when it is necessary to allocate a LRE. To minimize the penalty and drive force allocation efficiency, the LRE_penalty maximizes the number of sorties at each LRE. In implementing the model, the LRE_penalty can be manipulated to influence how easy it is for the model to allow an LRE allocation. The greater the penalty factor, the less likely the formula model will allocate an LRE to a requirement. The lesser the penalty factor, the more likely an LRE will be allocated to each requirement

The objective function must balance the LRE_penalty with the overall intent. In this scenario CCDR's requirements are greater than the total ISR FMV capacity. Requirements need all of the available capacity allocated to CCDR requirements and we want to maximize the number of sorties that each LRE supports. If the LRE_penalty is set too high, the objective function will not allocate LREs to the requirements. If the penalty is set too low, LREs are allocated without maximizing the efficiency in the number of sorties that each LRE can support.

$$-\sum_{ij}(value_{ij}\_penalty)(elastic\_variable$$

Lastly, subtracting the sum of the product of $value_{ij}$_penalty and its associated elastic variable ensures feasibility through the elastic constraint of equation (3). The $value_{ij}$_penalty is the trade-off between FADM priority and CCDR's platform preference, as represented by the platform preference factor. The higher the $value_{ij}$_penalty, the greater the FADM priority influences the optimized solution. The lower the $value_{ij}$_penalty, CCDR platform preference priority influences the optimized solution.

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2. Base Model—FADM Prioritized Results

As decision influencers, may want to provide an optimized recommendation strictly based on FADM priority agnostic to the consideration of the type of platform to meet each requirement. This scenario assumes any of the FMV ISR platforms can equally meet the capability requirement. Using the data developed in the previous sections, this subsection presents the initial or *base* model results. The lower chart in Table 3 shows that the model allocates one-hundred percent of the force provider capacity. However, only 902 hours per day of the 1902 hours per day requirement are allocated. This means that 47 percent of the CCDR requirement is satisfied.

The highest thirteen FADM requirements receive FMV capacity. Twelve of those 13 requirements are fully allocated resources. Requirement number 218005 is the next highest FADM priority of 1.3.1, with a FADM weight factor of 86. As shown in Table 3 of the Hours Allocated row, the model allocates 39 hours per day.

Implementing a FADM prioritized model can inform decision makers by providing a solution that shows how forces could be allocated if the objective function is strictly enforcing GEF direction. With fewer assets available than CCDR requirements demand, this method will also show the capability gaps in force allocation. For the force providers and DOD budget personnel, the gaps highlight areas where additional resources can be committed to meet strategic objectives. Although a clearly prioritized optimization model is useful for planning purposes, it does not reflect the reality of ISR FMV force allocation. In fiscal years 2015 and 2016, the SECDEF ordered force allocation was not exclusively based on FADM priority (Secretary of Defense 2015; 2016). The GFMAP considered several additional factors including emerging strategic goals, domestic and international politics, and force provider readiness.

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Table 3. Base Model -FADM Prioritized Results

	USAFRICOM			USCENTCOM						USEUCOM					USNORTHCOM		USPACOM		USSOUTHCOM	
Requirement Tracking Number	118001	118002	118003	218001	218002	218003	218004	218005	218006	318001	318002	318003	318004	318005	418001	418002	518001	518002	618001	61800
Requirement Hours/Month	1100	200	300	4700	700	22100	180	13700	8700	550	730	180	90	30	180	240	100	720	360	3000
Requirement Hours/Day	36	7	10	155	23	727	6	450	286	18	24	6	3	1	6	8	3	24	12	99
FADM	**1.2.3**	**3.1.1**	**1.2.3**	**2.2.5**	**1.2.2**	**1.2.3**	**1.2.3**	**1.3.1**	**1.3.3**	**1.2.3**	**1.2.3**	**1.2.4**	**1.2.6**	**1.2.6**	**1.1.2**	**2.1.7**	**1.2.2**	**3.3.7**	**2.1.7**	**2.1.7**
FADM Weight Factor	91	30	91	49	92	91	91	86	84	91	91	91	88	88	99	54	92	10	54	54
MQ-1B	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MQ-1C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MQ-9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P-3 AIP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
EMARSS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	USAFRICOM			USCENTCOM						USEUCOM					USNORTHCOM		USPACOM		USSOUTHCOM	
Value$_{ij}$	118001	118002	118003	218001	218002	218003	218004	218005	218006	318001	318002	318003	318004	318005	418001	418002	518001	518002	618001	61800
MQ-1B	91	30	91	49	92	91	91	86	84	91	91	91	88	88	99	54	92	10	54	54
MQ-1C	91	30	91	49	92	91	91	86	84	91	91	91	88	88	99	54	92	10	54	54
MQ-9	91	30	91	49	92	91	91	86	84	91	91	91	88	88	99	54	92	10	54	54
P-3 AIP	91	30	91	49	92	91	91	86	84	91	91	91	88	88	99	54	92	10	54	54
EMARSS	91	30	91	49	92	91	91	86	84	91	91	91	88	88	99	54	92	10	54	54
	USAFRICOM			USCENTCOM						USEUCOM					USNORTHCOM		USPACOM		USSOUTHCOM	
Results	118001	118002	118003	218001	218002	218003	218004	218005	218006	318001	318002	318003	318004	318005	418001	418002	518001	518002	618001	61800
MQ-1B	0	0	0	0	12	144	0	0	0	0	24	0	0	0	0	0	0	0	0	0
MQ-1C	0	0	0	0	0	259	6	11	0	4	0	6	3	1	6	0	3	0	0	0
MQ-9	0	0	0	0	0	168	0	28	0	14	0	0	0	0	0	0	0	0	0	0
P-3 AIP	0	0	0	0	0	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EMARSS	36	0	10	0	11	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MQ-1B LRE Allocated	0	0	0	0	1	12	0	0	0	0	2	0	0	0	0	0	0	0	0	0
MQ-9 LRE Allocated	0	0	0	0	0	12	0	2	0	1	0	0	0	0	0	0	0	0	0	0
Hours Allocated	**36**	**0**	**10**	**0**	**23**	**727**	**6**	**39**	**0**	**18**	**24**	**6**	**3**	**1**	**6**	**0**	**3**	**0**	**0**	**0**
% of Requirement Met	100	0	100	0	100	100	100	9	0	100	100	100	100	100	100	0	100	0	0	0

Force Provder Capacity	**Hours/Day**	**Hours/Day Allocated**	**% Allocated**
MQ-1B	180	180	100
MQ-1C	300	300	100
MQ-9	210	210	100
P-3 AIP	112	112	100
EMARSS	100	100	100
LRE Capacity	**Sorties/Day**	**Sorties/Day Allocated**	**% Allocated**
MQ-1B LREs	15	15	100
MQ-1C LREs	15	15	100

The upper chart shows the complete set CCDR requirements used in the (base) model and what platforms were allocated to meet those requirements. In this (base) model platform consideration is the same for all requirements. The lower chart contains the force provider capacity by platform and how many hours and the percentage of the capacity is allocated by platform.

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3. CCDR Platform Consideration Sensitivity Analysis

Combatant Commanders have the best insight to what specific platforms can best meet their requirements. However, coordination is required that looks across the whole ISR enterprise for capabilities. JFCC ISR is responsible for providing that coordination. For example, a partner nation may not allow remotely-piloted aircraft flown from their country. In order to mitigate those external factors and meet the mission requirement, the CCDR or JFCC-ISR may prioritize a manned platform type. Additionally, certain platforms are better equipped for particular missions. This section conducts some sensitivity analysis by changing input data from our base model presented in section IV.D.2.

With no other changes to the base model, Table 4 shows how sensitive the model is to a change of $value_{ij}$ parameter for a particular platform. This change may represent when the platform consideration is modified based on new information or just to examine model sensitivity. In this example, the scale associated with requirement number 218003 changes for ISR platforms of EMARSS and P-3 AIP from 1 to 1.5 and which results in a change in the associated *scales* for remotely piloted aircraft to 0.5 from 1. The associated $value_{ij}$ changes from 91 to 136.5 and from 91 to 45.5 for the manned and remotely piloted aircraft, respectively. These changes simulate the preference for manned ISR platforms to meet the 218003 requirement.

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Table 4. Combined CCDR and FADM Prioritized Model Results Example 1

	USAFRICOM			USCENTCOM						USEUCOM					USNORTHCOM		USPACOM		USSOUTHCOM	
Requirement Tracking Number	118001	118002	118003	218001	218002	218003	218004	218005	218006	318001	318002	318003	318004	318005	418001	418002	518001	518002	618001	618002
Requirement Hours/Month	1100	200	300	4700	700	22100	180	13700	8700	550	730	180	90	30	180	240	100	720	360	3000
Requirement Hours/Day	36	7	10	155	23	727	6	450	286	18	24	6	3	1	6	8	3	24	12	99
FADM	**1.2.3**	**3.1.1**	**1.2.3**	**2.2.5**	**1.2.2**	**1.2.3**	**1.2.3**	**1.3.1**	**1.3.3**	**1.2.3**	**1.2.3**	**1.2.4**	**1.2.6**	**1.2.6**	**1.1.2**	**2.1.7**	**1.2.2**	**3.3.7**	**2.1.7**	**2.1.7**
FADM Weight Factor	91	30	91	49	92	91	91	86	84	91	91	91	88	88	99	54	92	10	54	54
MQ-1B	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MQ-1C	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MQ-9	1	1	1	1	1	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P-3 AIP	1	1	1	1	1	1.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
EMARSS	1	1	1	1	1	1.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	USAFRICOM			USCENTCOM						USEUCOM					USNORTHCOM		USPACOM		USSOUTHCOM	
Value$_{ij}$	118001	118002	118003	218001	218002	218003	218004	218005	218006	318001	318002	318003	318004	318005	418001	418002	518001	518002	618001	618002
MQ-1B	91	30	91	49	92	45.5	91	86	84	91	91	91	88	88	99	54	92	10	54	54
MQ-1C	91	30	91	49	92	45.5	91	86	84	91	91	91	88	88	99	54	92	10	54	54
MQ-9	91	30	91	49	92	45.5	91	86	84	91	91	91	88	88	99	54	92	10	54	54
P-3 AIP	91	30	91	49	92	136.5	91	86	84	91	91	91	88	88	99	54	92	10	54	54
EMARSS	91	30	91	49	92	136.5	91	86	84	91	91	91	88	88	99	54	92	10	54	54
	USAFRICOM			USCENTCOM						USEUCOM					USNORTHCOM		USPACOM		USSOUTHCOM	
Results	118001	118002	118003	218001	218002	218003	218004	218005	218006	318001	318002	318003	318004	318005	418001	418002	518001	518002	618001	618002
MQ-1B	36	0	0	0	12	0	0	132	0	0	0	0	0	0	0	0	0	0	0	0
MQ-1C	0	0	10	0	11	0	6	108	104	18	24	6	3	1	6	0	3	0	0	0
MQ-9	0	0	0	0	0	0	0	210	0	0	0	0	0	0	0	0	0	0	0	0
P-3 AIP	0	0	0	0	0	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EMARSS	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MQ-1B LRE Allocated	3	0	0	0	1	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0
MQ-9 LRE Allocated	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0
Hours Allocated	**36**	**0**	**10**	**0**	**23**	**212**	**6**	**450**	**104**	**18**	**24**	**6**	**3**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
% of Requirement Met	100	0	100	0	100	29	100	100	36	100	100	100	100	100	100	0	100	0	0	0

Force Provder Capacity	**Hours/Day**	**Hours/Day Allocated**	**% Allocated**
MQ-1B	180	180	100
MQ-1C	300	300	100
MQ-9	210	210	100
P-3 AIP	112	112	100
EMARSS	100	100	100
LRE Capacity	**Sorties/Day**	**Sorties/Day Allocated**	**% Allocated**
MQ-1B LREs	15	15	100
MQ-1C LREs	15	15	100

Requirement number 218003 in Table 4 shows how platform consideration influences the objective formula.

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The last row of Table 4 shows that the model allocates FMV capability to the fourteen highest FADM priority requirements. Twelve of the fourteen requirements receive 100 percent allocation. Requirement number 218003 and 218006 receive partial allocation. Requirement number 218006 has a FADM priority of 1.3.3 and a value, or objective function coefficient, of 84. It is the next lowest FADM prioritized requirement and the last requirement to receive the equivalent of 36 percent of its FMV requirement. Requirement number 218003 has a FADM priority of 1.2.3 and a value of 91. It received 29 percent (212 of 727 hours per day) of its requirement. The results show that the platform consideration $scale_i$ of 1.5 for manned aircraft for this requirements received some allocation, but at the expense of overall allocation of FMV ISR, because the change of remote piloted platform consideration *scale* to 0.5 resulted in no FMV capability for that requirement. The MQ-1B, MQ-1C, and MQ-9 capacity was allocated to lower FADM priority requirements (e.g., requirement number 218005), because the value of 86 is more than twice the value of 45.5 for which requirement number 218003 receives for one hour of FMV.

The objective function manages the trade-off between FADM priority and platform consideration. Table 5 illustrates how FADM influences the objective function to a greater extent than platform consideration does. Using the same data illustrated in Table 4, in addition to changing the platform consideration of requirement number 418002 from 1 to 1.5, the objective function did not allocate any MQ-1B or MQ-1C capability to fulfill this requirement.

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Table 5. Combined CCDR and FADM Prioritized Model Results Example 2

	USAFRICOM			USCENTCOM						USEUCOM					USNORTHCOM		USPACOM		USSOUTHCOM	
Requirement Tracking Number	118001	118002	118003	218001	218002	218003	218004	218005	218006	318001	318002	318003	318004	318005	418001	418002	518001	518002	618001	618002
Requirement Hours/Month	1100	200	300	4700	700	22100	180	13700	8700	550	730	180	90	30	180	240	100	720	360	3000
Requirement Hours/Day	36	7	10	155	23	727	6	450	286	18	24	6	3	1	6	8	3	24	12	99
FADM	**1.2.3**	**3.1.1**	**1.2.3**	**2.2.5**	**1.2.2**	**1.2.3**	**1.2.3**	**1.3.1**	**1.3.3**	**1.2.3**	**1.2.3**	**1.2.4**	**1.2.6**	**1.2.6**	**1.1.2**	**2.1.7**	**1.2.2**	**3.3.7**	**2.1.7**	**2.1.7**
FADM Weight Factor	91	30	91	49	92	91	91	86	84	91	91	91	88	88	99	54	92	10	54	54
MQ-1B	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1.5	1	1	1	1
MQ-1C	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1.5	1	1	1	1
MQ-9	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P-3 AIP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
EMARSS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	USAFRICOM			USCENTCOM						USEUCOM					USNORTHCOM		USPACOM		USSOUTHCOM	
Value$_{ij}$	118001	118002	118003	218001	218002	218003	218004	218005	218006	318001	318002	318003	318004	318005	418001	418002	518001	518002	618001	618002
MQ-1B	91	30	91	49	92	0	91	86	84	91	91	91	88	88	99	81	92	10	54	54
MQ-1C	91	30	91	49	92	0	91	86	84	91	91	91	88	88	99	81	92	10	54	54
MQ-9	91	30	91	49	92	0	91	86	84	91	91	91	88	88	99	54	92	10	54	54
P-3 AIP	91	30	91	49	92	91	91	86	84	91	91	91	88	88	99	54	92	10	54	54
EMARSS	91	30	91	49	92	91	91	86	84	91	91	91	88	88	99	54	92	10	54	54
	USAFRICOM			USCENTCOM						USEUCOM					USNORTHCOM		USPACOM		USSOUTHCOM	
Results	118001	118002	118003	218001	218002	218003	218004	218005	218006	318001	318002	318003	318004	318005	418001	418002	518001	518002	618001	618002
MQ-1B	36	0	0	0	12	0	0	132	0	0	0	0	0	0	0	0	0	0	0	0
MQ-1C	0	0	10	0	11	0	6	108	104	18	24	6	3	1	6	0	3	0	0	0
MQ-9	0	0	0	0	0	0	0	210	0	0	0	0	0	0	0	0	0	0	0	0
P-3 AIP	0	0	0	0	0	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EMARSS	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MQ-1B LRE Allocated	3	0	0	0	1	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0
MQ-9 LRE Allocated	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0
Hours Allocated	**36**	**0**	**10**	**0**	**23**	**212**	**6**	**450**	**104**	**18**	**24**	**6**	**3**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
% of Requirement Met	100	0	100	0	100	29	100	100	36	100	100	100	100	100	100	0	100	0	0	0

Force Provder Capacity	Hours/Day	Hours/Day Allocated	% Allocated
MQ-1B	180	180	100
MQ-1C	300	300	100
MQ-9	210	210	100
P-3 AIP	112	112	100
EMARSS	100	100	100
LRE Capacity	**Sorties/Day**	**Sorties/Day Allocated**	**% Allocated**
MQ-1B LREs	15	15	100
MQ-1C LREs	15	15	100

Requirement number 418002 in Table 5 shows that FADM influences allocation trade-off more than platform consideration.

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Combining and balancing FADM and platform consideration into the optimization model allows decision makers a model that more closely resembles current allocation methods. This result is expected because the $value_{ij}$ parameter is made up of two components, the platform consideration (i.e., the $scale_i$, and FADM weight W_i). The first represents the returns to scale or consideration for a particular platform and the second represents the tradeoff among the different requirements. In other words, the former provides the regional focus to a specific geographic area or preference and the later provides more of a global influence that balances strategic priorities across all of the CCDRs.

As this chapter has shown, this model highlights the areas where there may be trade-space for additional allocation opportunities, which may not be apparent using the current process outlined in Chapter II. For example, if the only means to provide capability to a specific ISR requirement is allocating manned aircraft, the model will show what requirements will be affected to meet that limitation. Additionally, by interpreting the results, the CCDR can assess where their requirement priorities are evaluated globally across all of the CCDR's requirements. The Joint Staff can evaluate the data to verify that the results support the military objectives of the National Military Strategy. If the results do not support the strategic objectives, then the CCDR priorities and the force provider capacity must be scrutinized to mitigate the capability and requirement gaps. The impact implications are important to the Combatant Commanders for mitigation options and important to the SECDEF for accepting the risk associated with the recommendation.

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V. RECOMMENDATIONS AND CONCLUSION

This thesis critically examines the Global Force Management allocation process and the factors that influence it. With the insight gained to the process, this proof of concept applies a methodical optimization formulation to a complex ISR force allocation problem that is complicated by significantly less capacity than demand. This optimization model and its methodology developed as part of this thesis uses full motion video capability and notional requirements to model the applicably of optimization, but may be easily generalized for use in other ISR capabilities (e.g., COMINT, in the Global Force Management allocation process). The data and platforms will differ; however, the basic optimization formulation will be the same.

The base model only considered FADM for allocation prioritization. Results show that with only 902 hours per day of FMV capacity to meet 1902 hours per day of requirements, the optimized solution provided 100 percent of the requirement capability to 12 of the 20 CCDR requirements. Additionally, the model provided a partial allocation of 39 hours per day or nine percent of the requirement to the single next lowest FADM priority requirement. These results are useful to inform senior decision makers within the DOD of which requirements will not receive a capability allocation. The results can be compared against the actual Global Force Management Allocation Plans to highlight which lower FADM priorities are actually receiving a force allocation. The differences can show a strategic misalignment between CCDR priorities and global strategic priorities. For force providers and DOD budget personnel, the gaps highlight areas where additional resources can be committed to meet strategic objectives.

Combining and balancing FADM and platform consideration into the optimization model allows decision makers a model that more closely resembles current allocation methods. The results of the combined model change if the objective function coefficient is modified (i.e., the $value_{ij}$ parameter) for a particular platform. This change may represent where the platform consideration is modified based on new information or just to examine model sensitivity. The objective function manages the trade-off between FADM priority and platform consideration. The combined model closely simulates how

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the force allocations recommendations are made because it takes into account regional geographic realities while managing global strategic priorities.

The research, methodology, and analyses presented successfully prove that this optimization model will objectively inform senior decision makers in the Department of Defense for intelligence surveillance reconnaissance Global Force Management allocation.

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VI. FUTURE RESEARCH

The next iteration (and a separate thesis project) would be the refinement of this model to consider risk. Risk to mission is assumed by the prioritization inherent in the FADM. The force provider assumes risk to force in the force offering. These assumptions are a good start to rotational fiscal year force allocation. However, the model can be adapted to include a risk value. For example, if the Joint Staff or JFCC ISR recommend that a force provider increase capacity to beyond what was initially offered, it would be useful to account for risk to force specifically in the formulation.

Risk can be considered in the model using a multi-objective formulation and adding risk as a consideration in the formulation. For this method to work, the model will assume that $value_{ij}$ is much greater than risk and will ignore risk initially. Then use the model to solve for $value_{ij.}$ Finally, the model will use the solution for $value_{ij}$ to establish an additional constraint and solve for $risk_{ij}$. The model's objective is to compare the risk to force of adding capacity at the expense of future force readiness against the risk to mission of the CCDR for not meeting a capability requirement.

A risk informed model would become the basis for an optimization model that can address emergent requirements. Emergent requirements are CCDR requirements for forces within the current fiscal year. As this notional model shows, all of the force provider capacity is used. In order to allocate additional capability to new requirements, the forces would come from one of three options.

The first option would be to order additional capacity from the force providers. This option comes with a cost to future force readiness. For example, if the recommendation is that the Air Force to provide additional MQ-9 capacity, the additional qualified pilots and sensor operators needed may come from the training units. Pulling instructors from the training unit to meet the demands of operational requirements reduces the number people who are able to train the next cycle of crews. This may have significant impact to follow on rotational capacity. The risk to force would become the significant factor to the model.

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The second option would recommend the reallocation of additional capacity from one CCDR to a different CCDR. For example, USNORTHCOM may need additional FMV capability to monitor a Russian exercise off the coast of Alaska. There is no additional force provider capacity to allocate to meet the emergent requirement. Notional reallocation options to consider include moving counter drug assets out of USSOUTHCOM or moving assets out of USCENTCOM who are supporting combat operations. In this notional scenario, the risk to USSOUTHCOM mission priority is less than the risk to combat operations in USCENTCOM. The risk to mission is the most significant factor to the model.

A third option would include contracting FMV capacity from a commercial vendor. This option has a dollar cost associated to it. Using a model that can objectively optimize recommendations while taking into account risk, may show that the dollar cost is significantly less than the cost to force readiness or the cost to the risk to mission. Not only will the model provide context for decision, it will provide transparency to the CCDRs, force providers, the Joint Staff, and the Department of Defense.

Combing the optimization model described throughout this thesis with a risk informed model that can be implemented for the force allocation of all ISR capabilities is a logical evolution that optimizes the force allocation decision process that informs the SECDEF for force decisions and responsibility.

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APPROVAL

The undersigned certify that this thesis meets masters-level standards of research, argumentation, and expression.

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About the Author

Lieutenant Colonel Seward E. Matwick graduated from the United States Air Force Academy with a Bachelors of Science in Mathematics in 2001. After receiving his commission, he attended the Massachusetts Institute of Technology and graduated with a Masters of Science in Materials Science and Engineering in 2002. He attended Euro NATO Joint Jet Pilot Training (ENJJPT) at Sheppard AFB, TX. His first operational assignment was in the F-16 at Misawa AB, Japan from 2005 to 2008 where he participated in Operation Iraqi Freedom. Next, he served as an exchange officer to the Royal Air Force at RAF Valley, United Kingdom where he flew Hawk T-1s. After serving as an instructor pilot for the RAF, he transitioned to flying the MQ-1 and MQ-9 at Creech AFB, NV. During that tour, he served as a deployed detachment commander in support of Operation Juniper Shield and as the 22d Reconnaissance Squadron's Director of Operations. He then served one year on the combined, joint staff as the Key Resolve Exercise Branch Chief in the CJ37 at Yongsan AB, Republic of Korea before being selected to attend the Air Force's School of Advanced Air and Space Studies. Following his assignment at Maxwell AFB, Lt Col Matwick was assigned to the 432 AEW, Creech AFB.

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Abstract

Demand for UAS is here to stay, and the U.S. Air Force force structure needs to adjust away from a contingency mindset to an enduring capability. AF leaders have turned their attention to this challenge, but difficulty normalizing training in such a dynamic field is elusive. The current AF training model has struggled to meet rising demand. What the AF needs is a new training strategy. This thesis examines AF and Army UAS training, why they are different, and what strategy the AF should adopt. Behind such simple questions lie different organizational structures and visions. Despite common technologies, each service approached UAS from different starting points, and created different training models. The AF built its RPA training based on its other aviation training programs, and hindered the organization's ability to deal with automation, significant personnel changes, and airspace integration. Conversely, the Army's UAS training community started with small, remote-controlled drones over 25 years ago at Fort Huachuca, Arizona. It has grown and expanded into new platforms with new capabilities, and its model of universal enlisted operators trained to operate as an organic divisional asset remains. The AF and Army's training programs each create a different product and, in turn, reflect institutional disagreement over what skills should be imparted. The Air Force's conflict between utility and tradition in its UAS training will have a profound effect on the AF, whose ultimate raison d'etre is to fly, fight, and win—in air, space and cyberspace. In the end, this study argues for a training strategy that leverages the RPA weapon system's unique modularity to produce well-trained RPA pilots more quickly.

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Introduction

The Air Force still has an enterprise that is undermanned, overworked, and demoralized while facing a potential mass exodus of pilots and insufficient training infrastructure to replace these losses

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Tom Cotton, U.S. Senator,
Committee on Armed Services Opening Statement,
"Army Unmanned Aircraft Vehicle and Air Force
Remotely Piloted Aircraft Enterprises,"
16 March 2016

On March 16, 2016, the Senate's Committee on Armed Services questioned General Herbert J. Carlisle, Commander of the AF's Air Combat Command and General David G. Perkins, Commanding General of the Army's Training and Doctrine Command. The hearing and subsequent testimonies addressed issues raised in a Government Accountability Office report titled "Unmanned Aerial Systems: Further Actions Needed to Fully Address Air Force and Army Pilot Workforce Challenges."[1] In the report, the GAO concluded that the AF had not fully addressed pressing issues of personnel requirements, retention difficulties, and producing enough pilots through its training pipeline. The result, as stated by Senator Tom Cotton of Arkansas in his opening remarks, is that "Despite literally dozens of reviews, task forces, studies, and reports on unmanned aircraft enterprises by the Department and the GAO, much room for improvement remains. It is plain that the Department is still struggling with [this] transformation."[2]

The Department of Defense grapples to manage the unmanned aerial systems' remarkable rise. Though unmanned flight dates back to the infancy of aviation itself, technological capabilities did not meet military and political demand until the 90s when advancements in space communications, computer processing, intelligence gathering, precision weaponeering, robotics, and network centric warfare coalesced into one

[1] Government Accountability Office, *Unmanned Aerial Systems Further Actions Needed To Fully Address Air Force And Army Pilot Workforce Challenges* (Washington D.C., 2016).
[2] Statement of Senator Tom Cotton in "Army Unmanned Aircraft Vehicle and Air Force Remotely Piloted Aircraft Enterprises," unclassified testimony before Senate Armed Services Committee (Washington D.C.: 16 March 2016).

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culturally-redefining military platform. From the Balkan conflict in 1995 to Operations Iraqi Freedom and Enduring Freedom, demand for unmanned drones had turned into an uncontrolled conflagration. As drone missions increased tenfold, operators were pushed relentlessly to meet the insatiable demand. Rapid growth resulted in a series of haphazard improvisations in operations, personnel management, and training. Anticipated drawdowns in Iraq and Afghanistan, however, have not provided an expected respite, and pressing demand has risen in Libya, Syria, Niger, and Somalia. Demand for UAS is here to stay, and the force structure needs to adjust away from a contingency mindset to an enduring capability. AF leaders have finally turned their attention to a long-overdue training bill, but normalizing training in such a dynamic field is proving elusive. What the AF needs is an entirely new training strategy.

As the two generals testified, sitting beside each other, they described vastly different problems. The disparate issues reflected different approaches each service took to Unmanned Aerial Systems (UAS) operational employment, personnel management, and training. Strikingly, despite operating remarkably similar platforms produced by the same manufacturer, General Carlisle stated, "The MQ-1C, the Gray Eagle, and the MQ-9 Reaper are totally different systems. The tactics, techniques, and procedures doctrine would be similar, but the actual training on the system between the MQ-9 and the MQ-1C are significantly different."[3] To outside audiences, these differences are not intuitive. While the Army and Air Force may have justified integrating unmanned aircraft in their services based on unique competencies, roles, and mission requirements, the security environment has forced increased overlap. In actuality, Army and AF employ similar aircraft utilizing similar capabilities, operating in the same airspace, and supporting the same customers. This leads one to conclude that service culture is the primary differentiator for any remaining program differences.

A historian of technology, Thomas P. Hughes, provides the academic framework for such thinking in his theory on technological momentum. He states, "The social constructivists have a key to understanding the behavior of young systems; technical

[3] Statement of General Herbert Carlisle USAF in "Army Unmanned Aircraft Vehicle and Air Force Remotely Piloted Aircraft Enterprises," unclassified testimony before Senate Armed Services Committee (Washington D.C.: 16 March 2016).

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determinists come into their own with the mature ones."[4] In layman's terms, sociologists advocating technological momentum posit that innovations are initially strongly susceptible to cultural shaping. Hughes argues that time drives what influences advancement. Early in a systems development, sociocultural pressures shape how a system integrates, and, in older systems, technology determines change. In the case of UAS, its formative stage gave both services the leeway to incorporate a new weapons system into its respective cultures. Despite common technologies, each service approached UAS from different starting points to create a different training pipeline.

The rise of UAS presents a unique opportunity to compare and contrast two training pipelines and determine how each services' organizational values manifested. Each training program creates a different product and reflects institutional disagreement over what skills should be imparted despite remarkably similar end-state capabilities. If Hughes' theory is correct, UAS maturation will drive the AF and Army training programs closer together, and, in the process, test the services' underlying cultural assumptions. Current efforts, however, drive the community closer to the AF's manned flying communities rather than Army's UAS. Whether such a strategy is wise or even possible, or whether the AF can realize RPA's utility within its cultural confines, is the focus for this thesis.

This study hopes to fill a literature void that has heretofore left the divide between Army UAS and AF RPA operations and training relatively unexamined. Previous studies briefly described the different services' approaches to UAS operator training, but not explored the cultural reasons why they are different. This thesis examines AF and Army UAS training, why they are different, and what strategy the AF should adopt going forward. Behind such simple questions lie organizational structures and differing visions that make untangling the issue difficult. Underlying assumptions, particularly for the AF, start to unwind when increasing automation, significant personnel changes, and airspace integration push RPA's future away from AF tradition. This conflict between utility and

[4] Thomas P. Hughes, "Technological Momentum", in *Does Technology Drive History? The Dilemma Of Technological Determinism*, 3rd ed. (Cambridge, MA: MIT Press, 1994), 112.

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tradition will have a profound effect on the AF, whose ultimate raison d'etre is to fly, fight, and win—in air, space and cyberspace.

Overview

This study focuses on the Army and AF's medium altitude, long endurance (MALE) UAS operator training pipelines, starting from the initial course and onto qualification for the MQ-1C Gray Eagle and MQ-9 Reaper, in an effort to compare training for similar platforms. The AF is currently phasing out its MQ-1B Predator, a more similar platform to the Gray Eagle. Reaper and Predator training are nearly identical, and, therefore, examining Reaper training is a reasonable substitute. When addressing both services, terminology will be industry standard: UAS and operator for example. Service specific verbiage like RPA and pilot are used when treating each service individually.

This thesis uses Edgar Schein's framework on organizational culture to understand the dynamics of change and the AF, its RPA community, and the Army. Schein defines culture as a series of assumptions a person makes about the group in which they participate. He divides assumptions into three levels. Each level becomes more difficult to articulate and change, and more influential on the other levels.[5] First are assumptions about external adaptation issues. Culture develops as groups express assumptions when making decisions on missions and strategy, goals, means, measurements, and corrections in response to external stimuli. On the second level are assumptions about managing internal integration. As groups decide how to work together, they create culture by the choices they make on internal integration issues like power distribution, friendship norms, defining rewards and punishments, and defining group boundaries. The third level comprises deeper cultural assumptions that reflect the group's view on fundamental issues like time, space, human nature, and the nature of human relationships. These deeper dimensions answer questions like how humans should interact and where leaders derive their power.

[5] Schein, 26.

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An observer can see these assumptions through artifacts, espoused beliefs and values, and underlying assumptions. Artifacts are visible organizational structures and processes that may be hard to decipher to outsiders. Examples include military insignia, corner offices, and designated parking spots. Espoused beliefs justify actions through codified strategies, goals, and philosophies. The AF's core values of integrity first, service before self, and excellence in all we do are examples of beliefs embodied in an ideology that "can serve as a guide and as a way of dealing with the uncertainty of intrinsically uncontrollable or difficult events."[6] When those values repeatedly produce success, groups transform them slowly into basic, nonconfrontable assumptions that provide stability and meaning. Underlying assumptions are extremely difficult to change.

The first chapter educates the reader on the origin of AF RPA training and describes the current Undergraduate RPA Training (URT) and MQ-9 Initial Qualification Training (IQT) syllabi. The chapter's historical look starts in 1996 and continues to the present to show how the influence of civilian leaders, capabilities requirements, and AF culture mixed to create RPA training. Chapter 2 describes the manning woes the training pipeline struggles to overcome and the current remediation plan in effect. Chapter 3 transitions to the Army's UAS community and explores how its training system reflects its unique beginning. Much more organically developed and resourced by the Military Intelligence Branch, Army UAS thrived under its sometimes watchful, sometimes neglectful eye.

Chapter 4 looks to the future to identify and explore approaching advancements that will either threaten or provide opportunities to the AF's training system and its normalization efforts. The chapter addresses three specific developments: increasing automation, the AF introduction of enlisted RPA pilots, and the Federal Aviation Administration's push to integrate UAS into the national airspace. It peels back how AF service culture and emerging change may shape RPA training. More automation, low expected retention, and the introduction of the enlisted pilot threaten not only the AF training culture but also its identity.

[6] Schein, 29.

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Chapter 5 establishes a comparison methodology and begins directly comparing both services' training pipelines. This chapter merges the insight gained into AF culture with emerging threats and opportunities to analyze possible RPA training strategies going forward. The first section presents a method to analyze, classify, and test current and potential strategies. The second section dissects the AF's current RPA training strategy of focused differentiation in the context of its broader Strategic Master Plan and in comparison to Army UAS training.

Finally, Chapter 6 takes the final step and answers what training strategy the AF should adopt as RPAs enter mainstream aviation. At that point, the AF will broaden its training strategy into either Low Cost Leadership or Differentiation. This chapter conducts a Strength, Weakness, Opportunity, and Threat (SWOT) analysis of each strategy and recommends a Low Cost Leadership course of action. To conclude, a five-question check scrutinizes this strategy recommendation to see whether the chosen strategy has a distinctive value proposition, a tailored value chain, trade-offs that are different from rivals, a good fit across the existing value chain, and whether there is continuity over time.

The AF and the Army offer competing views on the future of UAS training. Both services export its cultural values, as the Navy, USMC, and international partners watch and adopt best practices. Finding the right technical approach may require overcoming cultural barriers, but just as likely, an effective training strategy may be able to accommodate various cultures. Such a crisis presents an opportunity to course correct; now is the time to properly tailor RPA training to leverage today's capabilities while anticipating tomorrow's technology.

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Chapter 1
AF RPA Training History

Ultimately, all organizations are sociotechnical systems in which the manner of external adaptation and the solution of internal integration problems are interdependent and intertwined. Culture is … not easily reduced to a few major dimensions. Culture reflects the group's effort to cope and learn; it is the residue of that learning process.

Edgar Schein, Organizational Culture and Leadership

Edgar Schein creates logical stepping stones to explain how an organization's culture develops and influences decision making. Examining an organization's cultural origin and subsequent issues faced is an important step to understand how it makes decisions. This chapter will explain and then use Schein's framework to examine the origins of the AF's Undergraduate RPA Training and its status. The chapter will conclude by identifying the underlying assumptions, values, and artifacts reflected as the AF developed Undergraduate RPA Training (URT).

U.S. military operations in Afghanistan and Iraq required real-time information. As combatant commanders struggled to understand the battlefield, they relied increasingly on RPA's Intelligence, Surveillance, and Reconnaissance (ISR) coverage of full motion video. This demand relentlessly pressured the RPA community to increase its hours flown. Consequently, combat lines, then known as combat air patrols (CAPs), grew exponentially and outpaced the AF's will and ability to keep pace. Under these difficult conditions, the RPA community solved problems of member identity, goal setting, metrics selection, labor division, and correction. In the process, it created a culture around learned solutions to these problems. URT is more than a training course; it is the cultural manifestation of "the ultimate problems that every group faces: dealing with its external environment and managing its internal integration."[1]

[1] Schein, 85.

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Context Surrounding URT Standup

Schein states, "If the environmental context is changing, such conflict can be a potential source of adaptation and new learning."[2] This certainly describes the Air Force's predicament in 2007 as it struggled to understand the context in Iraq and take appropriate action to quell the rising counterinsurgency. Shein's cultural framework includes five steps of adaptation that organizations continuously cycle through in response to external change: mission and strategy, goals, means, measurements, and correction. On January 10, 2007, President Bush addressed the nation and covered each step. He frankly admitted, "It is clear that we need to change our strategy in Iraq."[3] Current actions based on faulty assumptions were not meeting goals nor achieving peace, and the stakes of defeat meant losing the "decisive ideological struggle of our time."[4] He then articulated a new strategy and new metrics:

> The most urgent priority for success in Iraq is security, especially in Baghdad. Our troops will have a well-defined mission: to help Iraqis clear and secure neighborhoods, to help them protect the local population, and to help ensure that the Iraqi forces left behind are capable of providing the security that Baghdad needs.[5]

The President explicitly declared new assumptions: protecting the local population and strengthening Iraqi forces would achieve victory. This change required a different force structure, and he authorized twenty thousand additional soldiers to Iraq and increased deployment durations. Instead of kinetic strikes and force to win, the troop surge marked a mission refocus to security. President Bush closed his speech by defining what success looked like. "Victory in Iraq will bring something new in the Arab world -- a functioning democracy that polices its territory, upholds the rule of law, respects fundamental human liberties, and answers to its people."[6]

President Bush's new approach set in motion a collision course between Secretary Robert Gates' mandates and the AF's reluctance to address ISR supply shortcomings. The AF struggled to accept its tactical, supporting role and adapt its skill set, weapons

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[2] Schein, 108.
[3] President George W. Bush, "President's Address To The Nation", (Speech, 2007).
[4] Bush, 2007.
[5] Bush, 2007.
[6] Bush, 2007.

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systems, and training output in reaction to the new character of warfare. In 2014, Gates described in his memoir how the AF resisted change. He commented, "Whatever the complications, the surge of troops in Iraq and mounting difficulties in Afghanistan required a surge in ISR capabilities. Indeed, in nearly every one of my weekly videoconferences with Dave Petraeus, first in Iraq and later in Afghanistan, he would raise the need for more ISR."[7] The AF did not agree with this assessment, and it made no plans to increase beyond the eight MQ-1 Predator combat lines it was providing. Each combat line provided over 20 hours of surveillance daily. Gates pushed for change but did not get a satisfactory response. His frustration mounted, as he surmised, "As the need for more ISR kept growing through the winter of 2007-8, it was clear my haranguing wasn't working."[8] Clearly, the external environment and its requirements were at odds with AF values. Airmen's culture needed transformation, but deeply held values do not change easily.

The AF's historical internal integration explain why the AF did not willingly pursue change. Previous decisions reveal institutional preferences for pilots and manned aircraft. Fighter pilots' monopoly on key leadership positions makes clear assumptions about power, status, rewards, and punishments. Asymmetric warfare created a need suited to unmanned aircraft and its long endurance capability, a need that traditional aircraft could not fulfill. Even when the skills and services provided by fighter pilots were found wanting, the AF refused to reexamine its underlying assumptions until Secretary Gates pushed it.

Unfortunately, Secretary Gates perceived that the AF leadership was shirking and out of touch.[9] Several developments confirmed his suspicions that AF leadership did not accept the urgency for more ISR and were not taking creative steps to acquire more. One was the AF's tone-deaf proposal to discontinue the U-2, a key strategic ISR asset. Another signal to Gates was the AF's preoccupation with unrelated acquisitions projects. Those projects, specifically the F-22 and a new bomber, reinforced AF cultural

[7] Robert M. Gates, *Duty: Memoirs Of A Secretary At War* (New York, USA: Knopf Publishing Group, 2014), 129.
[8] Gates, 129.
[9] In Peter Feaver's *Armed Servants: Agency, Oversight, and Civil-Military Relations*, he introduces a working-shirking continuum to describe the military's varied levels of compliance to its civilian leaders. He defines shirking as doing things the way those in the military want.

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assumptions about pilot primacy and its glorious struggle for conventionally attained air supremacy, but were at odds with Gates' desires and Petraeus' needs. Gates states,

> Then, at a time when we were trying to put every intelligence platform possible into the war, the Air Force proposed ending all funding for the venerable U-2 spy plane by the end of summer 2008. I thought proposing to ground it at this juncture was just plain crazy. Further, nearly every time Moseley and Air Force Secretary Mike Wynne came to see me, it was about a new bomber or more F-22s. Both were important capabilities for the future, but neither would play any part in the wars we were already in.[10]

Previous interactions with the AF as CIA director earlier in the 90s had primed Gates for this resistance. Then, he had tried to persuade the AF to develop drones to pursue its potential advantages of loiter, collection, and signals intelligence. He was rebuffed and told that people join the Air Force to fly airplanes, and drones had no pilot. When he returned to government in 2006, he was disappointed to see that "the Air Force mind-set had not changed."[11]

AF intransigence and Secretary Gates' determination would cost the AF in two long-lasting ways. First was the AF's miscalculated bid for executive agency over the RPA. On one hand, the AF had little enthusiasm for building its RPA fleet and providing the combatant commander and, by extension, the Army, with sufficient ISR. On the other, it was grasping for absolute control of this asset. Gates was loath to give oversight of RPAs to the AF.[12] Second, Gates dismissed the Secretary of Air Force Mike Wynne and General T. Michael Moseley, the CSAF. General Norton Schwartz, a C-130 pilot, replaced General Moseley. By selecting Schwartz, the only recent Chief of Staff not from the fighter or bomber community, Gates signaled the AF's need to fence mend with the Army and remedy its previous "stinginess in getting to ground commanders badly-needed UAV assets."[13] While Moseley had put on hold and then cancelled URT, his replacement, Schwartz gave the green light during a speech just a few months after taking over.[14]

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[10] Gates, 129-130.
[11] Gates, 127.
[12] Gates, 129.
[13] Carroll, Ward. "Schwartz a Chief to Mend Fences." *The Defense Biz* (Defensetech), June 13, 2008. http://defensetech.org/2008/06/13/schwartz-a-chief-to-mend-fences/.
[14] Jeff Wiseman (AETC/A3FR), interview by the author, 22 December 2016.

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Schwartz's command to grow the RPA fleet forced the AF to scrutinize its assumptions about internal integration. Group boundaries excluding unmanned aviation needed reexamination. Power and status from other communities toward RPAs would not be ceded willingly, but the RPA's sheer size, growth, demand, and capabilities could no longer be dismissed. Lack of rewards like professional military education (PME), promotions, or staff positions initially plagued the community, and significant effort continues to this day to reverse this perceived punishment.

AF Thoughts on URT

The AF then rapidly established initial classes as a Beta Test and then established a formalized Undergraduate RPA Training course. Despite its hurried response, much previous internal AF thought and debate over the years had gone into who should fly RPAs. While external conditions forced the AF to expand its RPA program, the AF had the latitude to use its cultural preferences to institute a solution. Organizations reflect internal assumptions in their decision-making, and the standup of URT stands as a strong embodiment of the AF's culture. "Beyond Butterflies," a 2007 SAASS thesis by then-Major Houston Cantwell, lends insight into the logic influential AF leaders used to craft URT. Cantwell's many interviews trace strategic leaders' thoughts and decisions over the years as they struggled to overlay AF culture onto a disrupting innovation.[15] These thoughts leading up to 2007 foreshadowed the establishment of a dedicated 18xx Air Force Specialty Code (AFSC) and training pipeline.

AF personnel policies on UAV aircrew are rooted with General Ronald Fogleman, former CSAF. In 1995, the AF had little interest or involvement in the Predator's Advanced Concept Technology Demonstrations (ACTD) process under DARPA. But then, three developments--operations in Bosnia that demonstrated UAV capability, interservice competition with the Army, and leadership interest--coalesced into a sudden service bid for Predator.[16] Fogleman anticipated that Predator was going to be fielded, and he felt the AF was best positioned to exploit the platform. Prior to AF

[15] Major Houston R. Cantwell, "Beyond Butterflies: Predator And The Evolution Of Unmanned Aerial Vehicle In Air Force Culture" (School of Advanced Air and Space Strategy, Air University, AL, 2007), 79.
[16] Thomas P. Ehrhard, Air Force UAVs: The Secret History (Arlington: Mitchell Institute for Airpower Studies, 2010), 50-1.

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interest, the Army had operated the Predator unit and was naturally suited to assume the position as lead service. Fogleman was disdainful of the Army's approach to UAVs and was convinced their poor service and safety record would implode the program. In response, he established a new UAV squadron, the first UAV squadron since 1979. Fogleman's position and eclectic background gave him the authority and perspective to identify this transition point and mobilize AF resources to get Predator.[17] His varied career path included a distinguished Forward Air Controller (FAC) tour in Vietnam as an F-100 pilot and a tour teaching history at the Air Force Academy. In the 1980s, Fogleman, as an Air Division commander, stood up ground-launched cruise missiles, something that had contrasted sharply with the AF's cultural affinity for flying airplanes. Prior to his CSAF appointment, he commanded Air Mobility Command and Transportation Command. These varied experiences broadened his aperture, and his weight of influence proved pivotal in wresting control of the Predator program from the Army.

Fogleman's time as CSAF marked the genesis of Predator, and he formulated the original policies that still affect the community's culture. In his bid for program control, Fogleman argued the Army's poor UAS record was in part due to its approach. Amongst fellow AF generals, he imbued the view that they were going to "treat it like an airplane."[18] He also provided the necessary personnel to assure Predator's early success. Besides standing up a dedicated UAV squadron, he assigned non-volunteer instructor pilots to fly the Predator UAV. "If this program fails," he commented at the time, "it won't be because of our pilots."[19]

This first requirement introduced initial values to Predator's emerging subculture. First, by requiring pilots, Fogleman defined the RPA's boundaries. Being a pilot was the critical criteria for inclusion. He had successfully excluded the Army and its enlisted operators, and navigators could volunteer only if they had personally procured their pilot licenses. Pilots surveyed overwhelmingly assessed that training requirements prior to

[17] Ehrhard, 51.
[18] Thomas Ehrhard, "Unmanned Aerial Vehicles in the United States Armed Services: A Comparative Study
of Weapon System Innovation," (Ph.D. Diss., The Johns Hopkins University, 2001), 593.
[19] Ehrhard, 593.

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Predator initial qualification training were roughly equivalent to undergraduate pilot training. Further, they believed that "manned aircraft flying experience [was] essential to effective employment of the Predator."[20] This survey had an air of authority despite lacking a formal requirements review. Essentially, junior pilots had supported the AF's defined boundaries.

Fogleman created a perception by assigning non-volunteers to a Predator tour. Pilots identified the tour as a punishment, a notion that would haunt the community. Communities subsequently relegated poor performers to RPA assignments, and the Predator developed the leper colony's curse of low status and power. Had manning requirements framed the assignment as a select opportunity available only to volunteers, whether pilots or officers with flying experience, the community's misfit label might have been avoided.

Staffing policy also fragmented the RPA subculture. The assignments drew from multiple communities each with their own subculture. After a three-year tour, pilots would return to their previous communities. To add to the fragmentation, separated ground control stations, constant shift work, and the lack of coordinated, socialized flying missions isolated squadron members. Loose personal bonds resulted, and camaraderie suffered. This weakened the potential institutional power of the RPA community and reduced its clout among other subcultures. When Fogleman abruptly resigned, no powerful advocate replaced him until General John Jumper four years later.

General Jumper picked up where Fogleman left off. He advocated arming the Predator with Hellfires and adding a laser designator while commander of ACC. As CSAF, he published an RPA strategic vision. He echoed Fogleman's approach of using pilots, stating,

> The original notion of using pilots was because of the Army experience [with UAVs]…If you treat it like an airplane it will act like an airplane…. We were trying to get the accident rate down and get the operator caused accidents down. We knew if we crashed a bunch of these things that we weren't going to get [the program] either. That's why we insisted on pilots.[21]

[20] William C. Tirre and Ellen M. Hall, *USAF Air Vehicle Operator Training Requirements Study* (Brooks AFB, TX: AF Research Laboratory, 1998).
[21] Quoted in Cantwell, "Beyond Butterflies," 79.

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As the AF gained RPA experience, Jumper softened on this issue and started advocating for a Combat Systems Officer concept. In February 2003, he directed a reengineering of undergraduate navigation training to incorporate a remotely piloted aircraft track in the new revised program. The Combat Systems Officer concept built upon traditional Undergraduate Navigator Training (UNT) to create "credentialed warriors." His 2005 RPA Strategic Vision conveyed this approach: "the Air Force vision is to develop a new career field to man these billets. Part of this transformation will be the creation of an RPA training program for new Air Force officers and enlisted personnel to transition directly into RPA."[22] The pipeline to create dedicated RPA pilots "hopelessly tied to future acquisition, employment doctrine, and career path development" would spur community investment and innovation.[23] Jumper's leadership laid the groundwork to change the community's initial assumptions about who would fly RPAs.

The step from vision to fruition took place in 2008. Internal disagreement existed about the desired training requirements for RPA personnel, but a near unanimous consensus within AF leaders emerged that an officer with developed airmanship was required. Some felt a rated airman was a prerequisite to flying safely in an integrated national airspace, some felt that high airmanship levels were required to solve dynamic problems, and some were concerned that a distinct career field would create second class citizens.[24] Ultimately, a new career field was created with a dedicated training pipeline. This satisfied two goals: the desire to impart needed technical skills and the cultural buy-in required for long-term success of RPAs. Those who recognized the future of RPA also recognized the large stake the AF had in the program. Then Brigadier General Charles Lyon, former 57th Operations Group Commander noted, "if anyone can fly a Predator then anyone can fly UAVs—any rank, any service. If anyone in any service can fly a UAV then the USAF cedes our authority over managing, commanding, and controlling the effects that take place from the air to anybody that wants to do it."[25] By creating a

[22] U.S. Air Force, *The U.S. Air Force Remotely Piloted Aircraft And Unmanned Aerial Vehicle Strategic Vision*, 2005, 19.
[23] Ehrhard as quoted in Cantwell, "Beyond Butterflies," 124.
[24] Cantwell, 101-2.
[25] Quoted in Cantwell, "Beyond Butterflies," 102.

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separate AFSC, the AF had attempted to settle internal issues and better allow its people to concentrate on performing its mission. Schein's organization culture theory describes the path the AF followed to maintain operational relevance in the face of a disruptive technology: "the confrontation of survival issues most often is the critical stimulus that creates rapid consensus around the internal integration issues. The internal integration and external adaptation issues are thus interdependent."[26]

Building URT

Training is vital to military organization. Three elements are vital to the training process: tasks, conditions, and standards. Tasks are the tangible questions to be dealt with, conditions are the operating environment where the function is to be performed, and standards are the minimum of acceptable proficiency.[27] Training is task dependent and focused on a specific skill and the tools of that specialty in a stable environment with known conditions. In times of rapid changes to tasks, tools, or conditions, training by its very nature will struggle to maintain relevancy. The struggle to keep RPA training relevant when mission requirements and capabilities continue to evolve is substantial.

General Jumper retired from the AF on November 1, 2005, but not before setting the wheels in motion for a dedicated RPA pilot AFSC and training pipeline. The next stage involved translating the vision into a training course. That would fall to a recently retired F-15E Weapons Systems Officer named Lt Col Jeff Wiseman in Air Education and Training Command's A3FR branch. As the development progressed, he hired another recent retiree, Lt Col Robert Englehart. These two would build URT.

Undergraduate RPA Training was a piecemeal creation. It initially borrowed heavily from the Combat Systems Officer (CSO) training syllabus and some from Specialized Undergraduate Pilot Training (SUPT) to maintain a commonality across AETC's Undergraduate Flying Training.[28] Colonel Stephen Wilson, the AETC Assistant Operations Officer in 2006, recommended following SUPT's developmental

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[26] Schein, 134.
[27] Curtis E. LeMay Center for Doctrine Development and Education. *Volume 2: Leadership; Appendix C: Education and Training*, 8 August 2015. https://doctrine.af.mil/download.jsp?filename=Volume-2-Leadership.pdf.
[28] HQ AETC/A3F. *AETC Undergraduate Remotely Piloted Aircraft Training (URT) Powerpoint Brief*, 2016.

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methodology. Wiseman and Englehart heeded that advice. First, they identified the necessary skill sets required to operate UAVs by soliciting input via survey from the formal training unit at Creech AFB. The two contacted the FAA for input to ensure URT graduates would be qualified to transit in national airspace, a key requirement. Goals established at this phase included: to provide qualified graduates to enter RPA Formal Training Units, to impart foundational skills to meet RPA mission requirements, to impart the ability to operate in National Airspace System or International Civil Aviation Organization airspace, to grow and sustain professional RPA community, to train pilots—not operators, and to instill airmanship and flight discipline.[29] Second, Wiseman and Englehart borrowed tactical instruction from the CSO syllabus. Similar to CSO training, classroom academics would be in lockstep with computer-based training and simulation. Front loading contextual operational academics on tactics, authorities, and command structures was intended to ease the transition a recent graduate would make into the operational environment.

Third, a mandate existed from the start to maintain efficiencies, keep costs under control, and proceed quickly. Feedback from the Predator Formal Training Unit identified flight experience as crucial to follow-on training, and flight screening was placed as URT's first phase. In accordance with maintaining efficiencies, the then-AETC commander, General Stephen Lorenz, insisted on integrating this screening into other training pipelines in Pueblo, Colorado. Initially, 18 hours were allotted, same as SUPT candidates, to allow for local area flying and a solo flight. Later, the FTU and operational units requested more student instruction to increase airspace awareness. Subsequently, Initial Flight Screening expanded to 39 hours, adding more local flying as well as cross-country orientation.

In parallel to this developmental effort, officials conducted trials placing non-rated officers directly into the MQ-1 Formal Training Unit at Creech AFB. Lt Leslie's experience as the first test case demonstrates the difficulty the AF had adapting its bureaucracy to the RPA enterprise.[30] In 2005, Lt Leslie had been eliminated from SUPT, unable to overcome motion sickness. Before his dismissal, he had completed

[29] HQ AETC/A3F.
[30] Major Leslie, USAF, (49 Wg OGV), interview by the author, 7 Jan 2017.

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introductory academics, solo'ed, and progressed to his pre-contact check ride in the T-6. Thirty days out from administrative separation, Maj General Mark Zamzow, a family friend, contacted Leslie to see if he was interested in participating as the inaugural test member. A few months later, Leslie joined MQ-1 Class 06-03 along with members of the California Air National Guard. The FTU instructors enrolled him into the class without any special treatment or additional preparation. He successfully navigated the course, including a form 8 check ride. Along the way, his progress informed and refined AETC's developing syllabus. Upon graduation, Leslie received an e-mail from the Operations Group commander. In his e-mail, the OG relayed authorization for Leslie to wear aircrew officer wings. Without ceremony, he summarily went to the uniform store and purchased his wings.

Lt Leslie reported to the 15th RS and immediately met roadblocks. A running tally of issues mounted that following classes would later solve. Questions surrounded whether he was rated or not. Was he entitled to flight pay, to sign a flight authorization, or required to fulfill flying gate months? The Squadron Aviation Resource Management personnel could not enter him into their database tracker with his unique 17xx AFSC designation. How then would the SARM office record his flight hours? No authority pushed through any resolutions, and the squadron did not authorize Leslie to fly. Instead, he made himself useful in the squadron as a Mission Intelligence Coordinator (MIC) and then as the Senior MIC. Without a senior AF advocate pushing to overcome cultural hurdles, a distinctive Predator training pipeline was paused. In October 2006, without explanation, the AF notified Leslie that it had cancelled the trial. Lt Leslie transferred to the missile career field and bided his time.

In September 2008, General Schwartz directed the standup of URT, and in January 2009, the first RPA Beta test class started. Forty qualified volunteers across the AF applied, and ten joined the initial class. The Beta test trialed the syllabus, taking previous aircrew and non-aircrew alike through flight screening, then instrument training, and finally an RPA fundamentals course. The classes then reported to the Predator FTU and folded into established transition courses. Lt Leslie rejoined the RPA community and graduated from the fifth and final Beta test class. In May 2010, General Schwartz declared the trial a success, and five months later, the first URT class started. All

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accession sources contributed to the RPA pilot candidate pool, and the Air Force Personnel Center designated RPA pilots as the 18xx AFSC. In two short years, RPA training had morphed from the initial "go-do" order to concept to testing to production. Additionally, URT operated at a fraction of the cost of SUPT. AETC approximates URT costs at $65k per graduate while SUPT averages $560k per graduate.

Many RPA pilot milestones have followed. To date, 917 RPA pilots have graduated. Their many accomplishments include operating "solo" in combat since 2009, countless weapons deliveries, thousands of flight hours, instructor qualifications, serving on MAJCOM Staffs, graduating from the Weapons Instructor Course, and serving as squadron directors of operations. Initially, the community was skeptical of young RPA pilots arriving at Creech AFB. As their performance validated the training pipeline, direct MQ-9 billets became available. Starting in 2012, the MQ-9 FTU accepted RPA pilots for initial qualification training. The mixed community is making strides to transition toward 90% 18xx personnel.[31] The next imminent milestone is the community's first 18xx-designated squadron commander. URT grows more effective at graduating students as instructors gain experience and students manage course expectations better. Overall attrition numbers decrease each year. In 2011, attrition stood at 36%, and it declined to 10% by 2016. This final metric testifies to the program's success in filling ISR demand: RPA pilots will be the largest group of AF pilots by 2018, after only six years of existence.[32]

URT Description

URT, as it stands now, consists of three courses: RPA Initial Flight Training, RPA Instrument Qualification Course, and RPA Fundamentals Course.

RPA Initial Flight Training (RFT) shares a flight screening contract operation in Pueblo, Colorado with SUPT and UNT. Initially modelled as a screener, URT granted candidates 18 hours of flight instruction and was the greatest cause of attrition. This feedback combined with a reevaluation led to an increase in flight hours with potential for re-flying rides. Correspondingly, AETC/A3FR updated the course title from RPA

[31] 49th Operations Group RPA Mission Brief, Oct 2015.
[32] Lt Col Jason Green, "A Brief Look: The State of Remotely Piloted Aircraft (RPA) Operations Local, Global… Past, Present, and Future…," 2016.

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Introductory Flight Screening to RPA Introductory Flight Training. The training takes 8 weeks and consists of 35 training days. Students fly 39 hours in Diamond DA-20. Twenty-two flights are dual sorties, and five are solo. Academics include basic flight maneuvers, flight safety, emergency procedures, navigation, and communication. Students must pass the FAA's Private Pilot Knowledge Test. This stage is a contracted operation and costs $10k per student. Ninety-nine percent of attrition occurs in this phase.

The 558 Flying Training Squadron at Randolph AFB, Texas instructs the RPA Instrument Qualification (RIQ) course following flight training. Original concepts of URT considered an RPA track after T-6s in SUPT, but RFT along with a T-6 simulator-based instrument qualification course replaced the requirement. Over 56 training days, instructors deliver 140 hours of classroom academics and instruct 36 simulator sorties totaling 47 hours in a T-6-like Flight Training Device simulator. In later stages of the course, instructors link the simulators, and students interact in an air traffic pattern with each other and an Air Boss who controls the ensuing chaos. This forces students to act under stressful, unpredictable situations. Additionally, students receive emergency procedures training and practice applying corrective actions.

The last phase of URT is the RPA Fundamentals Course (RFC). Described as "a mile wide and an inch deep," it is designed to introduce students to operating an RPA in a tactical environment as well as educate them on tactical mission elements ranging from the unique physiology requirements of 24/7 shift work to traditional Close Air Support procedures. The course is 22 training days, and the syllabus allots 78 academic hours and 31 simulator hours. The simulators, called Predator Reaper Integrated Mission Environment (PRIME), replicate the console interfaces and displays students will see at the MQ-9 FTU. Course material includes physiology, joint force command & control, datalinks, bandwidth, GPS, threats, brevity, weapons, air defense, and mission systems. Upon URT completion, the 558 FTS hosts a winging ceremony and pins specially designed RPA wings on the new graduates.

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Figure 1: RPA Pilot Wings
Source: "U.S. Air Force Aeronautical Rating", En.Wikipedia.Org*, 2017*

Reaper FTU

The Predator and Reaper Formal Training Units have had much less internal controversy surrounding its operations or personnel. Its main struggle is graduating enough students in a timely manner to alleviate the community's manning woes. The AF is phasing out the Predator, and what follows here covers the General Atomics MQ-9 Reaper.

Beginning in October 2008, the 11 Reconnaissance Squadron conducted formal training at Creech AFB, Nevada under the 432d Air Expeditionary Wing. The first MQ-9 class started in February 2009, and in October 2009, formal training moved to Holloman AFB under Air Combat Command's 49th Wing. The AF reactivated three squadrons, the 6th Reconnaissance Squadron, 16th Training Reconnaissance Squadron, and the 29th Attack Squadron. To handle increasing demand, the AF reinstituted the 9th Attack Squadron in September 2012, and currently in 2017, the 6th RS is transitioning from the Predator to the Reaper.

The FTU Initial Qualification Training syllabus consists of 157 academic course hours, 22 simulators totaling 58 hours, and 22 sorties totaling 44 hours.[33] The seven academic phases are introduction, transition, ISR/Synthetic Aperture Radar employment, Basic Surface Attack (BSA)/Surface Attack Tactics (SAT), Air Interdiction (AI)/Strike Coordination and Reconnaissance (SCAR), and Close Air Support (CAS)/Combat Search and Rescue (CSAR). Handover training occurs in the transition phase to prepare students for remote-split operations (RSO) at their operational squadron.[34] An emergency procedure evaluation and an in-flight check ride awarding the student an AF Form 8 conclude the course.

[33] MQ 06 (IQT Change 2), 10.

[34] Handover training/remote split operations: transferring aircraft control from a local line-of-sight data link to a over-the-horizon satellite link controlled remotely. Both changing aircraft control and controlling an RPA remotely are two critical enabling capabilities of the RPA infrastructure.

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Recap

The RPA community has significant training hurdles in its future, but its recent success is astounding. In two decades, it transformed from a shoestring operation into the AF's most significant capabilities advancement in decades, possibly eclipsing the development of stealth and precision munitions. Basic technology and combatant commanders' insatiable demand for information created the exponential growth that led to today's RPA community. These challenges forced the RPA community to solve problems of identity, goals, and influence. In "dealing with its external environment and managing its internal integration," the RPA community created URT. [35] In the process, it took a pivotal step to establish its own culture.

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[35] Schein, 85.

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Chapter 2

Storm Brewing: RPA's Current Status

In the ISR portfolio alone, we grew an RPA industry from scratch that has become the oxygen the joint force breathes.

General David Goldfein
in CSAF letter to Airmen

Training is the connective tissue that enables Airmen to operate RPAs in a desired way to achieve a desired effect. Fundamentally, training has these requirements: a desired skill to achieve a desired effect, an instructor that possesses the knowledge and techniques to impart that skill, a student, and a tool to translate that applied skill into a result. The overarching assumption in a training environment is predictability. As Shein argues, when an operating environment changes due to external stimuli, an organization develops strategies and goals to respond based on its beliefs and values. An observer can reverse the process by examining an organization's artifacts, espoused values, and underlying assumptions to intuit its culture. Alternatively, if the observer already understands an organization's behavior patterns, he can predict its future decisions.

Few areas in the RPA community have remained static during times of rapid growth in an evolving security environment, yet the community elusively searches for continuity and a desire to achieve sustainable, steady operations. Figure 2 illustrates the exponential growth in combat lines provided by the AF since 2000, with more planned on the horizon. Drawdowns in Iraq and Afghanistan have not reduced persistent, armed ISR requests, as the Pentagon announced plans to increase daily RPA operations by 50% starting in 2019.[1]

[1] Brian Everstine, "DOD Plans 50 Percent Increase In RPA Caps By 2019", *Air Force Magazine*, 2015, http://airforcemag.com/DRArchive/pages/2015/august%202015/august%2018%202015/dod-plans-50-percent-increase-in-rpa-caps-by-2019-.aspx?signon=false.

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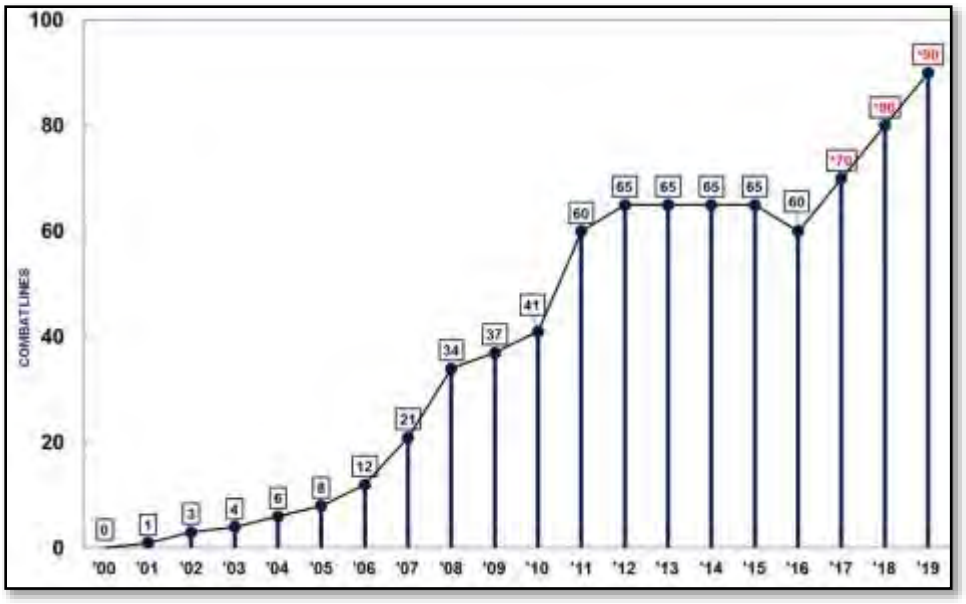


Figure 2: Past, present, and forecasted RPA Combat Lines by Calendar Year
Source: Lt Col Jason Green, "A Brief Look: The State of Remotely Piloted Aircraft (RPA) Operations Local, Global… Past, Present, and Future…"

Despite initial expectations that reduced operations in Iraq and Afghanistan would reduce RPA demand, the opposite has happened. RPA forces have dispersed across the globe, reducing efficiencies gained by concentrating forces. Forecasting on the supply side mirrors the difficulty of predicting demand as well. In 2012, staffs wrongly expected a reduction in force and underestimated future requirements. Planners under resourced the training pipeline, and instructor pilots now struggle to replenish work force requirements. Commanders wait expectantly to see if low retention rates materialize as the first batch of RPA pilots conclude their 6 year Active Duty Service Commitment (ADSC). Staffs struggle to estimate future requirements without historical attrition statistics to rely upon. Low manning sets up a vicious cycle, where stretched working conditions leads to job discontent which leads to increased attrition which then leads back to poor manning. In short, RPA pilots are in short supply, and solutions to escape the downward spiral involve short-term sacrifice, something that makes the problem more acute.

In 2015, Headquarters Air Force responded to community outcries, Congressional inquiries, and external audits. It developed a systemic set of

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initiatives to remedy the community's many issues, and an RPA Tiger Team formed to implement some 57 initiatives addressing manning, pay, scheduling, basing, and squadron organizations.[2] This chapter examines the Air Force's comprehensive and on-going response to its shortfall in three distinct steps. The first step increases training throughput, the second streamlines the training pipeline, and the third reduces attrition to lessen the need for replacement. The initiatives are consistent with larger AF culture, and parsing what those decisions mean at different levels of Schein's cultural assumptions provides greater understanding of how the AF makes choices. The examination of each responsive step will conclude by deconstructing decisions in the context of culture.

First Step: Increase Capacity

The community's on-going manning woes, lifestyle issues, and continuing fight for bureaucratic integration has received attention from Congress, the Governmental Accounting Office, RAND Corporation, and senior leaders. On March 16, 2016, General Herbert Carlisle, commander of Air Combat Command testified before the Senate Armed Services Committee. He addressed the approach needed to alleviate the community's shortfalls:

> The first step to fixing that is to increase the number of RPA crews by increasing the output of our training pipeline. Air Combat Command is responsible for the training of our Air Force's RPA pilots and sensor operators. We will graduate 384 next year which is 200 more than we have graduated annually in past years. This tremendous output is currently achieved with very limited resources as we strive to balance ACC's two main priorities: Provide for Today and Prepare for the Future.[3]

The AF wants 1400 RPA pilots to meet flying demands, staff requirements, and squadron overhead. It currently has 900. URT is doubling its output to close that gap. Accession sources continue to produce an abundant supply of willing URT candidates. According to its Director of Operations, the 558 FTS "is on track to produce 220 pilots [in 2016]. Next fiscal year [2017]-

[2] HAF/A3OC, *RPA Tiger Team Initiatives Update Brief*. 28 Jul 2016.
[3] Statement of General Herbert Carlisle, USAF in "Army Unmanned Aircraft Vehicle and Air Force Remotely Piloted Aircraft Enterprises," unclassified testimony before Senate Armed Services Committee (Washington D.C.: 16 March 2016).

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384 pilots. In perspective, Laughlin AFB, the AF's largest pilot training base, produces 300 pilots annually."[4] The 558 FTS expanded the flight training contract at Pueblo, installed more simulators, stood up more student flights, and added contract instructors to aid in the instrument qualification course and the RPA fundamentals course. The 12th Operations Group is establishing a student support squadron in the summer of 2017 specifically to alleviate increased administrative demands on the 558 FTS.

URT program managers have scaled productions smoothly to meet demand. It contracts out flying operations and relies on simulators and in-class instruction during RIC and RFC. The emphasis on simulator instruction increases scheduling reliability. Weather days exist only at Pueblo for RFT. Production therefore is predictable and timely. Fundamentals taught in RIC do not require RPA experienced contractors or AF instructors. Additionally, URT operates out of Randolph AFB, home of Air Education and Training Command, in San Antonio, Texas. The desirable location provides a large pool of flight instructors to drawn from. Attracting current and qualified RPA pilots from operational assignments has previously been a struggle attributed to URT instructor positions not qualifying for flying gate months. The AETC/A3FR staff corrected the oversight in January 2017, and more pilots are now eligible for an instructor assignment. Should additional RPA pilots be required, a new squadron in a new building will be required as flight rooms, briefing rooms, simulators, and instructors are all fully resourced. In short, the expansion to 384 RPA pilots per year has required great effort from the 558 FTS, but the squadron expects to achieve its production requirements.

[4] Lt Col Jason Green (Director of Operations, 558 FTS), interview by the author, 22 Dec 2016.

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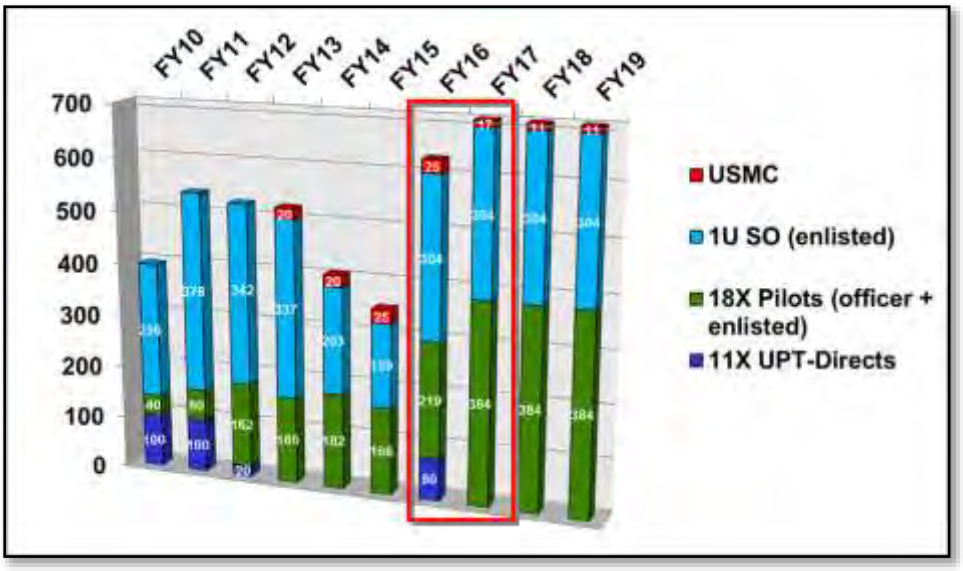


Figure 3: Historical and projected URT output
Source: Lt Col Jason Green, "A Brief Look: The State of Remotely Piloted Aircraft (RPA) Operations Local, Global… Past, Present, and Future…"

While URT has scaled to increase student production and has a viable plan of success, Holloman AFB's Formal Training Unit (FTU) falls further behind its required output. Squadrons are under high pressure to produce qualified graduates in a timely manner, but a multitude of issues conspires against this pursuit. Production requirements have grown, but the pipeline capacity struggles to adjust. The predominant issue is that instructors are under-resourced. Training squadrons use a metric called Basic Course Equivalency (BCE) to quantify the amount of time and resources required across training programs. Planners compute BCE requirements for instructor upgrades, launch and recovery instruction, and initial qualification training, and then ideally devote the timing and personnel resources to achieve the flying program. Problematically, though, no standard model translates BCE into clear staffing and time requirements.[5] No agreement exists on BCE assumptions, meaning that no commander can positively state his unit's production capability. The FTU needs an accepted model to link its capacity to its training burden.

[5] Ferro, Maj Jonathan Ferro and Maj Derek Benkoski. *Issues for the MQ-9 FTU: FY17 & Beyond*. 2016.

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The lack of clarity means that Headquarters Air Force, Air Combat Command, and the FTU Programmed Flying Training manager disagree on how much manpower is required to fix the problem. Headquarters Air Force dictates the Programmed Flying Training (PFT) program, but the RPA community's only PFT manager, the person with the clearest picture, resides at Holloman AFB. ACC resources the squadrons to provide student initial qualification training and instructor upgrade training but leaves out other requirements. The PFT manager communicates these discrepancies, but lacks authority to institute changes. Currently, FTU squadrons do not receive BCE credit for instructing Transition 2 and 3 courses for returning fliers. Daily launch and recovery operations and instruction incur a daily bill but are not reflected either. ACC tasked the two MQ-9 squadrons to transition the 6th ATKS instructor cadre from MQ-1s to MQ-9s, but the squadrons have not received additional resources.[6] New MQ-1 instructor pilots do not have 250 instructional hours, and, in accordance with AFI 11-2MQ-1&9, they require 50 hours flying the MQ-9 before upgrading. The PFT program does not account for this deficiency. Measurements tracking a squadron's instructors distort reality as well. A student in Flight Instructor Upgrade Training (FIUT) drains resources until qualified but counts against the squadron's Unit Manning Document (UMD) immediately after in processing. Upgrading instructors quickly alleviates the burden, but backlogs penalize squadrons twice. Ultimately, operational commanders and staffs plan and expect squadrons to achieve 120 BCE per year, but capacity only meets 78% of actual requirements. To meet expected output and cover additional requirements, each FTU squadron needs five additional qualified instructors, an 8% UMD increase.[7]

A few equipment challenges on the horizon will decrease BCE output to an unknown extent. The AF has scheduled MQ-9 Block 5 aircraft and Block 30 Ground Control Station cockpit upgrades in 2017. Current aircraft software is several generations behind operational units' software and is planned for upgrade

[6] The AF recently renamed the 6th Reconnaissance Squadron as the 6 Attack Squadron.
[7] Major Derek Benkoski (49th Wing Programmed Flying Training manager), interview by the author, 6 January 2017.

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as well. Instructors welcome these upgrades, but disruptions to aircraft availability, additional instructor training, and an updated syllabus will adversely affect student output. More simulators known as the Predator Mission Aircrew Training System (PMATS) will supplement current inventory, but it still falls short of requirements. Twelve operational PMATS are scheduled for March 2017, but unofficial PFT models forecast that eighteen are needed.

As a result, MQ-9 student production falls further behind, and prospects for erasing the deficit are overly optimistic. To lessen the widening gap between desired and actual production, the FTU surged in 2016. The FTU increased its student output from 280 BCE to 449, a 60% gain.[8] MQ-1 student production, which is healthy, masked the true gains. Col Robert Kiebler, the 49th Wing Commander who instituted the surge, called the plan unsustainable. Surge operations max out instructors routinely averaging 7 to 8 instructional events per week. Instructor events include academic instruction, phase briefs, simulator instruction, and flight instruction. To squeeze more productivity out of an instructor, squadrons introduced "super sorties," where two students share a single sortie. Initial calculations showed squadrons must surge to 2018, but the surge efforts continue to fall short. Figure 4 highlights the widening gap between required and expected effectiveness. As the situation worsens, the wing recently started advertising days behind the timeline to increase awareness. With the surge, MQ-9 students still graduate 25 days behind schedule. Students attend MQ-9 training as a temporary duty (TDY). Additional TDY days cost the AF $2.7 million per year. And despite all these stop-gap efforts, still there is a yearly shortfall of 24 pilots per year, roughly half an operational squadron.

[8] Colonel Rob Keebler, USAF (49th Wing Commander). "RPA Strategic Vision". Presentation, 2016.

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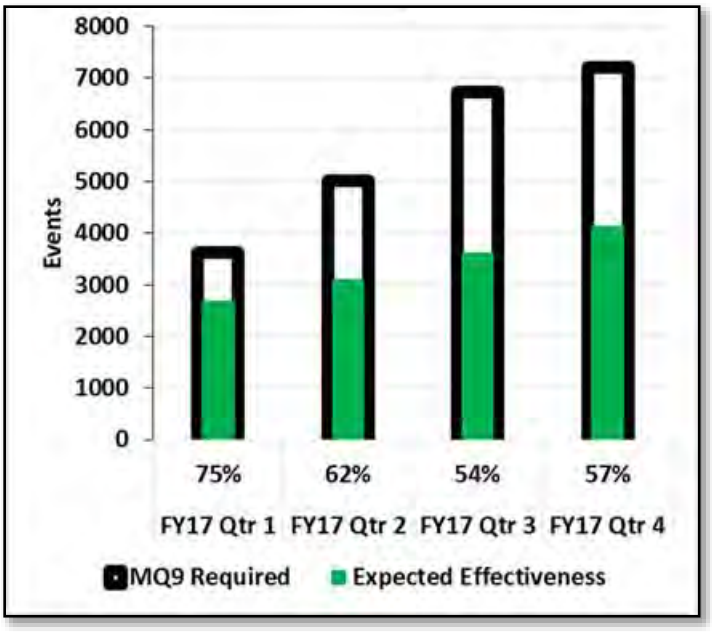


Figure 4: MQ-9 Projected Effectiveness for Fiscal Year 2017
Source: Major Jonathan Ferro and Major Derek Benkoski. Issues for the MQ-9 FTU: FY17 & Beyond. 2016.

Studies investigated launching a fourth FTU squadron, but two reasons drove recommendations to remain at three. One, the overhead costs and time to build a larger instructor cadre reduce current resources, exacerbating the immediate situation without seeing gains until much later. Consultants paid to recommend courses of action assess that the 49th Wing would see a net gain in 2022. Second, four FTU squadrons at full capacity surpass demand and overwhelm anticipated operational requirements. A wing of four FTU squadrons could train 334 pilots above that currently required, and would produce an extra 206 pilots once in sustainment mode.[9] Three FTU squadrons can produce 360 BCE, 145 more pilots per year than required to sustain operations once at full instructor strength.

To summarize, at current operating levels, the 49th Wing is unable to produce the expected number of qualified students. Without allotting more resources or resetting expectations, the surge strategy will not resolve the

[9] Booz, Allen, Hamilton. *Remotely Piloted Aircraft Pilot Production Pipeline Study Final Report*, 2016, ii.

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shortfall, and adding another training squadron will likely add too much capacity and take too long. Schein includes repair strategies as a step that groups cycle through as they adapt. The Air Force typically prioritizes operational requirements over other needs. In this case, training shortfalls affected combat squadrons' ability to sustain 65 combat lines. By convincing the Secretary of Defense to authorize a temporary reduction to 60 lines, the AF took remedial action and demonstrated its value on training. In an interview, an instructor pilot assessed his squadron morale as higher than his sister squadron's due to better perceived training, despite being further behind the timeline. Such an insight discloses deeper cultural values: training trumps time. In managing internal integration, staffs have yet to resolve boundaries and communicate work expectations. Power and authority reside at Air Combat Command and Headquarters Air Force staffs, but the knowledge and management reside locally at Holloman AFB. Leaders recognize that Air Combat Command's RPA branch is not structured to handle student training issues, and will transition the 49th Wing to Air Education and Training Command in 2018.

Second Step: Improve/Refine Pipeline

Another way to train more students is to increase pipeline efficiency or decrease its length. But, the current syllabus' sequential structure creates barriers to this solution. Rather than branching and opting students to several progression tracks, prerequisite events slow class progression. At the conclusion of each phase, classes regroup for academics and phase briefs. This forces students ahead of their class to wait. The two latest MQ-9 IQT syllabus iterations increased its scope, number of events, and time. The previous syllabus needed 49 training days; the current one requires 77 days, but takes 90 days due to attrition; and the draft syllabus on its way to approval needs 92. Air Combat Command resists cutting requirements deemed necessary by operational squadrons at syllabus review boards. As more training creeps into each IQT syllabus iteration, the FIUT syllabus has expanded 400%.[10] In response, the 49th Operations Group has

[10] Booz, v.

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waived a third of flights and shifted them to the simulator. The increased syllabus drives more time and resource investment precisely at a time when both are limiting factors.

Previously, course start dates were haphazard. A concerted effort to coordinate start dates between the squadrons to offset airspace, aircraft, simulator, and academic instruction requirements has increased efficiency. Trying to find more efficiencies like this prompted the AF to contract with the Booz, Allen, Hamilton (BAH) consulting company to study the process and make recommendations. Completed in 2016, their report included multiple proposals to streamline training which, according to their analysis, is the best approach to achieve the manning required within time constraints to operate sustainably.[11] The study notes that the most impactful and timely way to increase production is through reduced flying sorties, increased simulator sorties, and reducing duplicated training between URT and the FTU. These measures should have immediate impacts.

The report identified that the AF needs to conduct a formal, end-to-end training needs assessment (TNA) and training systems requirements analysis (TSRA). The two standard procedures define the required skills and determine the appropriate curriculum, delivery methodologies, and training devices appropriate to produce a basic qualified RPA pilot. Both studies are mandatory but not accomplished due to high operations tempo. Currently, the ACC Training Support Squadron Detachment 2 hosts syllabus review conferences to identify training requirements. Bringing together operational and training squadrons to identify requirements and shortfalls helps refine syllabi, but no agency has performed a technical or cost benefit analysis to assess the cost of proliferating mission requirements or judge how instructors should accomplish the syllabus. Surveys and conferences reflect institutional culture and values more than true technical training requirements. As an example, an Air Force Research Laboratory study in 1998 reported that most RPA pilots felt T-37 training was

[11] Booz, i.

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absolutely necessary to fly military aircraft- a demonstrably false impression, as the AF has since learned.

Training Task List	Not Applicable (1.00 - 1.50)	Nice-to-have < Necessary (1.63 - 2.38)	Absolutely Necessary (2.43 - 3.00)
T-3 Flying	8 (15.1%)	10 (18.9%)	35 (66.0%)
T-37 Instrument Training Maneuvers	0 (0%)	12 (28.6%)	30 (71.4%)
T-37 Navigation Training Maneuvers	0 (0%)	11 (26.8%)	30 (73.2%)
FAA Instrument Rating	0 (0%)	10 (35.7%)	18 (64.3%)
Predator Ground Control Station	0 (0%)	0 (0%)	23 (100%)
Predator Flying	0 (0%)	0 (0%)	38 (100%)
All Tasks	8 (3.6%)	43 (19.1%)	174 (77.3%)

Figure 5: Task Criticality as Assessed by Air Vehicle Operators in 1998.
Source: William C. Tirre and Ellen M. Hall, USAF Air Vehicle Operator Training Requirements Study (Brooks AFB, TX: AF Research Laboratory, 1998), 4.

As Booz, Allen, Hamilton noted, "As a result [of no formal requirements review], there is not a widely accepted understanding of the required capabilities RPA pilots should possess at Initial Qualification, nor agreement on appropriate curriculum and training methods to efficiently and effectively produce qualified RPA pilots."[12]

Though not an official TRSA, the Booz, Allen, Hamilton report argues to replace more flights with improved simulators to streamline the course and reduce redundancy between URT and the FTU. Figure 6 depicts BAH's recommendation to combine URT's RFT and RIC and shift RFC to the FTU. BAH concludes this is the most immediate and productive course of action available, but its authors fail to address how streamlining will increase production if the FTU's bottlenecks remain. In addition, the study recommends transferring Reaper IQT from ACC to AETC, a recommendation the AF accepted and plans to do in 2018. This will have two effects: it will establish unity of command for the entire production process, and it will introduce increased staffing overhead as

[12] Booz, iv.

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AETC brings its established manpower model to the FTU. The study echoes the 49th Wing PFT manager's assessment. It concludes that while the surge is beneficial, current FTU output is insufficient to make short-term improvement to the existing shortfall.

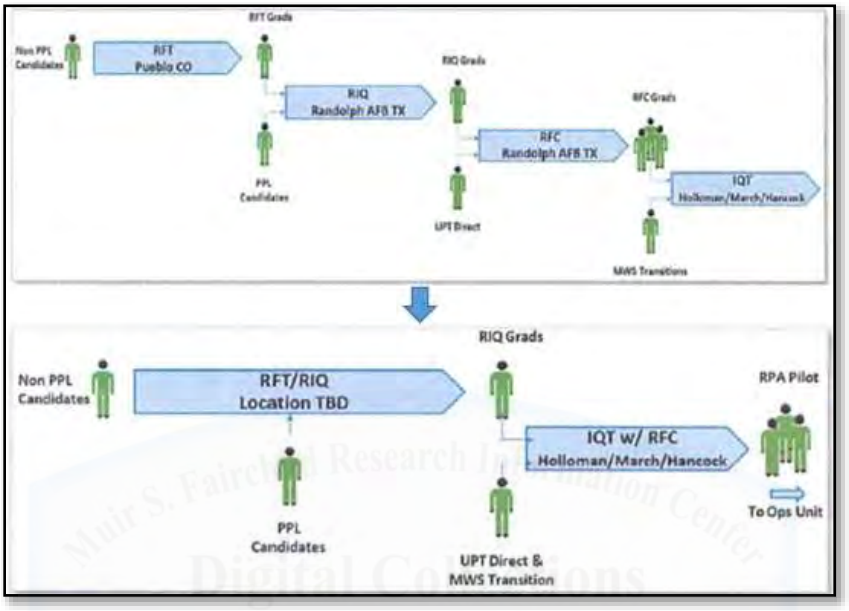


Figure 6: Streamlining RPA Pilot Production by Restructuring URT Sub-phases across URT and FTU. Source: Booz, Allen, Hamilton. Remotely Piloted Aircraft Pilot Production Pipeline Study Final Report, 2016, ii.

According to Schein, training is a visible organizational process, and, as an artifact, what it represents can be hard to decipher. In this case, the AF has shown a clear preference to ensure quality training across burgeoning mission sets rather than emphasizing quantity of graduates. Commanders have not elected to streamline training or combine courses despite recommendations. The reality of limited resources has forced leaders with the tough choice to pare back flight requirements, choosing production over quality. These reluctant choices are waivers and exceptions that reflect a reluctant, temporary value judgement.

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Third Step: Stop Impending Attrition

> *In April 2014 we also found that the Air Force may face challenges retaining UAS pilots. Pilots in 7 of the 10 focus groups we conducted at three Air Force bases indicated that retention of UAS pilots is or will be a challenge and UAS unit commanders in one location we visited and other Air Force officials stated that they were concerned with future retention rates of UAS pilots. As mentioned above, we recommended that the Air Force develop a tailored strategy that addresses both recruiting and retention of UAS pilots and the Air Force concurred.*
>
> Ms Brenda Farrell, Government Accountability Office's Director of Defense Capabilities and Management, testifying to Senate Armed Services Committee

Manning is also affected by outflow. The AF follows a typical pattern where demand is miscalculated, overproduction overcorrects, and then personnel separate. This induced oscillation has yet to visit the RPA community. Up to this point, outflow has been in form of completed Alpha tours, retirements, and 11U pilots (SUPT graduates) separating from the AF.[13] URT carries a 6-year Active Duty Service Commitment. Because 2018 will mark the first URT class' ADSC expiration, attrition within the community does not have any historical data to serve as a guide, and Headquarters Air Force A1, responsible for manpower projections, refuses to forecast attrition; it only uses actual data.[14] Using historical data works in other established communities, but not in the RPA community, where no such data exists. Organic research anticipates a grim outlook: the forecast is 64% overall 18xx attrition amongst those whose commitment is ending. That translates to 31% of the RPA pilot community that is expected to separate in 2018 (118 pilots) and 2019 (163 pilots). Currently, the MQ-9 Aircrew Retention Program (ARP) has a take rate of 36% compared to the AF pilot average of 59%. If the low take rate is a leading indicator of retention,

[13] Alpha tours are tours of duty away from a pilot's primary aircraft. Alpha tour options include pilot training, Introduction to Fighter Fundamentals, Air Liaison Officer, and RPAs. The AF recently discontinued RPA assignments as Alpha tours. At the conclusion of an Alpha tour, pilots typically return to their primary aircraft.
[14] Keebler, 2016.

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then the FTU should anticipate a dramatic correction in production in the coming years.

To preempt an exodus, the AF instituted multiple initiatives and a Culture and Process Improvement Program (CPIP). Dubbed the RPA get-well plan, 57 initiatives aim to achieve a community-wide 10:1 crew to combat line ratio and 100% FTU manning. This wide-reaching plan addressed ten different areas. Ones that address retention include decreasing operational requirements and increasing pay. Secretary of Defense Ash Carter approved a reduction in combat lines from 65 to 60 in order to alleviate the RPA community's state of constant surge. This freed a squadron's worth of manning to relocate to Holloman AFB. Moreover, the Secretary of Air Force rapidly implemented a $1500/month flight pay increment for the handful of RPA pilots whose commitment had expired. Then, once routed through Congress, the AF offered an increased retention bonus of $35k per year. General David Goldfein, CSAF, acknowledged the bonus as a crucial step to help "retain these valued aviators to execute our current operations and shape the future."[15] Reducing combat lines took buy in from the Secretary of Defense and required the AF admitting it could not meet combatant commanders' needs. The AF's institutional preference was to reduce combat capability rather than to reduce training requirements. The AF responded to a manning shortfall with an oft-repeated technique: the bonus amount equals fighter pilot bonuses, signifying parity and recognition.

Meanwhile, Culture and Process Improvement Program focuses on community standardization and stabilization. The program formalizes the squadron, group, and wing structure across the AF, stands up a new wing and operations group, establishes a dedicated launch and recovery squadron, builds dwell time, renames reconnaissance squadrons to attack squadrons (ATKS), and

[15] Secretary of the Air Force, *RPA Pilots Set To Receive $35,000 Annual Bonus*, 2016, http://www.af.mil/News/Article-Display/Article/911383/rpa-pilots-set-to-receive-35000-annual-bonus/.

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allows logging combat time.[16] A standard squadron will now consist of four combat lines; an ops group will consist of three combat squadrons and an OSS; and a wing will add a maintenance group and a launch and recovery squadron. Additionally, through CPIP, another wing and operations group will stand up, and, as announced in December 2016, one of those will be at Shaw AFB.[17] Dedicated launch and recovery squadrons allow Mission Combat Element (MCE) squadrons to focus on their combat mission without additional overhead from launch and recovery training and deployments. The realignment in responsibilities also allows LR squadrons to develop experience and retain trained personnel in the squadron. Other communities use a deploy to dwell metric to measure aircrew strain. The RPA community is adopting this metric to rotate squadrons out of combat lines to reconstitute and train. Ultimately, CPIP aims to create sustainable and predictable working conditions in an environment that has been anything but that over the past decade.

The two plans have reinforcing objectives. Normalization is the process of bringing something to a normal condition. Here, it brings RPAs into the AF's fold, but it also demonstrates that the larger AF is reevaluating its beliefs. Through CPIP, the AF signaled to RPA pilots and sensor operators their institutional value. Logging combat time reflects the AF's growing understanding of the significance and honor involved in remote warfare. Changing squadron names better conveys the multirole missions tasked to these squadrons.[18] Combat RPA squadrons belong to Air Combat Command and AF Special Operations Command, and both commands treasure their kinetic capabilities. While only a cosmetic move that requires new patches and signs, the renaming moves RPA "Attack" squadrons closer toward a shared identity with Air Combat Command's

[16] Secretary of the Air Force, *Air Force Approves RPA Initiatives*, 2016, http://www.af.mil/News/Article-Display/Article/717598/air-force-approves-rpa-initiatives/.
[17] Major Landon(ACC/A3MU), "Persistent Attack And Reconnaissance Division MA-1/MQ-9 Branch Brief", (Presentation, 2016).
[18] Dave Blair, "A Categorical Error: Rethinking 'Drones' As An Analytical Category For Security Policy", 2016, https://www.lawfareblog.com/categorical-error-rethinking-drones-analytical-category-security-policy.

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fighter squadrons. As more and more cultural artifacts overlap between the sub-communities, the grayer the distinction becomes between them.

Increasing squadrons, groups, and wings achieves multiple objectives. First, more units mean more leadership opportunities and therefore more promotions. More promotions translate to more advocacy via more RPA flag officers and more staff officers exercising influence. Second, having more squadrons enables units to rotate out of combat lines to train and reconstitute. Dwell time provides a respite from shift work and an opportunity for squadron events, upgrade training, and continuity training. Operational squadrons previously accomplished training in an ad-hoc manner in a combat zone, a unique feature to the RPA community. Rotating out of combat sorties like other communities allows operational units to adopt standard upgrade and continuity training practices. The initiatives also clarified unit manning by linking personnel requirements to a desired capability.

The two plans together are the AF's response to operate, train, and equip RPAs; they also are significant steps toward integrating the RPA community. An organization makes assumptions about managing internal integration. Schein states that power, status, group boundaries, rewards, and common language are areas where an organization discloses those assumptions. While no definitive prescription can account for individual decision-making, how an organization approaches retention reveals much about the organization's culture and values. By allocating pilot-level bonuses and flight pay, the AF has signaled its level of commitment to its RPA pilots. Borrowing from other communities' best practices moves the RPA closer to resembling manned flying operations and reduces cultural boundaries separating manned and unmanned platforms. Renaming squadrons and adopting a deploy-to-dwell metric reframes RPA's conceptual category and introduces more language commonality with manned aircraft squadrons. It demonstrates an inclusionary if unimaginative effort to promote the RPA community's sustainability and belongingness. Such measures are a welcomed departure from previous manpower decisions.

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Recap

Corporately, the active duty AF views its personnel system as a conveyor belt that loads recruits onto one end, uses them, and returns them back to society years later at the other. To maintain the health of the community, a steady flow of accessions ideally matches the same steady flow of separations. The AF prizes experience and therefore predictability. Once experience leaves the conveyor belt, it is gone, and the AF cannot hire an immediate substitute to replace the loss. By anticipating levels of attrition along progressive year groups, the AF can respond by loading more recruits onto the conveyor belt and trying to keep existing personnel from falling off. The RPA community's young existence means that the expected pull of separations is unknown. In anticipation, the AF has not stood by idly.

Managing the training pipeline is a response to the uncertainty of intrinsically uncontrollable or difficult events. Each decision tests the validity of corporate AF values. If the initiatives are successful, they will reaffirm corporate values and beliefs. But, if they are not, the RPA community will question and reexamine its deepest fundamental assumptions.

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Chapter 3

Army UAS Training

Our identity is strengthened through education, training, and experience.

Department of Army's
The Army Profession

Tension between the Air Force and the Army started before the National Security Act of 1947 when the Air Force became an independent service. Prior to and through World War II, there was suspicion, if not outright hostility, between many air and ground commanders over what equipment to acquire, how to allocate resources, and how to prioritize missions. Air Corps leaders, with the tangibly close realization of an independent Air Force, chose to "throw as much into bomber and pursuit forces as they could" to emphasize strategic bombardment to the detriment of air-ground integration.[1] Ground commanders viewed the effort as imbalanced and unsatisfactory and looked to find a solution.

The Secretary of War on 6 June 1942 ordered the formation of organic aviation assets to support artillery observation. Earlier, Major General Mark W. Clark, Lieutenant General McNair's Chief of Staff in Army Ground Forces, had approved and passed the recommendation to the War Department without McNair's knowledge.[2] When McNair discovered what had passed, he did not protest, and the War Department accepted the recommendation. Lieutenant General Henry H "Hap" Arnold vehemently opposed the move. Arnold argued to no avail that putting light planes in the ground forces would effectively "create a separate Air Force in the Army and that such a thing was unthinkable."[3] The budding Army Air Forces strived for centralized and unified command of air forces. The Army conversely had taken steps to decentralize control of air assets to ensure ground commanders received the reliable support they deemed necessary. A few months later in November 1942, Army aviation units entered into

[1] James W. Williams, *A History Of Army Aviation: From Its Beginnings To The War On Terror*, 1st ed. (New York: iUniverse, 2005), 33.
[2] Williams, 35.
[3] Williams, 37.

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combat on the North African coast to adjust artillery fire, gather intelligence, support naval bombardment, and direct bombing missions.

A nearly identical scene played out in 2007 in Operations Iraqi Freedom and Enduring Freedom. As mentioned in Chapter 1, General Petraeus' counterinsurgency and nation-building strategy dictated a surge and a need for more ISR. The USAF's failure to meet the Army's growing Reconnaissance, Surveillance, and Targeting Acquisition (RSTA) needs can be attributed to a lack of assets and to servicing higher priority requests, such as special operations and supporting troops in contact with the enemy. Colonel James G. Rose, Commander of Army Intelligence in 2007, observed, "Current and envisioned non-Army UAV systems are limited in their ability to provide responsive support to various requesting ground-maneuver units based on limited assets. When units were successful in requesting UAV support, communications problems, delays in data receipt, and retasking procedures/authority decreased the effectiveness and responsiveness of the UAV system."[4] With Secretary Gates' support, the Army procured an organic medium altitude, long endurance UAS capability to ensure future reliable ISR support despite Air Force protests.

As introduced in earlier chapters, examining an organization's artifacts, values, and underlying assumptions to understand organizational culture lends insight into current and future decision making. Army Headquarters states in its Army Regulation 350-1, "All training and leader development actions occur within the Army culture, a culture which embraces values and ethics, the Warrior Ethos, standards, and enduring principles and imperatives. Army training strategies serve to synchronize the role each training domain plays in building force readiness."[5] Thus, an organization's cultural origin is an important first step to understanding how it makes decisions.[6] Next, "from an evolutionary perspective, we need to identify the issues that any group faces from the moment of its origin through to its state of maturity and decline."[7] This chapter will use Schein's framework to examine Army UAS training, how it has dealt with its external

[4] Colonel James G. Rose. "Extended Range/Multi-Purpose (ER/MP) Unmanned Aerial Vehicle (UAV) Operational Requirements Document," 4.
[5] United States Army, *350-1 Army Training and Leader Development*, 2014, 2.
[6] Schein, 84.
[7] Schein, 87.

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environment and managed internal integration. The chapter will conclude by identifying the underlying assumptions, values, and artifacts tied to the organization.

Army UAS History

The Army generally views UAS as a valuable support tool, and the desire is to decentralize control and maximize autonomy and reliability. Beyond that, though, little controversy surrounds the program, especially in comparison to the USAF. The Army's training program values practicality, is more affordable, and requires less time. Consequently, civilian leaders use it as a measuring stick to scrutinize the Air Force's more expensive RPA training pipeline.

The Army's involvement in unmanned aircraft goes back to 1918 and Charles Kettering's Bug. In World War II, the Army developed drones for anti-aircraft target practice, and in the Cold War, the Signal Corps tested various reconnaissance platforms at Fort Huachuca, Arizona. In 1955, they introduced the RP-71, a precursor to the Shadow UAS.[8] It solved many ground commanders' problems with airborne reconnaissance: it launched rapidly, it imbedded with ground forces, and personnel quickly gathered and processed intelligence for immediate use by the commander. From the RP-71 came the SD-1 through SD-4 variants, but ballooning costs, an inability to overcome technical hurdles, and poor performance convinced the Army to cancel the programs. The Army and its industry partners then made little headway during the Vietnam War. The next significant UAS iteration for the Army was the Aquila in 1975. Before its cancellation in 1987, the program demonstrated significant capability leaps in its sensor and data-link packages and laser designation capability. The Navy and Marine Corps would continue Aquila's next iteration with the Exdrone, which they employed as the renamed the BQM-147 Dragon in Desert Storm.[9] Significant, cost effective, sustainable capabilities emerged shortly thereafter. The Army finally ushered in the drone age as it is known today when it fielded its RQ-5 Hunter UAS in 1995.

[8] John David Blom, *Unmanned Aerial Systems: A Historical Perspective* (Fort Leavenworth, Kansas: Combat Studies Institute Press, 2010), http://usacac.army.mil/cac2/cgsc/carl/download/csipubs/OP37.pdf, 50.

[9] Mark Farrar (2-13th Aviation Regiment Director of Training), interview by the author, 5 January 2017.

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Figure 7: RP-71
Source: John David Blom, Unmanned Aerial Systems: A Historical Perspective (Fort Leavenworth, Kansas: Combat Studies Institute Press, 2010), http://usacac.army.mil/cac2/cgsc/carl/download/csipubs/OP37.pdf, 49.



Figure 8: Aquila UAS
Source: "Lockheed MQM-105 Aquila", Wikipedia (Wikimedia Foundation, 2015.



Figure 9: Exdrone, Later Renamed BQM-147 Dragon
Source: Andreas Parsch, "BAI Aerosystems BQM-147 Exdrone", 2002, http://www.designation-systems.net/dusrm/m-147.html.

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Figure 10: RQ-5 Hunter
Source: "Hunter RQ-5A / MQ-5B/C UAV", accessed 1 March 2017, http://www.army-technology.com/projects/hunter/.

The first Army UAS operator was Master Sergeant Mark Farrar, now the 2-13th Aviation Regiment's Director of Training as a GS-14 employee. As he recounted, in 1986, the Training and Doctrine Command's (TRADOC) System Manager, Colonel Ted Fictel, formed a UAS Task Force consisting of 5 NCOs with broad latitude to "figure out how to integrate UAS into the Army."[10] The Colonel selected then-Sgt Farrar, with expertise in communications and stationed at the Army's Center for Military Intelligence in Fort Huachuca, Arizona, to the team. Other team members had expertise in aviation-related ground maintenance, aerial image observation, photo interpretation, and aerial maintenance. Although given flexibility, their budget was minimal. With it, they purchased and built several remote control (RC) aircraft kits. Serendipitously, an avid RC enthusiast and civilian, George Makowitz, was serving at Ft Huachuca as an interrogator. The team tapped into his expertise, and all learned to fly from him.

The group connected with a Marine Corps project officer, Captain Allan Watt at the Johns Hopkins University's Applied Physics Lab (APL). The Marine Corps had contracted with APL to develop an amphibious, expendable jamming platform. Capt Watt had a prototyped delta wing drone, the Exdrone, and he relied on APL's one qualified pilot for flight tests. The Army and Marine Corps began a collaborative relationship at Ft Huachuca, where restricted airspace and good weather permitted consistent flight operations and surrounding hills blocked electromagnetic interference.

[10] Farrar interview.

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The Marine Corps' payment was equipment, and the Army provided the operators, the developmental team, the runway, and airspace. The successful partnership achieved multiple milestones. The group achieved two long distance world records with handovers coordinated by line of sight radio communications. The Exdrone deployed to Desert Storm as the Dragon drone, and after successful testing, the intrepid group declared Ft Huachuca the Department of the Army's Unmanned Training Center. The title stuck when no one disputed the claim. The Army and Marine Corps continue to jointly train enlisted operators on the Shadow UAS.

Thus far, Army UAS had been small, entrepreneurial, innovative, and practical. Each UAS Task Force member had a specialty, and overlap developed as the team gained experience. Operators flew, conducted maintenance, and solved overlapping problems in radio or camera control or navigation. As the platform matured, the team wrote and amended a curriculum for future operators with each subject matter expert handling their respective section. The syllabus reflected their personal RC aircraft experiences and expectations of Army employment. The Army's first UAS company conducted both combat operations and testing. Operators visually accomplished takeoffs and landings. Personnel cross-trained to conduct maintenance while standing by for unplanned early recoveries. At that time, personnel were selected based on their maintenance aptitude. To that point, external pressures brought few fiscal resources and little oversight, and its initial success reinforced the decision to use NCOs and to work from small, hobbyist RC aircraft toward larger and more sophisticated UAS. Specialized NCOs able to perform generalized tasks across the spectrum of operations continued to be the UAS cornerstone.

In 2005, Military Intelligence Commanding General, Major General Barbara Fast, and Aviation Branch Commanding General, Brigadier General E.J. Sinclair, argued for UAS proponency within the Army. UAS had grown under MI, and MG Fast wanted to maintain control of the payload operator to ensure imagery responsiveness. UAS had been a boon for intelligence communities, and they jealously guarded such a capable asset. The emerging capability did not always escape cultural inertia; in MI's case, it surfaced in an unsuspecting way. As a case in point, imagery training occurs at Ft Huachuca, and for 2 years, black and white image interpreters successfully blocked upgrading the Shadow's camera to color full motion video.

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Despite MI's best efforts, on 19 Apr 2006, Aviation Branch took proponency of the operation they referred to as the "R/C club at Ft Huachuca." Aviation Branch intended to bring UAS in line with best aviation practices, and they had maneuvered to keep the crew dual qualified to aid flexibility and crew coordination. In reality, two things happened. One, the UAS program began to professionalize and normalize to Aviation Branch standards. Safety and maintenance records dramatically improved, but the shift was not to everyone's liking. Some tenured instructors bemoaned the move away from efficiency, innovation, and dedication. Two, in reorganizing, the UAS community lost a powerful advocate in Military Intelligence. Under MI, UAS brought a unique capability to the sub-culture, and its operationalized intelligence was prized. The reorganization under Aviation Branch established a pecking order similar to the USAF's situation with RPAs, and, similarly, UAS found itself at the bottom. Career Aviation Branch helicopter pilots without UAS experience rotated through officer leadership positions. The training center remained at Ft Huachuca and fell under 1st Aviation Brigade at Ft Rucker. The geographic separation hurt UAS advocacy, and it turned UAS training into an island on Ft Huachuca. Practically, this translated to lack of resources as prioritized by the Aviation Branch. The 2-13th Aviation Regiment must negotiate launch and recovery windows at Libby Airfield with tenant units and USAF squadrons at Davis Monthan AFB, AZ. Obtaining range time has been problematic as well, but as Forces Command (FORSCOM) and National Guard units ramp up UAS training at Ft Huachuca, range priority has increased.

In 2009, Army enlisted operators started flying the Warrior A, essentially an MQ-1 Predator, until Gray Eagle was fielded. Initially, they flew MQ-1s owned by Big Safari, the Air Force's rapid procurement force that oversees the acquisition, modification, and logistics support for special purpose weapons systems. At the Army's behest, General Atomics added point and click interaction to achieve ease of use and efficiency as well as an auto takeoff and land feature. Before the upgrade, warrant officers performed takeoffs and landings and handed off control to enlisted "cruise" operators for the mission. General Atomics lengthened the wings and added 2 hard points to allow the Gray Eagle to carry 4 Hellfire missiles. Increases in autonomy allowed Gray Eagle operations to have an enlisted, universal operator capable of

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executing all aspects of aircraft and payload control. Wider Army efficiency practices drove universal maintenance personnel to work on all UAS and universal ground control stations to operate Shadow and Gray Eagle. Simplicity of operations has strong value in the Army and has allowed it to maintain a widely trained force. Interoperable equipment, operators, maintainers, and UAS procedures will result in further dispersed UAS control beyond Army Aviation Branch.[11]

Current Army UAS Employment

A divisional Gray Eagle company is assigned to each of the Army's active duty Combat Aviation Brigades to provide ground force commanders organic reconnaissance, surveillance, security, and attack capabilities. Additionally, two larger Gray Eagle companies are assigned to Intelligence and Security Command (INSCOM), and two are assigned to Army Special Operations Aviation Command (ARSOAC). The companies organize to deploy as a standalone unit and conduct operations from one or more locations within their division area of operations. Each company consists of 127 soldiers and 12 air vehicles. With the company collocated, it can provide six simultaneous 24-hour missions per day. When geographically split, it can provide four to six combat lines.

In the development of UAS, the Army chopped its organic assets to divisions, with actual control delegated down to Brigade Combat Teams (BCTs). Gray Eagle followed this model. In a nearly opposite operational approach to the USAF, this can theoretically mean launching a Gray Eagle from an established runway away from the battlefield and then performing a line-of-sight handover to the division. In practice, however, once operators launch via line of sight control, they transfer the aircraft to KU band satellite control and continue flying the mission. USAF operators deal with the stigma of remoteness, but the Army operators embed as a platoon or company in a deployed combat aviation brigade (CAB). As UAS capabilities increase, CABs grow more accepting of enlisted operators' contributions and take concerted efforts to include the operators in collective training and missions. A unique outflow of these efforts and

[11] Major Ariel Schuetz (US Army TRADOC UAS Capabilities Manager), interview by the author, 3 March 2017.

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organizational structure is that "these platoons are employed with the AH-64 Apaches to execute manned/unmanned teaming for enhanced reconnaissance, security, and attack operations."[12] This present model dominates, but current events may morph this concept of operations closer to USAF methods, especially with INSCOM and ARSOAC formations.

Recent ISR Request for Forces (RFF) tests the Army's organic model. According to General David G. Perkins, the current Training and Doctrine Command (TRADOC) Commanding General, "Although designed to support Army division requirements, these formations have been recently deployed in support of combatant commanders separate from their divisions."[13] The Army responded by creating Gray Eagle companies at echelons above division (EAD) designed to conduct split operations. Assigned to both the Intelligence and Security Command (INSCOM) and the Army Special Operations Aviation Command (ARSOAC), these Gray Eagle companies have 165 soldiers and 12 air vehicles. Currently, the Army fields three Echelons Above Division (EAD) Gray Eagle companies and plans to stand up one additional company this year.[14] These companies are specially organized, trained, and equipped to conduct long-endurance, extended range, multidiscipline intelligence, and precision strike operations to provide timely intelligence and destruction of high value targets in joint organizations. Enlisted soldiers and warrant officers rotate through these units and conventional Army units throughout their careers.

Assigning organic UAS to divisions allows flexibility, but it has efficiency and expertise costs in operations and training. The Army's Human Resources Command assigns soldiers to either a BCT, CAB, or EAD after completing initial UAS training with no additional unit specific training. The gaining units incorporate soldiers into their operational unit's aircrew training program (ATP), which is designed to produce fully mission trained, combat-ready crewmembers. This training, specifically Readiness Level (RL) 2, parallels the Air Force's Combat Mission Ready (CMR) training conducted at the

[12] Statement of General David G. Perkins, USA in "Army Unmanned Aircraft Vehicle and Air Force Remotely Piloted Aircraft Enterprises," unclassified testimony before Senate Armed Services Committee (Washington D.C.: 16 March 2016).
[13] Statement of General Perkins, 2016.
[14] Statement of General Perkins, 2016.

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operational squadron level. RL 3 parallels an AF squadron's continuation training. The level of ATP training differs dramatically with each unit; BCTs have the least training, followed by CABs, followed by INSCOM and ARSOAC.

The ATP focuses on task proficiency to enable the execution of the unit's mission essential tasks. The process consists of progressing through three readiness levels (RL). Graduates from Fort Huachuca operate to an RL 3 standard. RL 3 focuses on training and demonstrating proficiency in basic launch, recovery, and flight tasks. RL 2 is specific mission training and focuses on training and demonstrating proficiency in those tasks required to execute missions. These tasks include reporting, air-ground operations, acquiring and engaging targets, conducting reconnaissance, and MUM-T. The third progression level is RL 1, continuation training. Once designated RL 1, the UAS crewmember is expected to maintain proficiency in base, mission, and special unit tasks by accomplishing semiannual and annual critical task iterations as well as meet semiannual flying hour minimums. RL 1 crewmembers must also pass an annual standardization flight evaluation and written examination.[15]

In testimony to the Senate Armed Services Committee, General Perkins reported difficulties achieving and maintaining RL 1. Operational Gray Eagle companies have a dismal record maintaining required readiness. Installations that maintain UAS assets do not necessarily have the appropriate infrastructure like airspace or Ground Based Surface to Air Avoidance (GBSAA) set up to permit transiting, the frequency spectrum needed to control its UAS, or suitable weather for consistent flying. After graduating from training at Ft Huachuca, young operators may not fly again for several months if they are assigned to divisions during initial fielding or if the installation is not properly equipped to support operations. As an example, the Army operates 104 Shadow units, and 86 failed to make their minimum flight hour requirements for various reasons.[16] Too often, the units sit boxed in the motor pool at home station, unable to train. Divisions that need ISR wartime capability collocate Gray Eagle companies regardless of whether the airspace environment is conducive to training. In the majority of locations, the companies are unable to achieve needed readiness levels. At Fort Irwin in southern California, the

[15] Statement of General Perkins in Senate, 2016.

[16] Bill Coleman (Gray Eagle Project Manager), interview by the author, 5 January 2017.

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runway can only handle single direction operations. At Fort Wainwright in Fairbanks, Alaska, difficult weather reduces the flight availability window, and environmental restrictions prohibit runway de-icing. Fort Carson has the most operating difficulties. Spectrum management, access to restricted airspace, mountains, and required GBSAA support are problematic. This led one instructor at Ft Huachuca to lament, "The Army wants the capability but not to manage and harness it."[17]

Schein states that cultural assumptions evolve around all aspects of a group's relationship to its external environment. "If the environmental context is changing, such conflict can be a potential source of adaptation and new learning."[18] Assumptions about adaptation to external stimuli to enhance survival is reflected in an organization's mission and strategy, goals, means, measurements, and corrections made. The Army's stated mission is to "fight and win our Nation's wars by providing prompt, sustained land dominance across the full range of military operations and spectrum of conflict in support of combatant commanders."[19] Seen in this light, the Army's UAS approach to gain and sustain land dominance by focused air-ground integration is appropriate, but because it is a support asset, it does not demand the means it needs. As the new security environment demands greater battlefield intelligence and possibly increased standoff distance due to threat, original decisions about UAS strategy and means need revisiting. The Army has realized errors and made corrections slowly. In the case of achieving poor readiness levels, it took Congressional involvement to raise the issue.

UAS Training Description

General Perkins in his Congressional testimony plainly laid out a fundamental underlying assumption: "the centerpiece of the Army's UAS strategy is the Soldier." Army's training is well equipped and experienced in transforming young high school graduates into cohesive operating units capable of wielding advanced weaponry on command. It naturally follows that enlisted soldiers and Noncommissioned Officers (NCOs) operate and maintain the Gray Eagle. The UAS overarching mission objective is

[17] Interview with Gray Eagle instructor from 2-13th Aviation Regiment, 5 January 2017.
[18] Schein, 108.
[19] "Organization: The United States Army," accessed 3 March 2017, https://www.army.mil/info/organization/.

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to take entry-level soldiers and create graduates able to conduct "air reconnaissance, surveillance, targeting and acquisition missions, plan and analyze missions, perform preflight, in-flight, and post-flight checks and procedures, launch and recover aircraft, and perform maintenance on communications equipment, power sources, wheeled vehicles and crane operations."[20]

Soldiers that enlist as either UAS operators or maintainers are among the Army's most capable. Soldiers who enter the UAS Military Occupational Specialty (MOS) must achieve a surveillance and communications (SC) score of at least 105 on the Armed Services Vocational Aptitude Battery military entry exam. This score is the highest SC score for entry into any Army MOS. Based on their particular enlistment agreement, these soldiers enter with a 4 to 6 year service obligation that begins at in processing. The Army has successfully attracted qualified applicants, but retention remains a problem. Currently, the Army offers UAS operators a reenlistment bonus of $45,000 for an additional five year commitment. Those that pursue the reenlistment develop into the UAS senior NCO force.

The Army has recognized how formative initial training is, and it deliberately approaches training as an opportunity to instill values while building force readiness. According to its Training regulation 350-1:

> All training and leader development actions occur within the Army culture, a culture which embraces values and ethics, the Warrior Ethos, standards, and enduring principles and imperatives. Army training strategies serve to synchronize the role each training domain plays in building force readiness.[21]

Accordingly, while in Enlisted Initial Military Training (IMT) and Advanced Individual Training (AIT), all aspects of a soldier's life are closely controlled. They live in dormitories, conduct daily physical training, do not consume alcohol, eat at dining facilities, take bus transportation on post, and receive formalized instruction up to 12 hours per day. The 2-13th Aviation Regiment, the UAS training unit, recognizes and rewards soldiers who are "skilled, tough, and ready around the clock."[22]

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[20] 2-13th Catalogue. *15W Common Core Course Design*. 2016.

[21] 350-1 Army Training and Leader Development (2014), 2.

[22] Mark Farrar (2-13th Aviation Regiment Director of Training), interview by the author, 5 January 2017.

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Since April 2007, graduates are awarded an Aviation Badge at course completion. Major General Virgil Packett, commander of the U.S. Army Aviation Warfighting Center at the time, unveiled the renamed Crew Member Wings as the new Aviation Badge. Packett in his commencement speech recognized the inertia against recognizing UAS operations and the value the Army places on uniform insignia. The petition to recognize UAS operators began in 1992. He commented, "It's a great day... because it's been a steep hill in order to be able to recognize, with this symbol of professionalism, these wings, the troopers that stand before you today. Now they can sit a little bit taller… with that shiny piece of brass on their chests that they have so duly earned." Captain Kyle Duncan, operations officer for the UAS Training Battalion in 2007, both credited and clarified the wings' meaning. His statement was a qualified compliment:

> They are not actually in the aircraft, but they are doing aviation duties. It's a credit to their skills, the hard work they do. They deserve this recognition. They are not pilots, but they are operating in theater, in aviation. They are not getting an aviator's badge; they are getting an aviation badge. We recognize them for their work, as part of aviation.[23]

As Duncan mentioned, the Aviation Badge is not an Aviator Badge, and UAS operators do not receive flight pay or incentive pay. The Aviation Badge is also awarded to aviation maintenance personnel at the completion of the Gray Eagle maintenance course.

Viewed through Schein's methodology, the Army places mediocre value on its UAS operators. For one, Aviation Branch does not reward the young enlisted trainees with promotion into senior leadership opportunities. In fact, a disincentive exists for promotion. Once promoted to Master Sergeant, Human Resources Command (HRC) changes the 15W operators' MOS to 15Z. A 15Z MOS is non-flying, and HRC assigns these Master Sergeants to any aviation positions like airfield operations, air traffic control, UAS operations, or aviation maintenance. The platoon leader retains operational authority, and an NCO oversees flight coordination. Officers from other Aviation Branch platforms fill UAS command and staff positions before returning to their aircraft. The UAS operators receive basic pay, not flight pay or Aircrew Incentive Pay (ACIP). The

[23] Rob Martinez, "New Policy Makes Soldier UAV Operators Eligible For Aviation Badge", 2007, https://www.army.mil/article/3012/new-policy-makes-soldier-uav-operators-eligible-for-aviation-badge.

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artifacts associated with UAS operations could be mistaken for any other Army unit. They share insignia with air traffic controllers, airfield operations soldiers, and maintenance soldiers. They wear standard issue Army Combat Uniforms (ACUs) in contrast to their flight suit or Army Aviation Combat Uniform (A2CU)-wearing pilot officer counterparts at Ft Rucker.



Figure 11: Army Aviation Badge
Source: 2-13th Catalogue. 15W Common Core Course Design. 2016.

The Army more closely subscribes to the Joint Staff's minimum training guidance as spelled out in its *Joint Unmanned Aircraft Systems Minimum Training Standards* (JUMTS) than the Air Force does. The Joint Staff classifies Gray Eagle and the MQ-9 Reaper as Group 4 Unmanned Aircraft because they weigh more than 1320 pounds, predominately operate under VFR in all classes of airspace below 18,000' MSL, and prosecute ISR missions and missions as described by Joint Mission Qualification (JMQ) levels A or B. JMQ A supports unit-level ISR and fires tasks, and JMQ B supports theater-level advanced ISR. The JUMTS also spells out levels of Basic UAS Qualification (BUQ) knowledge required for each UAS group. A UAS crew must possess the general aviation knowledge and UAS knowledge-based skills to operate UAS safely as required by crew duties or position. As a minimum, regardless of UAS type, a qualified crew must be capable of airspace design and operating requirements, air traffic control procedures, rules, and regulations, aerodynamics, including effects of controls, aircraft systems and emergency procedures, performance, navigation, meteorology, communication procedures, and mission preparation.[24] BUQ Level III is the knowledge and knowledge-based skills required to fly under VFR in all airspace classes except Class A. The JUMTS for Group 4 UAS is BUQ III and JMQ B, and the Army trains to this standard.[25]

[24] CJCSI 3255.01 Ch 1. *Joint Unmanned Aircraft Systems Minimum Training Standards, 31 October 2011, A-2*.
[25] CJCSI 3255.01, 4.

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Gray Eagle training has two frequently changing phases: currently they are an 8-week common core course and a 20-week Gray Eagle course. On completion of the initial phase, the soldiers possess requisite basic knowledge and skills required prior to training on a specific UAS system as well as common aspects of UAS operations within the Army and the Department of Defense. Academics also address the overarching structure of Military Intelligence and UAS operational role. Course attrition tends to be due to behavioral rather than academic or performance related issues. The pipeline front loads academics to reduce training investment while any student-related issues are addressed. The cost breakdown per student for the Common Core course is $11k for direct instruction and $5.6k in overhead costs. Pay, allowances, per diem, and travel incurred during an 8 week course amounts to $11.8k.[26]

During Module A, UAS operators receive in-depth instruction on the fundamentals of aerodynamics, doctrine, risk management, mission planning, flight safety, and navigation. The introductory module covers all knowledge necessary for a Federal Aviation Administration (FAA) Private Pilot's License. After four weeks of ground school, students take the FAA's Private Pilot Knowledge Test. Module B focuses on aeroscout operations to include visual identification of friendly and enemy vehicles and ground-based threats, base defense, and patrol concept of operations. Modules C and D quickly address Army aviation regulations and introduce gunnery in the eighth and final week.

[26] 2-13th Aviation Regiment Report entitled *Resident Training Cost per Graduate*, 2016.

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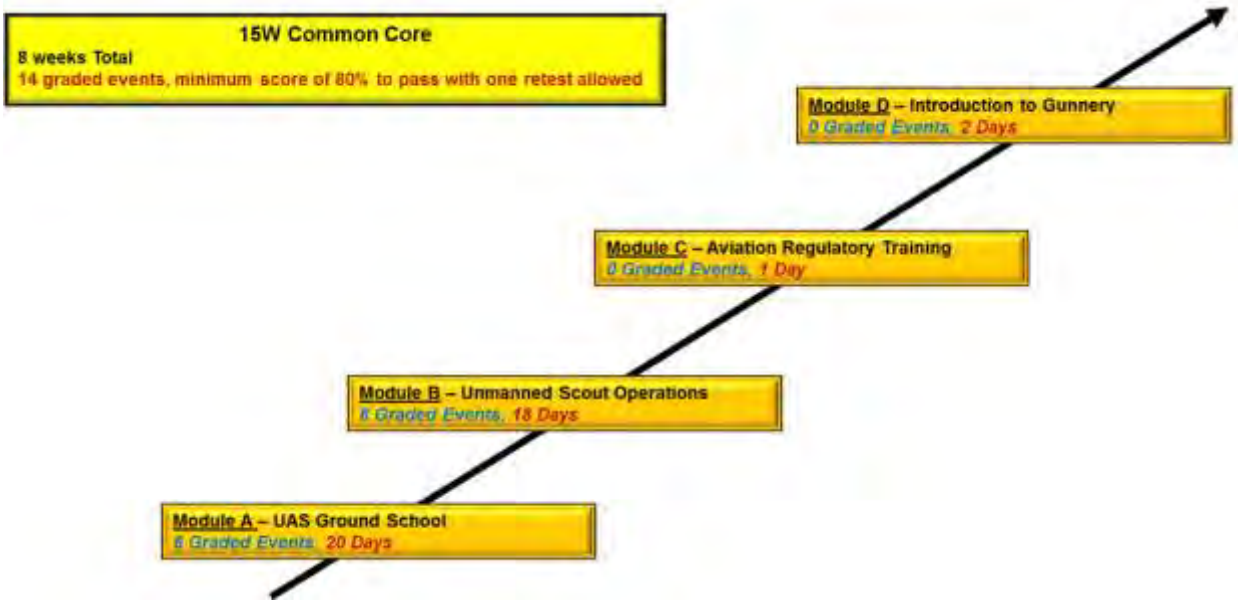


Figure 12: Common Core Training Modules
Source: 2-13th Catalogue. 15W Common Core Course Design. 2016.

After completing the Common Core, students track either to Shadow or Gray Eagle training. Previously, all students gained experience in the Shadow before progressing to the Gray Eagle. Upon graduation of either track, UAS students are expected to mission plan, prepare and conduct air reconnaissance missions, preflight, launch, remote pilot and recover an aircraft, perform emergency procedures, perform tactical and administrative radio communications, operate sensors for target detection, deploy ground and air systems, conduct maintenance/inspections on communication equipment, and be familiarized with gunnery operations. The Gray Eagle course consists of 8 modules and 680 hours of academic and flight instruction across 25 total weeks. The schoolhouse conducts six classes of sixty students per year. To train 360 students per year requires 24 hour operations, and instructors as well as aircraft are fully utilized. The cost breakdown per student over 25 weeks is $140k for direct instruction and flying costs. Overhead costs and student pay, lodging, and travel add an additional $41k.[27]

[27] 2-13th Aviation Regiment Report, 2016.

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Figure 13: Gray Eagle Training Modules
(Source: 2-13th Catalogue. 15W Common Core Course Design. 2016)

Currently, Gray Eagles operate exclusively in combat zones or restricted airspace unless granted a domestic Certificate of Authorization (COA) to transit with chase aircraft or observers. To enable further national airspace integration, Module G has shifted to emphasize and practice IFR flight. Renamed as Module A, the phase now consists of 57 hours of instruction and covers instrument flight rules, practical exercises, and a performance evaluation.

Officer and warrant officer platoon leaders supervise enlisted Gray Eagle operators. The schoolhouse conducts four week courses to transform incoming lieutenants into UAS platoon leaders. The overarching objective is teaching how to manage and supervise UAS personnel, programs, and operations in wartime and peacetime situations. Topics covered include understanding mission-essential UAS systems, equipment operations, and capabilities; applying aviation doctrinal concepts during different phases of UAS operations, mission planning, and execution; and advising the commander in the use of UAS assets. Additionally, the 2-13th Aviation Regiment teaches a 3-week Air Cavalry Leaders Course to incoming unit commanders in the UAS chain-of-command and staff assigned to units who work directly and indirectly

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with UAS units. The course covers capabilities, concept of employment, limitations, UAS-specific safety, maintenance, standardization, gunnery requirements, and training requirements.

Recap

The Army's UAS training community has operated at Fort Huachuca for over 25 years. It has expanded into new platforms with new capabilities, but its model based on universal enlisted operators trained to operate as an organic divisional asset just prior to deployment has remained. The focus on efficiency has streamlined the training pipeline. Ironically, at the operational level, the Army prizes flexibility over efficiency and possibly effectiveness. Soldiers are trained to fly the Gray Eagle, to operate its payloads, to conduct certain maintenance items, and to handle basing requirements. Comprehensive training enables platoons and companies to operate autonomously, but the decentralized approach prevents specialized focus and high-end capability. It also reduces readiness levels. Low retention plagues the community, but current production meets needed replacement demand.

The underlying focus remains to support and enable the ground forces commander and his mission. The artifacts, values, and assumptions are in accordance with that focus. Such simplicity has led to practical and sustainable decision-making in regards to UAS. The Army will be required to navigate two opposing trends in UAS. One is increased automation, enhancing ease of use. Given the lack of prestige and distinction placed on UAS operators, the UAS community will not resist this advancement. The other trend is future UAS integration further into Army units. This is already raising questions over who flies UAS, where is it organic, who can shoot, and how much money, time, and personnel should be put towards UAS or manned platforms. Currently, UAS is only 5% of Aviation Branch's budget. Aviation Branch funds UAS, but all Army branches want the capability or the promise of capability. Specific demands include cargo, command and control, and Chemical, Biological, Radiological and Nuclear (CBRN) defense. Unless Headquarters Army funds and prioritizes UAS requirements, only Aviation Branch UAS requirements will be funded and developed, leaving gaping holes on the emerging multidomain battlefield.

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Chapter 4-
Opportunities Knocking

This is an inflection point… The trend lines are unmistakable that the United States Air Force will be an increasingly unmanned aviation service.

General Norton A. Schwartz, CSAF,
in testimony to the Senate, 21 May 2009.

The RPA's origin has been tumultuous, and its future will remain so. Despite initial capabilities tracing back to World War I, the broad consensus is that unmanned aviation is still in its first generation of development; as General Mark Welsh opined: "Remember we're at the Wright flyer stage, we're just getting started."[1] Future threats and opportunities stand to revolutionize the RPA and bring it rapidly into its next generation. For the near term, technology and societal pressures will force the AF to adapt organizationally and in training more than an adversary will. In adapting, the AF itself will evolve. The impact on the organization is yet to be determined, but technology will undoubtedly leave its mark. As Schein commented, "Ultimately all organizations are sociotechnical systems in which the manner of external adaptation and the solution of internal integration problems are interdependent and intertwined."[2] This chapter transitions away from UAS history and the services' internal responses in forming a training strategy. This chapter looks to the future to identify and explore approaching developments. It addresses three specific developments: increasing automation, the AF introduction of enlisted RPA pilots, and the FAA's push to integrate UAS into the national airspace.

[1]Welsh, General Mark A. "National Press Club Speech", 2014. http://www.af.mil/Portals/1/documents/csaf/Nationalpressclub23April2014.pdf.

[2] Schein, 108.

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Development One: Automation

Organizations change cultural assumptions through the subtle, cumulative, and sometimes unintended impacts of new technology….

Edgar Schein, *Organizational Culture and Leadership*

Autonomy will be the driving force behind the development of a new generation of RPAs optimized for more complex air environments, and human distrust in autonomy will lie at the heart of limitations on the design and deployment of these aircraft.

Caitlin H. Lee, "Embracing Autonomy: The Key to Developing a New Generation of Remotely Piloted Aircraft for Operations in Contested Air Environments"

Unmanned aircraft benefited from a confluence of several critical technologies in the early 1990s, such as the Global Positioning System (GPS), advanced microprocessors, and wide-band satellite communication links. In combination, these developments allowed drones to break free from their seemingly perpetual emergent state. Automation in robotics has built upon those technologies to bring widely anticipated capabilities to air power. In 2009, then Chief of Staff General Norton Schwartz commented,

> Industry has already refueled an unmanned aircraft and demonstrated multi-aircraft control-all feats that only a few contemplated 10 years ago. It's not hard to imagine a multitude of other missions for our unmanned aircraft, including air transport, air refueling, suppressing enemy air defenses, forward air control, combat search and rescue, and more. It also is not difficult to imagine new operational concepts, such as groups of unmanned aircraft flying 'swarm' tactics.[3]

Rather than see General Schwartz's comments to fruition, the AF has clung to its UAS construct as seen in Figure 14. It has yet to exploit the promises of automation despite rapidly growing capabilities. Unfortunately, Figure 14 no longer matches external reality. The assumed correlations between capability, complexity, and size have not held. UAS are growing smaller and more capable, while overall complexity for the operator decreases. MQ-9 Reaper aircrews hone their skills to manually track moving

[3] General Norton Schwartz, "Future Of Unmanned Aircraft (Remarks At The Graduation Ceremony For The Unmanned Aircraft System MQ-1 Predator Course, 25 Sep 2009)", (Speech, Creech AFB, NV, 2009).

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vehicles, but off-the-shelf drones can now autonomously track targets using facial recognition. The Global Hawk has the wingspan of a Boeing 737, and high levels of automation through a keyboard and point-click mouse interface make it simple to employ. That ease of operation does not preclude its high capability: its effects are highly prized, and it routinely collects strategic ISR for multiple combatant commanders during a single sortie. All this means the dividing line separating SUAS operators and rated pilots based on aircraft performance has blurred.

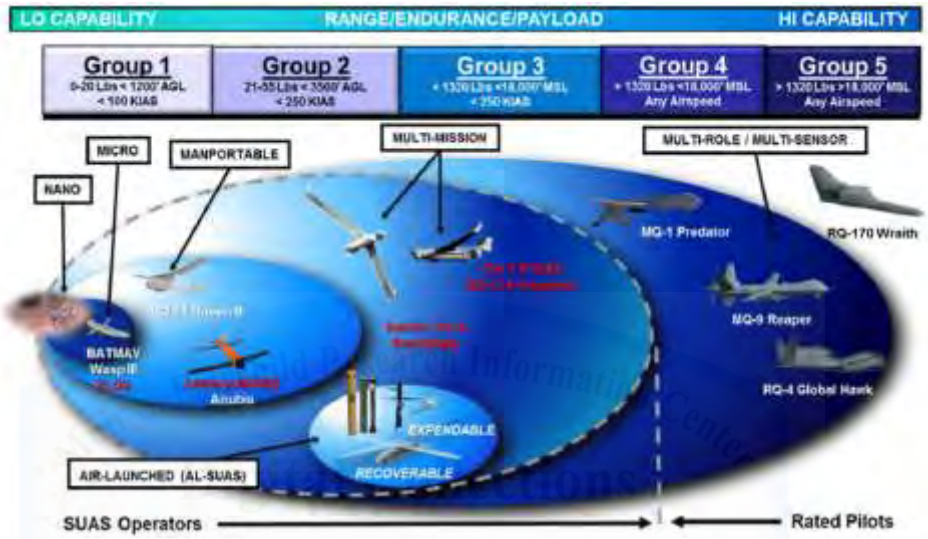


Figure 14: UAS Group Descriptions
Source: Lt Col Jason Green, "A Brief Look: The State Of Remotely Piloted Aircraft (RPA) Operations Local, Global… Past, Present, and Future…", 2016.

State of the art automation now resides in commercial, consumer-level Small UAS (SUAS). Once the realm of tactical employment by well-trained militaries, SUAS now provides tactical, possibly strategic, effects to the untrained and poorly funded. The Islamic State of Iraq and Syria (ISIS) currently employs SUAS as surveillance platforms, grenade launchers, mortar droppers, kamikaze bombers, and flying decoys that hide internal improvised explosive devices (IED). Recently, they have started using multi-ship tactics normally reserved for sophisticated air forces. Christopher Bolkcom, an employee of the US Congressional Research Service, highlighted this possibility in 2002 when he testified before Congress that seven particular features made UAS attractive to terrorist groups. Those seven features are low acquisition costs, ease of purchase, high accuracy, operational flexibility, ability to penetrate air defenses, high prelaunch

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survivability, and little to no infrastructure needed to deploy.[4] He failed to mention ease of use that requires little training. Such characteristics have allowed ISIS to replace expended assets faster than Iraqi forces can target drone factories. Don Rassler of the Combating Terrorism Center at West Point concludes the problem will worsen as capabilities improve:

> Future off-the-shelf drones will be able to carry heavier payloads, fly and loiter longer, venture farther from their controller and be able to do so via more-secure communications links. The increased speed of small drones and advancements in sensors and drone add-on technology (such as infrared and night vision cameras), will compound the problems for counterterror organizations.[5]

The threat has warranted a strategic response from the Department of Defense. Speaking alongside the Secretaries of the Navy and Army at the Center for a New American Security in October 2016, Secretary Deborah James announced the successful takedown of an ISIS drone that had previously killed four civilians. She then commented, "A top priority for me at the moment is this emerging danger that we're seeing in the Middle East in respect to unmanned aerial systems — these cheap, buy-them-over-the- internet, small drones. If explosives are placed on them, as we've seen a handful of times now in Syria and Iraq, they can do damage."[6] Comparatively, the AF has more resources yet has not pursued automation to the degree ISIS has. Several projects described below may change that.

Defense Advanced Research Project Agency's Aircrew Labor In-Cockpit Automation System (ALIAS) functions as a retrofitted vehicle management system in manned aircraft to alleviate pilot workload and crew requirements (see Figure 15). According to Dr. Dan Patt, DARPA's Tactical Technology program manager, ALIAS is a flexible, extensible automation toolkit for existing aircraft that enables safe, reduced

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[4] Christopher Bolkcom before Senate Governmental Affairs Committee, Subcommittee on International Security, Proliferation, and Federal Services, *Hearing on Cruise Missile Proliferation*, 108th Cong., 2[d] sess., 2002, 1–9.

[5]Don Rassler, *Remotely Piloted Innovation: Terrorism, Drones and Supportive Technology* (Combating Terrorism Center, US Military Academy, 2016), https://www.ctc.usma.edu/v2/wp-content/uploads/2016/10/Drones-Report.pdf.

[6] Brendan McGarry and Matthew Cox, "Air Force Zaps ISIS Drone With Electronic Weapon", *Defensetech*, 2016, https://www.defensetech.org/2016/10/24/air-force-zaps-isis-drone-with-electronic-weapon/.

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crew operations. Benefits include enhanced safety in operations, reduced training burden, more capability per dollar via enhanced human effectiveness, and a speeded transition to the next generation of automation and interface.[7] ALIAS highlights automation's scalability well. Rather than distinctly separate manned and unmanned platforms, automation can blend the two. Currently, the Army and SOCOM have agreements in place with DARPA to transition the technology. The Navy and Marines have expressed interest in integrating the capability into existing manned platforms, and DARPA expects commercial participation from Fed Ex in the air proof of concept phase.



Figure 15: ALIAS Inserts New Automation into Existing Aircraft to Enable Operations with Reduced Onboard Crew
Source: "ALIAS – Aurora Flight Sciences", Aurora.Aero, 2017, http://www.aurora.aero/alias/.

The AF stands as the lone service not participating. A retired AF pilot working for DARPA called the AF's lack of involvement in a program with so much potential "mysterious."[8] A ventured guess is culture. Historically, aeronautical engineers balanced flight stability with maneuverability. Maneuverable aircraft demanded skilled, attentive pilots, and therefore flying became prestigious. Technology that reduces the need for skill threatens the prestige given to pilots. Significant gains must offset technology if it reduces the need for skill. Initially, aviators viewed gauges, instruments, and indicators

[7] Daniel Patt, "Aircrew Labor In-Cockpit Automation System", (Presentation, 2016).
[8] Peter LeHew (DARPA Adaptive Execution Office Systems Engineering and Technical Assistance Manager), interview by author, 29 December 2016.

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of flight parameters as a threat before accepting how much safer they made flight. The F-16 had a Predictive Ground Clearance Avoidance System (PGCAS) for years that would notify the pilot of an impending crash into terrain, but it would not recover the aircraft automatically. The system needed a conscious pilot to recover the aircraft. In testing an Auto-GCAS, the overriding concern was uncommanded, undesired aircraft inputs.[9] Various levels of automatic recovery systems existed for three decades before the AF introduced Auto-GCAS in 2014.[10] Since its introduction, the automated system has saved four incapacitated pilots. Dr. Patt recognized that the AF loves technology but views it as a tool to aid human judgment not to replace it. He marketed ALIAS differently to each service. To the Army and Marine Corps, he emphasized the flexibility of ALIAS, how it provides staffing options based on mission requirements, threat levels, or costs. Leaders may identify a complex mission and elect two pilots to fly the aircraft, or they may elect to unman the aircraft for sorties in high-risk environments. To the AF, he emphasized that ALIAS augmented the pilot by offloading routine tasks. Patt envisions that, during critical phases of flight or emergencies, ALIAS can deliver timely information, warnings, and assistance to the pilot. He left out the obvious logical conclusion that, if successful, his program could unman the entire AF fleet.

The Army is working on developing the equivalent of a universal remote for its unmanned aerial systems. The capability allows training to be reduced, and for a universal operator to control multiple, different UAS without additional training.[11] The Scalable Control Interface (SCI) will combine the interfaces for Gray Eagle, Shadow UAS, and other small UAS into the system. If the program remains on schedule, the Army will field SCI by 2020. In the meantime, the Army's UAS Capabilities Manager staff is reevaluating mission management functions, redefining current UAS control terminology, and introducing new terminology to describe the control inner-relationships SCI will enable. Major Ariel Schuetz, the Army's Training and Doctrine Command UAS

[9] Guy Norris, "F-16 Flight Demonstrates Auto-GCAS Potential", *Aviation Week*, 2017, http://aviationweek.com/technology/f-16-flight-demonstrates-auto-gcas-potential.
[10] Guy Norris, "Auto-GCAS Saves Unconscious F-16 Pilot—Declassified USAF Footage", *Aviation Week*, 2016, http://aviationweek.com/air-combat-safety/auto-gcas-saves-unconscious-f-16-pilot-declassified-usaf-footage.
[11] J.D. Leipold, "Army To Go Universal With UAS Operator Training", *US Army*, 2016, https://www.army.mil/article/161492/Army_to_go_universal_with_UAS_operator_training.

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Capabilities Management operations officer, presented five different levels of operator authority and capability similar to computer software user permissions. A mission manager will serve the role of administrator where he will task aircraft, send mission plans, and assign aircraft to other managers, controllers, and users. Similar to a computer network administrator, the SCI manager will approve or deny requests from other users. Control that the manager can grant includes exclusive control, supervised usage, and unsupervised usage based on user qualification, need, situation, and command guidance. While SCI is in development, the Army is testing its techniques, tactics, and procedures via its current Manned-Unmanned Teaming (MUM-T) capability.

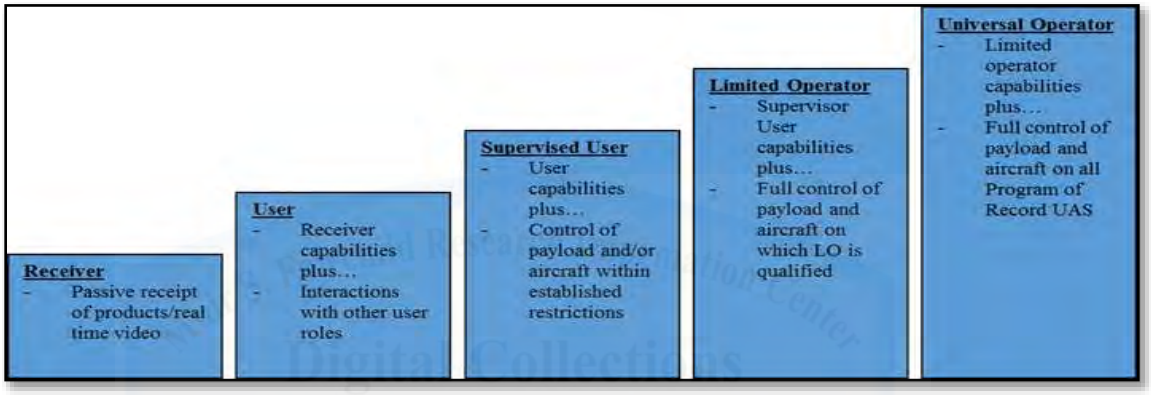


Figure 16: Army UAS Operator Terminology
Source: Army TRADOC UAS Capabilities Manager, Scalable Control Interface (SCI) Definitions, 2016.

In 2015, DARPA successfully demonstrated its Persistent Close Air Support (PCAS) concept. The program gives Joint Terminal Attack Controllers (JTACs) the ability to visualize, select, and employ munitions at the time of their choosing from optionally manned/unmanned aerial attack platforms. PCAS transfers decision making from the pilot to the JTAC via a weapon-carrying "smart rail" and an Android-based tablet.[12] Easily applicable to RPA, PCAS offers weapons solutions and delivery profiles as well as the ability to move weapons release closer to the release authority. An RPA Weapons Instructor Course (WIC) graduate commented that he did not see the utility of such a capability and reiterated that weapons release authority should reside with the

[12] Marshall Frith (DARPA PCAS Systems Engineering and Technical Assistance Manager), interview by author, 28 December 2016.

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pilot.[13] In line with that thinking, the AF's Air Combat Command and Special Operations Command do not plan to leverage the capability. Meanwhile, the Marine Corps and ARSOAC's 160th Special Operations Aviation Regiment are actively transitioning the concept to an operational capability.

Congress's 2017 National Defense Authorization Act funded $15 million toward integrating an automated takeoff and landing capability on the MQ-9.[14] The Army's MQ-1C Grey Eagle has had this feature since its acquisition, and the AF will "look to the army, who figured it out with the same manufacturer."[15] This overdue development brings two significant advantages to the MQ-9. First, it will ease training requirements. Currently, launch and recovery training takes 32 training days and costs approximately $99,000 per pilot.[16] The indirect cost is the pilot's time away from the operational mission. While pilots train in launch and recovery, squadrons conducting real world remote-split operations pay the manning bill. The just-in-time training model puts undue stress on the squadrons and is inefficient. The Culture and Process Improvement Program, as discussed in Chapter 3, will change this model to a dedicated, deployable launch and recovery squadron.

Second, auto takeoff and land functionality increases operational flexibility. Divert airfields, if required, would not require on station recovery crews--just the guidance system. In addition, according to General Atomics, the capability needs less runway length due to better landing precision.[17] Launching and recovering aircraft with automation eliminates the need to use a line of sight frequency. In turn, this reduces congestion and interference in the electromagnetic spectrum.

A third additional but uncertain impact of automated operations is reducing the deployed RPA footprint. The Global Hawk has automated takeoff and landing capability

[13] Interview with major from AF Chief of Staff Crisis Action Group, 30 November 2016.

[14] Dan Gettinger, Drone Spending in the Fiscal Year 2017 Defense Budget (New York: Center for the Study of the Drone, 2016), http://dronecenter.bard.edu/files/2016/02/DroneSpendingFy17_CSD_1-2.pdf.

[15] James Drew, "USAF To Automate MQ-9 Takeoffs And Landings", Flight Global, 2016, https://www.flightglobal.com/news/articles/usaf-to-automate-mq-9-takeoffs-and-landings-424975/.

[16] ACC does not track the cost of Initial Qualification Training, Flight Instructor Upgrade Training, or Launch and Recovery Training. Costs are estimated assuming $4,762 per MQ-9 flight hour, taken from Mark Thompson, "Costly Flight Hours", *TIME.Com*, 2017, http://nation.time.com/2013/04/02/costly-flight-hours/. Instruction is calculated at $33/hour of instruction, equivalent to Army UAS cost.

[17] Drew, 2016.

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as mentioned earlier. The community still deploys crews to monitor landings, but in much smaller numbers. At a collocated downrange location, MQ-1 Predator operations require eight aircrew, and Global Hawk operations require three for similar launch and recovery demands. When properly equipped, MQ-9 Reaper operations will drawdown to mirror Global Hawk operations, but the primary benefits of automated takeoff and land capability will lie primarily in a reduced training bill and increased operational flexibility.

Autonomy is not binary; it scales. "Autonomy is an 'adjustable' concept that one can employ to varying degrees, depending upon the role of an aircraft and its mission—a critical point because of the tendency to view autonomy as an all-or-nothing proposition."[18] The AF struggle to embrace autonomy demonstrates one cultural value trumping another; the value placed in the operator and maximizing platform performance through training that operator is taking precedence over the service's trust in technology. At present, technologies are adopted as long as they do not undermine the operator's importance. Emerging advancements that allow the operator to scale automation may ease this cultural transition toward more technologically determined values.

US adversaries like ISIS are embracing autonomy to overcome scarce resources, expertise, and training. Likewise, autonomy will force the AF to adapt or risk irrelevancy. As highlighted, multiple autonomous capabilities are presently possible or on the horizon, and they will affect RPA operations and therefore training. The AF has integrated many systems at automation level 7 through 10 (see Figure 17). Traditionally, the service scrutinized and debated systems above that level like the F-16's Automatic Ground Collision Avoidance System before implementation in an attempt to preserve as much flexibility and capability to the pilot as possible. Now, though, automation increases flexibility and capability. Scaling automation rather than toggling it on or off is the final step to build operator trust and ease the AF's cultural transition.

[18] Lee, 83.

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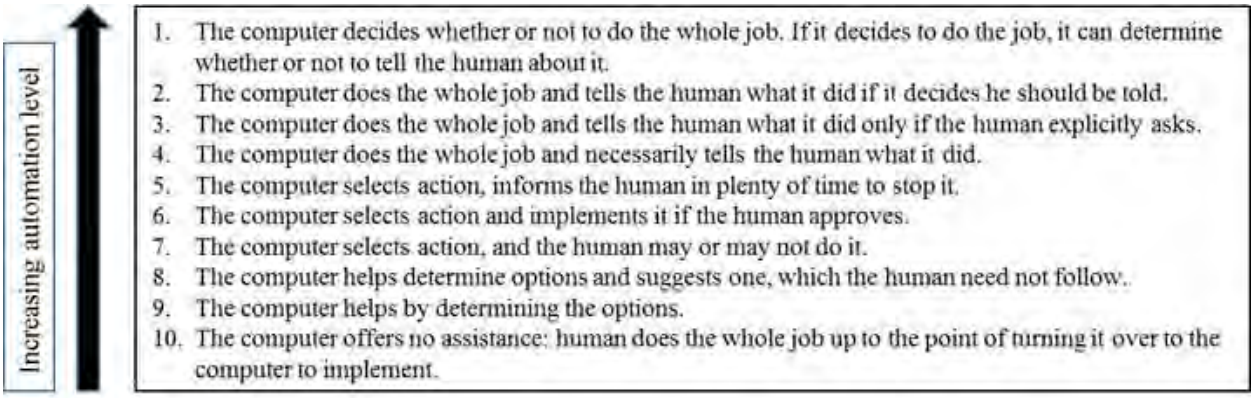


Figure 17: Automation Levels in Man-Computer Decision Making
Source: Caitlin H Lee, "Embracing Autonomy: The Key To Developing A New Generation Of Remotely Piloted Aircraft For Operations In Contested Air Environments", Air & Space Power Journal 25: 76-88.

Development Two: EPIC

On December 17, 2015, Secretary of Air Force James directed the integration of enlisted pilots into the RQ-4 Global Hawk community. This civilian mandate was a long time coming; in 2003, the Senate Armed Services Committee tasked the Air Force to "create a cadre of warrants to serve as pilots for unmanned aerial vehicles."[19] Twelve years later, James tasked ACC and AETC to develop an implementation plan to provide an additional avenue for capability growth.[20] In the fall of 2016, the AF implemented the Enlisted Pilot Initial Cadre (EPIC) program. The inaugural class of four candidates entered RPA Initial Flight Training in October 2016. One withdrew, and the three remaining transitioned to the RPA Instrument Qualification course and RPA Fundamentals Course to graduate successfully in the spring of 2017. The 558 FTS will produce 12 enlisted pilots in 2017. The AF selected EPIC candidates from enlisted aircrew career fields. As the AF transitions to full production, Air Force Personnel Center plans to accept NCO and SNCO applicants from any career field. Pilot officer candidates take an Officer Qualifying Test before entry to training; the AF will judge future enlisted applicants' aptitude based on their OQT score as well. In the EPIC program, an aptitude test has not been required, possibly due to oversight. AETC leaders did not make any URT syllabus changes to accommodate EPIC and, purposely, they did

[19] Colonel Timothy Schultz, UAS Manpower Exploiting A New Paradigm (Maxwell AFB: Air Force Research Institute, 2009), 38.
[20] Secretary of Air Force Deborah James, memorandum for record, 17 December 2015.

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not name the program a test, trial, or beta case. Lt Gen Darryl Roberson, AETC/CC, summed up the plan: "Right now, the going-in plan is that the training we give to the enlisted pilots is going to be exactly the same as what we're giving our officer pilots. So right now there is no difference. We did that very deliberately."[21]

Unfortunately, the EPIC program does not expand the training pipeline, the community's bottleneck, and therefore does not alleviate manning troubles. General Roberson was clear on that point as well: "The way that we're approaching this is each enlisted pilot that comes in is going to replace what would have been an officer. So it's not additive, it's a replacement for."[22] The Air Force Personnel Center calculates that it needs 100 total enlisted graduates in the next few years to pilot 70% of Global Hawk missions. In the 2017 National Defense Authorization Act, Congress increased the mandate to enlisted pilots flying the preponderance of Global Hawk missions by September 30, 2020. The NDAA declared, "The Secretary of the Air Force shall transition the Air Force to an organizational model for all Air Force remotely piloted aircraft that uses a significant number of enlisted personnel as operators of such aircraft rather than officers only."[23] The directive states that, if any enlisted pilots operate an RPA, then the AF needs to adopt an enlisted force model. The wording incentivizes the AF to prohibit enlisted pilots from flying the MQ-9 lest it transition to an enlisted-dominated career field.

The Active Duty Service Commitment for URT is 6 years. Assuming timely pipeline production, enlisted pilots will serve 5 years. If they perform commensurate to their officer counterparts during their first tour, the opportunity may open to transition enlisted RPA pilots to MQ-9 slots. Without an overriding reason to prohibit such a move, inertia will push enlisted RPA pilots to more platforms. Whether for enlisted or officer pilots, the current RTU curriculum is identical. If both groups graduate with the same qualifications, officers become financially unjustifiable. The Army's model then is

[21] Phillip Swarts, "Enlisted RPA Training To Begin In October, Head Of AETC Says", Air Force Times, 2016, https://www.airforcetimes.com/articles/enlisted-rpa-training-to-begin-in-october-head-of-aetc-says.
[22] Swarts.
[23] Senate, *S. 2943 National Defense Authorization Act for Fiscal Year* 2017, 114th Cong., 2nd sess., 4 January 2016, 398.

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a proven way to incorporate an enlisted/officer force. Officer expectations and therefore training will need modification.

The AF reintroduced enlisted pilots under a different context and with a different goal than their World War I or World War II brethren. Enlisted pilots served proudly and effectively in the Army Air Corps first during a time of light supervision and then during a frantic buildup leading to war. At the conclusion of World War I and World War II, rapid force reductions coupled with pilot commissioning programs meant the enlisted pilot legacy was short-lived.[24] Public justification for today's move by senior AF leaders has focused on enlisted talent. This strikes the author as disingenuous and confuses the narrative. Introducing an enlisted RPA pilot cadre signals a desire to reduce personnel costs and recognizes that RPAs require less skill to operate. Today's enlisted RPA pilot is not serving in a transitory position or as an expedient.

Development Three: FAA's National Airspace Integration of UAS

Difficulty integrating UAS into the national and international airspace slows large UAS growth in the civilian industry and the production of new unmanned aircraft types with expanded missions. Michael Huerta, the Administrator of the FAA, published a UAS integration roadmap in 2013 and commented on the hurdles integration faces,

> In moving forward, we recognize that the expanded use of unmanned aircraft presents great opportunities, but it's also true that integrating these aircraft presents significant challenges. There are operational issues that we need to address, such as pilot training. We also need to make sure that unmanned aircraft sense and avoid other aircraft, and that they operate safely if they lose the link to their pilot.[25]

Safety for the FAA is an overriding priority, and several UAS characteristics currently restrict integration. As highlighted in its roadmap:

[24] Lee Arbon, *They Also Flew: The Enlisted Pilot Legacy, 1912-1942* (Washington: Smithsonian Institution Scholarly Press, 1998), 45.
[25] Huerta, Michael. "Speech – UAS Roadmap". *FAA.gov*, 2013. https://www.faa.gov/news/speeches/news_story.cfm?newsId=15354.

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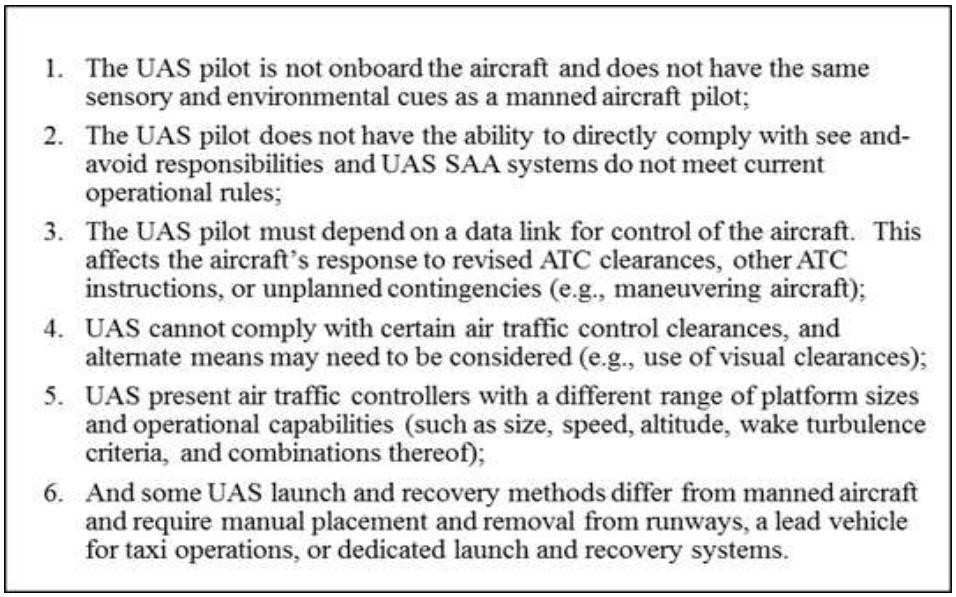


Figure 18: FAA UAS Integration Hurdles
Source: Federal Aviation Administration,. Integration of Civil Unmanned Aircraft Systems (UAS) In the National Airspace System (NAS) Roadmap. FAA, 2013. https://www.faa.gov/uas/media/uas_roadmap_2013.pdf, 18-9.

The six integration hurdles revolve around collision avoidance and control. Automating collision avoidance and ensuring aircraft control remotely present technological challenges. "Sense and avoid" capabilities must provide for self-separation and ultimately for collision avoidance protection between UAS and other aircraft analogous to the "see and avoid" operation of manned aircraft. The FAA judges "sense and avoid" technology as immature and far from an acceptable level of safety.[26] Additionally, airspace integration requires reliable control and communications systems. The FAA is crowd sourcing consensus-based recommendations from industry and safety organizations to shape its policy, program, and regulatory decisions. The resulting requirements need to support the minimum performance required to achieve higher-level (UAS level) performance and safety requirements.

The FAA's integration plan has three phases: special access, routine access, and normal access. Currently, UAS transit the national airspace predominately through special access channels that grant specific certificates of authorization (COA). The FAA levies numerous and varied operational restrictions in its COAs based on the

[26] Federal Aviation Administration, *Integration of Civil Unmanned Aircraft Systems (UAS) In the National Airspace System (NAS) Roadmap* (FAA, 2013), https://www.faa.gov/uas/media/uas_roadmap_2013.pdf, 19.

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airspace environment, UAS performance, and operator training. Neither the FAA nor DoD are satisfied with the inflexible system, but a shift toward more integration is conditions-based to ensure safety. In its mid-term phase of routine access, the FAA plans to shift to non-segregated access as policy, procedures, and technology permit. Emerging Ground Based Sense and Avoid (GBSAA) capabilities allows that routine access in localized operational areas, but its infrastructure does not permit flexibility or easy expansion. The final phase is normalized access. Developments that produce a robust Airborne Sense and Avoid (ABSAA) assurance will finally allow UAS to operate in the NAS with an equivalent level of safety and efficiency as manned aircraft. Promising technologies include electro-optic, infrared, and radar sensors, Automatic Dependent Surveillance-Broadcast, and Traffic Alert and Collision Avoidance System.[27] The FAA wants to transition from accommodating UAS via COAs to full integration, but policy waits for technology to create suitably safe conditions.

Clear solutions are not obvious for UAS airspace integration, but pressure from influential businesses like Amazon and FedEx, Department of Defense, Department of Homeland Security, and civilian customers make integration inevitable. Once that barrier falls, AF use of RPAs will proliferate to other missions like cargo transport and air refueling, and training requirements will morph further to accommodate required skills. RPA training focuses heavily on ISR and weapons employment even in URT. New aircraft types that perform different missions will necessitate new training objectives. Furthermore, an integrated airspace will explode demand in civilian industries. Civilian companies will target AF RPA pilots' expertise and provide financial incentives for RPA pilots to leave the service. The AF will have to react; its difficult job will be to manage experience levels, forecast trends, and train efficiently.

The AF pushes the FAA for increased UAS integration for practical reasons. COA negotiations are lengthy and produce inflexible and inconvenient operating conditions. As integration moves forward, the RPA community's assumptions about internal integration will change. An observer sees organizational culture in group boundaries and identification. Right now, large UAS are exclusively military and

[27] FAA Roadmap, 29.

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predominately weaponized. Not having civilian functionality has led bystanders to view UAS as war mongering, faceless machines. Integration will lead to proliferation and, in turn, familiarity lessening the stigma.

Recap

Cumulative developments like automation, societal shaping as seen in EPIC, and sequential efforts like the FAA's integration plan will thrust UAS into its second generation. Whether perceived as opportunities or threats depend on perspective. The AF's large budget, advanced military industrial complex, and highly trained and experienced personnel create many competitive advantages that are well suited to leverage automation, an enlisted force, and airspace integration. The advancements highlighted have technological roots, but it brings several deep cultural assumptions into conflict. They each increase air power's reach, flexibility, and affordability, but they threaten the skill required by an aviator. Carl Builder observed that, "when other means such as unmanned aircraft… became available, it was the aviators who revealed, by deeds more than words, that their real affection was for their airplanes and not for the concept of air power."[28] This runs counter to military professionalism and American expectations. The US calls on the AF to provide lethal air power as an instrument of national power, but the cornerstone has been the pilot. As that changes, how the AF defines reality, time, and space will expand, and leadership, vision, and a good strategy will be key to the AF successfully navigating the sociotechnical waters ahead. The next chapter dissects the AF's current RPA training strategy in contrast to the Army's. Service strengths and weaknesses implied in chapters one through three by way of comparison and the emerging opportunities discussed here will merge in a Strength, Weakness, Opportunity, and Threat (SWOT) analysis.

[28] Carl H Builder, *The Icarus Syndrome: The Role Of Air Power Theory In The Evolution And Fate Of The U.S. Air Force* (New Brunswick, NJ: Transaction Publishers, 1994), 32.

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Chapter 5
Strategy Analysis: AF RPA Training

The AF needs to reevaluate its current RPA pilot training strategy to prepare for future threats and opportunities. The AF reduced its ISR commitment from 65 combat lines down to 60 while combatant commanders increased their demand to 90. As Chapter 3 highlighted, the AF has been unable to scale production in a timely manner to meet increasing demand, and changing context will exacerbate the problem. In response, the Army has allocated more UAS resources to fill the gap. In essence, the AF has lost market share in an operating environment in which it clearly should be dominant. Debatably, the AF may recover with its current training strategy in the near term, but future opportunities and threats will require new approaches.

The first three chapters established a pattern of the external environment changing and the AF or Army subsequently adapting to meet needs. In the process, each service solved internal integration issues. The benefit of understanding each service's UAS origin and ensuing culture is an increased ability to identify organizational strengths and weaknesses. The last chapter forecasted three emerging developments that stand to reshape the UAS community. The first section of this chapter presents a method to analyze, classify, and test strategies. The second section dissects the AF's current RPA training strategy in the context of its broader Strategic Master Plan as well as in comparison to Army UAS training using a Strength, Weakness, Opportunity, and Threat analysis. The analysis concludes that emerging trends threaten to render the current strategy obsolete. Chapter 6 builds on that conclusion by analyzing two possible courses of action.

Methodology

This chapter conducts a Strength, Weakness, Opportunity, and Threat (SWOT) analysis for the AF's current training strategy. As implied in its name, a SWOT analysis is an analytical tool for understanding internal strengths and weaknesses and for identifying external opportunities and threats. Typically used in a business setting, SWOT analysis is useful in many decision-making situations to create a recommendation.

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Strengths and weaknesses include human resources, physical resources, financial situation, activities and processes, past experiences, and organizational culture. Opportunities and threats stem from external forces and include future trends, the local, national, or international economy, funding sources, demographics, the physical environment, legislation, and local, national, or international events.

Michael Porter, an influential business professor at Harvard Business School, posits that an organization in a competitive landscape has three generic strategies available to pursue. The first is a Low Cost Leadership strategy. There are three main ways to achieve cost leadership. The first approach is achieving high utilization rates. In a training environment, this means maximizing the use of resources like simulators, aircraft, classrooms, and instructors. Spreading fixed overhead costs over a larger number of graduates results in a lower unit cost. Runways, air traffic control towers, base hospitals, and aircraft are examples of overhead. The second dimension is achieving low direct and indirect operating costs. Standardizing a basic product keeps costs low by using fewer parts and using standard components. Low wages, low rent areas, and establishing a cost-conscious culture contribute to lower overhead costs. Cost reduction avenues include outsourcing, controlling production costs, and minimizing other costs like research and development. The initiative to reduce unnecessary weight like heavy paper publications or extra fuel on C-17 flights is an example of reducing direct operating costs. Another is not teaching multiple mission sets in a training course to reduce time and operating expense. The third dimension is control over the value chain to ensure low costs. For a supply chain, this could be achieved by buying in bulk, instituting competitive bidding for contracts, or working with vendors to keep inventories low.

Mass production becomes both a strategy and an end in itself. This can be an advantage: higher levels of output both require and result in higher market share. In turn, the firm's low costs and efficiencies create an entry barrier to potential competitors who are unable to achieve similar economies of scale. Disadvantages include lower loyalty from price-sensitive customers and a reputation for low quality. Another risk is that cost reduction is not unique, and competitors may copy your cost reduction strategies. Combatting this requires continuous improvement by investing in technologies aimed at reducing costs, maintaining efficient logistics, and keeping labor, material, and facility

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costs low. The desired result in a Low Cost Leadership strategy is, given a constant budget, to produce more through cost reduction.

Differentiation, the second strategy, involves making your products or services different from and more attractive than those of your competitors. Uniqueness in features, functionality, durability, support, or image characterizes valued, differentiated products. Providing contrasting products or services is a successful strategy when the target customer is not price-sensitive, customers have specific and under-served needs, and the company has unique resources and capabilities. A differentiation strategy is successful not by increasing market share but by achieving brand loyalty or a price premium. Organizations see gains when a price premium outweighs the added cost of specialization. Conversely, differentiation is a poor strategy if competitors can easily copy the product, method, or service provided. As an example, the C-17's capability to land on unimproved strips does not appeal to the airline industry, the dominate aircraft purchaser, but it did appeal to air forces around the world. To execute a differentiation strategy successfully, organizations need: good research, development and innovation; the ability to deliver high-quality products or services; and effective marketing to communicate the benefits offered by the differentiated offerings.

A Focus strategy, the third option, divides the existing market and then adopts a Differentiation or Low Cost Leadership strategy to serve that niche market. By understanding the dynamics of that market and the unique needs of customers within it, smaller companies then develop uniquely low-cost or well-specified products to outcompete broader market strategies. The firm typically looks to gain a competitive advantage through product innovation or brand marketing rather than efficiency. By serving customers in a unique market well, a small company's advantages include strong brand loyalty and less competition. The barrier to entry for competitors is deep, local knowledge. Disadvantages include difficulty expanding to dissimilar markets.

AF Strategic Master Plan

In 2015, the AF released its 20-year Strategic Master Plan (SMP) to lay out five strategic vectors that identified priority areas for investment, institutional change, and operational concepts. The aim is to provide coherency and a unified direction across the

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AF. One can also sift through the SMP to see how the AF answers fundamental questions about the service it provides and how it sees the future of armed conflict. Of the five strategic vectors, two in particular pertain to current RPA operations. The second strategic vector charges the AF to maintain a robust and flexible global ISR capability.[1] To accomplish this, Headquarters Air Force champions a "rebalance [of] resilient ISR sensors, systems, and processes toward operations in high-end contested environments," and advocates increased capabilities "against critical target sets in highly contested environments."[2] The third strategic vector complements the second: "Ensure a full-spectrum capable, high-end focused force."[3] The consequences of not achieving freedom of maneuver are dire: "Without high-end air, space, and cyberspace capabilities, these denied regions will pose significant, if not insurmountable, obstacles to friendly forces. Our greatest value to the joint force is dealing with these advanced threats…."[4] AF strategists, in crafting the SMP, used "high-end" 18 times and "deterrence" 22 times in 65 pages. The AF is positioning itself to win, or at least deter, in a Cold War II. As acquisitions and missions develop to counter near peer nation states, training will need to adjust.

Digital Collections
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[1] Headquarters, Air Force. Strategic Master Plan, 2015. http://www.af.mil/Portals/1/documents/Force%20Management/Strategic_Master_Plan.pdf, 3.

[2] *Strategic Master Plan*, 2015, 43.

[3] *Strategic Master Plan*, 2015, 3.

[4] *Strategic Master Plan*, 2015, 45.

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Figure 19: Platforms Tailored to Future Conflicts as Described in the Strategic Master Plan
Source: Author's original work

Clearly, the AF wants to refocus on the high-end spectrum of conflict where its role is more deterrence than brute force. This contrasts with the modern security environment and where the bulk of RPA training and assets are focused. RPAs matured during low intensity conflicts, and RPA platforms reflect that beginning. They operate in permissive environments and are primarily intelligence-gathering assets. Several noted security experts in academia disagree with the AF's prognosis on future conflicts. Mary Kaldor in *New and Old Wars* posits that, in the context of globalization, war between states in which the aim is to inflict maximum violence is becoming an anachronism. Present-day actors transcend previous geographic and political boundaries. The wars are fought for political goals using tactics of terror and destabilization that do not abide by the rules of modern warfare, and top down approaches to resolve issues favored by strong nation states are likely to fail. "Since the new wars are, in a sense, a mixture of war, crime, and human rights violations, so the agents of cosmopolitan law-enforcement have to be a mixture of soldiers and police."[5]

David Kilcullen in *Out of the Mountains*, identifies population growth, urbanization, littoralization, and networked connectivity as four emerging megatrends and correspondingly suggests that conflict is increasingly likely to occur in coastal cities,

[5] Mary Kaldor, New and Old Wars, 1st ed. (Cambridge: Polity Press, 2012), 12.

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in underdeveloped regions, and in highly networked, connected settings.[6] The answer is "co-designing" a response to improve resilience. Outsiders bring training, mentoring, technical skill, functional knowledge, research, support, and technical assistance, and locals bring insight, hyperlocal context, spatial understanding of systems logic, day-to-day flow, and ultimate action to implement the program.[7] In this new security environment, "the paradox is that although there are no purely military solutions, there are also no solutions without the ultimate sanction of coercion to enforce the order that makes joint action possible."[8]

Finally, Emile Simpson's central proposition in *War from the Ground Up* is that the traditional model of war as a bipolar conflict between two discrete political units is no longer helpful to understand or exploit the modern battlefield. Whereas nation-states fought past wars to achieve a military end state, soldiers today conduct armed action to directly seek political outcomes. Military leaders now must consider the impact of their actions not only on the enemy but also on a diverse set of audiences.[9]

Since its origin, the USAF has historically had difficulty transitioning its focus away from near peer adversaries to the low intensity conflicts in which it frequently finds itself. If academics are right, the AF's current strategic preparations for great power war may be setting the service up for future identity problems and a capabilities mismatch similar to Operations Iraqi Freedom and Enduring Freedom. Positioning training well to accommodate high-end capabilities and low-end conflicts may be problematic.

Comparison Difficulties

Several factors make direct comparisons between Army and AF RPA training difficult. Cost differentiation is one. Army accounting includes fixed overhead costs and variable direct costs like student pay, lodging, and travel. Because the Army relies on remote split operations less than the AF, UAS operators deploy more frequently and for

[6] David Kilcullen, Out Of the Mountains: The Coming Age of the Urban Guerrilla, 1st ed. (Oxford: Oxford University Press, 2013).

[7] Kilcullen, 255.

[8] Kilcullen, 257.

[9] Emile Simpson, War From The Ground Up: The Coming Age Of The Urban Guerrilla, 1st ed. (New York: Columbia University Press, 2013).

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longer periods than do their RPA counterparts. Combat zone pay and tax relief programs bolster their take home pay. Furthermore, the Army Military Occupational Specialty (MOS) code for UAS is currently 15W regardless of UAS type. Data tracking UAS operators does not distinguish between Gray Eagle or Shadow operators. Finally, distilling the cost of just flight training to compare costs is subjective. The Army trains each operator to fly the aircraft and operate its sensor suites rather than specializing each task the way the AF does.

Compounding difficulties in comparison, many factors make AF costs unpredictable. For instance, at the FTU, temporary duty (TDY) costs amount to $100 per student per day. Additional training time due to poor weather or lack of instructor availability means additional TDY lodging and per diem costs. In 2016, FTU classes graduated on average 25 days late. This added up to $2.7 million in additional TDY costs.[10] It does not help that no AF staff is tracking RPA operating, training, or personnel costs to a high fidelity. Amazingly, ACC does not know exactly how much the MQ-9 FTU or Launch and Recovery course costs.[11]

Another cost variable difficult to track is AF personnel costs. They vary wildly, and a complete lifetime cost analysis is elusive due to multiple variables tracked across multiple staffs. Different personnel costs start with officer commissioning sources and AF education assistance. An Air Force Academy education costs $322,750 per graduate, whereas the AF often does not incur any undergraduate education cost for Officer Training School accessions.[12] Both commissioning sources feed officers to URT. In addition, Aviation Retention Pay packages offered by the AF vary each year, and an individual's aviation experience determines his Aviation Career Incentive Pay (ACIP). The recent ARP package for 2017 is $35k/year for 5 years return of service but previous years were $25k/year with a 20-year aviation service option.[13] The program's take rate

[10] Major Derek (49 WG Program Flying Training manager), interview by the author. Over e-mail, 2017.

[11] Major Justin (ACC A3MU staff), interview by the author. Over e-mail, 2017.

[12] General Accounting Office, *DOD Needs To Enhance Performance Goals And Measures To Improve Oversight Of Military Academies*, GAO-03-1000 (Washington D.C., 2003), http://www.gao.gov/new.items/d031000.pdf, 2.

[13] Stephen Losey, "$175K Bonus For Air Force Drone Pilots Now Available", *Air Force Times*, 2017, https://www.airforcetimes.com/articles/air-force-offers-bonuses-up-to-175-000-for-drone-pilots.

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varies each year as well. Another variable difficult to account for is supplemental income like Base Allowance for Housing (BAH). DoD determines BAH by location costs and scale the allowance proportionally to rank. An O-5 with dependents stationed at Creech AFB receives $2022 per month for housing, while an E-3 without dependents at Ft Huachuca is entitled to $624.[14] Personnel become more expensive as their Total Active Rated Service (TARS) increase. AF members have longer service commitments, and a greater percentage of rated personnel retire than do Army UAS operators. Finally, AF staff billets require more qualified field grade officers costing more than similar Army positions.

Comparison of Current AF and Army Training Pipelines

This section employs considered judgement to compare AF RPA training and Army UAS training based on time, qualifications, personnel, and cost. Previous sections and chapters have alluded to these differences; this section discusses and presents the comparisons using quick-reference visuals. It then transitions to a SWOT analysis based on the AF's current strategy of Focused, Differentiation compared to the Army's Low Cost Leadership strategy. The comparison includes the AF's RPA training including URT and the MQ-9 RTU but not Launch and Recovery training that many RPA pilots never attend. Army's UAS training includes the Common Core course and Gray Eagle qualification course. Several quick-reference figures and tables are included.

Figure 20 displays a comparative training timeline for each service. URT and the FTU take 40 weeks combined. This does not include frequent delays or any holding time between courses. Conversely, the 15W training pipeline is considered Advanced Individual Training (AIT), and graduation dates are non-negotiable. Infrequently, students who are unable to complete the syllabus due to poor weather or other extenuating circumstances still depart to their gaining unit on time.

[14] "BAH Calculator", Defensetravel.Dod.Mil, 2017, http://www.defensetravel.dod.mil/site/bahCalc.cfm.

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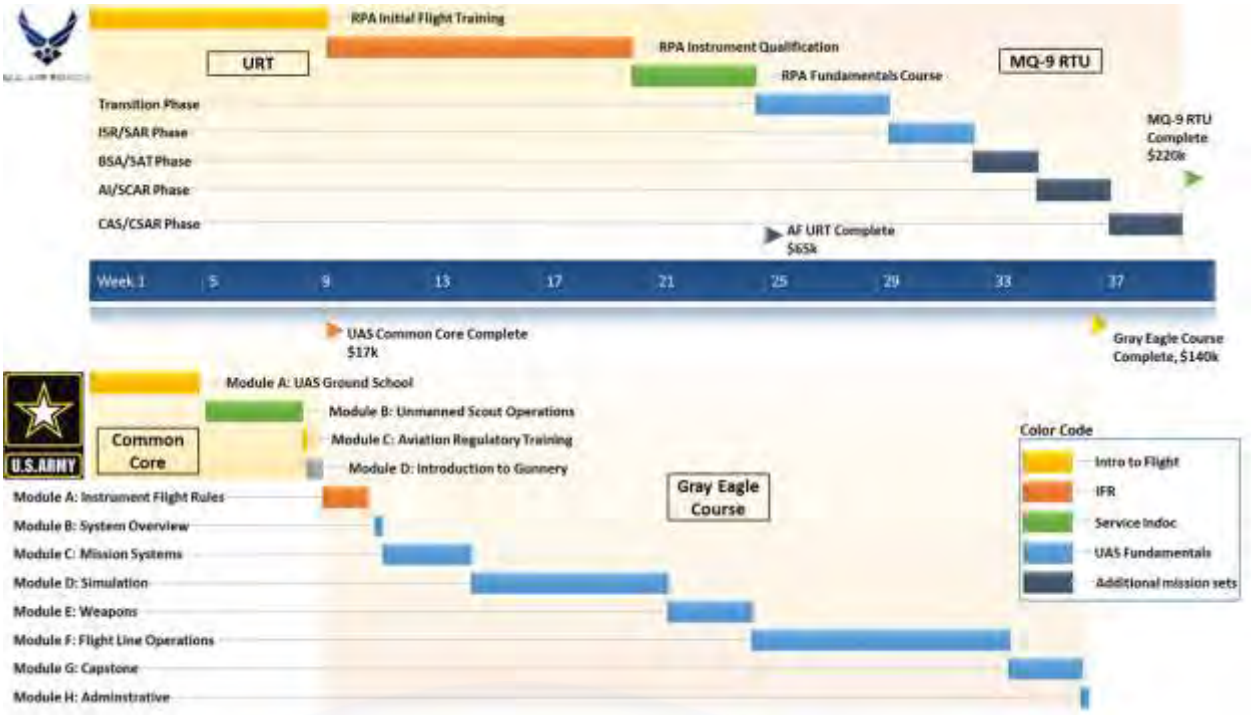


Figure 20: USAF RPA Training Pipeline Compared to USA UAS Training Pipeline
Source: Author's original work

At first glance, the training timelines appear similar, but the final products are significantly different. Gray Eagle training includes airfield operations, deployed setup and disassembly, and launch and recovery operations. The AF's launch and recovery (LR) course covers comparable material, but only deploying crews receive the just-in-time training. The course is 19 to 32 training days and costs approximately $99k. Some squadrons utilize contractors downrange for launch and recovery; those squadrons rarely send any pilots to LR training. The final five weeks of MQ-9 training is devoted to advanced mission sets like Surface Attack Tactics, Air Interdiction, Strike Coordination and Reconnaissance (SCAR), Close Air Support, and Combat Search and Rescue. The Gray Eagle course introduces basic gunnery and then allows follow on units to tailor further training to its particular mission.

Despite the comparison difficulties as explained earlier, personnel and training costs are a significant point of contention and deserve analysis. The following analysis focused on personnel costs irrespective of BAH costs, hazardous duty pay, tax-free deployments, or pensions in order to simplify the comparison. Flight pay and bonuses are included. The AF has roughly 915 RPA pilots. When extrapolated from AF-wide

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statistics, the estimated rank distribution for RPA pilots is: 125 O-1s, 129 O-2s, 398 O-3s, 242 O-4s, 180 O-5s, and 62 O-6s.[15] This averages to a yearly salary, including ACIP and a 55% bonus take of $35k/year, of $95k. The bonus take rate reflects the AF historical average. Adding retirement costs using the Top 3 Retirement plan adds approximately another $110k/year of service to O-5 and O-6 retirees.

The Army has 2370 total 15W personnel.[16] The current breakdown is 577 E3s, 719 E4s, 527 E5s, 348 E6s, and 199 E7s. These numbers include Gray Eagle and Shadow UAS operators that function as both pilots and sensor operators. This averages to a yearly salary of $36k. 15Ws do not receive ACIP, but the Army offers retention packages from $11k to $45k as needed. Table 1 lays out the course hours and costs for each segment of training. Total cost for URT and the MQ-9 RTU is $285k, and the cost for the Common Core and Gray Eagle courses is $157k.

Table 1: RPA/UAS Hours and Cost Breakdown Per Student

	URT: RFT/RIQ/RFC	**MQ-9 FTU**	**MQ-9 LR**	**Common Core**	**Gray Eagle**
Academic Training					
Course Hours	**273:** 62/133/78	157.5		328	272
Device Training					
Sessions	**52:** 0/36/16	22			37
Hours	**77.3:** 0/46.8/30.5	57.8			164
Mission Support	**81:** 0/41/40	68.7			
Flight Training					
Missions	**27:** 27/0/0	22			26
Hours	**39:** 39/0/0	44			178
Mission Support		88			16
Total Hours					
	470: 101/221/148	416		328	630
Total Cost					
	$65k: $10k/$35k/$20k	$220k		$17k	$140k

Source: Author's original work. FTU cost estimated by assuming similar academic instruction cost as Gray Eagle at $33/hr. Flight hour cost of $4762 taken from Time's "Costly Flight Hours." Student costs were estimated using $100/day per diem and 102 average training days.

[15] Data extrapolated from Rated Officer Retention Analysis, http://access.afpc.af.mil/vbinDMZ/broker.exe?_program=DEMOGPUB.static_reports.sas&_service=pZ1pub1&_debug=0.

[16] Kent A. May (Aviation Military Analyst, OPFD Directorate), interview by the author. 8 March 2017.

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Current AF Strategy: Focused Differentiation

RPA employment has focused on low intensity conflicts. Its role, partly dictated by aircraft and architecture design and partly mandated by the character of recent conflicts, has been primarily persistent attack. Training has followed suit. Determining and understanding the AF's RPA training strategy depends on who is considered the end user. If viewed as serving "organize, train, and equip" major commands such as Air Combat Command, RPA training focuses on the low intensity conflict/persistent attack niche market as a low cost leader in comparison to other Combat Air Force (CAF) platforms. In this regard, RPA training strategy has mirrored the AF's RPA employment strategy of low cost. Compared to the fighter/bomber community, the RPA community downplays differentiation possibilities and trumpets its Low Cost Leadership in combat employment. The MQ-9 costs $4,762 per hour, the F-22 costs $68,362 per hour, and the B-1 costs $57,807 per hour.[17] The training arena is similar: the schoolhouses instruct a specific mission set, ISR and persistent attack, much more affordably than do other similarly capable platforms. MQ-9 Initial Qualification Training is estimated at $220k per student, and the F-16 RTU costs $2.7 million.[18]

Changing the targeted consumer to the combatant commander reveals a slightly different training and employment strategy. Selecting the combatant commander as the customer prioritizes the warfighter's needs and ultimately the defense of national interests over internal organizational needs. The combatant commander advertises his request for forces in terms of specific capabilities needed. To fulfill those needs, the AF has chosen a relative strategy of Focused, Differentiation. In comparison to the Army, AF RPAs deliver more employment flexibility and mission sets beyond ISR. Employment, manning, and training are relatively more costly, but the premium price brings with it higher end kinetic capability like interdiction, close air support, and search and rescue. The AF's reluctance to lower training standards or decrease the number of mission sets instructed in order to graduate more students to meet rising demand demonstrates its adherence to a Focused, Differentiation strategy. Whether the strategy is

[17] Mark Thompson, "Costly Flight Hours", TIME.Com, 2017, http://nation.time.com/2013/04/02/costly-flight-hours/.

[18] HQ AETC/FMATT, *Representative Officer Aircrew Training Costs, Table A34-1*, 2014.

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successful or not depends on the combatant commander's ability to discern between similar platforms' performance and the demand for one product over another.

A Focused, Differentiation training strategy has several strengths and weaknesses when compared to the Army's Focused, Low Cost Leadership strategy. RPA training enables a unique capability that other AF platforms cannot match: unparalleled loiter with on-call strike. Its limited multi-role capability provides more options than Army UAS. Moreover, as the RPA community has adopted the wider AF's model of organizing, training, and equipping, it has integrated into the AF culture. Benefits of that include empowered, capable personnel with opportunities for promotion and community advocacy.

Two significant weaknesses exist with the current strategy. One is that lengthy training creates an obstacle to upscale production quickly. Efforts to expand the training pipeline started in 2014, and significant progress has yet to be realized. Second, and most important, the value of training differentiation is in doubt. The vast majority of RPA tasking involves lengthy transiting and ISR. Additional mission sets are required much less frequently. As Army Gray Eagles fold into the Global Force Management Allocation Plan (GFMAP) and combatant commanders use them interchangeably with MQ-9s, the premise that enhanced training brings differentiation will be tested.

Trends highlighted in Chapter 4 will force the AF to change its training strategy. Automation, national airspace integration, and the shift to enlisted pilots will cause RPAs to flourish even more. This success in itself threatens the focused nature of RPA training. As RPAs and its missions proliferate, AF training will move from its niche of persistent attack to focus upon broader employment, rendering a Focused, Differentiation strategy obsolete. As the AF acquires unmanned transport aircraft, air-air platforms, or rotary wing aircraft, URT's RPA Fundamentals Course will no longer apply to all graduates. The 558 FTS will need either to amend or remove the course to keep training relevant. Automation threatens the current Focused, Differentiation strategy by reducing the need for flight training. Unless training incorporates additional skills to accentuate this trend, differentiation will not be achieved.

Moreover, the Congressional mandate to use enlisted pilots for RPAs threatens the current training strategy. Officers as pilots imply a better product on varying levels,

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but success in the EPIC program will erode that belief. This could have far-reaching organizational consequences, as it could ultimately lead to the AF adopting an Army personnel model. Conversely, that RPA pilots receive well-rounded, comprehensive training brings with it the flexibility to adapt to new opportunities. The current training construct allows pivoting to new and possibly complex mission sets. Furthermore, the FAA considers the level of IFR training provided at URT the gold standard, and, as UAS integrates into the national airspace, URT graduates will be well prepared to take advantage of the opportunity.

	AF: Focused differentiation	Army: Focused Low Cost
Strengths	Delivers unique persistent attack capability -- Other AF platforms cannot -- Limited multi-role capability Integrated in AF culture -- Empowered, capable personnel -- Advocacy, CSAF/Congressional visibility	ISR focus -- LR and sensor suite training included Lowest cost -- High utilization rate via 24 hr ops -- Low labor costs -- Shorter timeline -- Able to outproduce poor retention
Weaknesses	Difficulty scaling to meet demand -- Longer training pipeline -- Unable to drive out competition Value of differentiation in doubt -- ISR accounts for 99% operational tasking -- Unique RPA architecture not maximized -- Army GFMAP support	Enlisted operators -- No vested advocate -- Low ranking SMEs Kinetic employment introduced
Opportunities	Well rounded, comprehensive training -- Allows scaling to more complicated missions -- Current construct allows pivoting to new mission sets -- IFR training best positions AF to implement UAS national airspace integration	
Threats	Automation reduces need for flight training Congressional mandate for enlisted pilots Poor retention expected increases burden	

Figure 21: Current Training Strategy SWOT Analysis
Source: Author's original work

Recap

In review, this chapter covered several topics that led to identifying and analyzing the AF RPA community's Focused, Differentiation training strategy. It introduced SWOT analysis as the methodology to compare current and future training strategies. The chapter discussed RPA training in the greater scope of the AF's Strategic Master

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Plan and security environment. The SMP identifies two vectors that inform future acquisitions and strategic direction as "high end" and "deterrence" related. Several national security experts posit that the US and its allies need opposite capabilities as war devolves within the boundaries of corruptly governed poor states. Training to employ sophisticated, expensive platforms in low-end conflicts may be problematic. Transitioning, this chapter identified comparison difficulties when assessing Army and AF programs due to different metrics, accounting methods, locations, and skills taught. Then, the chapter compared URT and MQ-9 Initial Qualification Training against UAS Common Core and Gray Eagle course. With the comparison as a backdrop, a Focused, Differentiation strategy was identified as the AF's current RPA training strategy. The AF has a tendency to gold plate its training as well as its equipment. Conversely, the Army employs a Focused, Low Cost Leadership strategy. Each strategy brings advantages and disadvantages.

Edgar Schein describes three stages of organizational life: early growth, midlife, and decline. Founders influence culture most in early growth, and they embed their beliefs by what they pay attention to and measure, how they allocate resources, rewards and status, and how they recruit, select, and promote.[19] Chapter 1 painted a descriptive picture of Generals Fogleman, Jumper, and Schwartz transmitting their values through formative decisions. Quality over quantity has recurred as a consistent theme, first when mandating rated officers and, now, when not rewarding commanders for graduating students on time. In midlife, cultural change mechanisms are from systematic promotion and technological seduction. As RPAs enter midlife, automation, national airspace integration, and the shift to enlisted pilots will inevitably bring RPAs out of its niche ISR market and into mainstream aviation. A Focused strategy is for organizations with small market share. When the preponderance of air platforms are RPAs, a Focused training strategy will no longer match its environment. Consequently, the AF will broaden its strategy into either Low Cost Leadership or Differentiation. As it transitions, they will also force assumptions about external adaptation to change. The next chapter will conduct a SWOT analysis of each strategy and recommend a future course of action.

[19] Schein, 246.

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Chapter 6
Other Strategies, Examined

Dr. Thomas P. Hughes, a noted historian, argues that, "younger developing systems tend to be more open to sociocultural influences while older, more mature systems prove to be more independent of outside influences and therefore more deterministic in nature."[20] If his hypothesis holds, as RPAs transition out of its initial growth phase into midlife, founders' leadership influence will wane, and technology will shape training more. Consequently, automation, national airspace integration, and the shift to enlisted pilots will inevitably bring RPAs out of its niche ISR market and into mainstream aviation. At that point, the AF will broaden its strategy into either Low Cost Leadership or Differentiation. This chapter first examines the possibility of joint training. The chapter then merges the insight gained into AF culture with the emerging threats and opportunities forecasted in Chapter 4 to consider, through a SWOT analysis, possible RPA training strategies going forward. A course of action is recommended. To conclude, the final step subjects the strategy recommendation to a five-question check as prescribed by Michael Porter. Porter argues that a good strategy creates and sustains competitive advantage by having a distinctive value proposition, a tailored value chain, trade-offs that are different from rivals, a good fit across the existing value chain, and continuity over time.[21]

Joint Training, the Obvious Solution?

> *We are disturbed that the Department of Defense has no standardized training program for UAS pilots and personnel. The continued lack of consistent and uniform training standards is simply unacceptable. In addition to collecting critical intelligence, the Department's UAS programs carry out sensitive strike missions that should require high standards and specialized training.*
>
> Senator John McCain, in letter to Secretary of Defense Ash Carter, 2015

[20] Thomas P. Hughes, "Technological Momentum", in *Does Technology Drive History? The Dilemma of Technological Determinism*, 3rd ed. (Cambridge, MA: MIT Press, 1994), 101.
[21] Joan Magretta, *Understanding Michael Porter*, 1st ed. (Boston, MA: Harvard Business Review Press, 2012). Kindle edition, 1147.

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This thesis originally intended to examine how the Army and AF have thus far justified separate training programs to Congress and what combined training would look like. On the surface, joint UAS training appears to be an obvious solution to the AF's staffing shortfall. The media and Congress have repeatedly inquired about merging UAS and RPA training into a single pipeline to create efficiencies.[22] Both services have dismissed the idea, and without civilian leaders intervening to force the issue, RPA training will probably remain service-specific. Despite operational context, societal pressures, and technology forcing the services to converge on UAS operations, the benefits of joint training are a mirage. Civilian leaders have the power to force joint training and deeper service interdependence of course, but their true motivations and the benefits of innovation lie in keeping them separate. Even Senator McCain's comment above may have ulterior motives. Fort Huachuca, Arizona, the site of the Army's only UAS training center, would serve as a likely location for joint training. Although duplication creates inefficiencies, it also creates competition. Civilian leaders use interservice rivalry to prevent shirking and encourage working. In his doctoral thesis on military innovation, Owen Cote posits that civilian leadership has structured the Department of Defense to function via interservice competition. The benefit is increased innovation: "Periods of intense and overt interservice competition in the US during the Cold War have covaried with periods of radical doctrinal innovation. Periods of relative interservice calm, or collusion, have covaried with periods of relative doctrinal stagnation."[23]

Had Cote written his thesis today, UAS stagnation under centralized control and innovation due to inter-service competition would be a persuasive case study. In *Air Force UAVs: The Secret History*, Thomas Ehrhard traces the stuttering progression of AF RPAs. He documents previous unsuccessful efforts to consolidate and centralize control of UAV development under the UAV Joint Program Office and the Defense Airborne

[22] Mark Pomerleau, "Should Drone Training Be A Joint Operation?", *Defense Systems*, 2016, https://defensesystems.com/articles/2016/03/18/air-force-army-uas-training.aspx.
[23] Owen Reid Cote, Jr, "Politics Of Innovative Military Doctrine: The US Navy And Fleet Ballistic Missiles" (DPhil in Political Science, Massachusetts Institute of Technology, 1996), 46.

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Reconnaissance Office. His report's final sentence captures his assessment: "The meteoric rise and fall of centralized UAV management provided strong evidence that 'pluralism and untidiness' indeed may be the only way for the US military to achieve weapon system innovation with the UAV."[24] Along with service-driven UAS innovation comes different platforms, different cultures, and different training approaches. Currently, the role of service rivalry in driving innovation outweighs potential gains in interdependence and interoperability

Should Congressional mandate override this arrangement, a viable joint URT would simply amalgamate Army and AF training to form a standardized foundation. A possible joint syllabus is quickly proposed here by taking portions from each service's training program and removing others. First, a joint syllabus would remove the contracted flight training course from the AF's training and change the final RPA fundamentals course to include more visual identification academics and scout maneuver fundamentals (depicted in Figure 22). Instrument qualification would remain, and the Predator/Reaper simulator training in the AF's final fundamentals course would be removed. The streamlined course would take 21 weeks and cost approximately $45k per student.



Figure 22: Possible Joint Undergraduate RPA Training Timeline
Source: Author's original work

[24] Ehrhard, 57.

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This training pipeline requires concessions from both services, and both services would have valid objections. By moving more instruction to an earlier course, the Army would need to shorten its Gray Eagle course to focus on aircraft systems and employment. Overtraining Shadow UAS operators who do not need months of instrument flying rules would offset benefits gained. By eliminating RPA Flight Training, the AF would argue that its URT graduates would lack airmanship. In addition, unless the AF implemented personnel changes as well, commingled AF officers and Army enlisted would raise difficult questions over uniform wear, incentive pay, and off-duty expectations. Another difficulty JURT would face is responding to rapidly evolving capabilities and mission requirements. Whereas joint undergraduate pilot training has remained relatively unchanged for decades, URT adjusts frequently. In JURT, frequent joint staffing would be required to prevent program obsolescence, and managing the inevitable culture clash would be a significant hurdle. Edgar Schein presents three options to manage cultural conflict from a merger:

> The two cultures can be left alone to continue to evolve in their own way. A more likely scenario is that one culture will dominate and gradually either convert or excommunicate the members of the other culture. A third alternative is to blend the two cultures by selecting elements of both cultures for the new organization, either by letting new learning processes occur or by deliberately selecting elements of each culture for each of the major organizational processes.[25]

To broker disputes, the AF would make the most convincing bid for executive agency of the training program but could easily alienate the Army if it institutes doctrine heavy-handedly. Past URT, implementing joint training is not practical on different weapons systems. Each service develops its own UAS that require specialized training. Should civilian leadership force a joint acquisition, they could also naturally extend combined training.

In the only example of joint UAS training, the Marine Corps opportunistically sends officers to URT and enlisted marines to Army UAS training. As the Marine Corps considers purchasing MQ-9s, several officers attend URT each year. The Marine Corps currently operates the same Shadow UAS as the Army, and its enlisted operators go

[25] Edgar Schein, *Organizational Culture and Leadership*, 3rd ed. (San Francisco, CA: John Wiley & Sons, 2004), 316.

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through the Army's Common Core and Shadow course. At course conclusion, the Marine officers and enlisted join for operational training where officers learn to lead and supervise in a tactical setting. This example is short-lived: as the Marine Corps transitions away from the Shadow to the RQ-21A Blackjack, they plan to standup service-specific training at Cherry Point Marine Corps Air Station, North Carolina.

Joint RPA training has several potential pitfalls but also several mitigating factors. Merging training is not a strategy; it is combining and selecting best practices. Some services can achieve efficiencies, but only in early training phases where instructors teach foundational skills. The minimal efficiencies gained arguably do not outweigh benefits of inter-service competition and innovation. Both services have dismissed the idea of joint training, and without civilian leaders intervening to force the issue, RPA training will remain service-specific. Despite its apparent benefits, joint training undercuts many of the goals and objectives civilian leaders most desire from their military services.

Low Cost Leadership

The AF's service-wide strategic bias for Differentiation does not mean RPA training has to follow suit. Rather, the RPA community could pursue a training strategy that embraces mass production aided by increasing automation, rising demand from RPA's national airspace integration, and societal pressures to enlist the RPA pilot force. Cost leadership is about minimizing the cost of delivering products or services. There are two different successful outcomes possible in a cost leadership strategy. The first is increasing the assets contributed to a combatant commander by the AF without expanding its budget. The second is maintaining its contribution and diverting leftover capital toward other demands.

A danger of pursuing a low cost strategy is confusing operational effectiveness (OE) as strategy. Low cost leadership uses mass production to leverage economies of scale. Amortizing overhead costs quickly and reducing direct variable costs create barriers to entry. Out producing adversaries serves as a deterrence or forces a less-threatening asymmetric response. Conversely, OE refers to a competitor's ability to perform similar activities better than rivals through execution or best practices. Quality management or continuous improvement programs are examples. Simply improving

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operational effectiveness does not provide a robust competitive advantage because rarely are best practice advantages sustainable. Rivals quickly copy best practices, and frequent imitation results in hypercompetition.[26]

The three ways to reduce cost are to increase utilization rates, to control the value chain to ensure low costs, and to reduce overhead and direct costs. In many ways, the AF has streamlined its operations to maximize the first two methods. Utilization rates in the simulators and aircraft at the FTU are already high. Wing scheduling regularly programs 16-hour flying windows to accomplish as many training events as possible per day. Some instructors think allotted training times in the syllabus are generous, and even more events could be scheduled to increase instructor utilization.[27] The current daily flying window is long when compared to other AF flying programs. The MQ-9's primary sensor is an infrared video camera, meaning that night operations do not hamper training. The AF could gain higher utilization by instituting round the clock operations. In comparison, the Army UAS program operates 24 hours per day on weekdays. The AF uses remote split operations (RSO) in training, but diverting training sorties is not common enough to be seamless. Adverse local weather still cancels training sorties, thus lowering utilization and graduation rates.

Controlling the value chain is possible through renegotiated contracts with suppliers and manufacturers like General Atomics, but such an endeavor is enterprise-wide. Training platforms are bound to operational weapons systems. Contractor labor costs contribute to the value chain and are high for two reasons: remote training location and required instructional experience. Alamogordo, New Mexico, the home of Holloman AFB, is a small, desolate town not known for its expansive labor pool or amenities. Companies lure qualified contractors through higher salaries. Additionally, contractors can demand higher salaries because the various FTU syllabi teach multiple missions. This requires higher skilled employees. The town and businesses of Alamogordo rely heavily on the base as a source of revenue, and, therefore, moving the FTU and its

[26] Magretta, 1108.

[27] 9th ATKS instructor pilot at Holloman AFB, NM, interview by the author, 22 December 2016.

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associated labor pool to somewhere less costly is politically difficult. Conversely, URT has neither problem. San Antonio offers amenities and provides a deeper labor pool of AF retirees and flight instructors in general.

The greatest value savings is in reducing direct costs. Reducing mission sets or eliminating courses instantly shortens the pipeline. Moving live sorties to the simulator is cheaper and more reliable, and as better simulators come on line, differentiating between the two will become more difficult. Replacing officer pilots with enlisted operators reduces labor costs immediately. As those enlisted operators complete their active duty service commitment, lower paid contractor opportunities will appear attractive. Two ensuing side effects counteract. One, contractor opportunities will tempt more enlisted operators to leave the AF. Two, the AF provides many of those contractor opportunities and can offer lower contracts. The Army UAS pipeline produces its enlisted operators using methods that are easily replicated. Accordingly, its strategy falls under the category of operational effectiveness.

Without making significant structural changes or changes that are difficult to imitate, the AF can emulate the Army UAS pipeline to silence critics and improve production. In a lightly implemented low cost strategy, the AF could adopt the Army's best practices. Eliminating URT's initial flight training would trim URT by 1 month and save $10k. By instructing enlisted operators in only emergency procedures, aircraft handling, ISR, and Basic Surface Attack, squadrons could reduce the MQ-9 course by 5 weeks, a 30% reduction. Without further costs or increased manning, the FTU squadrons could graduate 50% more students in the same time. The AF would save $104k by eliminating 11 flying sorties, 7 simulator sorties, 41 hours of academic instruction, and $3.5k in per diem costs per student. This would push the training burden downstream to operational squadrons, but those squadrons would provide additional mission training when needed and in an applicable format. Squadrons already tailor mission qualification training to a squadron's designed operational capabilities (DOC) statement and provide follow-on upgrades when experience allows. This just scratches the surface of potential.

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Low cost leadership typically means generalization. In the age of specialization, though, carefully combining sheer size with required skills can achieve low cost. An analogy is a large hospital with many surgeons. Each surgeon brings valuable knowledge, but no single doctor knows every procedure or technique. During a procedure, surgeons operate as teams to complement each other's skill set. Having doctors narrow their field of study does several things. One, it reduces the education burden while allowing deep expertise. Already, medical school, residency, and specializations consume years and possibly decades of study and training. Medical students achieve familiarity in a core curriculum and in-depth knowledge in an area of interest. In-depth knowledge provides the most value. Two, specialization enables proficiency and currency. Surgeons repeatedly apply their skills to similar medical situations. That focused practice keeps their skills honed, and their knowledge current. Three, surgeons in an operating room create efficiencies by complementing each other's skills. The result is that when each doctor brings a skill to surgery, a team can perform operations that are more complicated better.

Manned aircraft platforms have adopted primary missions that suit their aircraft flying characteristics and capabilities. This specialization complements a strike package the way a surgeon supplements an operating room. Pilots, to a much lesser extent, attempt to do the same when they focus on one particular airframe and develop the specific skills to fly that aircraft. However, skill sets cannot subdivide further. Physics dictates that all pilots must know how to conduct basic skills like takeoff, land, transit, talk to agencies on the radio, mission plan, fly on instruments, and handle emergency procedures. The RPA architecture is not bounded by those restrictions, but current operational and training practices barely scratch the surface of modularity possible. Operational squadrons use specified individuals to lead strikes, and aircrew cycle through the ground control station cockpits when fatigued. Otherwise, to minimize risk, RPA pilots are expected to perform in all stages of flight that may occur between the gaining handover and the losing handover. Having aircrew specialize in specific phases of flight would result in higher performance, increased currency, and much lower training costs. This would entail a paradigm shift away from an independent decision maker and toward a networked operator. Low cost through specialization works as long as the skill set can

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be accessed when needed. RSO creates efficiency by concentrating its personnel; it is an ideal operational model for specialization. Conversely, organic Army units, by definition, are decentralized and cannot specialize.

A second, more ambitious strategy builds on the first and further exploits RPA's modular capabilities. Strengths include a reduced training pipeline, easier scalability, and exploiting RPA's unique RSO architecture. A pared down core curriculum would introduce fundamental skills like gaining and losing handovers, aircraft handling, airspace transit, and ISR. Rather than 22 sorties in the current syllabus, only 8, maybe less, would be required. In Mission Qualification Training or, ideally, in later upgrades, individual operational squadrons would teach skill sets like emergency procedures, Basic Surface Attack, Surface Attack Tactics, Close Air Support, and Combat Search and Rescue as their area of responsibility required. The cost and time savings in such a strategy would be dramatic, but operational squadrons would have to alter the way they operate and how they manage and schedule their personnel. The strategy would force squadrons to transition from several independently operating aircrew to a networked, interdependent operation. This takes advantage of AF RPA's unique architecture in a way adversaries and other services would have difficulty imitating. Efficiency and networked operations do incur risk. Weaknesses include transferring the training burden to operational squadrons, cultural acceptance by a wider AF that prizes the anachronous independent decision maker, and difficulty managing personnel. Operations that parcel out skills more efficiently and sparingly reduce a squadron's ability to handle low probability events like multiple time-critical emergencies or intricate kinetic strikes.

Current trends provide opportunities and threats to a low cost leadership strategy. As automation increases in capabilities, it will drive manpower and training requirements down further. In a low cost construct, when specialized skills become obsolete, course modules can be easily eliminated. Society and technology are already network centric; specialized training serves as a mechanism to force the RPA community to network. Modular training also complements the enlisted pilot mandate and the AF's current enlisted force structure. Qualifying RPA pilots initially as 3-level apprentices equates to the AF's current classification system. As the RPA pilot gains further specialized skills, he can transition to a 5-level journeyman, then 7-level craftsman, and finally a 9-level

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superintendent. Graduated qualifications make attrition less costly. A modular, enlisted-based system also repositions officers as mission commanders and supervisors. It allows focused training on employing a complete weapons system through leadership, reaffirming an ideal officer/enlisted construct. Pending UAS national airspace integration means more growth. Having a scalable training system will ensure that the AF can respond quickly to shape the environment and maximize new opportunities.

Although the strategy presented attempts to leverage US and AF advantages, other nations are intently watching the AF execute. The AF should expect both adversaries and allies to adopt proven best practices. The greatest threat though is existential. If automation and artificial intelligence drive pilots further from the cockpit and commoditize air-mindedness, is a separate AF justified? Martin van Creveld in his "Rise and Fall of Air Power" argues that it is not. He concludes that, with the possible exception of space vehicles, there is "no convincing reason why they should be part of an independent service. Supposing that twenty-first-century wars will be mainly of the low-intensity kind...there probably is no compelling case for independent air power at all.[28] A low cost strategy will not cause this shift, but it will hasten it.

Air University Digital Collections
Air University–Maxwell AFB, AL

[28] Martin Van Creveld, "The Rise and Fall of Air Power", *The RUSI Journal* 156, no. 3 (2011): 48-54.

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Low Cost Leadership Training Strategy

	AF	Army (Focused Low Cost Leadership)
Strengths	Shorter training pipeline Scaleability- handle increasing and changing demand Unique RSO architecture exploited --Increased Modularity, Efficiency --Increased performance through specialized skills	Better utilization rate with 24 hr ops LR and sensor suite training included
Weaknesses	Specialized training burden on downstream squadrons Cultural, bureaucratic acceptance Personnel, skills management possibly unwieldy	Decentralized control --RSO architecture not used --Generalized skill set
Opportunities	Automation will increase capabilities, drive manpower and training requirements down further Modular training complements enlisted pilot mandate Pending UAS national airspace integration means more growth Modular training complements enlisted pilot mandate Network centric warfare Poor retention less costly	
Threats	Best practices quickly copied Existential reason for AF	

Figure 23: Low Cost Leadership Training Strategy SWOT Analysis
Source: Author's original work

Differentiation Strategy:

A differentiation strategy complements the AF's Strategic Master Plan and is a grander version of today's RPA training strategy. It values high quality training and maximizing a platform's capabilities. To execute a differentiation strategy successfully, the AF needs to continue its current vector: good research and development; the ability to deliver high-quality services; and effective communication to justify the differentiated offerings' price premium. While current efforts to distinguish added capabilities lack appreciation, as future full spectrum capabilities come online, the AF will have the right personnel in place to optimize them. Complicated, complex weapon systems that deliver strategic effects will validate this strategy's price premium.

The RPA community has grown and developed under heavy influence from the wider AF. As the AF's largest community, the reverse is starting to take place. Its size and resource requirements mean that it is influencing AF culture. A training strategy

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inline with the Strategic Master Plan will be more readily received. Jeff Smith in *Tomorrow's Air Force* surmises, "There are signs that the USAF is moving toward major organizational change that will focus on the full spectrum of war rather than on a particular facet, context, or weapon system."[29] RPAs transcend conventional thought about weapon systems; they cross cyber, space, and air domains easily. RPAs jump instantly from tactical intelligence gathering to strategic interdiction. RPAs represent this organizational change, and its maturing officer corps is well positioned to lead tomorrow's Air Force. Ensuring institutional recognition through promotion nurtures RPA's advancement. Promoting talent within is critical, and a differentiation training strategy cultivates that talent.

The differentiation strategy does not change the current problem of scaling to meet demand. The current MQ-9 syllabus is an optimistic 77 training days long. A revised syllabus currently in staffing adds 15 more planned days; this trend is in the wrong direction. Furthermore, what warfighters consider low-end capability requiring little training is outpacing high-end growth and will squeeze the AF into narrower responsibilities. UAS growth has been at low price points, exactly where the value of differentiation is in doubt. The glaring question is, if premium training is not appreciated now, what will more automation do?

A differentiation training strategy makes logical sense as the UAS capability envelope expands and unmanned aircraft further models manned aircraft training. The differentiation strategy presents several opportunities. The primary opportunity of pursuing high-end platforms and training is extending current airpower capabilities beyond manned aircraft limitations. Relegating low-end missions to the Army reduces inter-service rivalry and ensures a peaceful coexistence (Figure 24). Fully exploring options at the intersection of network centric warfare, RSO, and unmanned flight will require talented, empowered warfighters that fully understand UAS potential and limitations. Operating in contested, degraded environments is a barrier to wider RPA employment. Whether solving that problem technologically or tactically, talented, well-trained personnel are needed. As UAS proliferates and off-the-shelf technology reduces

[29] Jeffrey J Smith, *Tomorrow's Air Force: Tracing The Past, Shaping The Future*, 1st ed. (Bloomington: Indiana University Press, 2013), 158.

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the AF's competitive advantage, knowledge will be the deciding advantage. Additionally, in the early days of airspace integration, trust from society and regulators will be low until a track record is established. If the AF retains its reputation for highly trained RPA pilots, not only will integration be smoother and more expansive, but the AF will have first mover advantage into the airspace.

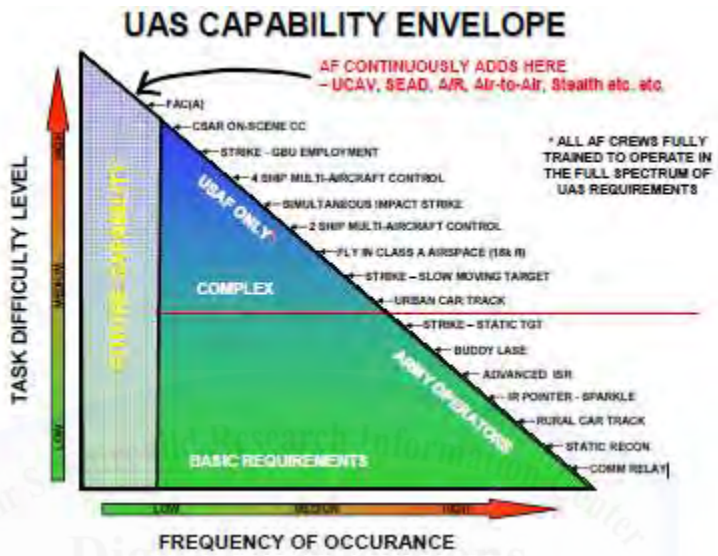


Figure 24: USAF and Army UAS Interdependence Model
Source: Major Travis A. Burdine, ""Organic" Army Unmanned Aircraft Systems: The Unhealthy Choice for the Joint Operational Environment" (Air Command and Staff College, Air University, 2008, 29.

Significant threats loom for a differentiation strategy. If the security environment favors frequent low intensity conflicts, high-end capabilities developed through differentiation are good for conventional deterrence but not for real world conflict. In addition, automation is moving the pilot further away from the cockpit and reducing the need for training not increasing it. Moreover, the Congressional mandate for enlisted pilots favors simplifying training and reorganizing the force structure. Poor expected retention will increase the training burden and further test this strategy.

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Differentiation Training Strategy

	AF	Army (Focused Low Cost Leadership)
Strengths	Training to push aircraft capabilities -- Full multi-role capability -- Knowledge to pursue unique RPA architecture Influences AF culture; in line with SMP -- Future senior leaders in rise of RPA generals -- Advocacy, CSAF/Congressional visibility	ISR focus -- LR and sensor suite training included Lowest cost -- High utilization rate via 24 hr ops -- Low labor costs -- Shorter timeline -- Able to outproduce poor retention
Weaknesses	Difficulty scaling to meet demand -- Longer training pipeline -- Unable to drive out competition Value of differentiation in doubt at low end	Enlisted operators -- No vested advocate -- Low ranking SMEs Kinetic employment introduced
Opportunities	Well rounded, comprehensive training -- Allows scaling to new platforms, move closer towards full spectrum capabilities -- Current construct allows pivoting to new, more complicated mission sets -- IFR training best positions AF to implement UAS national airspace integration	
Threats	Low end conflicts mismatch for capability Automation reduces need for flight training, trend moving pilot further away from cockpit Congressional mandate for enlisted pilots Poor retention expected increases burden	

Figure 25: Differentiation Training Strategy SWOT Analysis
Source: Author's original work

Strategy Recommendation:

A Low Cost Leadership training strategy with low initial training requirements supplemented by follow-on specialized training is the AF's best way forward. A successful low cost strategy will produce enough qualified graduates to satisfy growing needs while allowing follow-on skill specialization. Skill specialization in turn enables differentiation. Unclear prioritization in implementation will blur a low cost and a differentiation strategy and yield muddled results. For example, if the AF develops an RPA air-air platform, it would replace current manned platforms only if the cost-benefit ratio improved. Is this Low Cost Leadership strategy or Differentiation? The dilemma is not whether to eschew the full spectrum of air power in the pursuit of low cost. The question is what should be prioritized. In implementation, a strategy and, therefore, a culture is made apparent by what is prioritized and what metrics are tracked. Ironically, a successful Low Cost Leadership training strategy introduces Differentiation.

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The five tests of a good strategy include an examination of whether the proposal brings a unique value proposition, a tailored value chain, trade-offs that are different from rivals, a good fit across the value chain, and continuity over time.[30] A value proposition asks whether distinct value is being offered to a chosen set of customers at the right relative price. In a Low Cost Leadership strategy, end customers are combatant commanders and never the services tasked to organize, train, and equip. Combatant commanders' chief, unquenchable desire is for more information. Air power has a proven ability to provide valuable intelligence especially in areas difficult to access otherwise. If customers value quantity over quality, high price sensitivity requires discount pricing and ready availability.

A Low Cost Leadership strategy delivers a tailored value chain. Remote split operations counter Army aviation doctrine of decentralizing assets. The Army has reluctantly investigated RSO to fulfill requirements in Syria and Iraq; it is a model that forces divisions to relinquish control of their assets. Conversely, AF doctrine espouses centralized command, and RSO fits well with that air power tenet. Remote split operations is the key enabling piece in driving a low cost training strategy.

A strategy that relies on low initial training and then further specialization provides low cost but does have unique trade-offs. The downside to this low cost strategy is that few single operators would possess the knowledge to operate in isolation. The assumption is that more value lies in a group of personnel with highly specialized skills than with generalists. The Army designs its companies as generalists so they can deploy as organic assets in direct support of divisions or brigade combat teams.

Pursuing a different strategy than the wider AF, albeit just in training, comes with risks. The fourth test asks whether pursuing a low cost training strategy would be enhanced by other AF activities. Yes, the AF has the support structure required for any flying activity like restricted training airspace, runways, staffing, and transferable experience. The misfit, especially if not communicated effectively, is cultural. A pitfall for low cost producers is poor quality and a poor reputation. The AF prides itself on the

[30] Joan Magretta, *Understanding Michael Porter*, 1st ed. (Boston, MA: Harvard Business Review Press, 2012), Kindle edition, 1187.

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exact opposite. Inevitably, though, technological trends will carry more force than cultural legacies (Figure 26).

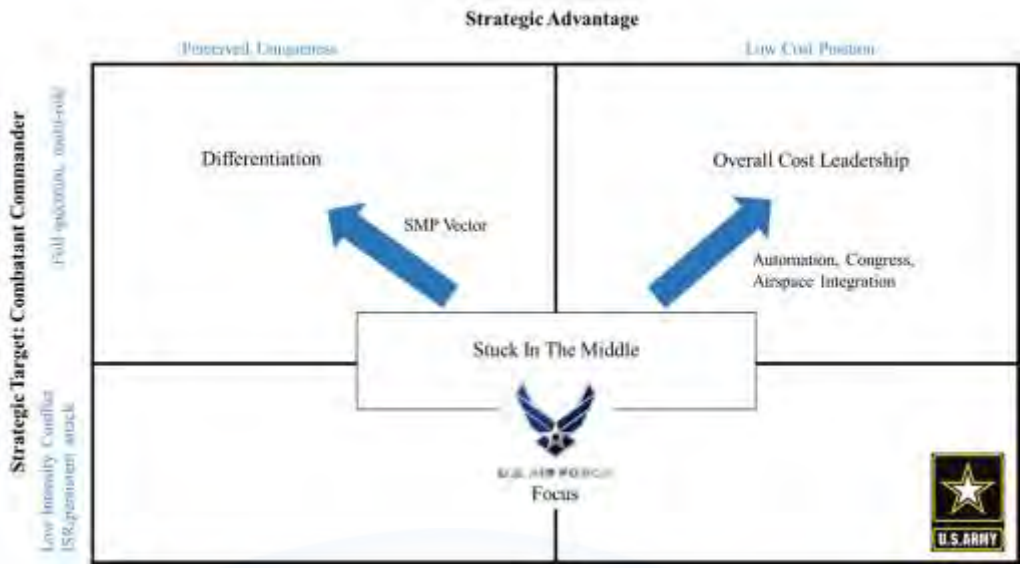


Figure 26: AF and Army UAS Employment and Training Strategy
Source: Author's original work

Finally, the strategy departs from current practices but does so flexibly. Operational squadrons already carry out upgrade training and have tiered operators titled wingman, flight leads, and instructors. A strategy provides a general vector whereby training syllabi are slowly reduced or divided into separate courses and organizations slowly adjust.

Recap

Automation, national airspace integration, and the shift to enlisted pilots will force the AF to broaden its strategy into either Low Cost Leadership or Differentiation. A SWOT analysis highlighted the advantages and disadvantages of each strategy. Based on that analysis, a Low Cost Leadership strategy is the best future course of action. Evaluating that course of action highlighted potential cultural conflict as the wider AF pursues a differentiated, high-end Strategic Master Plan. Based on how the AF employs RPAs, a Low Cost Leadership training strategy provides the AF a distinctive competitive advantage not only in comparison to the Army but to adversary air forces and allies alike. The recommended approach to low cost training is much different than the Army's current model. Using RSO provides modularity; it is an advantage not easily modeled

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and requires extensive multi-domain support. Producing enough timely RPA pilots to meet the demand for ISR collection is the customers' priority. Less time in military training equates to less cost. Finally, the proposed strategy is unique amongst all aviation training, and it is this strategy rather than competing on execution or in a race to the bottom line that will sustain the RPA community in the future.

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Conclusion

Independence—one of the hallmark traits of military aviators, is challenged by the connectivity of UAVs.

Major Houston Cantwell, *Beyond Butterflies*

UAS training evolved differently under the AF and Army due to to their different starting points and respective cultural influences. The surge of American forces into Iraq in 2007 highlighted the AF's lingering resistance to expand its RPA force. Up to that point, the AF had borrowed from the existing fighter and bomber pool to pilot its RPAs while keeping its RPA pilot training pipeline on hold. AF senior leaders explicitly desired rated pilots to fill RPA cockpits in stark comparison to Army UAS enlisted operators. When pressure grew to provide more combat lines, the AF and a new Chief of Staff responded by rapidly instituting a dedicated RPA pilot training pipeline to produce specialized unmanned operators. The training model mimicked other AF undergraduate training programs like UPT and UNT. It was those two things, the initial insistence to operate RPAs with rated pilot officers and building URT from other rated programs, that both reflected and reinforced the AF's cultural influence on the RPA community.

Conversely, the Army's UAS training community started with small, remote-controlled drones over 25 years ago at Fort Huachuca, Arizona. It has grown and expanded into new platforms with new capabilities, but its model based on universal enlisted operators trained to operate as an organic divisional asset remains. The focus on efficiency has streamlined the training pipeline. Notably, at the operational level, flexibility is prized over efficiency and possibly effectiveness. Soldiers are trained to fly the Gray Eagle, to operate its payloads, to conduct certain maintenance items, and to handle basing requirements. The decentralized approach incurs costs in its specialized focus and in high end capability potential. It also costs in reduced readiness levels. Poor retention plagues the community, but current production meets needed replacement demand. Ultimately, the underlying focus remains to support and enable the ground forces commander and his mission. The artifacts, values, and assumptions are in accordance with that focus. Such simplicity has led to practical and sustainable decision making in regards to UAS.

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The AF, in building the RPA training pipeline, reaffirmed its underlying assumptions rather than reevaluating them. The notion that RPAs are just like manned aircraft but remotely piloted continues as the AF pursues 65 initiatives in its RPA Get-Well Initiatives and Culture and Process Improvement Programs. A quick example of this alignment is renaming Ground Control Stations (GCS) to cockpits. The result is that each training program creates a different product and, in turn, reflects institutional disagreement over what skills should be imparted. This is despite similar end-state capabilities, at least similar enough to end state customers. This conflict between utility and tradition has yet to profoundly ripple through the AF, whose raison d'etre is to fly, fight, and win—in air, space and cyberspace.

The current AF training model has struggled to meet rising demand. Rather than accommodating AF tardiness, combatant commanders have looked elsewhere. As Global Force Management Allocation Plan needs are filled by Army Gray Eagles, skill differentiation is called into question. Moreover, three emerging trends--automation, enlisted pilots, and national airspace integration--will either exacerbate this demand/supply gap or force the AF to reevaluate its RPA training strategy. An analysis combining AF RPA strengths and weakness with the opportunities and threats these emerging trends brings recommends the transition to a low cost strategy to leverage remote-split operations and the modularity it provides. Prioritizing low cost achieves mass production which in turn creates more opportunity for modularity. This is the training paradigm that can achieve cost-prioritized differentiation.

A Low Cost Leadership strategy adopts automation and welcomes its irresistible rise. While automation threatens a differentiated training strategy by undermining the value of training provided, a low cost strategy views automation as an opportunity. Regardless, the unstoppable march of technology will shape AF operations and subsequently training. Automation combined with network centric warfare will force internal meaning making, and the result will be a dramatic culture shift.

Modularity undercuts an underlying assumption deeply held by the AF that aviation requires airmen instead of chauffeurs, independent decision makers instead of operators. This is a key justification for officers as pilots, but it is in contradiction to RPA's true advantage: network-centric operations. This struggle has played out since

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1900, when Wilbur Wright wrote to Octave Chanute conjecturing that flight required piloting skill more than machine stability.[1] That skill subsequently meant differentiation from society. Different characterizations of pilots would evolve, but a dominant theme that aviators were more than machine operators, that they were independent professionals, emerged. The notion developed that aviators were "mechanical angels, carrying the 'winged gospel' of modernity" rather than chauffeurs.[2] Technological developments like autopilot, flight instruments, and now, automation and networked operations have modified this image. Automation and networked operations reduce individual control but lends tremendous opportunities. The stability gained enable longer flights, less physical risk, real-time intelligence dissemination, and quicker responses. Automation and networked machines may also hold the key to solving current operational dilemmas in contested, degraded environments or against anti-access adversarial strategies. It may also be hastening the end of the pilot as we know it.

Ultimately, this transition is indicative of the broader knowledge economy, but it creates an uncertain future for the AF. As technology advances, less importance is placed on activities that can be replaced by automation, and more on decision making and judgment. The rise of the RPA has highlighted the many external adaptations required to fully exploit these emerging capabilities, and these capabilities possible are barely being realized. The AF has evolved since its origin, and as groups evolve, "the assumptions they develop… reflect deeper assumptions about more abstract general issues around which humans need consensus in order to have any kind of society at all."[3] It is these deep assumptions that provide strongest resistance when threatened, but automation and connectivity are driving its change within the AF. The AF has yet to accept this trend, and it undermines its commitment to innovate through air power. How the AF attempts to make meaning of its external stimuli will reflect its deep cultural assumptions. In turn, how successful the AF response is will determine how drastic its culture will be affected.

Technological determinism makes transition inevitable, and AF culture will evolve. While how the AF will be forced to change and what it will look like is subject

[1] David A Mindell, *Digital Apollo*, 1st ed. (The MIT Press, 2008), 22.
[2] Mindell, 23.
[3] Schein, 137-8.

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to conjecture, determining a proactive, viable strategy based on theory and doctrine to leverage technology is vital. If steps are not taken to leverage opportunities technology provides, technology will dictate a passive, incoherent strategy. In addressing space strategy but applicable to any competitive enterprise dominated by technology, Everett Dolman stated,

> The difference between theory or doctrine-driven strategy and, say, technology-driven strategy is profound. The first integrates new technology into a coherent vision; the latter abandons foresight and follows the apparatus wherever it leads. One is proactive, the other reactive. One wins, the other loses.[4]

In years past, independent decision makers were required to pilot aircraft. As those pilots were promoted in rank, they transitioned to organizational decision makers and strategists. The AF built their institutional personnel model off this phenomenon. In the near future, independent decision makers will not be required to operate aircraft but to command missions. "Human commanders will need to control swarms at the mission level, giving overarching guidance, but delegating a wide range of tasks to autonomous systems. In the near term, this will entail a shift to mission-level autonomy and multi-vehicle control. In the long term, new command-and-control models are needed to allow humans to employ large swarms effectively."[5] What is most threatening is that this Army model is the future AF model.

[4] Everett C Dolman, *Astropolitik*, 1st ed. (London: Frank Cass, 2002), 148-9.
[5] Paul Scharre, *Robotics On The Battlefield Part II The Coming Swarm* (Center for a New American Security, 2014), https://s3.amazonaws.com/files.cnas.org/documents/CNAS_TheComingSwarm_Scharre.pdf, 35.

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Appendix – Interviews Conducted

1. Jason Green, Lt Col, USAF Director of Operations, 558 FTS
2. Jeff Wiseman, Lt Col, USAF (ret.), AETC/A3FR
3. Peter LeHew, Lt Col, USAF (ret.), DARPA Adaptive Execution Office Systems Engineering and Technical Assistance Manager
4. Marshall Frith, DARPA PCAS Systems Engineering and Technical Assistance Manager
5. Bill Coleman, 2-13th Aviation Regiment Gray Eagle Program Manager
6. Mark Farrar, MSgt, USA (ret.), 2-13th Aviation Regiment Director of Training
7. Ariel Schultz, Major, USA, TRADOC UAS Capabilities Manager operations officer May, Kent A, US Army OPFD Directorate, Aviation Military Analyst
8. Leslie, Major, 49 Wg OGV
9. Derek, Major, 49th Wing Programmed Flying Training Manager
10. Justin, Major, ACC/A3MU

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The purpose of the study was to provide a review of current Army, Navy/USMC, Air Force, DARPA, OSD, NASA and industry aviation S&T plans, and to assess the use of innovative technologies that increase capabilities, overall mission effectiveness, survivability and lethality, while reducing sustainment requirements. From those reviews, the study team recommended the Army (1) conduct operational effectiveness analyses on system-of system concepts; (2) assess heavy vertical lift options; (3) revise the unmanned aerial system road map; and (4) develop manned/unmanned teaming systems.

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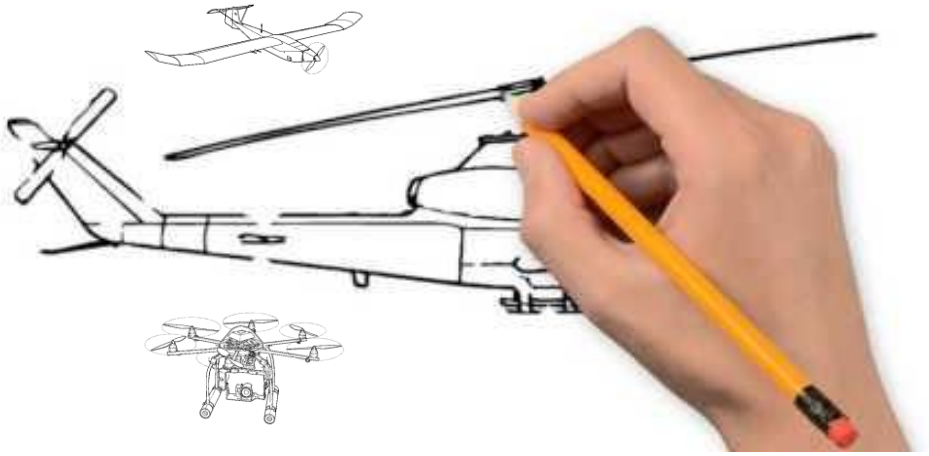
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Final Report
February 2016



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EXECUTIVE SUMMARY - THE FUTURE OF ARMY AVIATION

This study was conducted by the Army Science Board (ASB) from January 2015 – October 2015 under the sponsorship of the HQDA G-3/5/7. The reference task title for the study is "Army Science and Technology for Army Aviation 2025-2040." As stated in the Terms of Reference (TOR) signed by the Secretary of the Army, the overarching objective of the study was to identify and assess Science and Technology (S&T) enhancements capable of being fielded during the 2025 – 2040 timeframe that will:

- Increase Army Aviation's expeditionary capabilities to support full-spectrum military operations, and
- Reduce its sustainment tails and logistics footprint.

Fundamental to making any recommendations on S&T enhancements for Army Aviation in 2025-2040 is the assumption that the character of warfare is changing and that the role of Army Aviation in this future must also change. The character of warfare is clearly evolving rapidly, evidenced by significant new threats to Army Aviation and indications that they will continue to grow. These threats span the spectrum from sophisticated next-generation air defenses to capabilities that utilize widely available inexpensive assets, such as swarms of small Unmanned Aircraft Systems (UAS), which can be easily procured through commercial outlets.

The study team believes that the most promising opportunity to overcome these threats is a "system of systems" approach involving formations of manned vertical lift aircraft and unmanned aircraft systems tied together by manned-unmanned teaming (MUM-T). The technical performance required of the "aviation system" and the elements needed in these various operational scenarios must be determined. Thus, a specific starting point and our most important recommendation, is to perform operational effective analyses that will inform the details of needed technical systems that incorporate emerging technologies and quantify requirements for these systems.

The study team identified the more general technology trends and opportunities that should enable viable solution options for addressing the threat space, as well as improve safety, lethality, and survivability for the manned-platforms, while reducing life cycle cost. Viewing Army Aviation as a complex system, a "system of systems," requires enhancements and development of the various systems and components. An enhanced investment in Army Aviation Research and Development (R&D), with greater focus on evolving capabilities in several areas to include UAS and autonomy, will enable a new "Army aviation system" to be fielded in 2025-2040 and provide the S&T foundation for a rapid evolution of capability beyond 2040. We also noted that the current timelines for development and fielding of several new systems are driven more by funding availability than by technology limits. Increased focus aviation R&D will permit rapid development of truly "integrated" systems, leading to more rapid fielding of the needed formations of systems.

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The Army Science Board had previously conducted three recent studies that provided relevant background for global trends in science and technology (S&T) and that identified the opportunities and challenges that are likely to face the Army in this time period (2025-2040):

1. "The Strategic Direction for Army Science and Technology" (2012)
2. "Army Science and Technology Essential Core Competencies" (2013)
3. "Decisive Army Strategic and Expeditionary Maneuver" (2014)

The ASB has recognized that as the global rate of change of S&T continues to increase, the technical and operational challenges and opportunities for the conduct of warfare in this period should also increase.

In conducting the study, the team made more than 30 visits to Government and industry organizations and reviewed over 500 documents. Visits with Mr. John Shipley (Army Special Operations Aviation), LTG Kevin Mangum (Deputy Commanding General, TRADOC), MG Michael Lundy (Commanding General, US Army Aviation Center of Excellence) and others in the intelligence community, were particularly illuminating for the team in that they provided specific information concerning the severity and complexity of both current and recognized future threats to Army Aviation. These threats (and potential opportunities) include those from cyber, lasers, the electromagnetic spectrum, UAS swarms, and MANPADS. While the threats identified are important to Joint and coalition aviation in general, the lower-altitude environment of Army Aviation is particularly problematic for portions of the potential threat space.

The extensive input gained through all of these visits and interactions provided the study team the background to form a consensus and clear "working assumption" that the character of war is changing rapidly and the proliferation of relatively low-cost and evolving threats will only increase and become more uncertain by 2025 and beyond. Thus, the current military aviation environment and the rapid evolution of adversary options provided the study team a contextual input that went beyond technologies that may be useful in individual aviation vehicles and/or weapons systems.

The study team found that the Future Vertical Lift (FVL) family of systems represents the current planning for future of Army Aviation manned (and optionally manned) vertical lift systems. FVL is currently an initiative within the Army Aviation S&T portfolio and is not expected to become a Program of Record (POR) until after the current Program Objective Memorandum (POM). It was noted that the cost of the heavy lift option may preclude it from being a viable option. The team found that several significant technology initiatives within the Army Aviation S&T portfolio apply to both legacy and future manned systems. These technologies include ITEP/FATE engine insertion, DVE capabilities, CBM/PHM capabilities, ASE improvements, and greater MUM-T. Current Army Aviation UAS assets consist of the Raven, Puma, Shadow, and Gray Eagle systems. These systems are all fixed-wing, have limited autonomy and limited MUM-T capability, and are essentially dedicated to one or two mission areas.

The study team organized the findings and recommendations of the study into three categories/recommendation sections:

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- Context: Character of Warfare in 2025 and Role of Army Aviation
- Addressing Capability Gaps: Development and Acquisition
- S&T Portfolio: Innovation and Game Changers

As stated earlier, the most important recommendation is to perform operational effective analyses that will inform the details of needed technical systems that incorporate emerging technologies and quantify requirements for these systems. Following from this recommendation, the study team suggests that the envisioned aviation fighting "system" would generally have more than one vehicle/system participating, and has used the phrase "system of systems" to describe the approach. Also in the first category/recommendation section, the study team recommended that, if heavy lift is determined to be cost-prohibitive, it should not be assumed to be available in analyses, wargames, and exercises.

The future Army Aviation capability must include an expanded use of UAS assets that are, in most cases, viewed as "complements" and "extensions" to manned aviation. Enablers for near-term options would require work in UASs, mission systems, aviation systems integration, and the development of testbeds to develop and validate technical and operational concepts. The study team also recognized the importance of cost and speed in the introduction, acquisition and operation of more capable future Army Aviation "systems." Following from these general observations, in the second category/recommendation section, the study team found that the capability gaps to enable viable options in the 2025-2040 time period would very likely need increased emphasis in the following areas:

- Unmanned Aircraft System (UAS) Vehicles
- Modernization of Legacy Rotorcraft Systems
- Future Vertical Lift (FVL) Acquisition with Speed and Simplicity
- Aviation Mission Systems
- Aviation Systems Integration and Testbed

The need for a strong aviation S&T portfolio to enable new options in this rapidly changing 21st century environment is also needed. In the third category/recommendation section, the study team found that due to the dynamic nature of the global technology environment, there exists a needed for increased emphasis in the following areas:

- Advanced and Disruptive Systems S&T
- S&T Investment Strategy

A summary of the key recommendations for each of the three categories/recommendation sections follows. Note that these recommendations are not in priority order but rather in hierarchical order beginning with system of system recommendations, followed by technology building blocks, and then by preparing to address emerging technology through S&T investment. The team believes that all nine recommendations are essential to the future of Army aviation. The first recommendation, to perform system of systems operational analyses must be acted on first because it will provide details to define the remaining recommendations. It is anticipated

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that the analyses will indicate that some areas require more improvement than others and hence are more urgent and require great investment. For example, UAS development will most likely require greater investment. The emphasis on early integration of these building block areas is also essential for the "Future Army Aviation system of systems" to be optimized and effective in the field.

Recommendations for Context: Character of Warfare in 2025 and Role of Army Aviation

1. System of Systems Operational Effectiveness Analyses: The ASB recommends that TRADOC conduct operational effectiveness analyses of potential system of systems concepts in a cost-constrained environment that address capability gaps for Army Aviation in 2025 and beyond in complex threat environments. Concepts should include holistic air-ground approaches, high/low mixes of collaborative manned/unmanned systems, FVL performance characteristics, higher levels of autonomy, PNT in denied GPS environments, attritable UAS assets, and enhanced lethality of DE weapons. These analyses must include the development of CONOPS and architectures for the most cost-effective concepts. As mentioned before, this is the most important recommendation. Army aviation must move away from the platform-centric approach currently employed to that of a system of systems. The significant advantages to Army Aviation of such an approach for survivability and lethality with its corresponding great potential cost advantages must be embraced moving forward. The results of these systems of systems operational effectiveness analyses are critical in guiding the path forward for Recommendations 3 – 6.

2. Affordability of Heavy Vertical Lift: The ASB recommends that TRADOC assess interim and future heavy vertical lift options for meeting Army CONOPS and documented JCIDS capability needs for expeditionary and operational maneuver and recommend the road ahead. If the development of heavy vertical lift capabilities proves to be cost-prohibitive, alternatives must be considered (e.g., CH-53K at 18 stons, and Joint Precision Air Drop System – JPADS). If there are no plans for HVL, do not assume it is available in analyses, wargames, and exercises.

Recommendations for Addressing Capability Gaps: Development and Acquisitions

3. UAS Vehicles: The ASB recommends that ASA(ALT) revise UAS Roadmap to expand both near-term and future UAS vehicle options, some of which should be compatible with speed, hover, and range of current and future manned aircraft, with attributes compatible with distributed functionality among UAS (ISR, lethality, …) as informed by the results of system of systems operational effectiveness analyses (Recommendation 1). It should be noted that both the Navy and Air Force have much more mature visions for UAS than the Army.

4. Modernization of Legacy Rotorcraft Systems: The ASB recommends that ASA(ALT) continue S&T and road-mapping efforts for modernizing legacy systems with emphasis on those technologies that are also applicable to future vehicles (e.g., ITEP/FATE engines, DVE capabilities, and greater MUM-T) as informed by the results of system of systems operational effectiveness analyses (Recommendation 1).

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5. Future Vertical Lift Acquisition with Speed and Simplicity: The ASB recommends that ASA(ALT) develop an evolutionary acquisition approach for FVL to allow for earliest possible fielding consistent with funding constraints, as informed by the results of system of systems operational effectiveness analyses (Recommendation 1). The JMR-TD vehicles are close in size and aerodynamic performance capability to the FVL medium class system and industry's substantial investment should be leveraged to get the next-generation rotorcraft in service as soon as possible. It is key that requirements creep be kept to a minimum using successful acquisition examples such as the F-16 program as a guide, i.e., keep the initial designs simple but incorporate modularity for future updates.

6. Aviation Mission Systems: The ASB recommends that AMRDEC/ADD expand mission system technology development, currently focused on DVE, to enable advanced formation concepts in future manned and unmanned platforms, and legacy platforms as appropriate, as informed by the results of system of systems operational effectiveness analyses (Recommendation 1). Needs include additional advanced mission systems (e.g., offensive and defensive DE capabilities) and open systems architectures.

7. Aviation Systems Integration and Testbed: The ASB recommends that RDECOM build the components of an integrated "survivable" system (MUM-T, attritable assets, secure comms, PNT, open operating systems, autonomy, high/low mix, distributed functions across future "formations"). The ASB also recommends that RDECOM, building on Recommendation 1 with relevant content from Recommendations 2-6, develop an aviation integration testbed for experimentation and validation of technology, prototypes, and concepts. Potentially include demonstration (such as JMR-TD), prototype, surrogate, and operational systems.

Recommendations for S&T Portfolio: Innovation and Game Changers

8. Advanced and Disruptive Systems S&T: The ASB recommends that RDECOM, in order to address expanding complex threats and opportunities, develop advanced technologies for an integrated/holistic, manned/unmanned architecture/system to ensure survivability and mission success. The ASB also recommends that ASA(ALT) include in the Army's S&T portfolio leap-ahead technologies (e.g., counter-DE, counter-UAS, advanced materials).

9. S&T Investment Strategy: The ASB recommends that AMRDEC/ADD continue active participation in VAATE and RAMPED engine development. The ASB further recommends that RDECOM explore innovative mechanisms for external collaboration (university, industry, etc.), such as grand challenges (similar to the DARPA construct). Lastly the ASB recommends that ASA(ALT), after exploring leveraging opportunities with other R&D activities, advocate more funding for Aviation S&T.

Summary

In order to overcome the complex threats that Army aviation will face in the future, it is essential to adopt a system of systems approach. As noted above, the team's recommendation to perform

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"System of Systems Operational Effectiveness Analyses" is the most critical of all the recommendations because it informs the remaining recommendations. Recognizing that the technical and operational details will follow from these analyses, the ASB strongly recommends that Army Aviation move away from the current platform-centric approach to focus on the systems of systems approach. Due to the distributed nature of systems of systems approaches, there are compelling advantages to Army Aviation for flexibility, safety, survivability and lethality with significant potential cost advantages.

A complete list of the ASB findings and recommendations is provided in the following table. As already pointed out, all nine recommendations are essential to the future of Army aviation. The first recommendation, to perform system of systems operational analyses must be acted on first because it will provide details to inform the remaining recommendations

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Topic	Findings	Recommendations
Context: Character of War in 2025 and Role of Army Aviation		
1. System of Systems Operational Effectiveness Analyses	Increasing threat sophistication and proliferation (e.g., missiles, UAS, cyber, and directed energy) pose critical concerns. (Classified annex provides additional details) Platform-centric survivability must evolve to a manned-unmanned system-centric approach with new CONOPS and TTPs. A system of systems architecture should include manned-unmanned teaming, supervised autonomous systems, and secure communications.	**TRADOC:** Conduct operational effectiveness analyses of potential system of systems concepts in a cost-constrained environment that address capability gaps for Army aviation in 2025 and beyond in complex threat environments. Concepts should include holistic air-ground approaches, high/low mixes of collaborative manned/ unmanned systems, FVL performance characteristics, higher levels of autonomy, PNT in denied GPS environments, attritable UAS assets and enhanced lethality of DE. Develop CONOPS and architectures for the most cost effective concepts.
2. Affordability of Heavy Vertical Lift	Heavy vertical lift (20-30 stons) is required by the Army CONOPS for expeditionary and operational maneuver, validated by JROC (documented in the FVL and JHL ICDs) and supported by Unified Quest 2014, and "2012 Gaining and Maintaining Access: An Army-Marine Corps Concept." However, development of a new system is cost prohibitive within likely future Army modernization (RDA) funding before 2040. Interim solutions able to provide more limited capability are available (e.g., CH-53K at 18 stons, and Joint Precision Air Drop System – JPADS) and could provide viable options.	**TRADOC:** Assess interim and future HVL options for meeting Army CONOPS and documented JCIDS capability needs for expeditionary and operational maneuver and recommend road ahead • If development of HVL is cost prohibitive, consider alternatives. • If there are no plans for HVL, do not assume it is available in analyses, wargames, and exercises.
Addressing Capability Gaps: Development and Acquisition		
3. UAS Vehicles	The USN/USMC and USAF have strong visions for the expanding role of UAS and manned-unmanned teaming in aviation missions. DARPA, USN/USMC and USAF are investing in next generation UAS technology options that offer potential capability for Army aviation. New UAS are needed to fully exploit manned–unmanned synergy and collaboration of manned systems with supervised autonomous systems within a system-of-systems architecture.	**ASA(ALT):** Revise UAS Roadmap to expand near-term and future UAS vehicle options, some of which should be compatible with speed, hover, and range of current and future manned aircraft, with attributes compatible with distributed functionality among UAS (ISR, Lethality, …) as informed by the results of system of systems operational effectiveness analyses (Recommendation 1)
4. Modernization of Legacy Rotorcraft Systems	Legacy rotorcraft systems (AH-64, CH-47 and UH-60) are expected to remain deployed until at least 2060, requiring modernization investment. Within the current limited budget, Army aviation S&T is investing in technologies that apply to both legacy and future manned systems. These technologies include: ITEP/FATE engine insertion, DVE capabilities, CBM/PHM capabilities, ASE improvements, and greater MUM-T.	**ASA(ALT):** Continue S&T and road-mapping efforts for modernizing legacy systems with emphasis on those technologies that are also applicable to future vehicles, as informed by the results of system of systems operational effectiveness analysis (Recommendation 1).
5. FVL Acquisition with Speed and Simplicity	JMR-TD and FVL provide focus for Army Aviation S&T for next generation rotorcraft systems and provide a solid basis for much needed capability improvements (Ref. FVL ICD); however, there is no funding for FVL in the POM. The JMR-TD vehicles are close in size and aerodynamic performance capability to the FVL medium class system. The current FVL schedule leads to an IOC of the first system in the mid 2030s. It should be beneficial to accelerate this timeline through an evolutionary acquisition approach if funding allows. The JMR-TD, DARPA X planes, USN/USMC prototyping efforts, and industry investment support talent development and retention in rotorcraft government and industry teams.	**ASA(ALT):** Develop an evolutionary acquisition approach for FVL to allow for earliest possible fielding consistent with funding constraints, as informed by the results of system of systems operational effectiveness analyses (Recommendation 1).

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Topic	Findings	Recommendations
6. Aviation Mission Systems	Army S&T mission system programs include Lethality, Survivability, Teaming & Autonomy, Human-System Interface, Avionics, and Networks. RDECOM DVE goals are appropriate and feasible - Progress at AMRDEC, CERDEC, and ARL in sensors, flight control, cueing, computing, and networking. Reduced pilot workload arising from DVE technologies should increase operational mission capacity (e.g., formations with UAS). Advanced sensors (e.g., IR, visible, and hyperspectral) are being developed. Additional advanced mission systems (e.g., offensive and defensive directed energy) and open system architectures are needed. DoD provides singular modeling and wind tunnel capabilities (NASA Ames)	**AMRDEC/ADD:** Expand mission system technology development, currently focused on DVE, to enable advanced formation concepts in future manned and unmanned platforms, and legacy platforms as appropriate, as informed by the results of system of systems operational effectiveness analyses (Recommendation 1)
7. Aviation Systems Integration and Testbed	Concepts developed in Recommendation 1 and new technical capabilities referenced in Sections 2-6 (individually and as integrated systems) will require extensive testing. Some initial work is found in CERDEC I2WD open systems efforts and DARPA's System of Systems Integration, Technology and Experimentation (SoSITE). Fully integrated joint vision for aviation in DoD is not evident. Coalition environment should be considered.	**RDECOM:** Build the components of an integrated "survivable" system (MUM-T, attritable assets, secure comm, PNT, open operating systems, autonomy, high/low mix, distributed functions across future "formations"). **RDECOM:** Building on Recommendation 1 and Sections 2-6, develop an aviation integration testbed for experimentation and validation of technology, prototypes, and concepts. Potentially include demonstration (such as JMR TD), prototype, surrogate, and operational systems.
S&T Portfolio: Innovation and Game Changers		
8. Advanced and Disruptive Systems S&T	Army aviation is at a crossroad of challenge and opportunity. • The challenge: threat sophistication will demand a transformation in the nature of warfare in 2025 and beyond (missiles, UAS, DE, Cyber). • The opportunity: technology is emerging that enables significant improvement in aviation capabilities. Advanced technology solutions are required, including: UAS, autonomy, manned-unmanned collaboration, communications, directed energy, sensors, condition-based and near-zero maintenance technology/concepts, and other discoveries from the S&T enterprise. There is relevant work in other Services, DARPA, and NASA that should be leveraged.	**RDECOM:** To address expanding complex threats and opportunities develop advanced technologies for an integrated/holistic, manned/unmanned architecture/system to ensure survivability and mission success. **ASA(ALT):** Include in S&T portfolio leap-ahead technologies (counter-DE, counter-UAS, advanced materials)
9. S&T Investment Strategy	Based on findings in Sections 1-8, the capabilities of Army Aviation S&T must evolve rapidly (e.g., need to expand UAS and autonomy activity); thus the level of S&T activity must expand beyond the manned aviation S&T portfolio, which is currently well managed. Army S&T investment has led to successful ITEP and FATE engine developments; the transition of these S&T efforts to PORs is essential to both FVL and modernized legacy platforms. Current S&T investment is insufficient to achieve the needed transformation and to maintain overmatch in 2025 and beyond.	**AMRDEC/ADD:** Continue active participation in VAATE and RAMPED engine development. **RDECOM:** Explore innovative mechanisms for external collaboration (university, industry, etc.), such as grand challenges (similar to DARPA construct). **ASA(ALT):** After exploring leveraging opportunities with other R&D activities, advocate more funding for Aviation S&T.

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1 INTRODUCTION

In January 2015, the Secretary of the Army requested the Army Science Board to conduct a comprehensive study of Army Aviation focused on science and technology important to the continuing development of advanced capabilities for Army Aviation assets. The G3/5/7 was identified as the study sponsor. As stated in the Terms of Reference (TOR) for the study, provided in Appendix A, the study objective was "to identify and assess Science and Technology (S&T) enhancements capable of being fielded during the 2025-2040 timeframe that will increase Army Aviation's expeditionary capabilities to support full-spectrum military operations and reduce its sustainment tails and logistics footprint."

The TOR specified three tasks for the study team:

1. Review current Army, Navy/USMC, Air Force, DARPA, OSD, NASA and industry aviation S&T plans, modernization plans and ongoing developments, as well as relevant Force 2025 and Beyond Campaign activities.
2. Address the use of innovative technologies that increase capabilities, overall mission effectiveness, survivability and lethality while reducing sustainment requirements, including logistics footprint and frequency of resupply. Include, but not necessarily be limited to, the following key focus areas for improvement:
    a. Near-zero maintenance platforms and systems,
    b. Exploitation of unmanned aircraft systems,
    c. Meeting the challenges of emerging threats, and
    d. Enhancing the ability to operate worldwide in a variety of stressing and degraded visual conditions.
3. Determine the feasibility and risks associated with each of the findings and recommendations.

This ASB report describes the conduct of the study; discusses Army Aviation challenges, needs, and opportunities; reviews ongoing aviation S&T activities in numerous areas; and provides numerous findings and recommendations important to enhancing future Army Aviation capabilities. A comprehensive briefing describing the study in detail was completed and approved by a vote of all members of the ASB in July 2015. A summary briefing of study findings and recommendations was presented to the Secretary of the Army, the Chief of Staff of the Army, and other senior Army officials in October 2015.

1.1 Study Team, Visits, and Literature Survey

The study team established to address these tasks, identified in Appendix B, included ASB members with significant technical expertise and experience in a wide range of disciplines:

- Physics
- Materials science
- Energy
- Fluid dynamics
- Technology transition
- Signal processing
- Robotics
- Electronics

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- Aerospace engineering
- Electrical engineering
- Mechanical engineering
- Nuclear engineering
- Strategic planning
- Systems engineering and integration
- R&D management
- Directed energy weapons
- Command and control
- Optical communications
- Armor/anti-armor technology
- Helicopter systems
- Weapons systems
- Military aviation operations

To obtain the comprehensive and detailed information required to address the specified tasks, members of the study team made over 30 visits to Army and other organizations actively involved in the development of advanced capabilities pertinent to Army Aviation. These organizations are listed below:

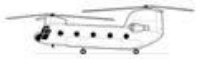
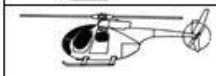
- Army
  - Aviation and Missile Research Development and Engineering Center (AMRDEC)
    - Aviation Development Directorate (ADD)
    - Weapons Development and Integration Directorate (WDI)
  - PEO Aviation and Program Managers (AS, CH, UH, AAH, ASH, NSRWA, FW, UAS)
  - US Army Aviation Center of Excellence (USAACE)
  - US Army Aeromedical Research Laboratory (USAARL)
  - Combat Readiness/Safety Center
  - TRADOC Capability Managers (UAS, Lift)
  - Communications Electronics Research Development and Engineering Center (CERDEC)
    - Night Vision & Electronic Sensors Directorate (NVESD)
    - Intelligence and Information Warfare Directorate (I2WD)
  - Army Research Laboratory (ARL)
  - Army Special Operations Aviation (ARSOA)
  - Operational Support Airlift Agency (OSAA)
  - Vertical Lift Research Center of Excellence (Georgia Tech)
- Other Services
  - Navy – Naval Air Systems Command (NAVAIR)
  - Air Force – Air Force Research Laboratory (AFRL)
- Joint/DoD
  - Future Vertical Lift IPTs
  - Defense Advanced Research Projects Agency (DARPA)
- Other
  - NASA Headquarters
  - NASA Langley Research Center
  - NASA Ames Research Center
  - Army Aviation Association of America (Quad-A)
  - Vertical Lift Consortium
  - Industry organizations

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Lines of inquiry associated with these visits are summarized in Appendix C. Information and observations responsive to Task 1 are provided in Appendices D, E, F, G, H, and I. Study findings, observations, and recommendations associated with Tasks 2 and 3 are presented in Sections 3 and 4 below. Appendix J provides the final briefing presented in July 2015. Appendix K provides a list of acronyms and abbreviations used in this report. Numerous documents collected and reviewed in conducting the study are cited in the Bibliography in Appendix L.

1.2 Current Army Aviation Platforms

The Army currently employs the six rotary wing aircraft, as described in Figure 1-1. The Little Bird (also called the "Killer Egg") is used only by SOCOM. The Kiowa observation helicopter is being retired. The Lakota is only approved for use in CONUS, where it is used as a trainer. The remaining three aircraft, the Chinook, Black Hawk, and Apache, form the core of Army Aviation. Note that these platforms were designed more than 30 years ago and are expected to remain in the fleet through 2060.

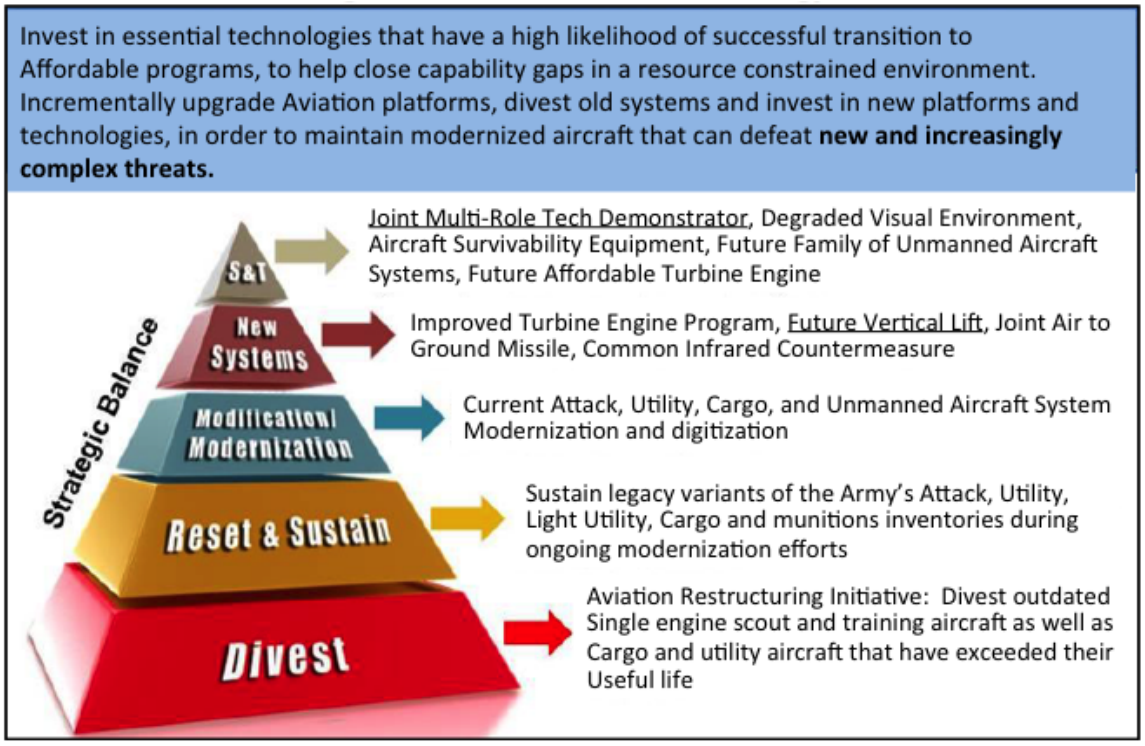
Army Legacy Rotorcraft	Name / Designator	Role	IOC/ Retire?	Status	Max Takeoff	Max Load	Cruise Speed/ Range	Developer (inventory)
	Chinook CH-47D/F	Cargo	1962 / 2060	Block II available in 2020	50,000 lb	28,000 lb	130 kt / 400 nm	Boeing (503)
	Black Hawk UH-60	Utility	1979 / 2060	Upgrades + ARI transfer*	23,500 lb	2,640 lb int, 9,000 lb ext	159 kt / 640 nm	Sikorsky (1,565)
	Apache AH-64	Attack	1986 / 2060	Upgrades + ARI transfer*	23,000 lb		143 kt / 257 nm	Boeing (756)
	Lakota UH-72	Trainer, CONUS only	2007 / ???	ARI use for training	7,900 lb	3,950 lb	133 kt / 370 nm	Eurocopter (307)
	Kiowa OH-58D	Observa-tion	1969 / soon	ARI retire*	5,500 lb	1,700 lb	110 kt / 140 nm	Bell (618)
	Little Bird A/MH-6	SOF	1980 / ???		3,100 lb	1,500 lb (6 pax)	135 kt / 232 nm	McDonnell Douglas / Boeing (47)

* ARI – Aviation Restructuring Initiative

Figure 1-1 Army Legacy Rotorcraft

Figure 1-2 illustrates the Army Aviation Modernization Strategy. S&T efforts sit at the top of the pyramid; they include the Joint Multi-Role Technology Demonstration (JMR-TD) and Degraded Visual Environment (DVE) activities, which are the largest Army Aviation S&T efforts. As Army Aviation S&T efforts mature over time, emerging advances are incorporated into new systems, such as JMR-TD technologies that will inform the Future Vertical Lift (FVL) program. Other new systems, such as the Improved Turbine Engine Program (ITEP) engines, are part of the modernization of select legacy systems. Still other emerging technologies support sustainment of legacy systems. Finally, at the base of the pyramid outdated systems are divested.

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Source: Army Equipment Modernization Strategy, March 2015 (Annex E – Aviation) - G8

Figure 1-2. Army Aviation Modernization Strategy

The Aviation Restructuring Initiative (ARI) is a five-year plan to reduce Army Aviation costs while addressing fleet obsolescence and sustainment issues. It was approved by the CSA in December 2013, with the first execution order issued in April 2014. The ARI calls for the Army to:

- Cut three of the 13 active-duty combat aviation brigades; Army Reserve component would retain 12 aviation brigades – 10 in the National Guard and two in the Army Reserve.
- Retire OH-58 Kiowa Warriors and TH-67 trainers (both single-engine aircraft).
- Use Apache to fill Kiowa's reconnaissance and scout role.
- Replace TH-67 training helicopters with dual-engine LUH-72 Lakotas.
- Move Apaches from the Guard to active Army and, in turn, provide the Guard with UH-60 Black Hawks. This plan has been controversial for the Guard.
- Have 20 Apache battalions in active components.

The National Guard has proposed retaining more crews and units, but some units would only be partially equipped. Cost Assessment and Program Evaluation (CAPE) analysis indicates that the Army plan is not sized for prolonged stability operations. The National Guard alternative costs $89M to $176M annually plus a one-time cost difference of approximately $500M. Congress postponed the transfer of Apaches until FY2016 and established a National Commission on the Future of the US Army that will conduct two studies: (1) the structure of the Army and policy

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assumptions related to the size and force mixture of the Army, and (2) transfer of Apaches from the Guard to the active Army. The ARI will not be discussed further in this report.

The Army also has a fleet of over 339 fixed wing aircraft, all commercial derivative aircraft. The fleet includes three categories of aircraft:

- Special Electronic Mission Aircraft (SEMA):
  - EO-5 Dash 7, RC-12 Huron (Guardrail), B-300 Beechcraft
- Transport Aircraft:
  - Warfighting Combatant Commanders: C-12 Beechcraft, C-26 Metroliner, UC-35 Cessna
  - Executive Transport: C-20 Gulfstream, C-37 Gulfstream
- Mission Support Aircraft:
  - RDT&E: C-208, T-34
  - USMA Flight Laboratory: CE-182
  - Golden Knights Parachute Team: UV-18 Twin Otter, C-31

In addition to its rotary wing and fixed wing aircraft, Army Aviation also employs four unmanned aircraft systems (UAS), described in Figure 1-3. Raven and Puma are both small hand-launched UAS used for ISR missions. The Shadow is a larger UAS, also used for ISR missions. Gray Eagle is a much larger UAS that can carry Hellfire missiles as well as an ISR pod. Only Shadow and Gray Eagle can be controlled by manned aircraft (Apache AH-64E) in Manned-Unmanned Teaming (MUM-T) operations.

Legacy Army UAS	Name / Designator	Role	IOC	Payload	Max Takeoff	Cruise Speed/ Endurance	Developer (# built)
	Raven RQ-11A/B	Small UAV, Hand launch	1999	ISR	4 lb	30 kt / 1-1.5 hrs	AeroVironment (19,000+)
	Puma RQ-20A		2007	ISR	13.5 lb	45 kt max / 2 hrs	AeroVironment (1,000+)
	Shadow RQ-7A/B	Short Range Tactical	2002	ISR	375 lb	70 kt / 9 hrs	AAI Corp (~500+)
	Gray Eagle MQ-1C	Predator Upgrade	2009	ISR pod / Hellfire	3,600 lb	150 kt max/ 30 hrs	General Atomics (~100)

Figure 1-3. Army Legacy Unmanned Aircraft Systems

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2 ARMY AVIATION CHALLENGES, CAPABILITY NEEDS AND SYSTEM CONCEPTS

2.1 Challenges Facing Army Aviation

Army Aviation is facing multiple challenges that require new ways of thinking regarding the character of Joint warfare in 2025 and beyond, as well as how Army Aviation should be employed to be most effective in the integrated Joint battlespace of the future.

2.1.1 Survivability

Among the most pressing of these challenges is the growth and proliferation of advanced threats that place Army Aviation assets at high risk. The Capstone Concept for Joint Operations: Joint Force 2020[1] highlights the issue of the proliferation of sophisticated threats and the need for new Concepts of Operation (CONOPS) for countering the threats and maintaining overmatch:

> "Our nation and Armed Forces are transitioning from a decade of war to a future that presents us with a security paradox. While the world is trending toward greater stability overall, ***destructive technologies are available to a wider and more disparate range of adversaries***. As a result, the world is potentially more dangerous than ever before. ***New concepts of operation are needed*** to address the security paradox we face."
>
> "The diffusion of advanced technology in the global economy means that middleweight militaries and non-state actors can now muster weaponry once available only to superpowers. The ***proliferation*** of cyber and space weapons, precision munitions, ballistic missiles, and anti-access and area denial capabilities ***will grant more adversaries the ability to inflict devastating losses***. These threats place our access to the global commons at risk, target our forces as they deploy to the operational area, and can even threaten forces at their points of origin. Meanwhile, adversaries continue to explore asymmetric ways to employ both crude and advanced technology to exploit U.S. vulnerabilities. Consequently, the capability advantage that U.S. forces have had over many potential adversaries may narrow in the future. Adversaries will not only have more advanced capabilities in every domain. More of them will have the ability to simultaneously fight across multiple domains."

Figure 2-1 illustrates some of the threats facing Army Aviation today and in future conflicts. These threats span the spectrum from sophisticated next-generation air defenses to capabilities that utilize widely available inexpensive assets, such as swarms of small Unmanned Aircraft Systems (UAS), which can be easily procured through commercial outlets. Currently, the most worrisome threat is posed by man-portable air defense systems (MANPADS) such as the systems shown in Figure 2-2. Some of these threats are discussed in a classified annex to this report.

[1] Joint Chiefs of Staff, *Capstone Concept for Joint Operations: Joint Force 2020*, Washington, DC, 10 Sept 2012, http://www.defenseinnovationmarketplace.mil/resources/JV2020_Capstone.pdf.

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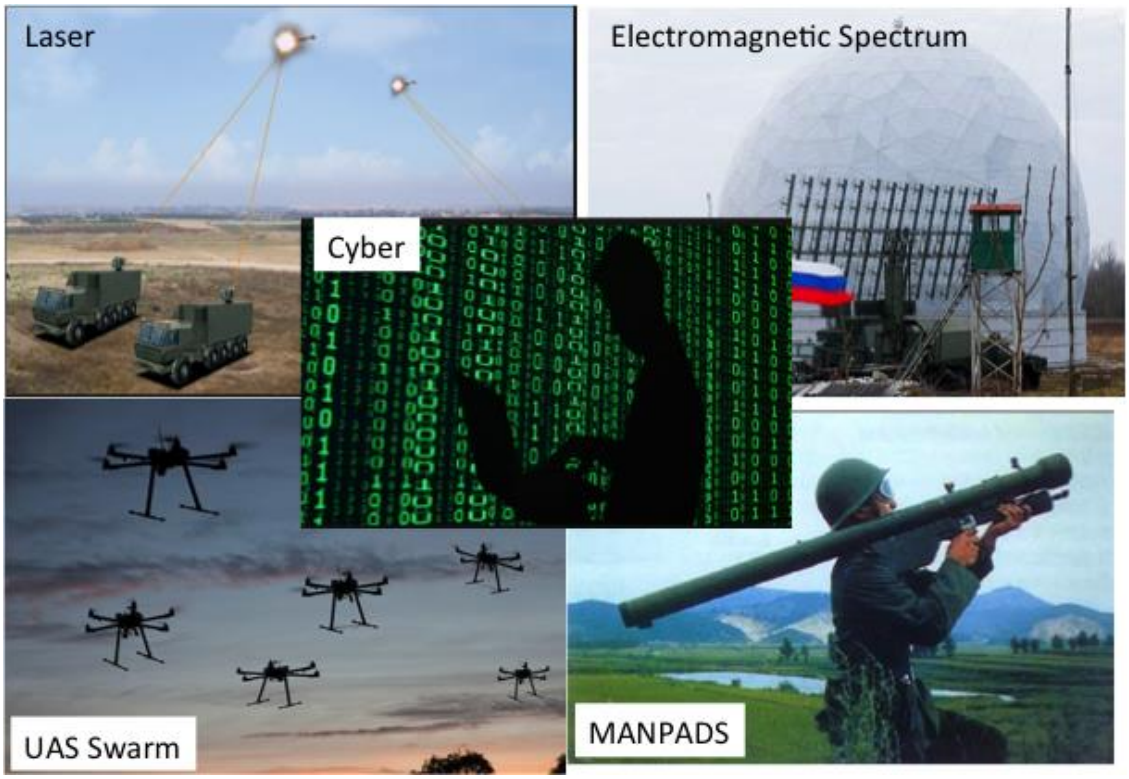


Figure 2-1. Complex Threats and Opportunities

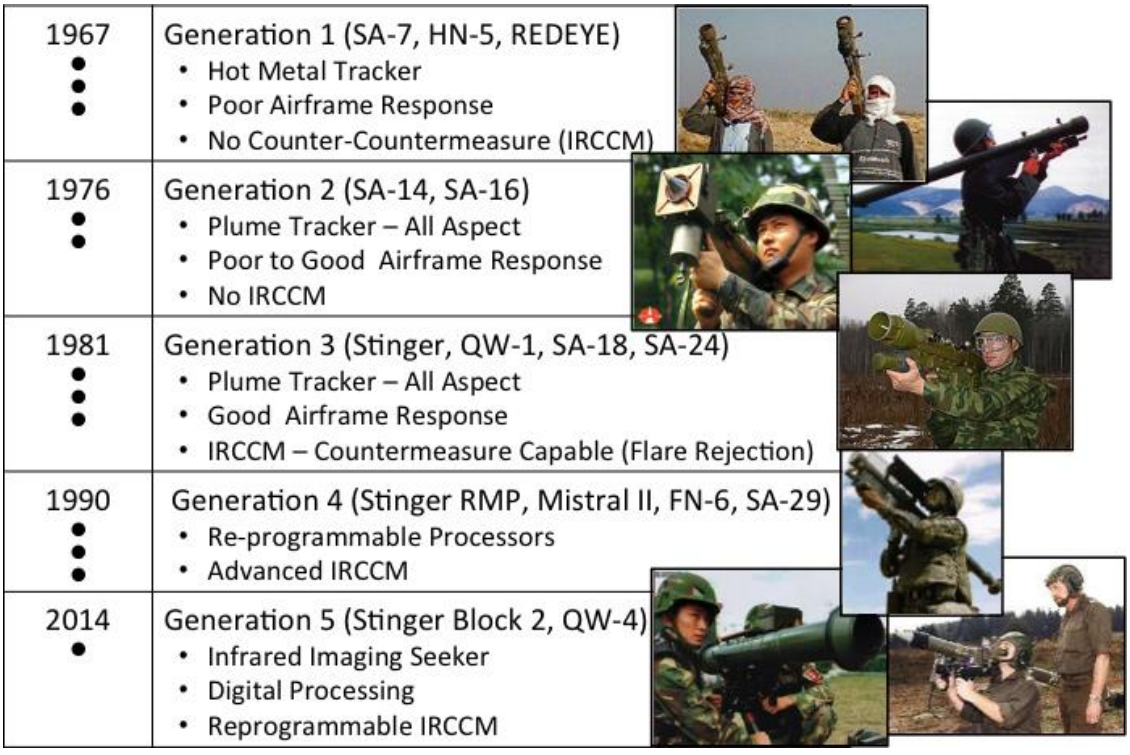


Figure 2-2. Generations of IR MANPADS

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2.1.2 Vertical Lift for Expeditionary and Operational Maneuver

A second pressing challenge is the inability of current Army Aviation systems to satisfy the need for strategic, expeditionary, and operational maneuver of dispersed mechanized forces in austere areas of operation in the face of capable anti-access and area denial (A2/AD) threats in future conflicts. The recently released Army Operating Concept[2] highlights the need for operational maneuver and sustainment to point-of-need for dispersed forces:

- Respond Globally: "When called upon, globally responsive combined arms teams ***maneuver from multiple locations*** and domains to present multiple dilemmas to the enemy,..."
- Conduct Joint Combined Arms Operations: "Joint combined arms operations create multiple dilemmas for the enemy. Army forces ***achieve surprise*** through ***maneuver across strategic distances,*** and arrival at unexpected locations. Army forces have the mobility, protection, and firepower necessary to strike the enemy from unexpected directions. In high ***anti-access and area denial*** environments, ***dispersion*** allows future army forces to evade enemy attacks, deceive the enemy, and achieve surprise."
- Sustain High Tempo Operations: "Army sustainment units integrate efforts with the Joint Force to ensure unimpeded sustainment flows across the land, air, and maritime domains. These units provide supplies and services to the ***point of need..***."

The burden on Army vertical lift assets for providing supplies on the battlefield was increased as a consequence of the decision to retire the C-23 Sherpa cargo plane and transfer the fixed-wing supply mission to the Air Force. Army commanders who need small quantities of supplies must either wait until there is an available, scheduled AF C-130 or send a rotary wing vehicle to transport the material. This has led to increased workloads (and hence increased maintenance) for rotary wing aircraft.

Current Army Aviation assets cannot provide the heavy vertical lift (20-30 stons; see section 2.2) needed for expeditionary and operational maneuver of ***mechanized*** dispersed forces. This need was detailed in the 2014 Army Unified Quest exercises,[3] the 2014 ASB study on Strategic and Expeditionary Maneuver,[4] and the 2012 Army-Marine Corp Concept:[5]

- ***Unified Quest 2014***: "Self-deployable Army future vertical lift capabilities and joint shallow draft systems must be capability development options. These efforts are essential to future strategic, operational, and tactical maneuver and enable dispersed forces to maintain mutually supporting functions."

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[2] TRADOC Pamphlet 525-3-1, "*The U.S. Army Operating Concept: Win in a Complex World*, 2020-2040," 31 October 2014, http://www.tradoc.army.mil/tpubs/pams/tp525-3-1.pdf.

[3] Army Capabilities Integration Center, *Unified Quest 2014 Executive Report,* 12 March 2015, http://www.arcic.army.mil/Library/documents.aspx.

[4] Army Science Board, *ASB FY2014 Summer Study - Decisive Army Strategic and Expeditionary Maneuver, July 2014*.

[5] Army Capabilities Integration Center and Marine Corps Combat Development Command, *Gaining and Maintaining Access: An Army-Marine Corps Concept*, March 2012.

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- ***2014 ASB study on Decisive Army Strategic and Expeditionary Maneuver***: "Vertical lift is an essential enabler for synchronized distributed interdependent maneuver via unpredictable entry points."
- **2012 Gaining and Maintaining Access: An Army-Marine Corps Concept**: "Vertical maneuver of *mounted* forces provides the means to rapidly gain positional advantage over the enemy creating and magnifying the effects of surprise."

The challenge for the Army is the lack of funding necessary to develop and procure a heavy vertical lift system to satisfy these needs. Army Aviation funding is discussed in Section 2.1.5.

2.1.3 Aging Legacy Rotorcraft Systems and Future Vertical Lift

Army Aviation is continually faced with the challenge of trying to achieve an optimal balance of its R&D investments committed to modernizing/upgrading legacy rotorcraft platforms and to developing new systems that offer expanded performance capabilities and reduced sustainment compared to current systems. This balancing challenge is exasperated by the limited funding allocated to aviation efforts within the Army S&T portfolio (see section 2.1.5).

The Future Vertical Lift (FVL) Family of Systems (FoS) represents the future of Army Aviation manned (and optionally manned) rotorcraft systems. FVL is currently an initiative within the Army Aviation S&T portfolio and is not expected to become a Program of Record (POR) until after the current Program Objective Memorandum (POM). Therefore, if the program were to follow normal DoD acquisition processes for an ACAT I Major Acquisition Program and the Planning, Programming, Budgeting and Execution (PPBE) processes, an Initial Operating Capability (IOC) for FVL would not be expected until the mid-2030s. Once IOC has been achieved, at historical Army Aviation procurement funding levels it will take roughly 30-40 years to replace the legacy platforms.

It is expected, therefore, that legacy rotorcraft systems (AH-64, CH-47 and UH-60), which are all 1960-1970 vintage designs, will remain deployed until at least 2060. This century-long platform life would be rivaled only by the B-52 bomber, which has been re-purposed from its original mission to extend its utility. The noted Army rotorcraft platforms have undergone several upgrades over their lifetimes. At least one more major upgrade to these systems, however, will be required beyond those currently in progress or funded within the POM for them to remain operationally effective against evolving threats, as reflected in the FVL first aircraft timeline shown in Figure 2-3. Fortunately, several significant technology initiatives within the Army Aviation S&T portfolio apply to both legacy and future manned systems. These technologies include ITEP/FATE engine insertion, DVE capabilities, CBM/PHM capabilities, ASE improvements, and greater MUM-T.

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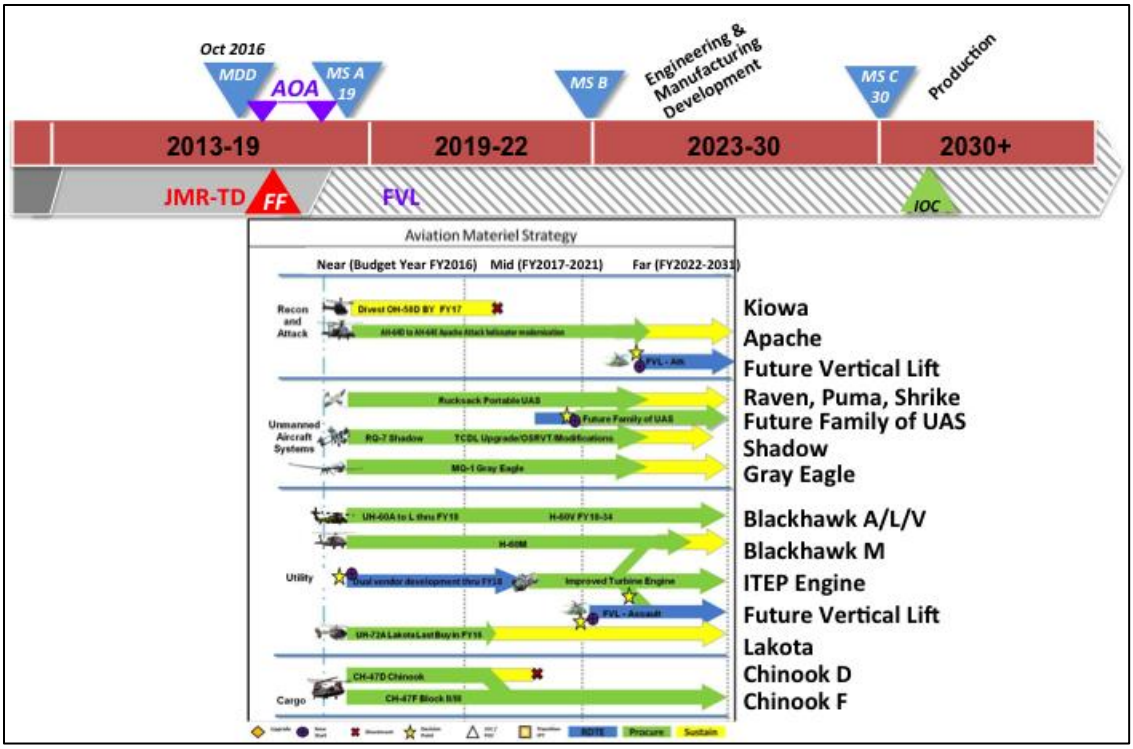


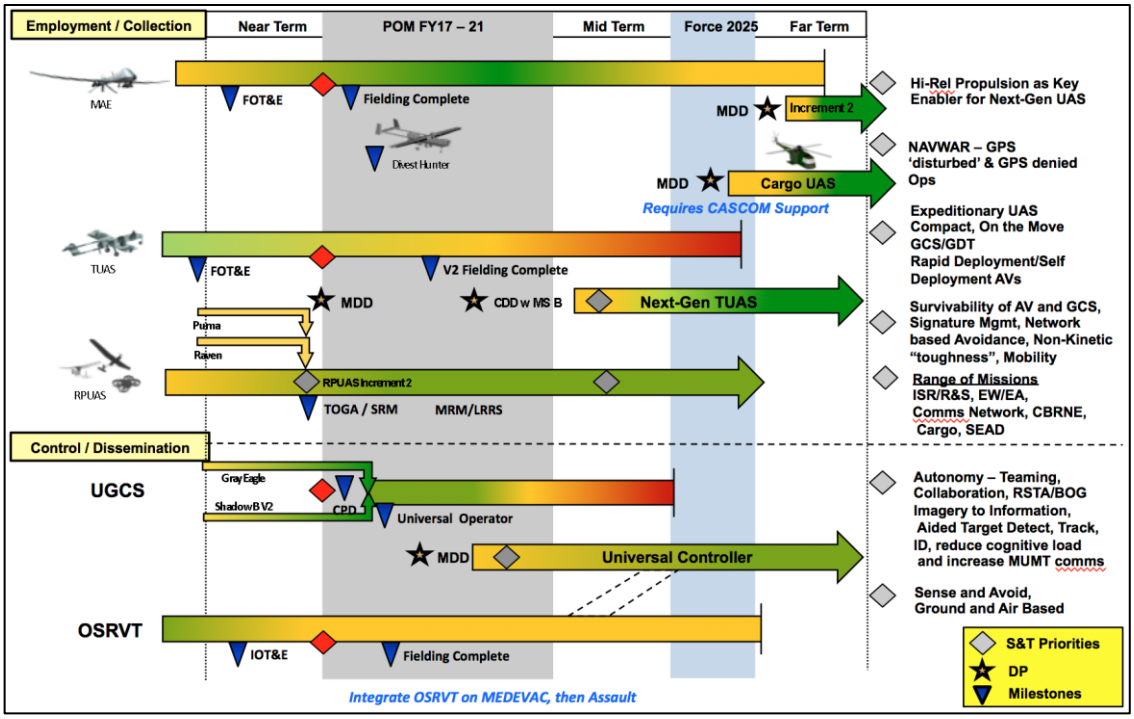
Figure 2-3. FVL – First Aircraft Timeline

2.1.4 Unmanned Aircraft Systems (UAS) and Manned-Unmanned Teaming (MUM-T)

Current Army Aviation UAS assets consist of the Raven, Puma, Shadow, and Gray Eagle systems. These systems are all fixed-wing, have limited autonomy and limited MUM-T capability, and are essentially dedicated to a single mission (ISR, although Gray Eagle can carry Hellfire missiles in addition to ISR payloads). Currently, the AH-64E has the capability to control the Shadow and Gray Eagle flight path and payload (but not takeoff or landing). Although the Army UAS Roadmap[6] cites plans to upgrade these platforms and eventually to develop replacements for some of them (see Figure 2-4), it lacks a clear vision for expanding the use of UAS as complements and extensions to manned aviation, rather than simply as ISR systems. Expanding the mission set and increasing autonomy for UAS are identified as far-term objectives in the roadmap, but very limited funding is currently allocated to achieving these objectives. Army S&T programs to advance manned-unmanned collaboration and UAS autonomy are discussed in Section 3.3.

[6] US Army UAS Center of Excellence, "*Eyes of the Army," U.S. Army Unmanned Aircraft Systems Roadmap 2010-2035*, 2010, http://www-rucker.army.mil/usaace/uas/us%20army%20uas%20roadmap%202010%202035.pdf .

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Source: UAS S&T Priorities Briefing by PM-UAS 30 Mar 2015

Figure 2-4. UAS S&T Priorities

In contrast to the Army Aviation UAS roadmap, the USAF and USN/USMC have bold visions for expanded roles/missions for UAS and greater use of collaborative MUM-T, as reflected in Figure 2-5. In the center of the USN "Sea Based Aviation" document cover page are three UAS systems: the Unmanned Carrier Launch Airborne Surveillance and Strike System (UCLASS) in the middle, the MQ-8 Fire Scout unmanned helicopter to the left of UCLASS and the RQ-21 version of the Scan Eagle UAS to the right. The UCLASS is intended to perform deep strike missions currently conducted by manned fighter/attack aircraft. The Secretary of the Navy has indicated that the F-35C should be the USN's last manned fighter jet. The RQ-21 is a modular design that allows a wide variety of mission payloads, providing multi-mission flexibility. Among the payloads either deployed or in development are SIGINT, EW, Communications Relay, SAR/GMTI, real-time targeting and wide-area persistent surveillance. The USAF illustrates the Unmanned Combat Air Vehicle (UCAV) flying in close formation with the F-22, providing "wingman" capabilities utilizing autonomous operations under supervised control of the manned fighter.

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Figure 2-5. The Navy and Air Force Have Visions for UAS

The need for similar unmanned capabilities within Army Aviation was highlighted by Unified Quest 2014,[7] which evaluated the key roles that UAS can and should play in the future Army integrated battlespace:

> **"Unmanned** air and ground platforms that enhance soldier decision-making and action with self-planning, self-navigation, and mission execution capabilities will have significant potential to change the future battlefield. ***The Army must develop concepts of employment for future autonomous and unmanned systems in the near-term to integrate them efficiently into the force in the far-term (2030-2040)."***

The rapidly advancing technologies associated with UAS, autonomous systems, and MUM-T should be viewed as a significant opportunity for Army Aviation to better integrate collaborative manned-unmanned capabilities into its future force. However, a major challenge in expanding the Army Aviation UAS portfolio, increasing MUM-T capabilities, and meeting this UQ vision is the small percentage of Army S&T funding allocated to UAS (see Section 2.1.5).

[7] Army Capabilities Integration Center, *Unified Quest 2014 Executive Report,* 12 Mar 2015, http://www.arcic.army.mil/Library/documents.aspx.

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2.1.5 Army Aviation Funding

Army Aviation must somehow meet all of the challenges detailed above within an S&T budget that is only about 8% of Army S&T funding (Figure 2-6). The lack of a robust budget is perhaps its most significant challenge that is outside of the Army Aviation community control.

The Army is the lead Service for DoD rotorcraft systems and technologies. The other Services are dependent on a robust Army Aviation S&T program. The Army should, of course, leverage technology developments by the other Services, NASA, and DARPA, as well as commercial industry initiatives. NASA rotorcraft spending, however, is down to $20M in FY2016, and DARPA investments in rotorcraft technology developments, while currently robust, are variable.

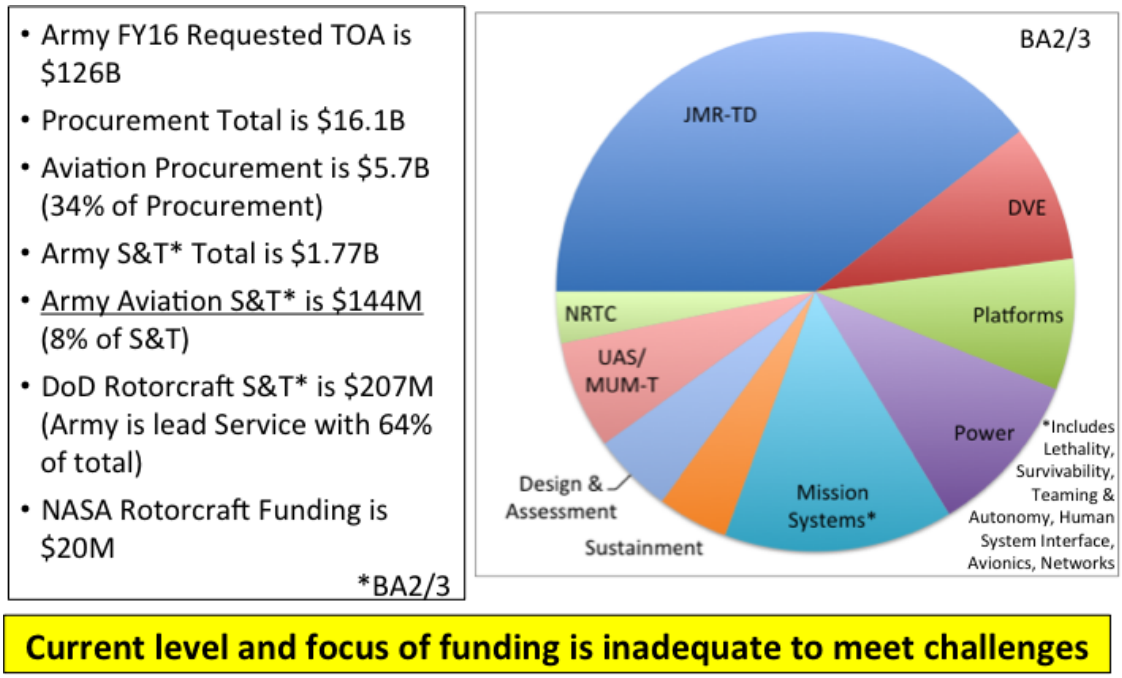


Figure 2-6. Meeting Future Challenges Demands a Robust Aviation Portfolio

Within the Army Aviation S&T budget, a healthy portion is devoted to the JMR-TD program, which provides the validation of aerodynamic and aeromechanics technologies for FVL. This Army investment is more than matched by industry participants in the program. The two JMR demonstrator aircraft are sized to match the medium class FVL, which will ultimately replace the AH-64 and UH-60 legacy systems. There is little current investment, however, to support an ultra-heavy class of vehicle that would satisfy the heavy vertical lift capabilities required for maneuver of mechanized dispersed forces. Also, and particularly vexing, is the small allocation of Army Aviation S&T to UAS and MUM-T. It is difficult to imagine how Army Aviation will satisfy its challenges and validated capability needs (discussed in Section 2.2) within these budget constraints.

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2.2 Army Aviation Capability Needs and Gaps

The Army Aviation capability needs and gaps to meet these challenges are well documented in JROC-validated Capability Based Assessments (CBAs) and Initial Capability Documents (ICDs) developed through the JCIDS process (Figure 2-7).

- System/Platform
  - Future Vertical Lift (FVL) CBA, 21 Jun 10
  - FVL Family of Systems (FoS) ICD, 8 Apr 13
  - Joint Future Vertical Lift (JFVL) ICD, Oct 09
  - Joint Heavy Lift (JHL) ICD, 12 Oct 07
  - Unmanned Systems ICD, 14 May 10
- Aircraft Survivability
  - Aircraft Survivability CBA, 6 Jan 09
  - Degraded Visual Environment CBA, 21 Jul 09
  - Aircraft Survivability ICD, 6 Oct 11

Figure 2-7. Army Aviation Capability Needs & Gaps Emanate from Validated JCIDs Documents

The capability needs and gaps for FVL are documented in the JROC approved FVL FoS CBA and ICD. Capability objectives in the FVL ICD document gaps associated with many of the challenges discussed previously in Section 2.1:

- **Operational and Tactical Vertical Movement:** The future force requires VTOL Aviation to support the operational and tactical movement of forces to achieve a position of advantage with respect to enemy forces. Vertical movement requires aerial delivery and airborne operations to move supplies, and insert/extract personnel and equipment across the range of military operations.
- **Destroy, Neutralize or Suppress Enemy Targets:** FVL should employ a variety of future and legacy weapons systems against a wide array of existing and emerging threats.
- **Air Reconnaissance, Surveillance and Target Acquisition:** Future systems should conduct the full range of intelligence, reconnaissance, surveillance and target acquisition missions. FVL FoS platforms will maintain surveillance of areas to detect, identify, prioritize and designate targets; increase responsiveness; and exploit the capabilities of interoperability between manned and unmanned systems.
- **Execute Network-Enabled Command, Control and Reporting:** FVL platforms should execute network-enabled C2 and reporting for SA, fires, JF integration and collaboration.
- **Aviation Sustainment, Maintenance and Supply Activities:** Future systems should increase platform availability, reliability, sustainability, maintainability, energy efficiency / reduced fuel consumption and logistics footprint.
- **Safety and Survivability of Aircraft and Personnel:** Protect the aircraft, aircrew and passengers departing controlled flight, from impacting hazards, effects of enemy

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weapons, and onboard aircraft fire or crash damage. Safety shall not be compromised by Hazards of Electromagnetic Radiation to ordnance, fuel, personnel, EMI, or ESD.

The FVL ICD translated these capability needs into performance objectives for three classes of vehicles: Light, Medium and Heavy (see Figure 2-8). As indicated, among the key performance objectives is higher speed than conventional helicopters can achieve, which drives the aircraft configuration choices to compound/hybrid or tilt-rotor concepts. JMR-TD is developing and testing demonstrators for these advanced concepts. The distinguishing feature between the FVL classes is payload, with the light configured to carry a SOCOM team (6 passengers), the medium to carry a squad (12-24 passengers) and the heavy a platoon (33-53 passengers).

Capability	**Performance Goal***	**Performance Value**
Worldwide Performance	Operate 90+% in Critical Regions	HOGE at 6 kft and 95°F
Combat Radius	Operate Across Army Division AO	424 km
Cruise Speed	Transit Army Division AO Within 1 Hour	170 – 300 kts
Internal Payload	L: 6 Passengers M: Squad and up to 20K H: Equivalent to USMC CH-53K	L: 2.5K+ lbs M: 5K – 20K lbs H: 20K – 30K lbs
External Performance	L: Equal to Internal M: M777 Howitzer and JLTV H: Equivalent to USMC CH-53K	L: 2.5K+ lbs M: 13K – 23K H: 30K
Passengers	L: SOCOM Team M: Squad H: Platoon	L: 6 M: 13 – 24 H: 33 – 53
Self Deployment	Transit Longest Leg of Pacific	3889 km

* L – Light, M – Medium, H - Heavy

Figure 2-8. FVL ICD Performance Objectives

A fourth class of vehicle that is discussed in the FVL ICD is the ultra-heavy class, which is capable of moving mechanized forces, including medium-weight armored vehicles. The capability needs for this class are documented in the Joint Future Vertical Lift (JFVL) ICD as well as in the Joint Heavy Lift (JHL) ICD. The capability needs in the JFVL ICD address the challenge of strategic and operational maneuver of dispersed mechanized forces in austere areas of operation:

- Transport forces over strategic and operational distances to points of need/effect bypassing traditional PODs;
- Conduct precision air delivery of supplies over strategic and operational distances with required velocity;
- Operate into austere, short, unimproved landing areas with limited infrastructure;
- Perform operational maneuver with medium weight armored vehicles and personnel;

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- Reposition medium weight armored vehicles and personnel by airlift;
- Minimize RSOI.

Critical capability needs for the Joint Future Vertical Lift system include a payload capability of 20-36 stons, the ability to self-deploy from CONUS to theatre, a mission radius with payload of 250-1000 nm, and a speed that allows for in-flight refueling.

The Aircraft Survivability ICD combines the aircraft survivability CBA with the Degraded Visual Environment (DVE) CBA. It addresses, therefore, both the need for survivability over the full spectrum of conflict against capable threats and the need for aviation assets to conduct operations in degraded visual environments. Requirements extracted from the ICD include:

- The future modular force will leverage aviation that is capable of deploying worldwide to conduct full spectrum operations and survive against lethal threats in a wide variety of physical environments and weather conditions that severely degrade pilot visibility.
- Survivable aviation assets will enable joint forces to conduct operational maneuver from strategic distances; deploy through multiple, unimproved points of entry, forcibly if necessary; and overwhelm hostile anti-access capabilities to rapidly bring and apply combat power to the enemy.
- These units will arrive in the AO with the ability to conduct immediate, simultaneous, distributed and continuous combined arms operations throughout the operational environment.

2.3 System Concepts to Meet the Challenges and Satisfy the Capability Needs

The challenges and capability needs for Army Aviation tend to group into three categories:

1. Survivability of aviation assets against proliferated capable threats,
2. Reliance on 1970 vintage legacy platforms beyond 2025-2040 until the advanced performance capabilities of FVL can be fully deployed, and
3. Vertical maneuver of dispersed mechanized forces required to implement the Army CONOPS.

Moreover, it is imperative to address these challenges within a budget-constrained environment and a relatively meager allocation of Army S&T funds to Army Aviation. System concepts and/or affordable solutions are required for each of these challenges to provide focus for Army Aviation S&T investments.

With respect to the first category, the current approach to survivability of Army Aviation systems is based on a traditional multi-layered approach centered on the platform, depicted in Figure 2-9 . The outer layer involves systems and techniques to avoid detection by a threat system, the next layer to avoid engagement by the threat, and so on. ROSAS, cited in the figure, is an AMRDEC Route Optimization for Survivability Against Sensors effort that seeks to demonstrate a real-time route planning system to avoid pop-up threats; it is intended to provide new capabilities for several of the protection layers. This layered “onion” approach has served well in the past. Next-generation threats and their proliferation, however, call into question how much longer this

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platform-centric approach can remain effective. On the one hand, it is not clear that the layering will provide adequate survivability against the advanced threats. Further, this platform-centric approach requires that all of the functionality of the "onion" (including threat detection and warning systems, countermeasure systems, signature management systems, active and passive protection systems, etc.) be integrated into a single platform. This approach results in a very high cost asset, which produces a very low ratio of threat kill cost to blue force loss cost. This cost ratio may place onerous limitations on the blue force commander on how and when to deploy aviation assets.

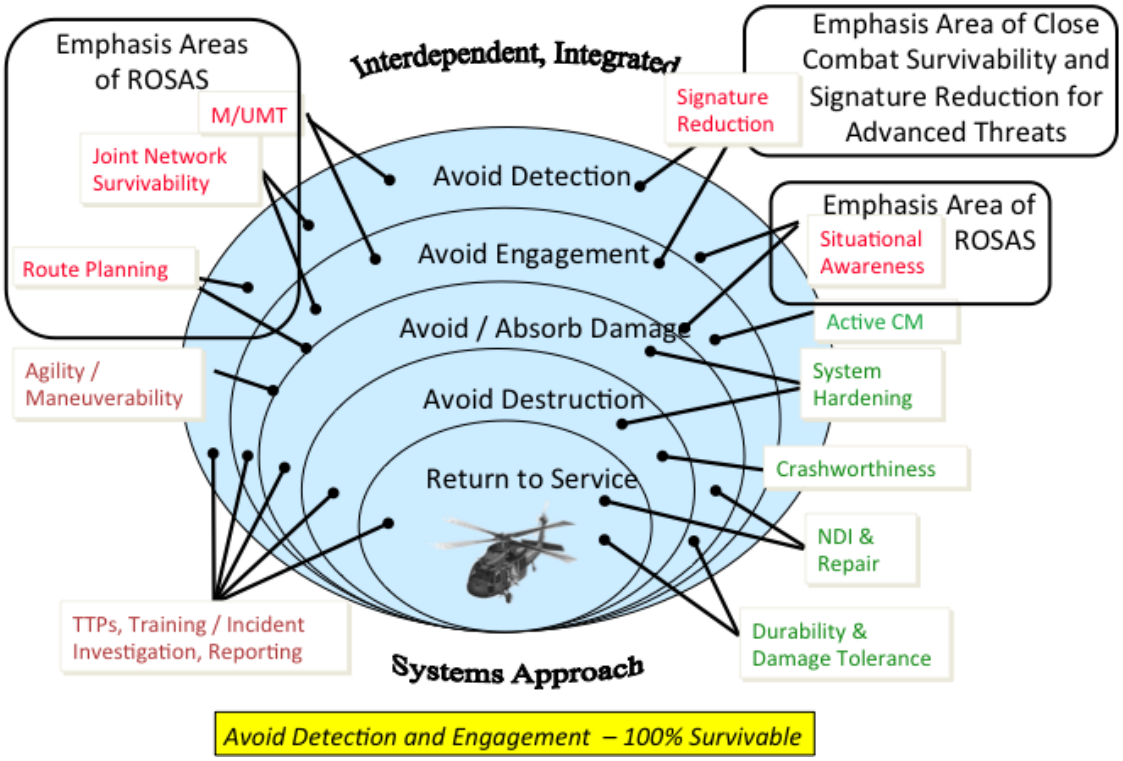


Figure 2-9 AMRDEC Total Survivability Paradigm – Platform-Centric

One approach to solving this platform-centric dilemma involves a system-of-systems (SoS) concept, which effectively adds another layer to the "onion" outside the platform itself, as illustrated in Figure 2-10. A limited number of elements of the SoS concept are already being implemented by means of the fusion of off-board information with on-board data and the recent upgrade of AH-64 to include Level 4 MUM-T capability with Shadow. However, a more robust vision for the future that takes fuller advantage of collaboration between manned and unmanned systems (similar to the USAF and USN/USMC visions illustrated earlier in Figure 2-5) is required to drive SoS solutions that fully exploit the synergy of unmanned systems operating in collaboration with the manned platform at the center of the "onion." Supervised semi-autonomous UAS can provide another layer important to survivability.

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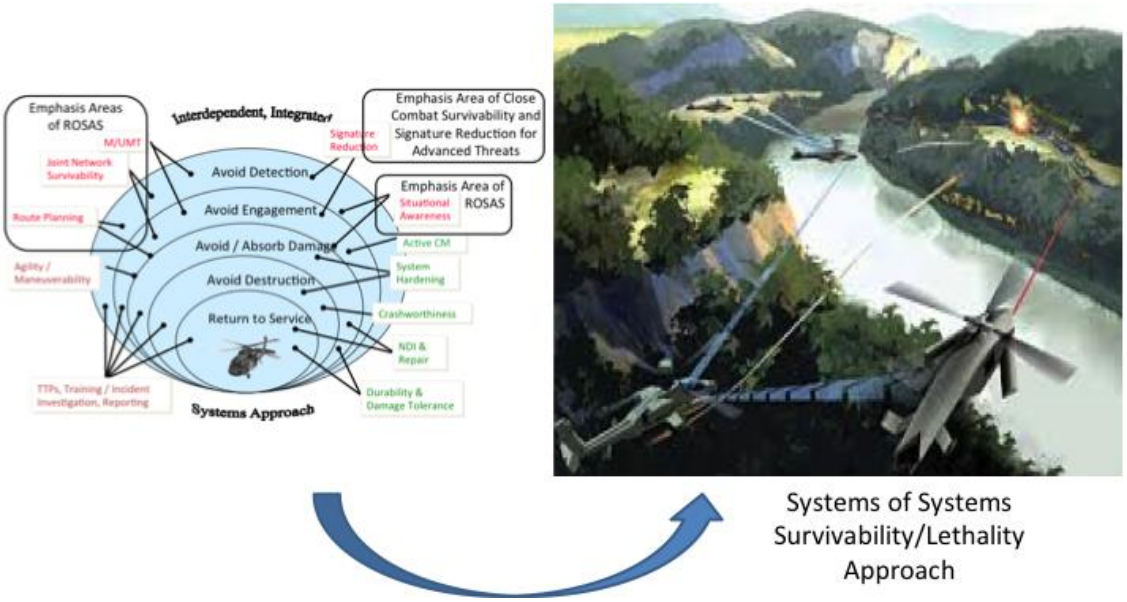


Figure 2-10 Total Survivability from a System-of-Systems Perspective

A top-level SoS concept for this outer layer of the "onion" is illustrated in Figure 2-11. In this concept, the manned aircraft serves as the mission supervisor, but much of the functionality to prosecute the mission is distributed onto UAS systems, which operate autonomously unless directed by the mission supervisor. Distributing the functionality improves mission and survivability and effectiveness in two ways. First, it greatly complicates threat response and adds a layer around the manned asset that the threat must defeat. Secondly, it reduces the cost of the manned asset, thereby reducing the ratio of cost of potential blue force asset loss to threat cost. This concept is discussed in more detail in Section 4.3. The UAS cost must, of course, be added to the overall blue force formation cost. However, in many cases the UAS may be of sufficiently low cost to be considered to be "attritable."

The second challenge category involves reliance on aging legacy rotorcraft systems until the Army can afford to make FVL a POR, develop the FVL aircraft, conduct OT&E, and gradually retire the earlier models as FVL variants are procured. As discussed previously, the current FVL schedule, which is driven by funding constraints as well as technology maturation, does not lead to an IOC of the *first FVL variant* (most likely the FVL-Medium replacement for either the AH-64 or UH-60) until the mid-2030 timeframe. After IOC, within anticipated procurement budget constraints, it will take a decade or two to replace the legacy system. It must be emphasized that this schedule applies only to the first FVL version. Funding constraints will limit development, testing, and procurement of the second and third variants to later timeframes.

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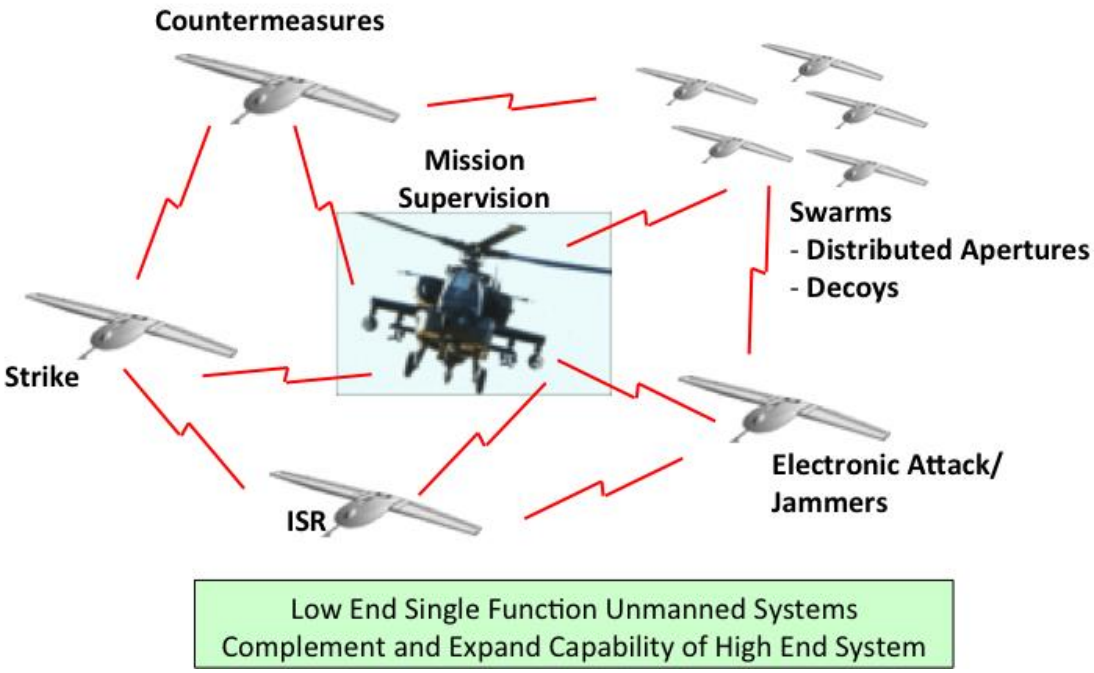


Figure 2-11 Distributed Functionality Collaborative System-of-Systems Concept

Acceleration of the FVL program would seem to provide some obvious benefits toward mitigating this issue. However, three roadblocks stand in the way of program acceleration: funding constraints, acquisition processes, and technology maturity.

Achieving affordability of FVL aircraft is critical to dealing with limited funding. Affordability, in turn, is driven by requirements. As the only new Army Aviation program on the horizon, FVL will be pressured by the operations community to have system and performance requirements that satisfy every possible operational need. Lack of requirements discipline is one leading cause of acquisition program failure. FVL will be no exception if the requirements process is not tightly managed and constrained. An approved DoD acquisition process, known as evolutionary acquisition, could prove to be of great value in managing requirements growth and in accelerating the introduction of FVL into the inventory. Under this acquisition strategy, the operational and acquisition communities would agree on a set of objective performance requirements, but also concur on a more limited set of the objectives that could provide an effective early operational capability. Pre-planned capability upgrades leading to the full set of objective requirements would also be defined. Such an approach would help not only to manage requirements, but also to accelerate IOC for a limited capability set.

Such acceleration, however, is dependent on technology maturity. In addition to unrealistic requirements and/or requirements growth, unrealistic evaluations of technology maturity is an additional significant cause of acquisition program failure. Fortunately for FVL, due to major industry investment, the JMR-TD demonstration vehicles will have greater fidelity and be more representative of the FVL-Medium operational design than would normally be expected. Parallel

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investments in the FACE/JCA open system architecture could provide the technology basis for some acceleration of a Milestone B DAB. This option is discussed in more detail in section 4.5.

The third challenge category is the lack of an Army Aviation capability to provide the heavy vertical lift necessary to support maneuver of dispersed mechanized forces in austere areas of operation. Because of the investment required to develop and produce the FVL-Medium class of aircraft, simultaneously developing an ultra-heavy class is simply not within the TOA of Army Aviation for the foreseeable future. Interim solutions that partially meet the heavy lift requirement are the only fiscally realistic options available to the Army. Potential interim solutions are discussed in section 4.2.

While this discussion has focused on the challenges facing Army Aviation, it is worth noting that many of the same forces driving the challenges also open opportunities for advancing Army Aviation to win in a complex world. In particular, expanded roles and missions for UAS and the better integration and collaboration of manned and unmanned assets provide the capability for new/improved roles and missions for Army Aviation as the character of future warfare continues to evolve. The system-of-systems distributed functionality concept introduced earlier (Figure 2-11) opens multiple new options for Army Aviation to contribute to Joint force effectiveness in future conflicts. As just one example, Army Aviation could play a more significant role in two missions that are normally tasked only to USAF forces: air superiority and SEAD. In the case of air superiority, lethal UAS under supervisory control of either Army or USAF manned attack assets could support the attack of threat airfields. SEAD missions could be enhanced through use of collaborative functionality formations that utilize UAS as stand-in jammers. Other opportunities are clearly possible, but they are limited for the 2025-2040 timeframe by funding constraints, particularly limited budgets for UAS and MUM-T.

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3 KEY INNOVATIVE TECHNOLOGIES: FOCUS AREAS FOR IMPROVEMENT

The study Terms of Reference requested that the team address the use of innovative technologies that increase capabilities, overall mission effectiveness, survivability and lethality while reducing sustainment requirements, including logistics footprint and frequency of resupply. This section explores such innovative technologies.

It should be noted that these innovative technologies will be most effective when integrated with other technologies. For example the Degraded Visual Environments (DVE) effort involves integration of sensor technologies, cueing technologies, and flight control technologies. The integration of unmanned systems, manned-unmanned teaming, and manned platforms into a system-of-systems provides the most promising means for affordable mission effectiveness. Incorporating Joint capabilities into an overall operating concept will help to ensure maximal effectiveness of these systems.

3.1 Challenging Environments

3.1.1 Degraded Visual Environments

In recent years, Army Aviation operations have experienced a series of serious accidents, several fatal, in which helicopters were losing stability as they landed in sandy areas of Iraq and Afghanistan. In 2010, a DoD study[8] found:

> "During Operation Enduring Freedom and Operation Iraqi Freedom (OEF/OIF), there were 375 rotorcraft losses with 496 fatalities from October 2001 to September 2009. Mishaps accounted for 81 percent of all losses with combat losses (i.e., aircraft shootdowns) accounting for the remaining 19 percent; 73 percent of the fatalities occurred in a combat theater. … The combined mishap loss rate (both combat non-hostile and non-combat) was 2.71 losses per 100,000 flight hours, slightly exceeding the loss rate due to combat hostile action. The in-theater mishap loss rate was ten times worse, and the out-of-theater loss rate was four times worse than the Congressional and SECDEF goal of 0.5 mishaps per 100,000 flight hours. Loss of situational awareness and other human factors accounted for more than 79 percent of the losses of airframe and fatalities. The primary causal factors are controlled flight into terrain and brownout."

The problem was that as the helicopters approached the ground they generated a large cloud of dust that completely surrounded the aircraft, causing a condition called "brownout" that virtually blinded the pilot. The brownout caused the pilot to lose orientation, which could cause the helicopter to tilt as it came close to the ground, with the rotors striking the ground. The Army identified this condition, which they called Degraded Visual Environment (DVE), and expanded it

[8] Mark Couch (IDA) and Dennis Lindell (Joint Aircraft Survivability Office), "Study on Rotorcraft Safety and Survivability," presented at American Helicopter Society 66th Annual Forum, DTIC A547531, May 2010.

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to include other environments that are visually degraded, as illustrated in Figure 3-1. Two of these environments are induced by the aircraft: brownout in dusty terrain and whiteout in snow-covered areas. Naturally occurring environments include smoke, sand/dust storms, fog, rain, clouds, snow, smog, night, and flat light. DVE mitigation became one of Army Aviation's three highest priority needs. In addition to safety considerations, a key objective of DVE capability development efforts is to enable commanders to conduct operations deliberately in DVE because they will have an advantage over the adversary.

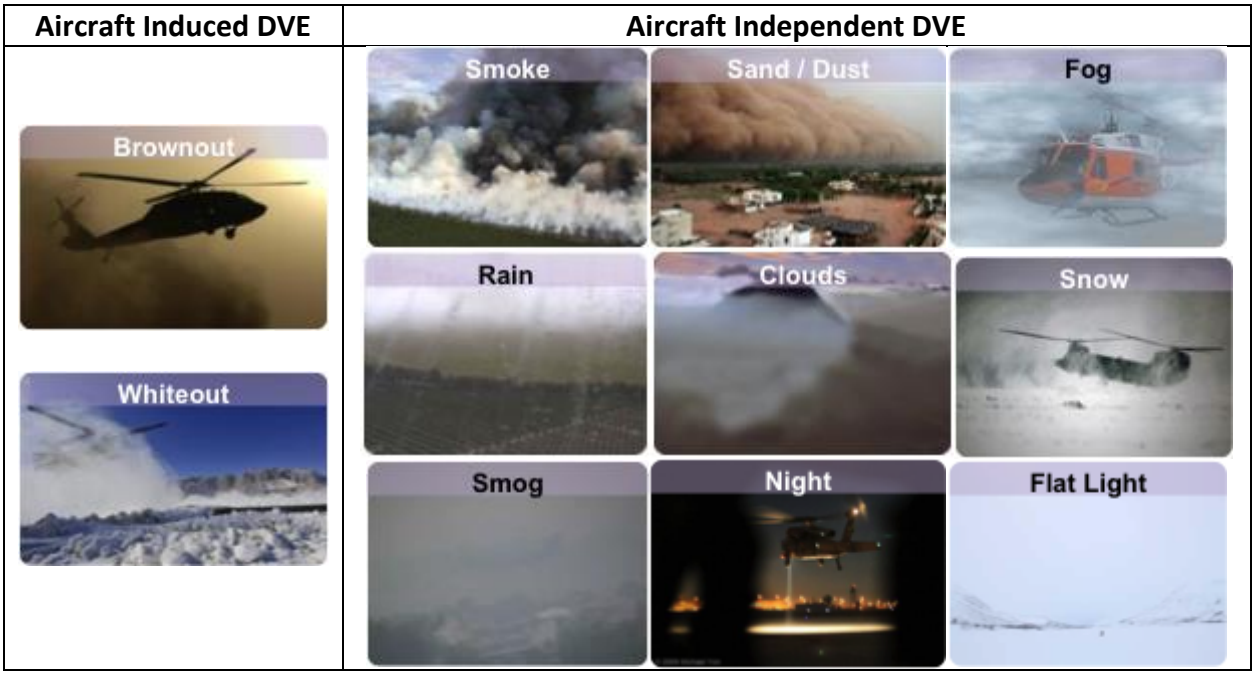


Figure 3-1. Degraded Visual Environments (2 + 9)

DVE mitigation is an RDECOM-wide effort based on integration of three technologies supported by complex computing. It includes work in three principal areas:

- Sensing – led by CERDEC
- Cueing – led by ARL (working with the US Army Aeromedical Research Lab - USAARL)
- Flight controls (to stabilize aircraft handling) - led by AMRDEC-ADD-AFDD

The threshold demonstration goals for the DVE program include rotorcraft pilotage capability in all limited visibility environments, all-around situational awareness, and the ability for multiple aircraft to cooperatively operate within DVE. The Army plans to test these goals by FY2020.

Limited Visibility Close to Ground – Sensor Development

Brownout is caused by the downdraft created by a helicopter as it lands over dust-covered ground. The cloud of dust creates a very opaque environment that makes it impossible for the pilot to see farther than one or two feet beyond the windshield of the cockpit. Sensors able to penetrate and generate images through the dust cloud are needed.

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Sensor development work pertinent to DVE is being conducted at Fort Belvoir by the Night Vision and Electronic Systems Directorate (NVESD), an important element of CERDEC. NVESD technologists have identified a spectral "window" in the long-wavelength infrared (LWIR) band through which electromagnetic radiation can penetrate. Exploiting this phenomenon they have developed a sensor sensitive to that wavelength that is able to "see" through dust clouds. Unfortunately, the technology does not extend to other DVE conditions. Nevertheless, in theaters where dust is prevalent, the Army should seriously consider funding the integration of such sensors with the flight operating systems of its helicopters to enhance the pilot's ability to ``see'' through brownout.

CERDEC and Army Research Laboratory are also investigating the potential use of ladar and radar systems to overcome DVE. For example, high-resolution ladar images could be collected and stored prior to entering the landing zone and integrated with lower-resolution but obscurant-penetrating RF data to provide pilots with enhanced imagery and improved overall visibility.

Cueing and Flight Control Development

Cueing alternatives such as combinations of visual, aural, and tactical cues are being evaluated by the US Army Aeromedical Research Laboratory (USAARL) to optimize pilotage and aviator workload. USAARL is planning to assess DVE solutions in real-world environments, including high workload, reduced cues, fatigued aviators, and environmental stress. AMRDEC is exploring revised symbology sets such as the BrownOut Symbology System (BOSS), which attempts to present a single symbology strategy from start to finish of the approach, thereby eliminating the need to change pages or change scales.

AMRDEC is also developing modern control laws (MCLAWS) to improve flight control in legacy systems. These techniques can support additional automated flight modes, enabling capabilities such as terrain and obstacle avoidance and automated safe-landing modes. MCLAWS-2 is designed to provide an attitude-command/attitude-hold response type for improved handling in near-Earth operations at night and in poor weather. In-flight tests on the UH-60 demonstrated that both pilot workload and heading errors were reduced.

Addressing DVE in Future Integrated Programs

The RDECOM S&T effort is focused on developing an integrated DVE-Mitigation (DVE-M) system to be demonstrated in 2020. Component technologies will be demonstrated through FY2015. DVE-M goals include multi-ship networking for sharing of data and increased threat awareness from fused sensor data.

The study team considers the RDECOM DVE goals to be both appropriate and feasible. In addition, reduced pilot workload arising from DVE technologies should increase operational mission capacity (e.g., enabling formations with UAS).

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Just as adversaries have been able to acquire or develop night vision technology after US forces demonstrated the ability to "own the night," it must be anticipated that over time adversaries will also be able to operate in DVE. To maintain the advantage as long as possible, care must be taken to protect the technologies where feasible.

3.1.2 High/Hot Environments

During the 1970s, the Army required helicopter engines that could transport an 11-person squad at 4,000 ft altitude at 95°F. Based on more recent experience, the requirement has been raised to carrying the same load to 6,000 ft altitude at 95°F.

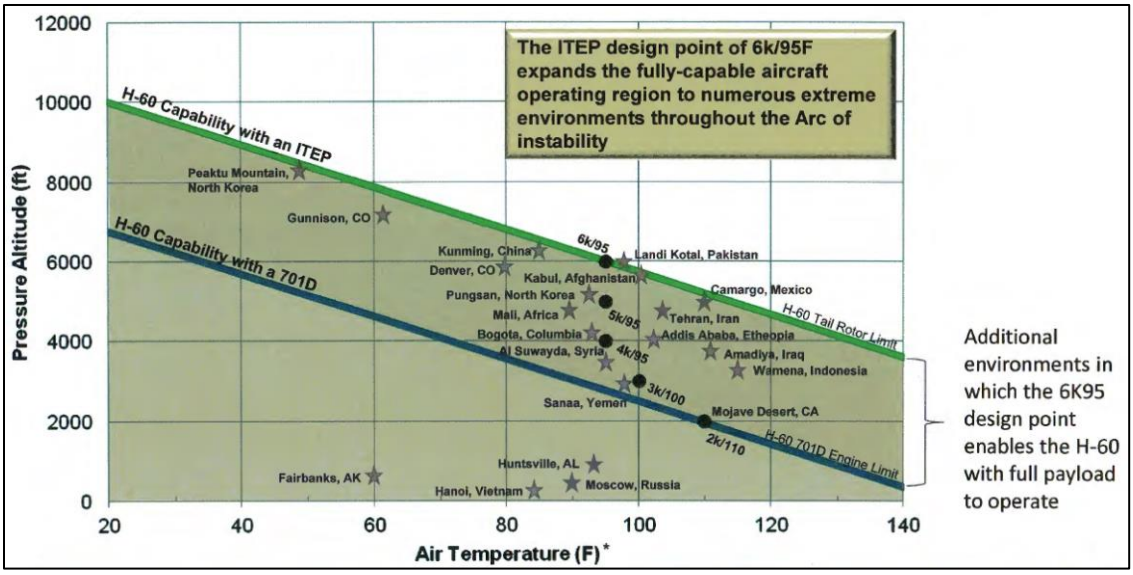
Higher altitude or hotter temperatures, or both, lead to lower air density, which in turn reduces the lift generated by the rotors or wings. Reduced density also degrades the performance of the aircraft engines, exacerbating the problem. The primary short-term means for overcoming the effect of low density is to reduce aircraft weight, usually by reducing payload or fuel load. For example, during the Iraq and Afghanistan wars, Black Hawk helicopters were regularly flown at higher altitudes and hotter temperatures than their engines were designed to withstand. With underpowered engines in those conditions, each helicopter could carry only five soldiers — about half of an 11-person squad.[9]

Over the longer term, vehicle and engine designs can be modified to improve performance. The Advanced Affordable Turbine Engine program is working to develop an engine that is the same size as the legacy Black Hawk's General Electric T700 engine but 50% more powerful and 25% more fuel efficient. This technology will be incorporated into the Improved Technology Engine Program (ITEP) that will undergo a downselect in 2018 and the first engine test in 2021.

Figure 3-2 shows the nominal operating environments for a Black Hawk powered by the T700 engine and by the ITEP. Note that several locations of interest, such as cities in Afghanistan, Iraq, Iran and Columbia, cannot be reached using the T700 engine without reducing payload. The ITEP supports both Apache and Black Hawk modernization programs. The Future Affordable Turbine Engine (FATE) provides similar improvements for the Chinook. These advanced engines will also support the Future Vertical Lift program.

[9] Valerie Insinna, "Fuel Efficient Engine to Increase Range, Power of Army Helicopters," *National Defense Magazine*, NDIA, January 2014.

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Source: Briefing by TCM Lift (COL Bentley), 11 June 2015.

Figure 3-2. Operating Environment for ITEP Engine

3.2 Condition-Based Maintenance and Near-Zero Maintenance Aircraft

Major advances in the development and use of aircraft health monitoring systems have been achieved over the last several decades. Such systems, now widely deployed on both commercial and military aircraft, offer significant potential for making maintenance operations a predictable and controllable activity. They enable the development and implementation of condition-based maintenance (CBM) practices that offer significant benefits in various areas compared to traditional corrective, preventative, and phased maintenance approaches. CBM is a maintenance process based on the known condition of various system components rather than a phased/scheduled inspection, repair, and replacement process. It involves monitoring the health and usage of components using sensors of various types to provide a rational basis for predicting individual component failure and establishing an appropriate timeline for repair and/or replacement actions. For fixed-wing aircraft, Boeing has successfully incorporated CBM into most of its aircraft systems, resulting in both reductions in maintenance costs and an overall increase in aircraft availability. CBM enablers have also been incorporated into numerous commercial and military rotary wing aircraft.

The Department of Defense has a longstanding commitment to implementation of CBM practices for a comprehensive range of defense systems, as reflected in establishment of its Condition Based Maintenance Plus (CBM+) Initiative in November 2002.[10] CBM+ is stated to be "an evolving set of maintenance capabilities focused on inserting technology into new and legacy systems that will improve supportability, lead to more efficient and effective business processes, and transform DoD's maintenance environment." It is intended to build on "the solid foundation of condition-based maintenance," but it also includes a wide range of other maintenance and

[10] Department of Defense, "Condition-Based Maintenance Plus (CBM+): A DoD Initiative," November 2014. http://www.rwappleton.com/downloads/CBMDODPublication.pdf.

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logistics considerations. CBM+ is "condition-based maintenance enhanced by reliability analysis; it is routine predictive maintenance based on the evidence of need and forecasted by analyzing data collected through automated sensors and systems." Development and implementation of effective CBM+ practices are intended to contribute to improved weapon system and equipment performance, as well as lead to enhanced readiness, more efficient maintenance, reduced logistics footprints, and associated cost savings.

Stated policy key tenets for CBM+ include (1) need-driven, reliability-centered maintenance, (2) embedded diagnostics and prognostics, (3) automated maintenance information generation, (4) analysis-based reliability and sustainability process improvements, (5) integrated information systems responding to equipment condition and tasking, (6) smaller maintenance and support footprints, and (7) improved operational availability and performance. Cited examples of CBM+ enabling features include (1) sensors, embedded onboard or off-board (portable) equipment interfaced to a platform, together with software programs to facilitate analysis, (2) data collection, (3) maintenance information systems network for both up line reporting/recording and downline support, (4) information tools (interactive electronic technical manuals, portable maintenance aids, computers, etc.), (5) engineering analysis to identify trends and provide a dynamic maintenance plan, and (6) systems integration linking logistics and maintenance.[11] Development and implementation of CBM+ capabilities is clearly a complex process. An ultimate issue is whether, and how soon, it might lead to desired near-zero maintenance aircraft (ZMA) for Army Aviation.

Over the last several decades, the DoD and the Services have made major investments in the development of technological capabilities important to the continuing advance of CBM capabilities. Early major investments by the Army led to the development of integrated vehicle structural health monitoring capabilities such as the IVSHM system, developed by Goodyear for Army Aviation in 2002, and health and usage monitoring systems (HUMS), such as the system developed for the UH-60 Black Hawk.[12] HUMS capabilities have subsequently been integrated into most Army rotary wing aircraft (AH-64D, OH-58D, and CH-47D helicopters; all US Army Special Operations Aviation Command helicopters). HUMS is a sensor-based monitoring system that enables preventative maintenance by measuring the health and performance of mission-critical components. It has been cited as "the kind of environment that CBM+ is trying to establish."[13] By continuously monitoring vibration at numerous points throughout the drive train and pinpointing mechanical faults before they become catastrophic failures, HUMS provides actionable information that allows the military operators to anticipate mechanical failures and make anticipatory maintenance decisions.[14] Realized benefits include greater aircraft availability,

[11] "Condition-Based Maintenance Plus (CBM+): A DoD Initiative," op cit.

[12] MAJ Marc P. Gaguzis, "Effectiveness of Condition Based Maintenance in Army Aviation," MS Thesis, US Army Command and General Staff College, Fort Leavenworth, KS, 2009, http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA502155.

[13] "Condition-Based Maintenance Plus (CBM+): A DoD Initiative," op. cit.

[14] Honeywell, "HUMS Systems Keep the US Military Mission Ready," 3 January 2013, https://aerospace.honeywell.com/news/hums-systems-keep-the-us-military-mission-ready.

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lower costs resulting from reductions in unplanned maintenance events, more optimal parts inventory management and logistics, and enhanced safety.

All of the Services have significant ongoing efforts to develop CBM+ capabilities, particularly for aviation systems. For the Army, those efforts are very comprehensive and extend across all of the principal RDT&E categories, as summarized in Appendix E - Army Aviation Efforts. Two major active Army efforts are the Autonomous Sustainment Technologies for Rotorcraft Operations (ASTRO) program and the Ultra Reliable Design program.[15,16] The ASTRO program is a jointly funded effort by industry and the Aviation Applied Technology Directorate of AMRDEC to develop and demonstrate technologies and methodologies enabling more efficient designs and reduce the maintenance burden for current and Future Vertical Lift (FVL) aircraft. Its principal focus is on advanced technologies for propulsion, structures, rotors, and drives. The objective of propulsion technology work is to demonstrate adaptive engine controls to optimize performance, component life, and maintenance schedule based on engine health. The structures technology effort seeks to develop technologies for assessing the structural integrity of a primarily composite airframe, verifying the integrity of composite repairs, and predicting remaining useful life. Rotors technology work is developing automated methods to sense rotor system track and balance and enable real-time adjustments in flight. Drive system technology activities include development of planetary gear failure detection and weight reduction technologies, culminating in an integrated transmission demonstration in FY2016.

The Army's Ultra-Reliable Design program will develop a set of tools, methodologies, and materials to apply ultra-reliability concepts to the design and operation of FVL aircraft. Ultra-reliability has been defined as an order of magnitude improvement in materiel reliability over the current standard, achieving higher availability while reducing life cycle costs and downtime associated with maintenance activities. The program will be executed in three phases:

- Phase 1 will assess materiel reliability of current Army aircraft in the Army fleet and key reliability drivers for future aircraft; identify and analyze effective design-for-reliability practices; identify current and future technology transition points applicable to FVL reliability; and recommend technology investments, reliability design criteria, and potential development or acquisition process changes required to achieve ultra-reliable rotorcraft design.
- Phase 2 will develop design tools, methodologies, and materials consistent with the findings of the Phase 1 assessment and applicable to the design of future aircraft.
- Phase 3 will develop and demonstrate modeling and simulation tools and components/ sub-systems to verify and validate the tools, methodologies, and materials developed in Phase 2.

[15] Paul Pantelis, "Sustainment Tech Area," AMRDEC briefing to ASB, 17 March 2015, AMRDEC Aviation Development Directorate – AATD.

[16] Paul Pantelis, Chief, Sustainment Tech Area, AMRDEC Aviation Development Directorate - AATD, private communication, Sept. 25, 2015.

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A noteworthy example of Navy efforts to develop CBM capabilities for rotary wing aircraft is its ongoing development of an Integrated Hybrid Structures Management System (IHSMS) as an important element of its Future Naval Capabilities program.[17] Its focus is on rotor and airframe components of USMC CH-53K helicopters. Principal objectives include reducing total ownership costs, increasing operational availability, and improving flight safety. The work includes developing advanced capabilities for load/load-history tracking for dynamic components and airframe hot spots, damage detection and monitoring, damage growth and criticality prediction, and micro-climate environmental monitoring. Enabling capability metrics/goals include significant reductions in material maintenance costs, maintenance man hours per flight hour, and weighted elapsed maintenance time. Detailed design work for the system architecture and technology integration on CH-53K have been completed, and planned functional and risk reduction tests are in progress.

Air Force activities to develop advanced CBM capabilities for fixed wing aircraft include sustainment work involving diagnostics and prognostics advanced technology development, particularly for aircraft engines. Near-term goals include the development of improved non-destructive inspection (NDI) tools. Mid-term goals include development of advanced automated NDI tools, CBM plus structural integrity, and probabilistic life prediction tools. Over the longer term, prognostics capabilities are intended to be an integral part of aircraft engine development. Ongoing Air Force Sustainment Transition efforts are intended to demonstrate selected sustainment technologies for transition into AF systems to increase readiness, reduce life cycle costs, and extend service life. They include assessment activities involving NDI and structural health monitoring for state awareness and diagnostics; prevention activities involving redesign, life enhancement, repair practices, and replacement concepts; and management practices involving fleet management, decision tools, reliability improvements, and infrastructure. Active Propulsion Sustainment efforts seek to demonstrate and transition technologies that improve safety, readiness, and cost. Technologies under development include prognostic health monitoring as an integral part of aircraft engine development.[18]

Various analyses have demonstrated the potential and realizable benefits of CBM capabilities. An early Army cost/benefit analysis for HUMS reported “an advantage in flight hours completed and operation readiness rates, coupled with a marginal decline in hours of non-mission capable for maintenance reported.”[19] A more recent Army analysis indicated that CBM+ efforts as of 2012 had demonstrated notable benefits with respect to combat power (mission capable rates) and aviator safety.[20] CBM-equipped aircraft demonstrated the ability to generate more flying hours

[17] NAVAIR, “Integrated Hybrid Structural Management System (IHSMS),” briefing to ASB, June 25, 2015, DISTRIBUTION D.

[18] C. Douglas Ebersole, “Next Generation Aerospace Systems,” Air Force Research Laboratory briefing to ASB, Aerospace Systems Directorate, 7 July 2015, DISTRIBUTION D.

[19] MAJ Marc P. Gaguzis, op. cit.

[20] US Army Aviation and Missile Command, *Army Aviation Condition Based Maintenance Plus (CBM+) Initiative Cost Benefit Analysis (CBA)*, 23 Jan 2012, AMCOM G3 Operations, Command Analysis Directorate.

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than the non-equipped fleet, lower mission-abort rates (up to 19.6% depending on platform variant), and contribute to enhanced safety through accident avoidance. The use of CBM equipment to accurately record flight hours was estimated to reduce scheduled maintenance burden by 12-22%, with corresponding savings in contractor labor and mean time between failures. Further, the Army Aviation CBM+ initiative was reported to be responsible for "hundreds of small, nearly unquantifiable gains in terms of troubleshooting time, precautionary landings that did not happen, avoided unnecessary maintenance procedures, and more." A business case analysis for the Navy IHSMS program previously described has shown a positive return on investment with respect to cost benefits and significant reductions in maintenance man hours and elapsed maintenance time.

For the Army, commitment to CBM+ has been Aviation first, and the importance of CBM practices to Army Aviation has long been recognized. In 2004, an *Army Aviation* article noted the great potential offered by CBM technology to monitor the health of aviation systems and subsystems through the use of on-board diagnostics (near-term goal) and on/off-board prognostics (long-term goal), leading to component reliability improvements, reduced maintenance manhours, and reduced aviation accidents and incidents.[21] Such capabilities were projected to lead to "a fully modernized and transformed sustainment environment for the future that supports multifunctional, expeditionary and combined-arms units on a distributed, non-linear battlefield." In a 2006 *Army* article, the Commander, US Army Aviation and Missile Life Cycle Command reiterated that potential and stated that the "Army's vision is to achieve CBM+ goals by the end of fiscal year 2015," but noted that "transition to CBM+ is contingent on incorporating enhanced technology on existing aviation systems and embedding those capabilities into future and developmental aviation systems."[22] Due to significant technical and implementation challenges, that goal has not been realized to date, even though large numbers and a variety of diagnostic sensors of various types have been incorporated into fielded aircraft. Nevertheless, continuing progress in the development of sensing and reporting technologies over many years has enabled the emergence of CBM practices as the desired standard for Army rotorcraft, and the Army remains committed to achieving the principal CBM+ goals: (1) reducing burdensome maintenance tasks currently required to assure continued airworthiness, (2) increasing aircraft availability, (3) improving flight safety, and (4) reducing sustainment costs.[23] The functional capabilities intended to be implemented on all Army aircraft onboard CBM systems include engine monitoring, dynamic system component monitoring, structural monitoring, exceedance recording, usage monitoring, electronic logbook interface, and electronics.

[21] LTC Kimberly Emberle, "Condition Based Maintenance: What It Means to Army Aviation," *Army Aviation Magazine*, December 31, 2004, pp. 48-50.

[22] MG James H. Pillsbury, Condition Based Maintenance for Army Aviation, Army Magazine, January 2006, pp. 27-30.

[23] AMCOM and PEO Aviation, *Condition Based Maintenance System for US Army Aircraft,* ADS-79D-HDBK, 7 March 2013, http://everyspec.com/ARMY/ADS-Aero-Design-Std/download.php?spec=ADS-79-HDBK_2013.049364.pdf.

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Despite considerable interest in and extensive RDT&E activity directed toward the development of advanced CBM+ capabilities for defense systems, clear commitments by DoD and the Services, considerable progress in selected areas, and noted recorded benefits, overall progress toward comprehensive implementation of CBM+ practices has been slow. CBM in many respects remains in an extended mid-state of development due to its overall complexity – reflected in part by the extensive range of relevant Army RDT&E activities summarized in Appendix E – and numerous technical and implementation challenges. An overarching problem is that the substantial infrastructure required for CBM did not exist when the Army committed to it, including diagnostic tools for data collection, established data analysis methodology, and effective "big data" management systems. Another factor contributing to the comparatively slow rate of CBM implementation is that program managers for specific systems and other interested groups, including depot maintenance personnel, logistics specialists, and financial managers, need to be made more fully aware of CBM benefits, commit to an integration plan, and then find the required resources. Differing interests and concerns of certain elements of the Army Aviation community have also had an impact.[24]

Diagnostic sensors of various types capable of providing information regarding vibration, stress and strain, cycle times, temperature, wear, and more of many system components, sometimes in combination with environmental factors (desert, arctic, high-humidity, usage, profiles, and more) have been applied to numerous Army aircraft. They reportedly are capable of generating hundreds of megabytes of data per aircraft per flight hour. But that data needs to be stored, moved, and analyzed in the context of detailed knowledge regarding degradation and failure of critical components. Obtaining such knowledge requires extensive testing under realistic operating conditions. The ability of diagnostic devices to accurately and reliably identify, classify, and quantify emerging problems under such conditions must be firmly established. Required robust data/information management systems remain under development, analyzing overwhelming amounts of flight data presents a significant challenge for engineers, too little is known regarding dominant degradation and failure mechanisms for many critical components, and the extensive testing of innumerable system components is cost prohibitive. The comprehensive component performance data and statistical confidence that lie at the heart of developing reliable prognostic algorithms is lacking. Although CBM+ can manage unscheduled maintenance needs very well by providing useful information suggesting that a particular component is exhibiting an off-nominal condition, leading to proactive maintenance action, false alarms can be problematic by requiring maintenance attention when none might be required. In that context, diagnostic and prognostic tools need to be more reliable than the components being assessed. Another limitation is that CBM processes require the ability to detect "graceful degradation" of monitored components; they cannot lessen the consequences of unanticipated catastrophic component failures. As noted in Army Regulation AR 750-1, "CBM does not lend

[24] Christopher Smith, US Army AMCOM, formerly the CBM lead for Army Aviation, private communication, 14 September 2015.

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itself to all types of equipment or possible failure modes and therefore will not be the sole type of maintenance practiced."[25]

The Army's longstanding interest in CBM+ processes is driven by their proven ability to enhance weapon system and equipment performance, contribute to enhanced readiness, enable more efficient maintenance, reduce logistics footprints, and provide significant cost savings, as previously noted. Comprehensive implementation of CBM+ processes is essential to achieving a desired Army objective of "near-zero maintenance aircraft" (ZMA) for well-defined operational periods. The concept refers to the goal of establishing a Maintenance Free Operating Period (MFOP) during which an aircraft can be expected to operate effectively for a specified number of flight hours, requires no scheduled maintenance actions, and maintains a high Operational Availability (A_O) during which it is able to perform a high percentage of intended mission profiles. Army goals for MFOP are 480 flight hours (Threshold) and 720 flight hours (Objective). Stated goals for A_O are 90% (Threshold) and 95% (Objective). Additional goals associated with the ZMA concept involve Mean Down Time (MDT) and Mean Time to Repair (MTTR) (unscheduled). MDT goals are the lesser of 4.5 days or 216 maintenance man hours (Threshold) and the lesser of 3.0 days or 144 maintenance man hours (Objective). MTTR goals are 3.0 maintenance man hours (Threshold) and 1.5 maintenance man hours (Objective).[26]

Given the current state of development of CBM+ capabilities, these goals must be viewed as potentially achievable only over the long-term, principally for FVL platforms where the appropriate means for incorporating CBM+ diagnostics and data management capabilities have been made an integral part of the aircraft design process. CBM+ implementation to the extent required to achieve near-zero maintenance capabilities for legacy aircraft presents near-insurmountable challenges because aircraft design, maintenance management procedures, and Army maintenance policy were not developed to be consistent with actual CBM+ practices. It may also be cost-prohibitive, where, as noted in Army Regulation AR 750-1, "CBM is best implemented as early as possible in the systems life cycle to minimize costs." While continuing to incorporate additional emerging CBM+ capabilities into legacy aircraft can be expected to enhance operational availability and provide maintenance cost and logistics benefits, it is not likely to achieve the stated goals of the ZMA concept for these aircraft.

3.3 Manned-Unmanned Teaming

Current Army Aviation UAS assets consist of the Raven, Puma, Shadow and Gray Eagle systems. These systems are all fixed wing, have limited autonomy, limited Manned-Unmanned Teaming (MUM-T) capability, and are essentially dedicated to a single mission (ISR, although Gray Eagle can carry Hellfire missiles in addition to ISR payloads). Currently AH-64E Apaches have capability for LOI 4 control (see Figure 3-3) of Shadow and Gray Eagle. Collaboration by means of MUM-T is constrained by lack of autonomy and by the UAS communications architecture; the UAS communicate primarily with ground control systems rather than directly with each other or with

[25] Department of the Army, *Army Regulation AR 750-1, Army Materiel Maintenance Policy*, 12 September 2013, http://www.apd.army.mil/pdffiles/r750_1.pdf.

[26] Paul Pantelis, private communication, op.cit.

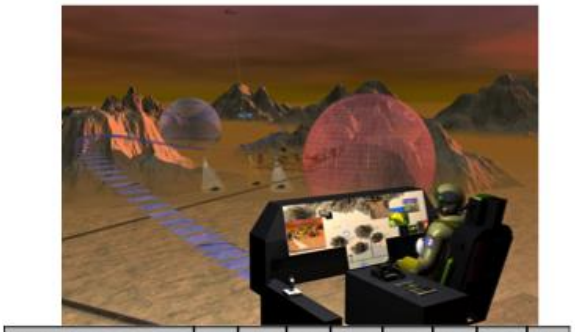
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other aviation assts. The lack of autonomy also adversely impacts the cost to operate UAS, because one or more operators are required for each UAS.

Level 1 – Indirect receipt/transmission of UAS related payload data
Level 2 – Direct receipt of UAS video and other sensor information
Level 3 – Control of the camera and sensors on the UAS
Level 4 – Control of the flight path and payloads
Level 5 – Full control of the UAS, including takeoff and landings

Figure 3-3. MUM-T Levels of Interoperability

Army Aviation recognizes the limitations associated with current UAS operability and has plans to improve autonomy and MUM-T capabilities. A key effort is the Synergistic Unmanned Manned Intelligent Teaming (SUMIT) program, described in Figure 3-4. This multi-year project is intended to demonstrate an integrated suite of aiding and autonomy technologies that will enable aviators to exploit UAS as an integral part of collaborative manned-unmanned teams. While these goals are noteworthy, the funding currently being provided to accomplish them is only about $5M/year.



MILESTONE	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21
SUMIT Part 1								
SUMIT PART 2								
S&T 32.2 M PE/Project: 63003/436	3.1	4.5	5.5	6.7	6.8	5.9	6.0	6.0

Purpose:

Demonstrate an integrated suite of aiding and autonomy technologies that enable Aviators to exploit Unmanned Aerial Systems as an integral part of a manned-unmanned team

- Develop Cognitive Decision Aiding to manage and interact with UAS over key aspects of the scout-attack mission
- Develop teaming capability for the next generation aviation systems

Product

PART 1: Future Rotorcraft Cockpit Definition

- Gov owned & run intelligent cockpit development environment to assess decision aiding techniques
- Limited user evaluations of decision aiding, multi-UAV supervisory control, OPV/Commanders Role & HMI

PART 2: Advanced Decision Aiding and MUM Technology

- Develop complex decision aiding to manage a MUM team in a future Scout/Attack mission in Gov simulator.
- Implement JCA standards for ease of integration to FVL, JMR and current fleet

PART 3 Flight Demonstration

- Demonstrate manned/unmanned teaming and decision aiding technologies

Payoff

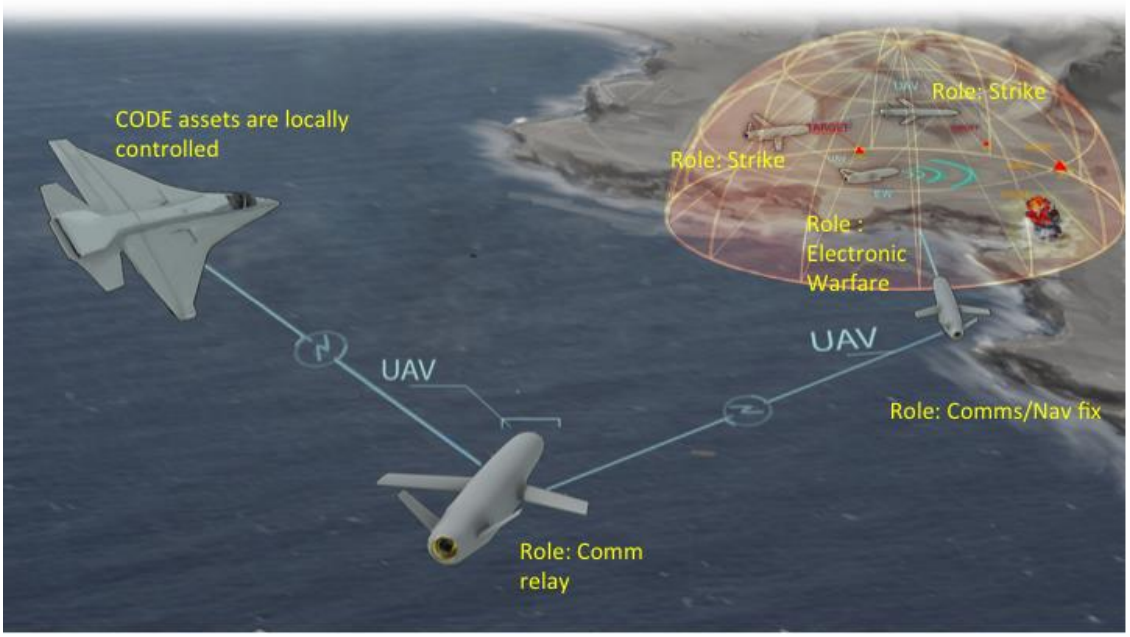
- JCA conformant cockpit the supports advanced decision aiding for MUM teams
- High levels of autonomy to reduce operator workload allowing for tactical MUM teaming
- Help define the future Air Mission Commanders Role
- Cockpit lessons learn will inform FVL and the future fleet

Figure 3-4. The Synergistic Unmanned Manned Intelligent Teaming (SUMIT) Effort

AMRDEC is also working with DARPA on the Collaborative Operations in Denied Environment (CODE) program, which is investigating collaboration not just of a UAS with a manned system but also among a number of UAS with distributed functionality, as illustrated in Figure 3-5. The program is specifically looking at expanding the mission capabilities of UAS through increased autonomy and inter-platform collaboration. In this concept, the manned aircraft serves as the

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mission supervisor, but much of the functionality to prosecute the mission is distributed onto low-cost UAS systems, which operate autonomously unless directed by the mission supervisor. Distributing the functionality improves mission effectiveness and survivability in two ways. First, it greatly complicates threat response and adds another survivability layer around the high-value manned asset that the threat must defeat. Secondly, it allows much of the functionality that would normally be required to be carried on one high-value manned asset off-loaded to relatively inexpensive modular UAS that can be tailored to carry payloads required for a particular mission. This reduces the ratio of cost of potential blue force asset loss to threat cost. At some acceptable low-cost level, the UAS platforms might be considered as "attritable."



Source PM UAS briefing

Figure 3-5. DARPA/AMRDEC Collaborative Operations in Denied Environment (CODE)

The SUMIT and CODE projects are noteworthy and can provide a good basis for the *eventual* development and deployment of semi-autonomous (i.e., supervised autonomy) UAS and collaborative MUM-T. However, greater emphasis and funding will likely be necessary to ensure that "eventual" falls within the 2025-2040 timeframe.

3.4 Survivability/Lethality

Army Aviation rotorcraft are an indispensable component of Army forces and play a critical role in the successful conduct of Army ground combat operations. The survivability, lethality, and overall operational effectiveness of these assets is of paramount importance as they provide attack/reconnaissance capability in support of ground operations, assault capability in moving troops and equipment around the battlefield, logistics support, and medical evacuations. Significant threats to aircraft survivability include enemy man-portable air defense systems (MANPADS), surface-to-air and air-to-air missiles, enemy UAS, electronic warfare and DE threats,

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and small- and medium-caliber projectiles from ground fire in pickup and landing zones. Aircraft survivability against such a broad spectrum of current, emerging, and projected future threats requires the development of synergistic survivability capabilities that include integrated planning, teaming, and both active and passive technologies.

Considerable discussion of rotorcraft survivability against such threats was provided in Section 2.1.1, which particularly emphasized the layered approach to survivability represented by the survivability "onion" depicted in Figure 2-9. Outer layers of the overall approach require capabilities to avoid detection and engagement, which can be achieved through EO/IR and acoustic signature reduction, other advanced technologies, and new CONOPS and TTPs. Improved situational awareness, more effective active countermeasures, and greater aircraft agility/maneuverability can enhance Army Aviation survivability by inhibiting detection and engagement by adversaries. Inner layers of the multi-layered approach are concentrated on avoiding or absorbing damage and avoiding catastrophic destruction, enabling the aircraft to complete its mission and remain available for future service. Armoring selected areas (providing passive protection systems for pilots and critical aircraft components against conventional small- and medium-caliber ballistic threats), incorporating redundancy into the most mission-critical systems, exploiting high-durability and damage-tolerant design features and materials, and various other factors, including advanced TTPs and training, are all important to enhancing survivability. The ability of rotorcraft to operate in degraded visual environments (DVE), discussed in Section 3.1.1 above, can also be expected to contribute to aircraft survivability by reducing aircraft visibility in the visual and IR spectral regions, thereby helping to avoid damage. Coordinated MUM-T operations, discussed in Section 3.3, represent another important potential contributor to future aircraft survivability.

A comprehensive range of integrated survivability capabilities is being actively investigated in Army research and development efforts by AMRDEC's Advanced Development Directorate. The work includes technologies important to all of the survivability layers depicted in Figure 2-9. Detailed discussion of those efforts is beyond the scope of this ASB study, but it may represent an opportunity for a future study focused principally on Army Rotorcraft Survivability and Lethality. Two specific AMRDEC/ADD aircraft survivability programs of note, however, are the Route Optimization for Survivability Against Sensors (ROSAS) program and the Close Combat Survivability (CCS) program.[27] A stated goal of the ROSAS program is to "demonstrate a real-time route planner function to provide rapid and survivable routes to safely evade the full spectrum of dynamic pop-up threats in complex terrain" and enable the aircraft to complete its mission objective. Payoffs include improved situational awareness and increased survivability of warfighters and aircraft against a robust spectrum of threats. Flight demonstrations on a test range of Modular Integrated Survivability (MIS) hardware and software are scheduled for FY2017. The CCS program seeks to develop and demonstrate "next-generation signature-reduction capabilities to delay/deny aircraft acquisition and engagement by the full spectrum of portable threat weapons." The program includes a focus on technologies that provide low rotorcraft

[27] Torrey Deas, "Mission System Survivability Technical Area Program Overview," AMRDEC/ADD briefing to ASB, March 2015.

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contrast against sky and terrain backgrounds under diurnal conditions. It also includes work to design an adaptive IR engine suppressor capability to optimize IR signature reduction and aircraft lift and range performance, as well as to develop real-time aural detection algorithms that include aircraft maneuver data. CSS program advances, which are transitioning into the Signature Reduction for Advanced Threats (SRAT) effort in FY2016, are intended for eventual transition to both the current and future fleet.

Army Aviation lethality principally derives from weapons deployed on Apache AH-64 platforms. The Apache is the Army's primary attack helicopter, described as "a quick reacting, airborne weapon system that can fight close and deep to destroy, disrupt, or delay enemy forces."[28] It was designed to fight and survive both during the day and at night, as well as in adverse weather conditions. Apache armament provides lethal capabilities against a wide range of targets. The most lethal weapon system deployed on the Apache is the 16 AGM -114 Hellfire missiles; up to 16 missiles can be carried in pods mounted on the stub wings. Hellfire variants featuring either tandem shaped charge, blast/frag, or thermobaric warheads are highly lethal/effective against medium- and heavy-armored combat vehicles, buildings, bunkers, and selected other high-value targets. Precision guidance over an effective range that extends out to about 8 km is provided by semi-active laser or mm-wave radar seekers. The lethality of Hellfire missiles has been demonstrated in recent combat operations in the Persian Gulf, Afghanistan, and Iraq.

Other highly lethal armament deployed on AH-64 Apaches include 70mm (2.75-inch) Hydra rockets, a 30mm M230 chain gun, and AIM-92 Air-to-Air Stingers (ATAS). The Hydra rockets provide lethal effects against enemy personnel, light armored vehicles, and other soft materiel targets; up to 76 rockets can be carried in pods mounted on the Apache stub wings. The M230 chain gun is an area weapon system providing accurate air support with minimal collateral damage. It produces lethal effects on various light- and medium-armored vehicles, enemy personnel, and other ground targets. The gun fires 30mm High Explosive Dual Purpose (HEDP) M789 ammunition to ranges of about 3 km with both significant penetration and fragmentation effects; lethal radius against unprotected, standing enemy combatants is about 3 m. Ongoing work at ARDEC is developing an M789 upgrade that will enhance M230 chain gun lethality by incorporating proximity fuzing and controllable air burst capabilities. The AIM-92 Stingers, which were developed from the shoulder-launched ground-to-air FIM-92 Stinger system, contain a blast/frag warhead with lethal capability against enemy fixed-wing and rotary-wing aircraft. Figure 3-6 shows the weapons loadout for an Apache AH-64. All of these systems are carried externally. As the Army transitions to higher speed rotorcraft, more aerodynamic designs will be required; effective means of internal carry must be incorporated into new platform designs.

[28] Global Security, "AH-64 Apache," downloaded February 2016 from http://globalsecurity.org/military/systems/aircraft/ah-64.htm

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Figure 3-6. Weapons Loadout for AH-64 Apache

The Black Hawk UH-60 is the Army's front line utility helicopter used for troop transport, air cavalry, aeromedical evacuations, and selected other missions. Lethal capabilities for most Black Hawks are provided by two pintle-mounted M60D or M240H 7.62mm machineguns located at the crew chief and gunner stations. The rate of fire for these weapons, which provide self-defense and fire-suppression capabilities, is about 600 rounds/min for the M60D and 750 rounds/min for the M240H. Their effective range is about 1100 meters.[29] Black Hawks fitted with the External Stores Support System (ESSS), which incorporates two stub wings each containing two hard points, provide significant potential for enhancing platform lethality by enabling deployment of an impressive array of additional armament. The enhanced lethal capabilities of such Black Hawks is reflected in the MH-60M Blackhawk, a highly specialized UH-60 variant developed for both assault and attack missions by Special Operations forces. The MH-60M is capable of carrying Hellfire missiles, air-to-air Stinger missiles, 70mm (2.75-inch) Hydra rockets, medium-caliber gun pods, or the Volcano minefield dispersal system. Additional armament can include two 7.62mm M134 Miniguns, forward facing, used for self-defense and landing zone fire suppression; the M134 is capable of firing up to 6000 rounds/minute and has an effective range of about 1000 meters.[30] Figure 3-7 shows an MH-60M Black Hawk firing a salvo of 2.75-inch rockets.

[29] Operator's Manual for Helicopters, Utility Transport, TM 1-1520-280-10, HQDA, 14 August 2009, Distribution D.

[30] American Special Ops, "MH-60M Black Hawk Helicopter," downloaded February 22016 from http://www.americanspecialops.com/night-stalkers/helicopters/mh-60.php

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Figure 3-7. MH-60M Black Hawk Firing a Salvo of 2.75-inch Rockets

The primary mission of Chinook CH-47 aircraft is to provide transport of troops, artillery placement, and battlefield resupply of ammunition, fuel, water, barrier materials, and other supplies and equipment. Other missions may include medical evacuation, aircraft recovery, firefighting, parachute drops, heavy construction, disaster relief, and search and rescue operations. CH-47 lethality is provided by pintle-mounted M60D or M240 7.62mm machineguns mounted in the forward right cabin door, left cabin escape hatch, and at the rear loading ramp to provide self-defense and fire-suppression capabilities similar to the Black Hawk UH-60. As noted for the Black Hawk, the rate of fire for these weapons is about 600 rounds/min for the M60D and 750 rounds/min for the M240H, with an effective range of about 1100 meters for both weapons.[31] The accuracy of some of these guns may be enhanced by co-aligned IR and visible lasers. The IR laser is intended to be used with night vision devices.

Additional lethal capabilities provided by Army Aviation are associated with the current and potential future use of UAS, MUM-T, and DVE. Gray Eagle is currently the only unmanned aircraft system deployed by the Army that carries armament. The aircraft has four hard points that can carry Hellfire AGM-114 missiles that are particularly effective against enemy main battle tanks and other hard, high-value targets. They provide a lethality complement to Apaches while eliminating the risk to Apache aircraft and crew. Small UAS swarms, under consideration for future development, can add an exciting advanced capability to air/land combat operations when

[31] Technical Manual, Operator's Manual for Army CH-47F Helicopter, TM 1-1520-271-10, HQDA, 18 December 2013

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new CONOPS and TTPs are developed to exploit their potential. UAS and coordinated MUM-T operations, discussed in Section 3.3 and including the SUMIT and CODE efforts, will also add a new facet to Army Aviation lethality. As previously noted, the AH-64E currently has the capability to control the Shadow and Gray Eagle flight path and payload. In addition to enhancing Army Aviation survivability, emerging DVE capabilities, discussed in Section 3.1.1, also offer important potential lethality benefits. The stated goal of the RDECOM/AMRDEC DVE-Mitigation (DVE-M) program is "to convert DVE into a combat multiplier," to create an advanced capability that enables commanders "to conduct operations deliberately in DVE with confidence" and ensure that their mission will be successful. DVE can provide a disruptive capability advance help "to maintain an asymmetric advantage on the battlefield, much like night vision technology."[32] Such an advantage will clearly enhance overall Army Aviation lethality.

Over the past decade, directed energy weapons have made significant technological advances in terms of power and effectiveness. One specific DE technology showing particular promise is optical fiber lasers, which are energy efficient, compact, and experiencing significant continuing technical advances. Such directed energy weapons have an "infinite" magazine and reach targets at the speed of light. It is important to note that both allies and potential adversaries have the technological capability to develop and field capable directed energy weapons, with both offensive and defensive applications. The Army should strategically plan for and embrace the future deployment of directed energy weapons on different types of Army Aviation platforms for both survivability and lethality purposes.

3.5 Platform Technology

3.5.1 Overview

The platform technologies S&T portfolio is designed to explore, develop, and transition critical technologies that enhance the performance, effectiveness, affordability, and survivability of Army Aviation. The ASB considers the portfolio to be generally well-balanced for manned systems; ongoing engine programs are especially well structured. There are two big-picture recommendations that clearly need to be implemented moving forward:

1. For manned systems, Army Aviation platform technologies must continue to be developed to support not only the modernization of the legacy fleet but also future vertical lift, especially in light of the ASB Recommendation Set #5, FVL with Speed and Simplicity. (See Section 4.5)
2. In light of the ASB Recommendation Set #3, UAS Vehicles, the platform technologies portfolio must be expanded and/or redirected to provide more focus on unmanned systems (see Section 4.3).

Five objectives have been laid out by AMRDEC for platform technologies that are designed to provide significant payoffs, including increased mission radius, increased payload capability, reduced O&S costs, decreased maintenance downtime, increased mission availability, and

[32] Kristofer Kuck, "RDECOM Rotorcraft DVE-Mitigation (DVE-M) Program," AMRDEC/ADD briefing to ASB, 17 March 2015.

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improved crew protection/survivability. As mentioned earlier, the ASB considers this portfolio to be reasonably balanced for manned systems and, with proper focus, many of the efforts can support unmanned platforms as well. These five objectives are:

1. Improve the weight, noise, and durability and cost of rotorcraft drive systems;
2. Improve the power-to-weight ratio, specific fuel consumption, durability and cost of turboshaft engines;
3. Provide lightweight, durable, and reliable structures for extreme environments and high op-tempo scenarios;
4. Improve crashworthiness and aircrew protection from conventional threats and directed energy weapons;
5. Reduce sustainment costs by providing usage-based designs, health-based adaptive controls, prognosis-based inspections/maintenance scheduling, and reliable designs.

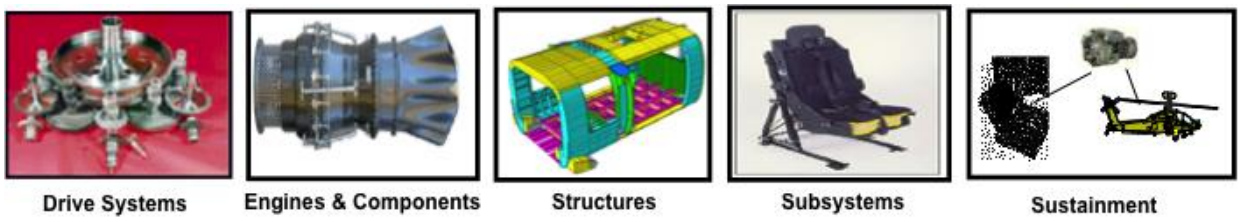


Figure 3-8. The Five Focus Areas for Army Aviation Platform Technologies

3.5.2 Drive Systems

Army Aviation's drive system S&T portfolio, described in Figure 3-9, consists of the Future Advanced Rotorcraft Drive System (FARDS) and the Next Gen Rotorcraft Transmission. As summarized in the figure, FARDS provides the aircraft drive train designers with a wide variety of validated approaches for significantly improving hp/wt ratio and reducing noise and cost compared to the existing fleet. These approaches are being achieved through advances in gearing, lubrication, housings, bearings and shafting, and materials. As the technologies mature, they are expected to transition to UH-60 and OH-58 upgrade programs.

The Next Gen Rotorcraft Transmission program is consistent with the Joint OSD Advanced Variable Speed Aircraft Transmission (AVSAT) program. Key program objectives are to demonstrate speed changing concepts (100-50% range), increase Oil Out Time by 50%, reduce O&S costs by 40%, and increase component life by 2000 hours. Transition targets are the current fleet as well as FVL. Figure 3-10 shows the Rotorcraft Drives Technical Area Roadmap.

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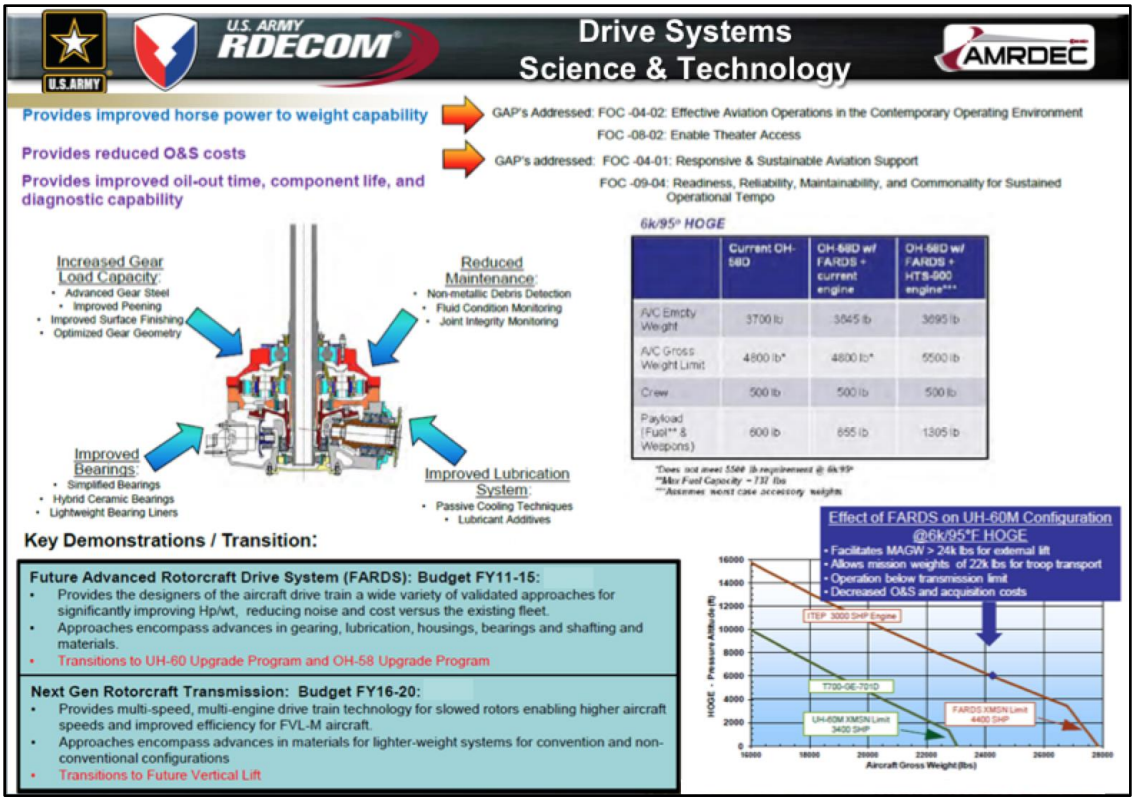


Figure 3-9. Army Drive Systems Science & Technology

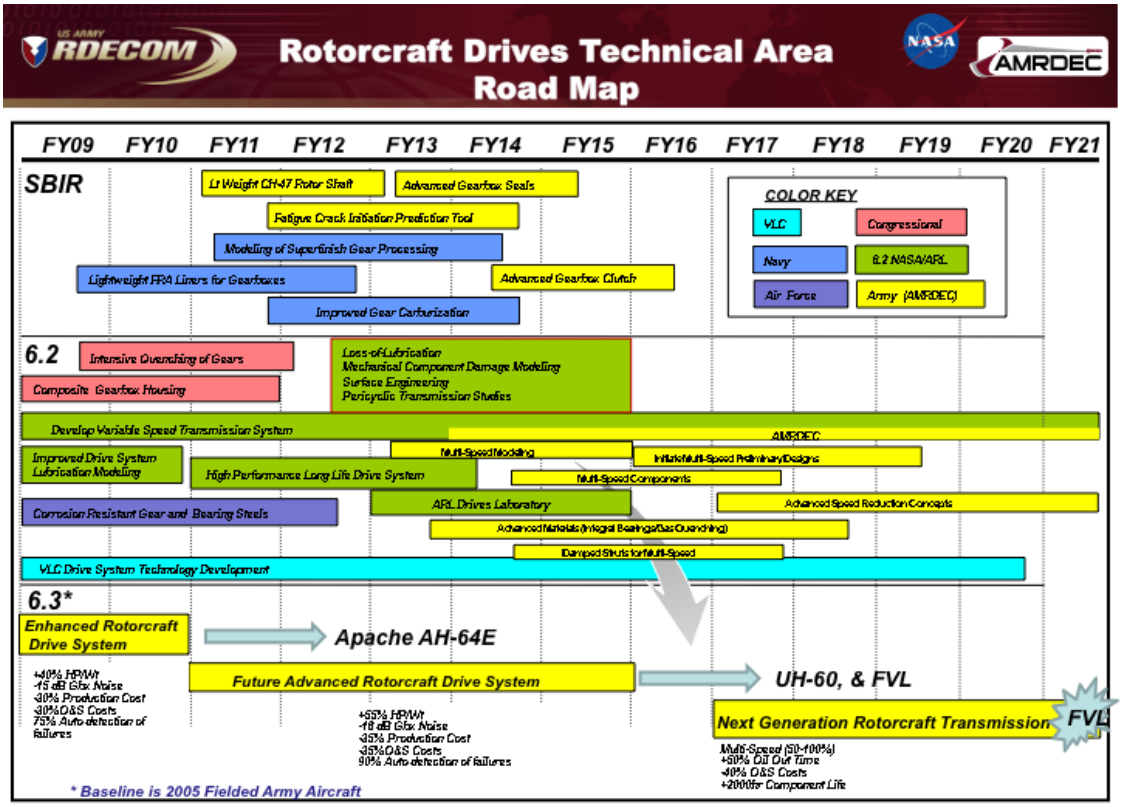


Figure 3-10. Rotorcraft Drives Technical Area Road Map

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3.5.3 Engines and Components

The ASB is very supportive of the Army engine programs and believes that continuing participation in the ITEP/AATE/FATE/Alternative Concept Engine initiatives should remain a high priority. These programs are leading to superior mission capability for current and future rotorcraft, as well as for increased energy efficiency and significant O&S cost reduction, which is important since engines are the top rotorcraft O&S driver. Figure 3-11 provides an overview of the Army Engine Science and Technology initiative showing gaps being addressed and future engine attributes. Figure 3-12 provides an overview of engine technology development from component development at the 6.2 Applied Research level to engine/component qualification programs at the 6.4 Advanced Component Development and Prototypes level and on to transition to legacy aircraft and FVL. Figure 3-13 provides details on the AATE program from its purpose to develop advanced affordable 3000-hp class turboshaft engine technology for Black Hawk, Apache, and FVL aircraft to the payoffs of improved payload and hot/high engine capability, as well as reduction in production and maintenance cost and logistics footprint. An example of the superior mission capability that will be achieved for current rotorcraft is discussed in Section 4.4 Modernization of Legacy Rotorcraft Systems, where insertion of ITEP/FATE engine technology into a Black Hawk platform provides a dramatic increase in range/payload. The Army Engine S&T roadmap is also presented in Section 4.4.

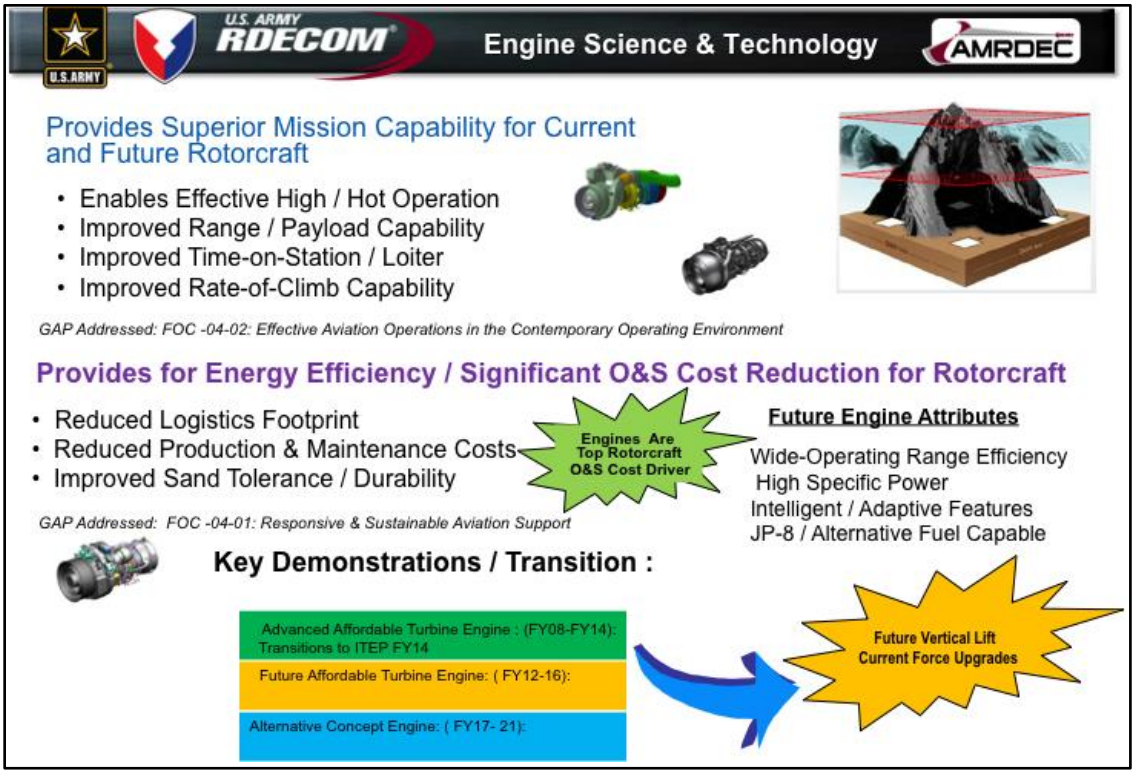


Figure 3-11. Army Engine S&T Showing Gaps Addressed and Future Engine Attributes

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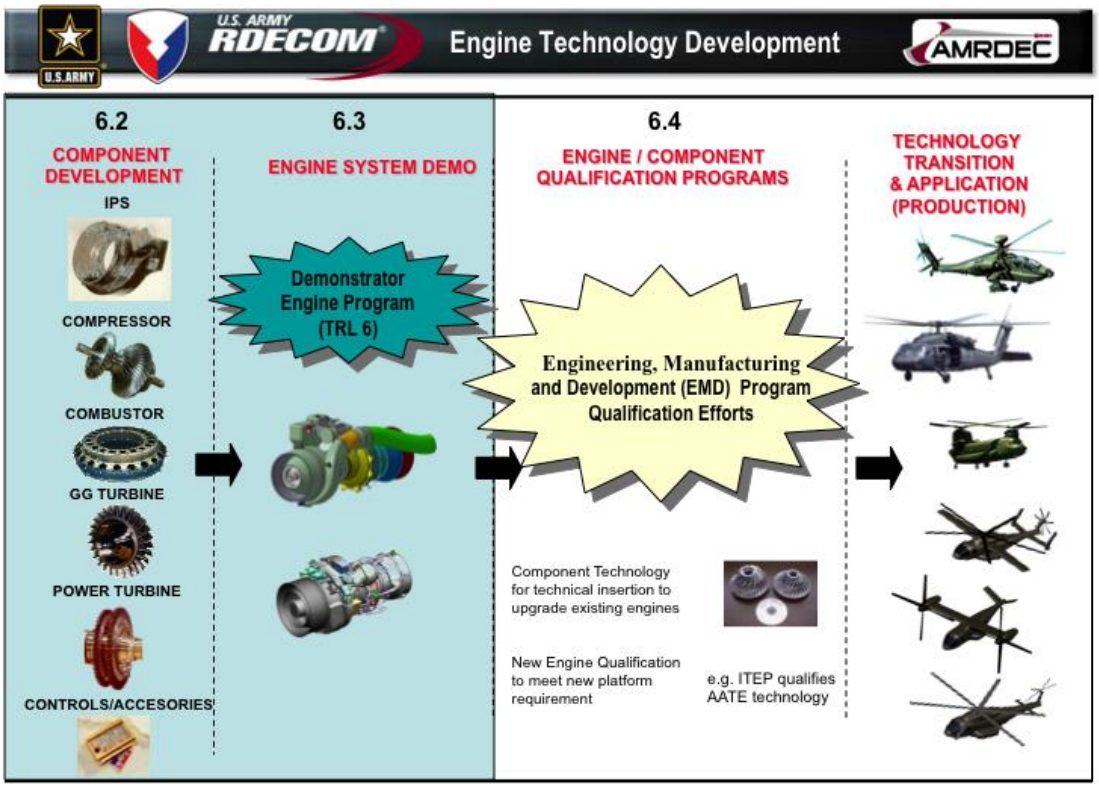


Figure 3-12. Engine Technology Development

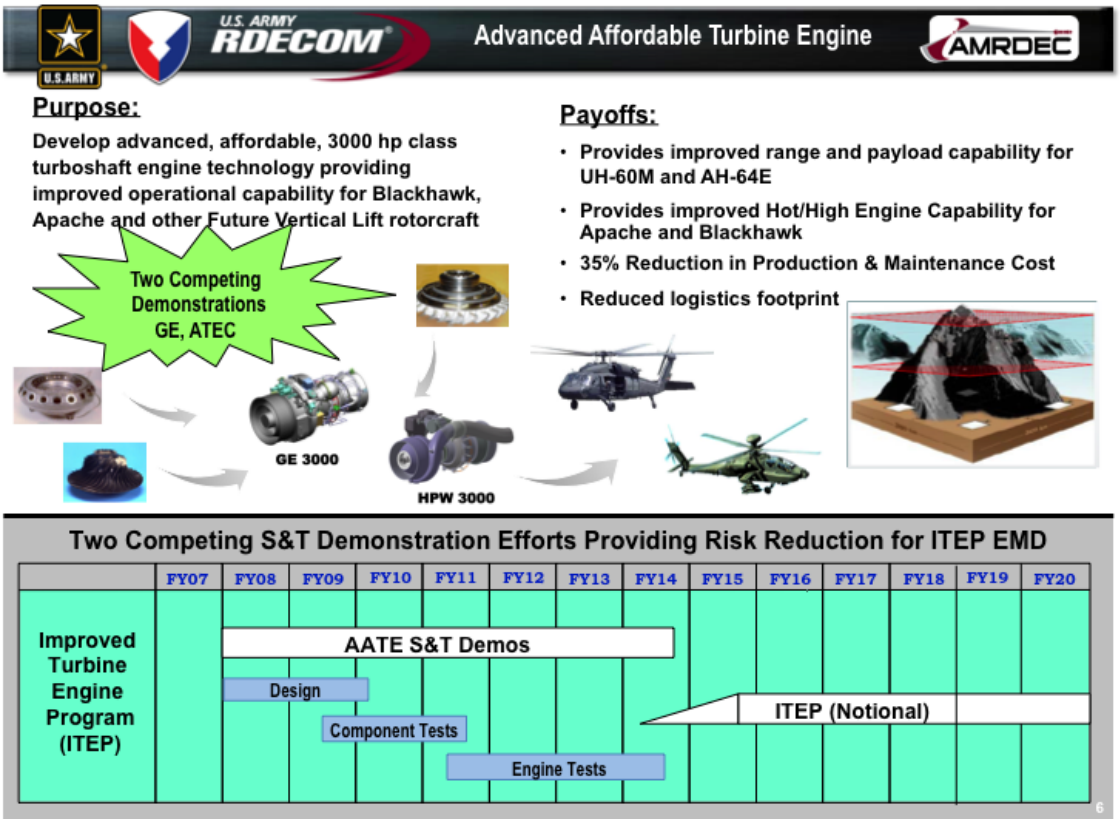


Figure 3-13. Advanced Affordable Turbine Engine (AATE), Purpose and Payoffs

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3.5.4 Structures, Subsystems, and Sustainment

AMRDEC has extensive platform programs focused on structures, subsystems, and sustainment that the ASB considers to be well-balanced for manned systems. Figure 3-14 presents the Structures S&T Roadmap out to FY2020, which shows how the structures S&T portfolio supports the JMR demonstrator. Figure 3-15 provides the Subsystems Roadmap with an overview of the subsystems portfolio, which has a strong focus on aircrew survivability technologies. Figure 3-16 provides the Operations and Sustainment S&T Roadmap extending from capability-based operations and sustainment to autonomous sustainment for rotorcraft operations, and finally moving toward embedded rotorcraft sustainment technologies. Information regarding the Army sustainment efforts in the context of condition-based maintenance and near-zero maintenance aircraft are provided in Section 3.2. Ongoing RDT&E activities pertinent to the development of CBM capabilities are summarized in Appendix E.

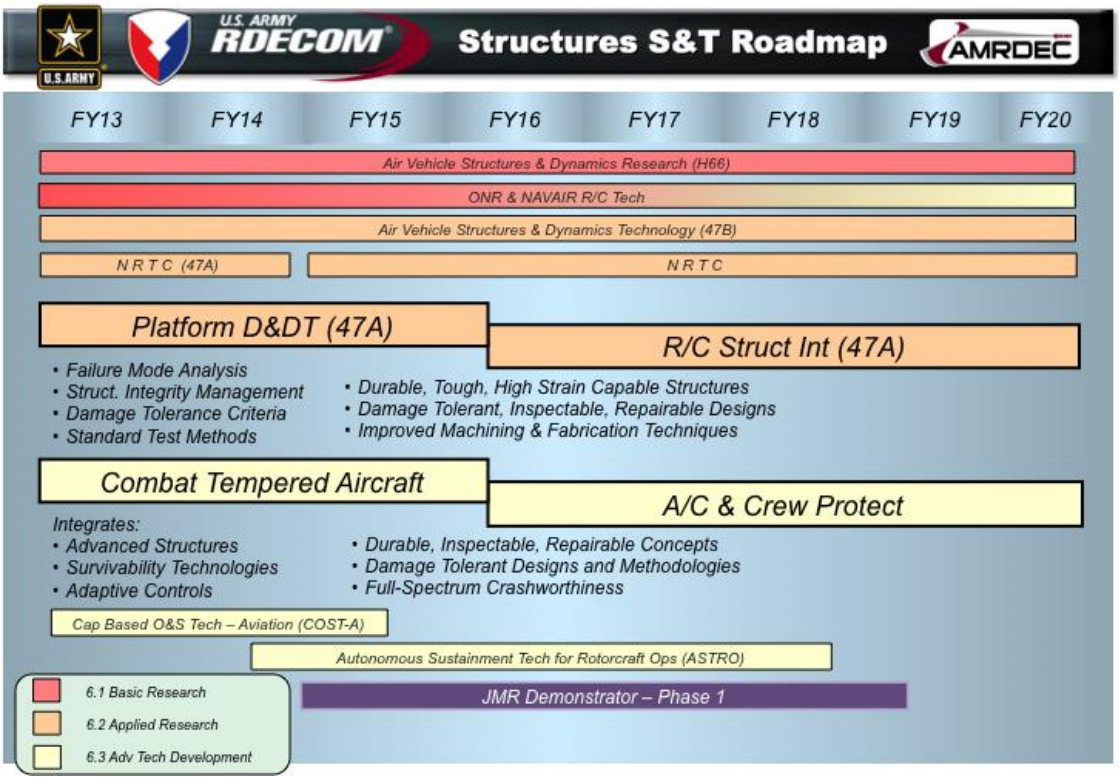


Figure 3-14. Structures S&T Roadmap

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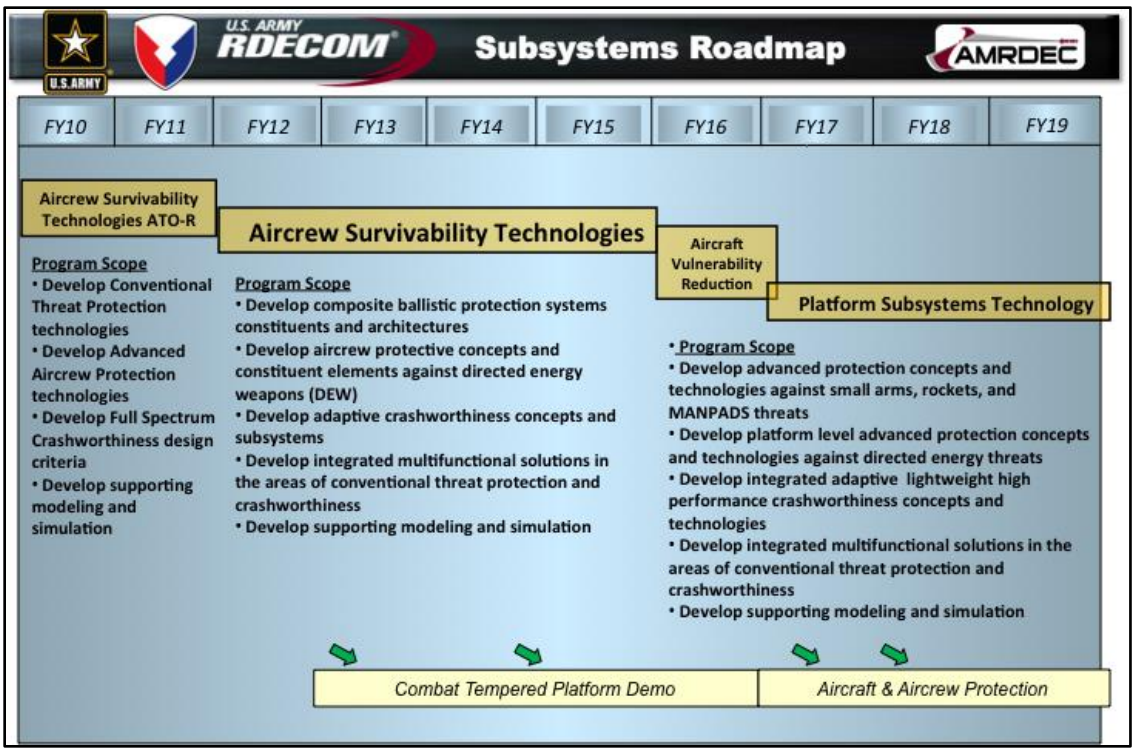


Figure 3-15. Subsystems Roadmap

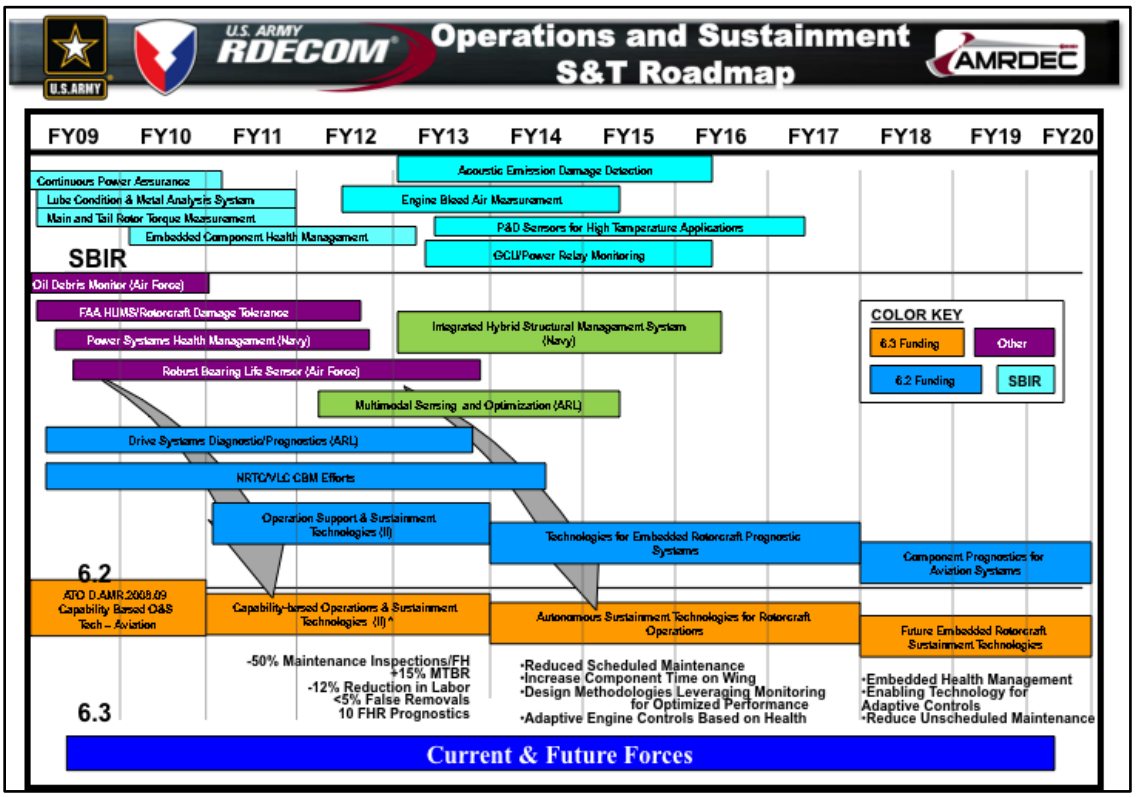


Figure 3-16. Operations and Sustainment Roadmap

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4 FINDINGS & RECOMMENDATIONS

Based on the information collected, the study team developed findings and recommendations on nine topics, as summarized in Figure 4-1.

Context: Character of Warfare in 2025 and Role of Army Aviation

1. System of Systems Operational Effectiveness Analyses
2. Affordability of Heavy Vertical Lift

Addressing Capability Gaps: Development and Acquisition

8. UAS Vehicles
9. Modernization of Legacy Rotorcraft Systems
10. FVL Acquisition with Speed and Simplicity
11. Aviation Mission Systems
12. Aviation Systems Integration and Testbed

S&T Portfolio: Innovation and Game Changers

10. Advanced and Disruptive Systems S&T
11. S&T Investment Strategy

Figure 4-1. Findings and Recommendations Overview

4.1 System of Systems Operational Effectiveness Analyses

The critical challenge to Army Aviation posed by the proliferation of threats was discussed in Section 2. These threats span the spectrum from sophisticated next-generation air defenses to capabilities that utilize widely available inexpensive assets, such as swarms of small Unmanned Aircraft Systems (UAS). The continued advancement and proliferation of MANPADS and SAM systems is of particular concern. The current approach to survivability of Army Aviation systems is based on a multi-layered approach centered on the platform. The outer layer involves systems and techniques to avoid detection by a threat system, the next layer to avoid engagement by the threat, and so on. This "onion" approach has served well in the past. However, next-generation threats, and the proliferation of these advanced threats, calls into question how much longer this platform-centric approach can remain effective.

One approach to solving this platform-centric dilemma is a system-of-systems (SoS) concept, which effectively adds another layer to the "onion" outside of the platform itself. A limited number of elements of the SoS concept are already being implemented by means of the fusion of off-board information with on-board data and the recent upgrade of AH-64 to include Level 4 MUM-T capability with Shadow. However, a more robust vision for the future that takes fuller advantage of collaboration between manned and unmanned systems is required to drive SoS solutions that fully exploit the synergy of unmanned systems operating in collaboration with the manned platform at the center of the "onion." Supervised semi-autonomous UAS can provide another layer to the onion.

Based on these findings, the first study recommendation is to conduct an SoS operational effectiveness analysis, as detailed in Figure 4-2. This analysis will result in a definition of the future

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Army Aviation architecture and CONOPS for effective operations against the intense threat environment that exists now and that will only become more challenging in the 2025-2040 timeframe. This analysis must consider and fuse all elements of the Joint integrated battlespace illustrated in Figure 4-3. All other recommendations of this study are dependent upon a firm foundational knowledge of the architecture and CONOPS resulting from this analysis.

Findings

- Increasing threat sophistication and proliferation (e.g., missiles, UAS, cyber, and directed energy) pose critical concerns. (Classified annex provides additional details)
- Platform-centric survivability must evolve to a manned-unmanned system-centric approach with new CONOPS and TTPs.
- A system of systems architecture should include manned-unmanned teaming, supervised autonomous systems, and secure communications.

Recommendation

- TRADOC: Conduct operational effectiveness analyses of potential system of systems concepts in a cost-constrained environment that address capability gaps for Army Aviation in 2025 and beyond in complex threat environments. Concepts should include holistic air-ground approaches, high/low mixes of collaborative manned/unmanned systems, FVL performance characteristics, higher levels of autonomy, PNT in GPS-denied environments, attritable UAS assets and enhanced lethality of DE. Develop CONOPS and architectures for the most cost-effective concepts.

Figure 4-2. Findings and Recommendation Set #1

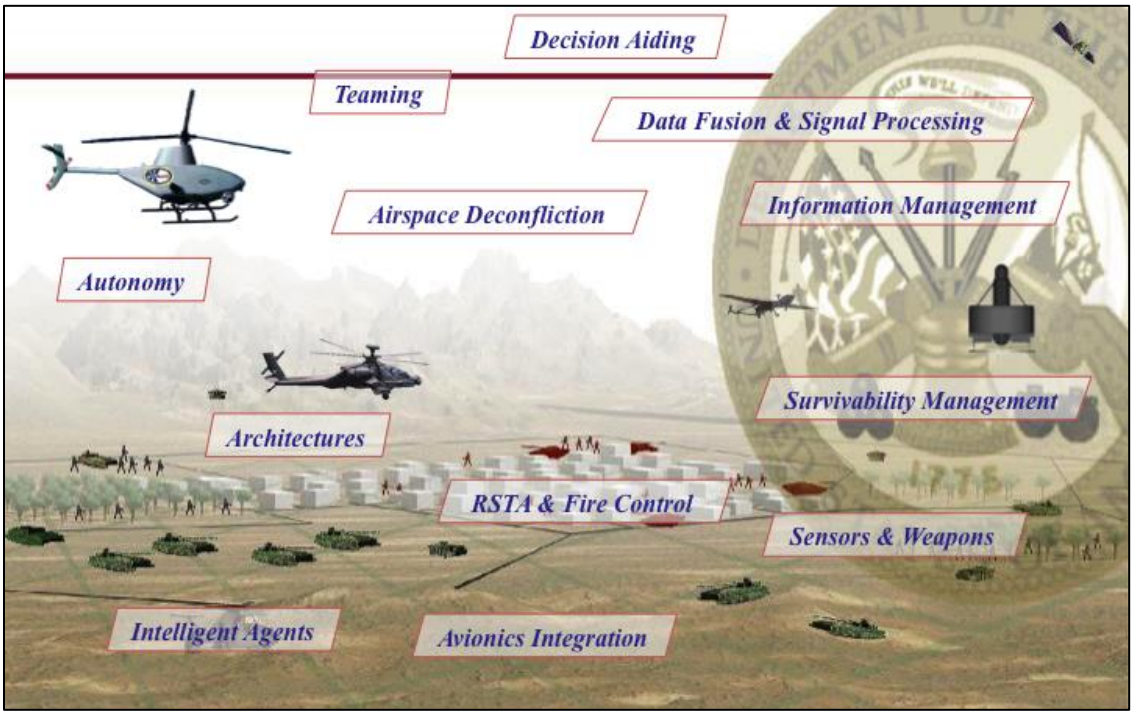


Figure 4-3. Notional Integrated Battlespace

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4.2 Affordability of Heavy Vertical Lift

The pressing challenge for Army Aviation systems to satisfy the need for strategic, expeditionary, and operational maneuver of dispersed mechanized forces in austere areas of operation in the face of capable anti-access and area denial (A2/AD) threats in future conflicts was discussed in Section 2. Current Army Aviation assets cannot provide the heavy vertical lift (20-30 stons) needed for expeditionary and operational maneuver of *mechanized* dispersed forces. This need has been detailed in numerous studies, exercises, and wargames, including the 2014 Army Unified Quest exercises,[33] the 2014 ASB study on Strategic and Expeditionary Maneuver,[34] and the 2012 Army-Marine Corp Concept.[35] The capability needs for this class are documented in the Joint Future Vertical Lift (JFVL) ICD as well as the Joint Heavy Lift (JHL) ICD.



Figure 4-4. Historical Heavy Vertical Lift Options

While the capability need for a vertical heavy lift system is well documented, it is clear that the Army cannot afford to develop such a capability within current or anticipated Army TOA for the foreseeable future. Therefore, the Army may have to rely on interim solutions to providing a partial capability (see Figure 4-4). The recommendation resulting from these findings, detailed in

[33] Army Capabilities Integration Center, *Unified Quest 2014 Executive Report,* 12 Mar 2015, http://www.arcic.army.mil/Library/documents.aspx.

[34] Army Science Board, *ASB FY2014 Summer Study - Decisive Army Strategic and Expeditionary Maneuver,* July 2014.

[35] Army Capabilities Integration Center and Marine Corps Combat Development Command, *Gaining and Maintaining Access: An Army-Marine Corps Concept*, Mar 2012.

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Figure 4-5, calls for TRADOC to reassess interim and future Joint heavy vertical lift options to determine a viable road ahead.

Findings

- Heavy vertical lift (20-30 stons) is required by the Army CONOPS for expeditionary and operational maneuver, validated by JROC (documented in the FVL and JHL ICDs) and supported by Unified Quest 2014, and "2012 Gaining and Maintaining Access: An Army-Marine Corps Concept."
- However, development of a new system is cost prohibitive within likely future Army modernization (RDA) funding before 2040.
- Interim solutions able to provide more limited capability are available (e.g., CH-53K at 18 stons, and Joint Precision Air Drop System – JPADS) and could provide viable options.

Recommendation

- TRADOC: Assess interim and future HVL options for meeting Army CONOPS and documented JCIDS capability needs for expeditionary and operational maneuver and recommend road ahead
  - If development of HVL is cost prohibitive, consider alternatives.
  - If there are no plans for HVL, do not assume it is available in analyses, wargames, and exercises.

Figure 4-5. Findings and Recommendation Set #2

4.3 UAS Vehicles

As discussed previously in Section 2, UAS can and should play a significant and expanded role in future Army Aviation CONOPS. Although the Army UAS Roadmap[36] cites plans to upgrade current platforms and eventually to develop replacements for some, it lacks a clear vision for expanding the use of UAS as complements and extensions to manned aviation, rather than simply as stand-alone single mission (ISR) systems. Expanding the mission set and increasing autonomy for UAS are identified as far-term objectives in the roadmap, but very limited funding is currently allocated to achieving these objectives. In contrast to the Army Aviation UAS roadmap, the USAF and USN/USMC have bold visions for expanded roles/missions for UAS and greater use of collaborative MUM-T.

The rapidly advancing technologies associated with UAS, autonomous systems and MUM-T should be viewed as a significant opportunity for Army Aviation to better integrate collaborative manned-unmanned capabilities into its future force. Concepts similar to the distributed functionality SoS concept in Figure 4-6 are critically important to the survivability and lethality of Army Aviation and require a focus on introducing new UAS designs into the Army Aviation inventory and effectively integrating these new assets into a collaborative manned-unmanned environment. A major challenge in expanding the Army Aviation UAS portfolio, increasing MUM-

[36] US Army UAS Center of Excellence, "*Eyes of the Army," U.S. Army Unmanned Aircraft Systems Roadmap 2010-2035*, 2010, http://www-rucker.army.mil/usaace/uas/us%20army%20uas%20roadmap%202010%202035.pdf .

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T capabilities, and meeting a bold vision, however, is the small percentage of Army S&T funding allocated to UAS developments.

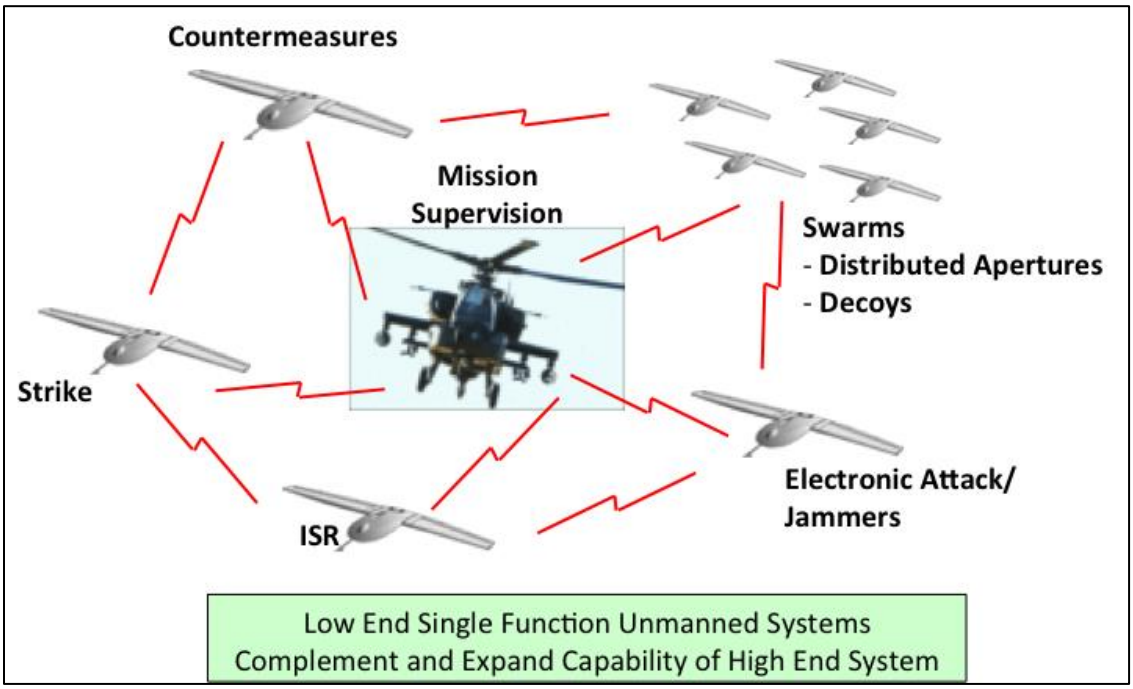


Figure 4-6. Distributed Functionality Collaborative System of Systems Concept

The ASB recommendation in this area, detailed in Figure 4-7, is for ASA(ALT) to review and revise the UAS roadmap as necessary to identify and embed near-term and future UAS that are capable of satisfying the Army Aviation SoS architecture and CONOPS that will emanate from the SoS operational effectiveness analysis (Recommendation Set #1).

Findings

- The USN/USMC and USAF have strong visions for the expanding role of UAS and manned-unmanned teaming in aviation missions.
- DARPA, USN/USMC and USAF are investing in next generation UAS technology options that offer potential capability for Army Aviation.
- New UAS are needed to fully exploit manned–unmanned synergy and collaboration of manned systems with supervised autonomous systems within a system-of-systems architecture.

Recommendation

- ASA(ALT): Revise UAS Roadmap to expand near-term and future UAS vehicle options, some of which should be compatible with speed, hover, and range of current and future manned aircraft, with attributes compatible with distributed functionality among UAS (ISR, Lethality, …) as informed by the results of system of systems operational effectiveness analyses (Recommendation Set #1)

Figure 4-7. Findings and Recommendation Set #3

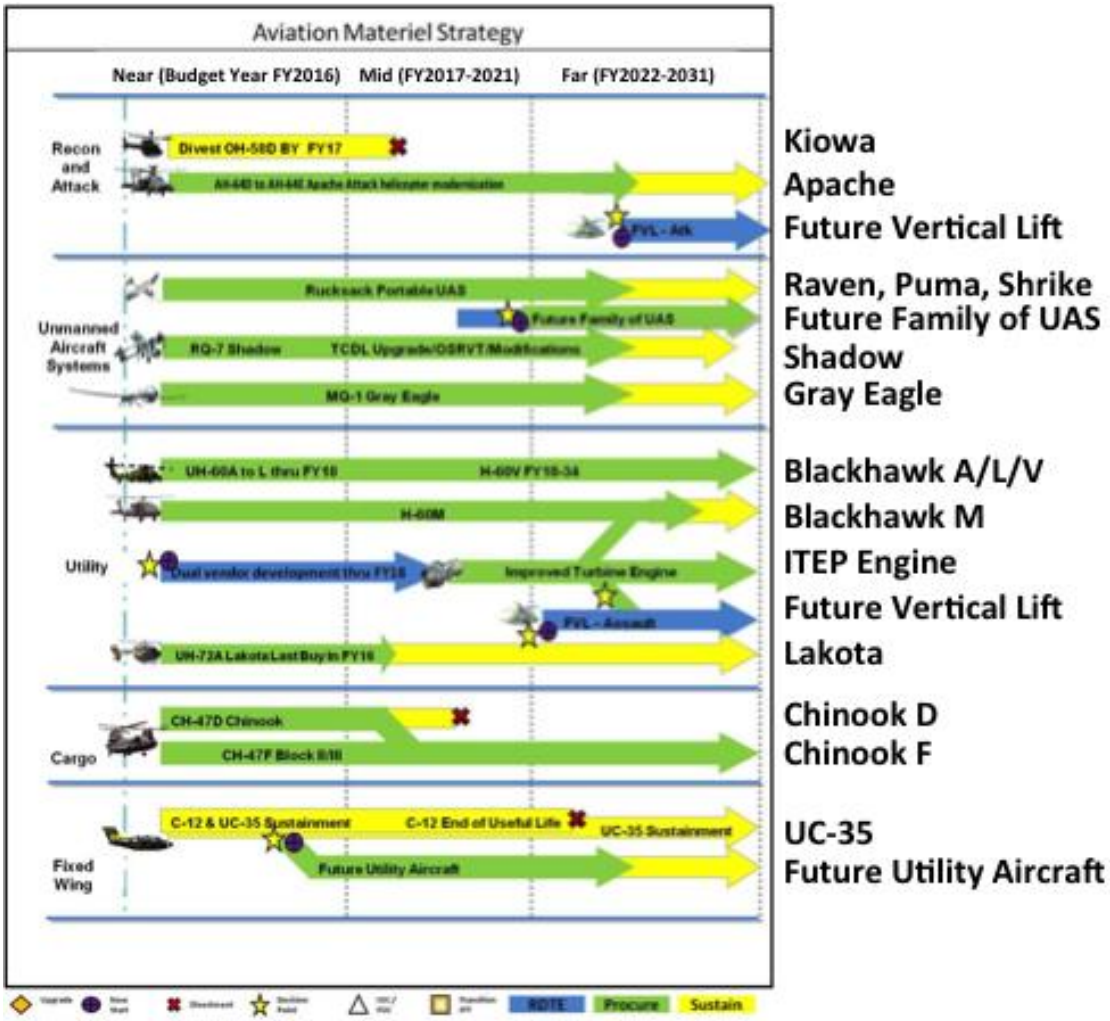
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4.4 Modernization of Legacy Rotorcraft Systems

Army Aviation is continually faced with the challenge of trying to achieve an optimal balance of its R&D investments committed to modernizing/upgrading legacy rotorcraft platforms and developing new systems that offer expanded performance capabilities and reduced sustainment compared to current systems. The Future Vertical Lift (FVL) Family of Systems (FoS) represents the future of Army Aviation manned (and optionally manned) rotorcraft systems. FVL is currently an initiative within the Army Aviation S&T portfolio and is not expected to become a Program of Record (POR) until after the current Program Objective Memorandum (POM). Therefore, if the program were to follow normal DoD acquisition processes for an ACAT I Major Acquisition Program and the Planning, Programming, Budgeting and Execution (PPBE) processes, an Initial Operating Capability (IOC) for FVL would not be expected until the mid-2030s. After IOC, at historical Army Aviation procurement funding levels, it will take roughly 30-40 years to replace the legacy platforms.

It is expected, therefore, that legacy rotorcraft systems (AH-64, CH-47 and UH-60), which are all 1960-1970 vintage designs, will remain deployed until at least 2060. This century-long platform life would be rivaled only by the B-52 bomber, which has been re-purposed from its original mission to extend its utility. These Army rotorcraft platforms have undergone several upgrades over their lifetimes, and the Army plans to continue modernization of these platforms until FVL is deployed (Figure 4-8).

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Source: Army Equipment Program in Support of President's Budget 2016.

Figure 4-8. The Army Plans to Retain Legacy Systems Far Into the Future

However, since it will take several decades of FVL procurement to replace all legacy platforms, at least one more major upgrade to these systems will be required beyond those currently in progress or funded within the POM for them to remain operationally effective against the evolving threat. Fortunately, several significant technology initiatives within the Army Aviation S&T portfolio apply to both legacy and future manned systems. These technologies include ITEP/FATE engine insertion, DVE capabilities, CBM/PHM capabilities, ASE improvements, and greater MUM-T. The RDECOM advanced aircraft engine program (see Figure 4-9) is a perfect example of the type of dual-purpose technology program that yields benefits to both future and legacy aviation systems. The operational utility of inserting ITEP/FATE engine technology into a legacy system is illustrated in Figure 4-10 by the dramatic increase in range/payload of the Black Hawk platform. The vertical dashed line (at a radius of 200 km) in the figure illustrates a doubling of payload capacity in transitioning from the current engine to the ITEP engine.

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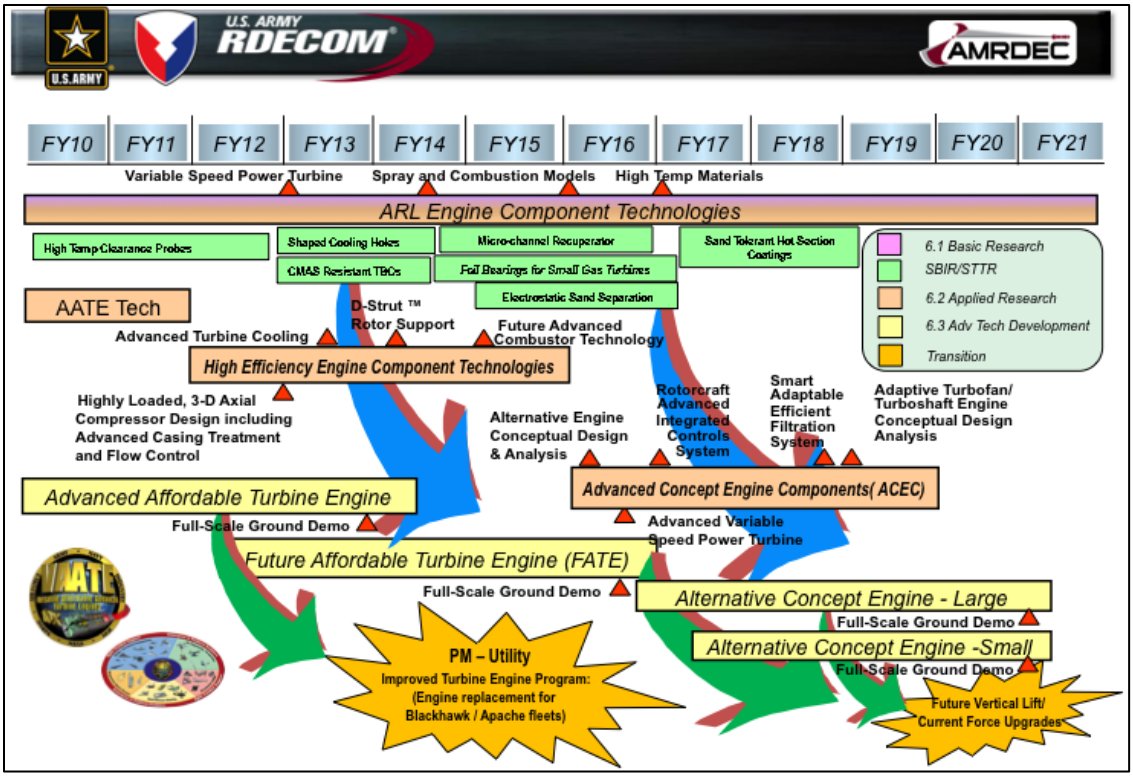


Figure 4-9. Army Aircraft Engine S&T Roadmap

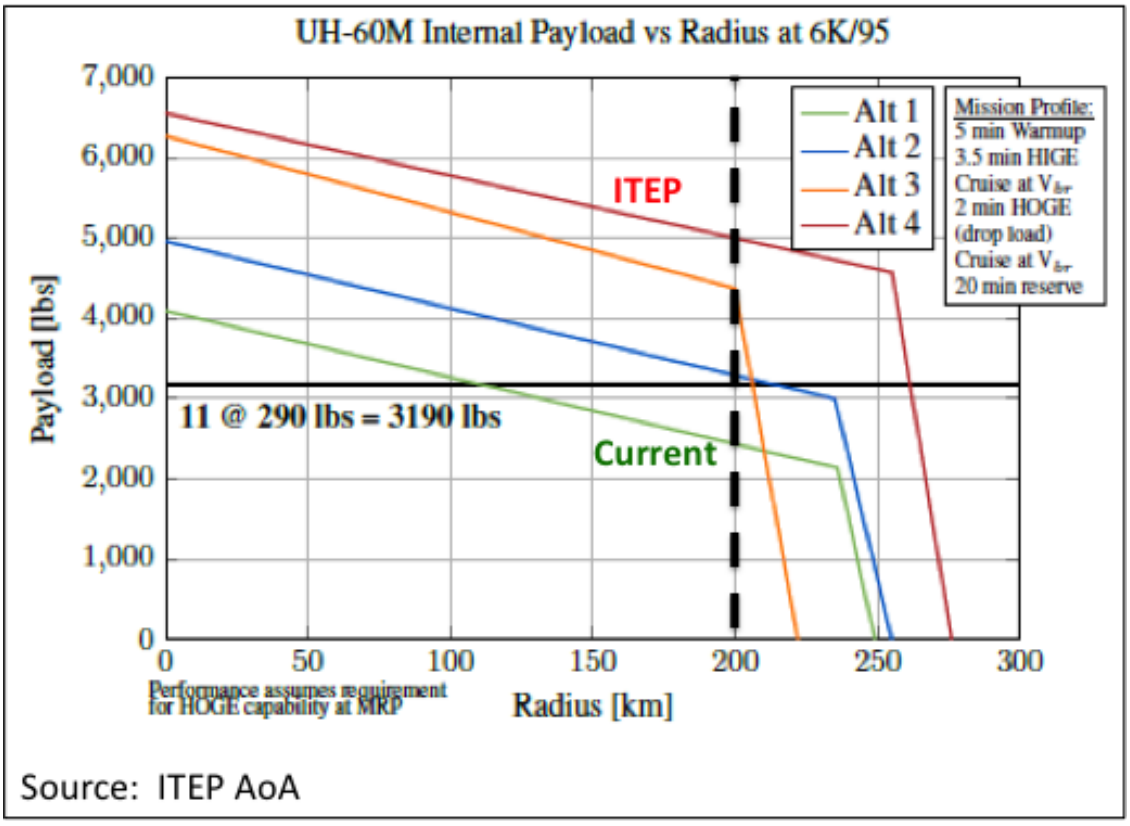


Figure 4-10. ITEP Provides Significant Improvement in Performance of Legacy Platforms

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The recommendation resulting from these findings, detailed in Figure 4-11, is to continue S&T investment in dual use technology programs that benefit legacy systems as well as FVL.

Findings

- Legacy rotorcraft systems (AH-64, CH-47 and UH-60) are expected to remain deployed until at least 2060, requiring modernization investment.
- Within the current limited budget, Army Aviation S&T is investing in technologies that apply to both legacy and future manned systems.
- These technologies include: ITEP/FATE engine insertion, DVE capabilities, CBM/PHM capabilities, ASE improvements, and greater MUM-T.

Recommendation

- ASA(ALT): Continue S&T and road-mapping efforts for modernizing legacy systems with emphasis on those technologies that are also applicable to future aircraft, as informed by the results of system of systems operational effectiveness analysis (Recommendation 1).

Figure 4-11. Findings and Recommendation Set #4

4.5 FVL Acquisition with Speed and Simplicity

The current FVL schedule, which is driven by funding constraints as well as technology maturation, does not lead to an IOC of the *first FVL* variant (most likely the FVL-Medium replacement for either AH-64 or UH-60) until the mid-2030 timeframe (see Figure 4-12). After IOC, given anticipated procurement budget constraints, it will take a decade or two to replace the legacy system. It must be emphasized that this schedule applies only to the first FVL variant. Funding constraints will limit development, test and procurement of the second and third variants to later timeframes. The study team noted that an opportunity exists to perform an Analysis of Alternatives (AOA) between MDD in October 2016 and Milestone A in 2019. Flight data would be collected during this period to support the AoA.

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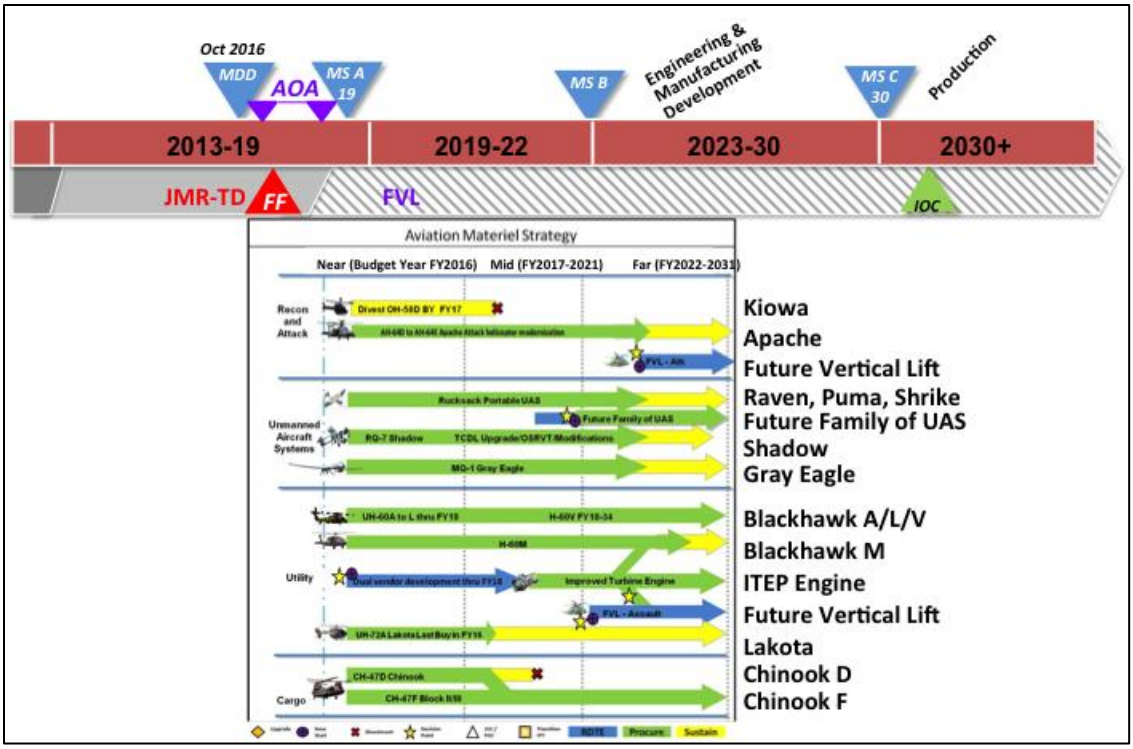


Figure 4-12. FVL – First Aircraft Timeline

Affordability of FVL is needed to deal with limited funding. Affordability, in turn, is driven by requirements. As the only new aviation program on the horizon, FVL will be pressured by the operational community to have system and performance requirements that satisfy every possible operational need. Lack of requirements discipline is one leading cause of acquisition program failure. FVL will be no exception if the requirements process is not tightly managed and constrained. An approved DoD acquisition process, known as evolutionary acquisition, could prove to be of great value in managing requirements growth and in accelerating the introduction of FVL into the fleet. Under this acquisition strategy, the operational and acquisition communities would agree on a set of objective performance requirements, but also agree on a more limited set of these objectives that could provide an effective early operational capability. Pre-planned capability upgrades leading to the full set of objective requirements would also be defined. Such an approach would help not only to manage requirements but also accelerate IOC for a limited capability.

Such acceleration, however, is dependent on technology maturity. In addition to unrealistic requirements and/or requirements growth, unrealistic evaluations of technology maturity is the other most significant cause of acquisition program failure. Fortunately for FVL, due to major industry investment, the JMR-TD demonstration vehicles will have greater fidelity and be more representative of the FVL-Medium operational design than would normally be expected. Parallel investments in the FACE/JCA open system architecture could provide the technology basis for some acceleration of a Milestone B DAB.

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An acceleration of the FVL program would also be of significant benefit to the health of the US rotorcraft industry, which has eroded over the past several decades due to the lack of military development programs. It should be remembered that the backbone platforms of the Army rotorcraft fleet (i.e., UH-60, AH-64 and CH-47) are all essentially 1960-1970 vintage designs and developments. The decline of US market share in the commercial helicopter market provides evidence that US leadership in rotorcraft system design and development is eroding. As indicated in Figure 4-13, the total share of US industry *combined* is only 25%, while the two European companies, Airbus Helicopters and Augusta Westland, have almost 60% of the world market.

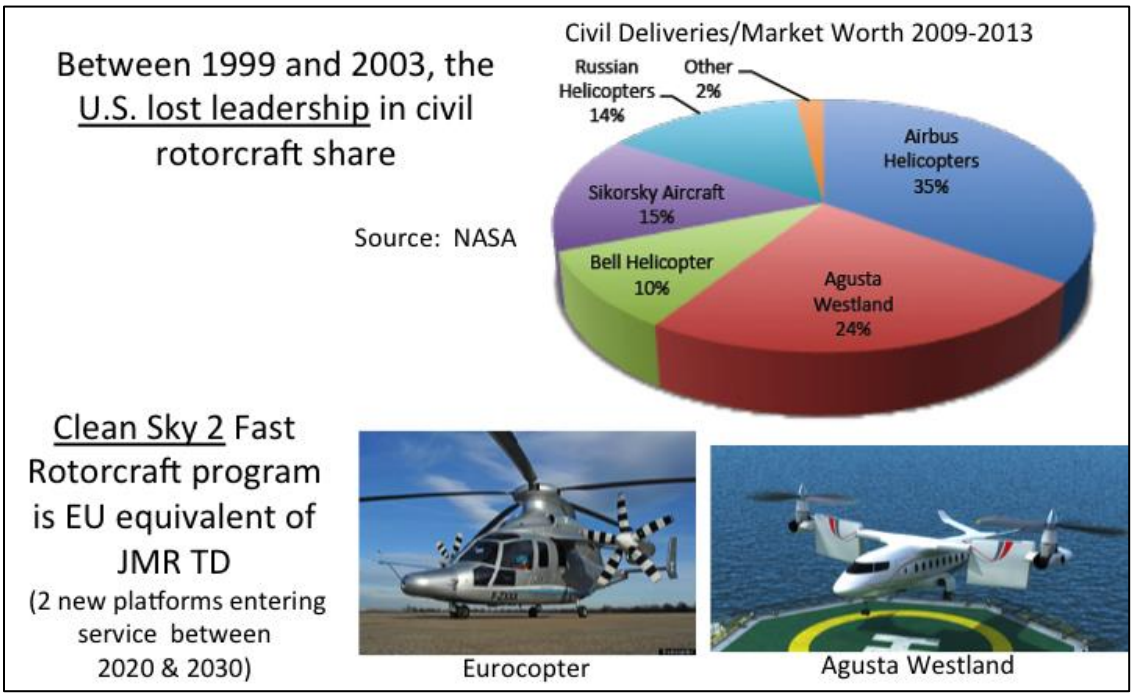


Figure 4-13. Worldwide Competition

Among the programs being sponsored by the European Union is the Clean Sky 2 Fast Rotorcraft Program, which has performance attributes similar to FVL and which is building two prototypes very similar to JMR-TD. A robust US rotorcraft industry is essential for the future of Army Aviation, but that is certainly not assured in this global environment.

These findings lead to the recommendation, detailed in Figure 4-14, that ASA(ALT) should develop an evolutionary acquisition approach for FVL to allow for earliest possible fielding of a new rotorcraft consistent with budgetary realties.

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Findings

- JMR-TD and FVL provide focus for Army Aviation S&T for next generation rotorcraft systems and provide a solid basis for much needed capability improvements (Ref. FVL ICD); however, there is no funding for FVL in the POM.
- The JMR-TD vehicles are close in size and aerodynamic performance capability to the FVL medium class system.
- The current FVL schedule leads to an IOC of the first system in the mid-2030s. It should be beneficial to accelerate this timeline through an evolutionary acquisition approach if funding allows.
- The JMR-TD, DARPA X planes, USN/USMC prototyping efforts, and industry investment support talent development and retention in rotorcraft government and industry teams.

Recommendation

- ASA(ALT): Develop an evolutionary acquisition approach for FVL to allow for earliest possible fielding consistent with funding constraints, as informed by the results of system of systems operational effectiveness analyses (Recommendation Set #1).

Figure 4-14. Findings and Recommendation Set #5

4.6 Aviation Mission Systems

RDECOM has numerous S&T efforts ongoing at AMRDEC, CERDEC, ARDEC, and ARL aimed at improving the mission system capabilities of Army Aviation systems. The majority of these efforts focus primarily on manned aviation systems, either for upgrading legacy systems or toward providing the technology base for future systems (i.e., FVL). That balance extends across all areas affecting affordability and mission effectiveness (e.g., lethality, survivability, sustainability, and maintainability), as well as all subsystems (e.g., airframe, power, propulsion, sensors, avionics, secure communications and networks, weapons). A much smaller portion of the RDECOM S&T portfolio is dedicated to unmanned systems, including several projects that advance state-of-the-art of autonomy, compatible mission systems, and manned-unmanned teaming (see Section 3.3). Many of the S&T projects, however, while aimed primarily toward manned or optionally manned systems, in fact have dual applicability to unmanned systems as well. For example, much of the CERDEC sensor and ASE development work is equally applicable to manned and unmanned systems.

Of particular note for potential dual use is the Degraded Visual Environment (DVE) work being conducted by AMRDEC and CERDEC. Focused principally on providing the means for manned rotorcraft systems to operate safely in a variety of degraded visual environments (see Figure 4-15), the effort includes the development of modern control laws to improve flight control in legacy systems. These techniques can support automated flight modes that enable capabilities such as terrain and obstacle avoidance and automated safe landing modes also applicable to unmanned systems. In addition, one of the objectives of the project is to demonstrate multi-ship networking, illustrated in Figure 4-16, which could support the distributed functionality manned-unmanned teaming concepts previously discussed in Section 4.3.

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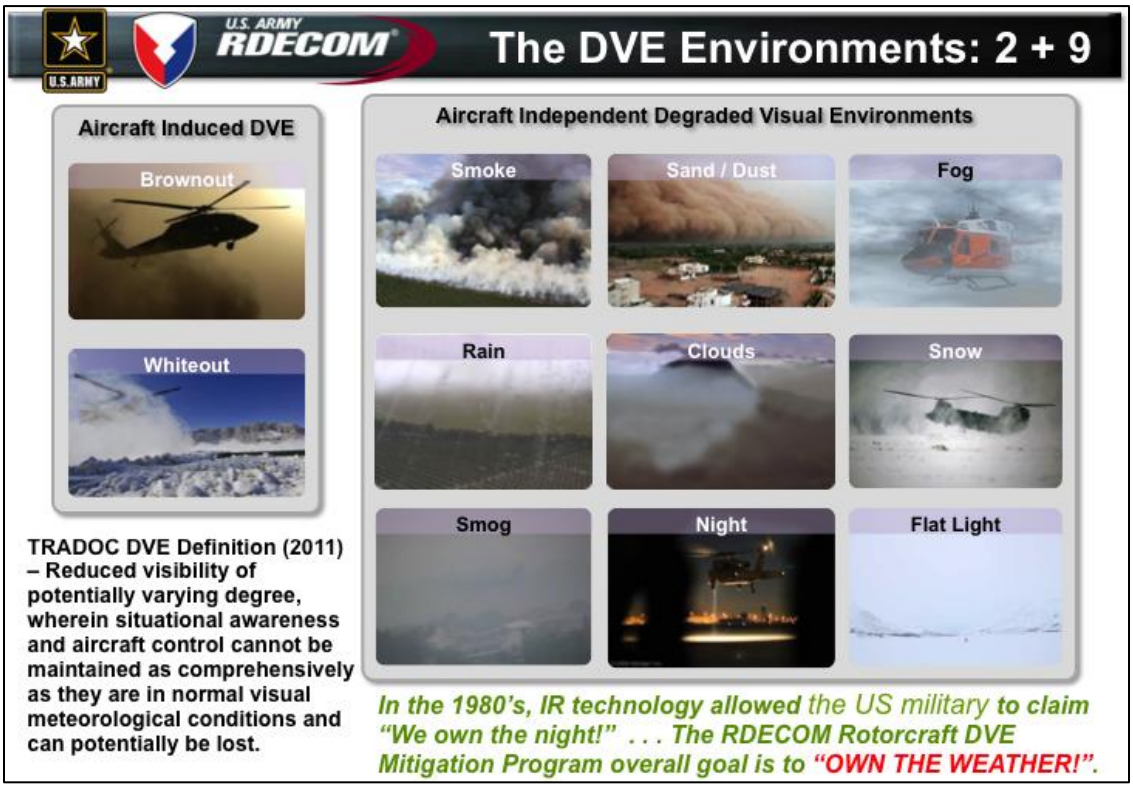


Figure 4-15. RDECOM DVE

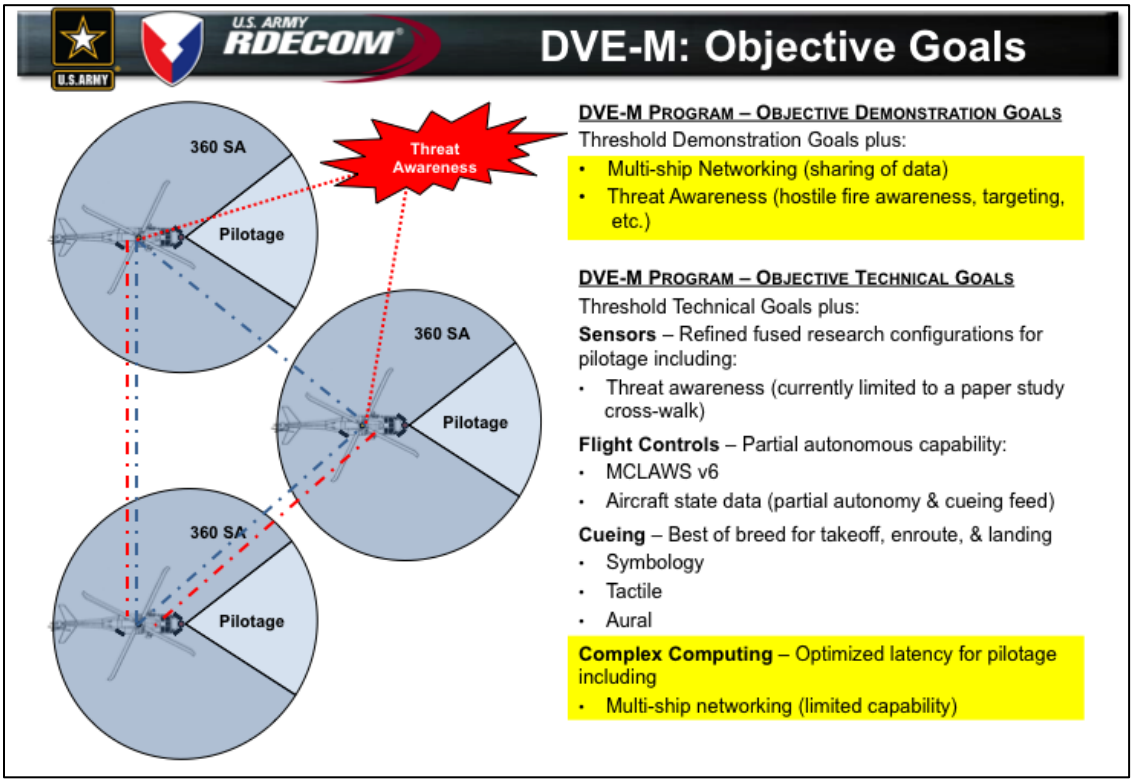


Figure 4-16. DVE-M Objective Goals

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The mission systems work is vital to the future of Army Aviation and exploits much of the unique rotorcraft modeling, simulation and test facility capabilities that are resident within the Army S&T community by virtue of the Army's role as the DoD lead for rotorcraft systems. The recommendation in this area, included in Figure 4-17, is to expand mission system technology development, currently focused on DVE, to enable advanced formation concepts in future manned and unmanned platforms, and legacy platforms as appropriate, as informed by the results of system of systems operational effectiveness analyses (Recommendation Set #1).

Findings

- Army S&T mission system programs include Lethality, Survivability, Teaming & Autonomy, Human-System Interface, Avionics, and Networks.
- RDECOM DVE goals are appropriate and feasible - Progress at AMRDEC, CERDEC, and ARL in sensors, flight control, cueing, computing, and networking.
- Reduced pilot workload arising from DVE technologies should increase operational mission capacity (e.g., formations with UAS).
- Advanced sensors (e.g., IR, visible, and hyperspectral) are being developed.
- Additional advanced mission systems (e.g., offensive and defensive directed energy) and open system architectures are needed.
- DoD provides singular modeling and wind tunnel capabilities (NASA Ames)

Recommendation

- AMRDEC/ADD: Expand mission system technology development, currently focused on DVE, to enable advanced formation concepts in future manned and unmanned platforms, and legacy platforms as appropriate, as informed by the results of system of systems operational effectiveness analyses (Recommendation Set #1).

Figure 4-17. Findings and Recommendation Set #6

4.7 Aviation Systems Integration and Testbed

The system-of-systems concepts likely to emerge from the operational effectiveness analysis (Recommendation Set #1) will require an extensive modeling, simulation, experimentation and testing capability to validate operational utility, as well as to ensure that the system elements are well integrated. This capability requires an integrated aviation systems testbed, which may include M&S, laboratory prototype bench testing, operationally realistic prototype demonstrations, and SoS field experimentation in which elements interface and integrate under realistic operational conditions. Such an integrated testbed does not currently exist. However, some critical elements exist or are in development upon which the integrated capability could be built. The geographical distribution of these elements presents an integration challenge, which will rely on networking capabilities for real-time interaction when necessary.

Foundational to the testbed are the core capabilities resident within AMRDEC for the M&S, test and evaluation of rotorcraft systems. The AMRDEC and NASA wind tunnel facilities are national assets for both Government and industry testing of design concepts and validation of computer design/evaluation codes. The rapid prototyping capabilities within AMRDEC for flight demonstration and testing of advanced subsystems and components on rotorcraft test assets is

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also a critical element for an integrated testbed. It is also possible that the JMR-TD demonstration vehicles could be utilized for prototyping demonstrations after the JMR flight test objectives have been completed.

CERDEC has a variety of world-class laboratories for aircraft survivability testing and evaluation that are important elements of the integrated testbed. Among these are anechoic chambers, seeker countermeasures effectiveness hardware-in-the-loop facilities, and several aircraft survivability equipment laboratories. CERDEC has a future vision for holistic integrated air and ground survivability capability that would facilitate the development of system and system-of-systems applications that enable intelligent integration of survivability systems that would progress beyond platform centric survivability (see Figure 4-18) to system-of-systems solutions (Figure 4-19). The proposed Future Holistic Adaptive Survivability Technology (FHAST) project that would develop a state-of-the-art suite of integrated electronic warfare capabilities to protect air and ground platforms from emerging threats would be a significant step toward the integrated testbed capability.

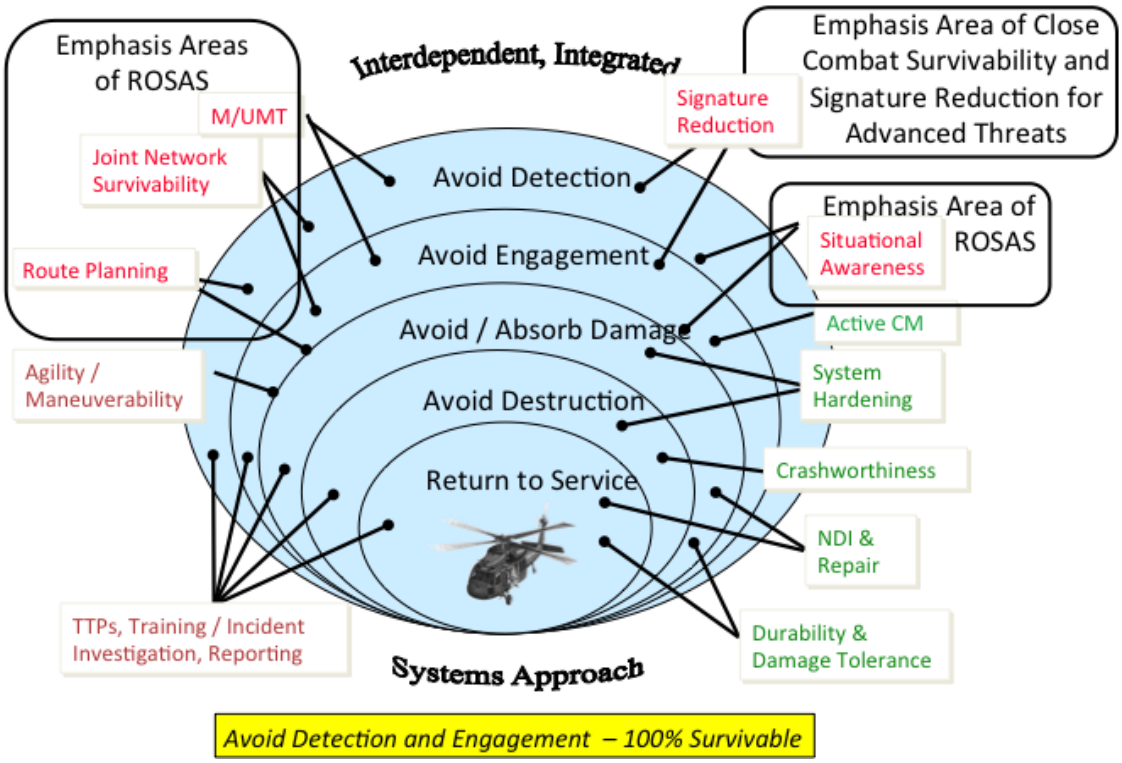


Figure 4-18. AMRDEC Total Survivability Paradigm – Platform-Centric

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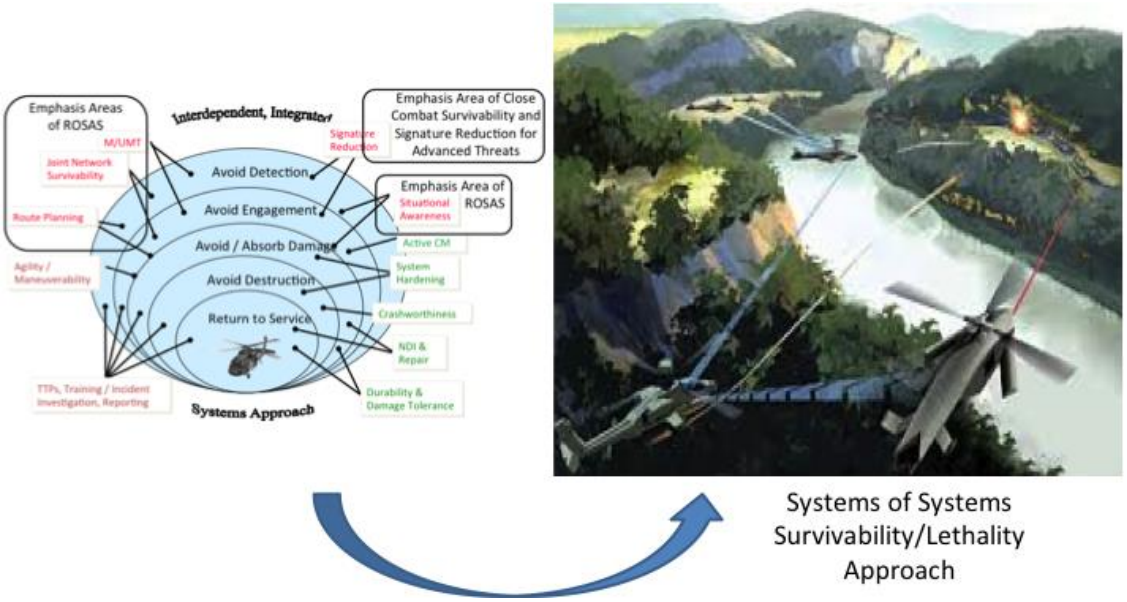
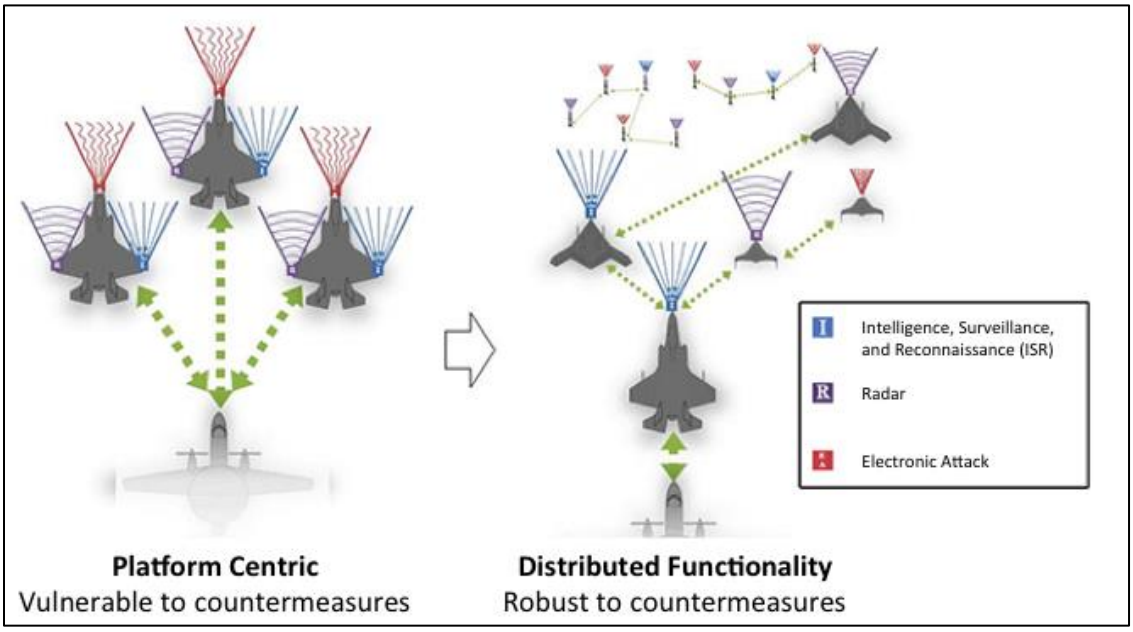


Figure 4-19. Total Survivability from System-of-Systems Perspective

DARPA can also contribute to the integrated testbed by means of its system-of-systems M&S capabilities that are being utilized to examine SoS concepts, such as the SoSITE project, illustrated in Figure 4-20.



Source: DARPA SoSITE Website

Figure 4-20. System of Systems Example

The recommendations emanating from these findings, detailed in Figure 4-21, are for RDECOM to pull together the building blocks to develop an integrated aviation testbed.

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Findings

- Concepts developed in Recommendation 1 and new technical capabilities referenced in Sections 2-6 (individually and as integrated systems) will require extensive testing.
- Some initial work is found in CERDEC I2WD open systems efforts and DARPA's System of Systems Integration, Technology and Experimentation (SoSITE).
- Fully integrated joint vision for aviation in DoD is not evident. Coalition environment should be considered.

Recommendations

- RDECOM: Build the components of an integrated "survivable" system (MUM-T, attritable assets, secure comms, PNT, open operating systems, autonomy, high/low mix, distributed functions across future "formations").
- RDECOM: Building on Recommendation 1 and Sections 2-6, develop an aviation integration testbed for experimentation and validation of technology, prototypes, and concepts. Potentially include demonstration (such as JMR TD), prototype, surrogate, and operational systems.

Figure 4-21. Findings and Recommendations Set #7

4.8 Advanced and Disruptive Systems S&T

Army Aviation is at a crossroads of opportunity and challenge – opportunities to be found in emerging technologies that will enable significant advances in aviation and challenges posed by technology advances and availability among our adversaries. In the current climate, information about many emerging technologies and new applications of technology is available to everyone with an Internet connection.

In order to leverage technological opportunities and avoid technological surprise, it is essential for Army S&T to address leap-ahead technologies that support Army Aviation. As illustrated in Figure 4-22, there are several areas of innovation currently being addressed, sometimes by other Services and agencies. For example, the DARPA X-Plane effort is evaluating new rotorcraft technologies to achieve higher speed, and numerous organizations, including the Army, are exploring directed energy options. The Navy is examining the utility of UAS swarms, and the Air force is investigating air-launched UAVs. The Army must ensure that it is positioned to incorporate new concepts having significant potential to improve platform performance and reliability as well as to exploit unmanned aerial vehicles and manned-unmanned teaming to full advantage.

In particular, a shift toward a formation of unmanned systems controlled by a manned aircraft offers significant promise toward reducing the overall risk and cost of selected missions. If single-purpose UAS (e.g., ISR, strike, electronic warfare, or comms) can be used as illustrated in Figure 4-23, each asset is less costly than if every platform is designed to perform all functions. Even if one asset is lost, the remaining assets can continue to carry out the mission.

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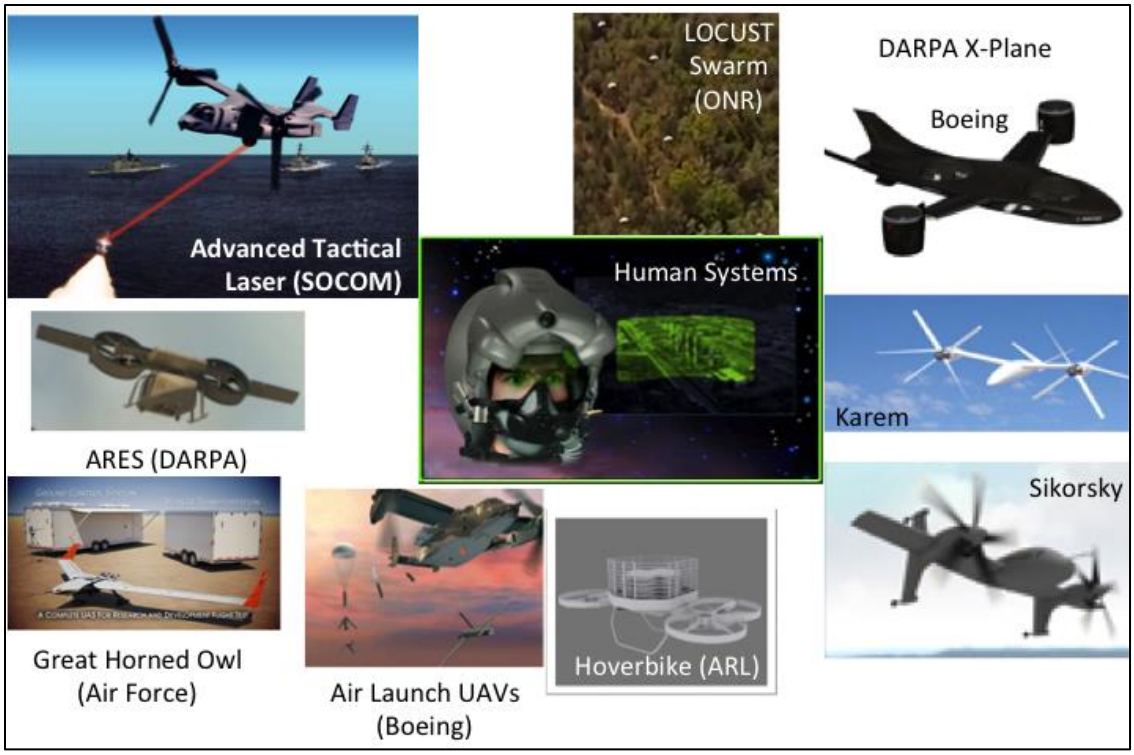


Figure 4-22. Aviation Innovation Examples

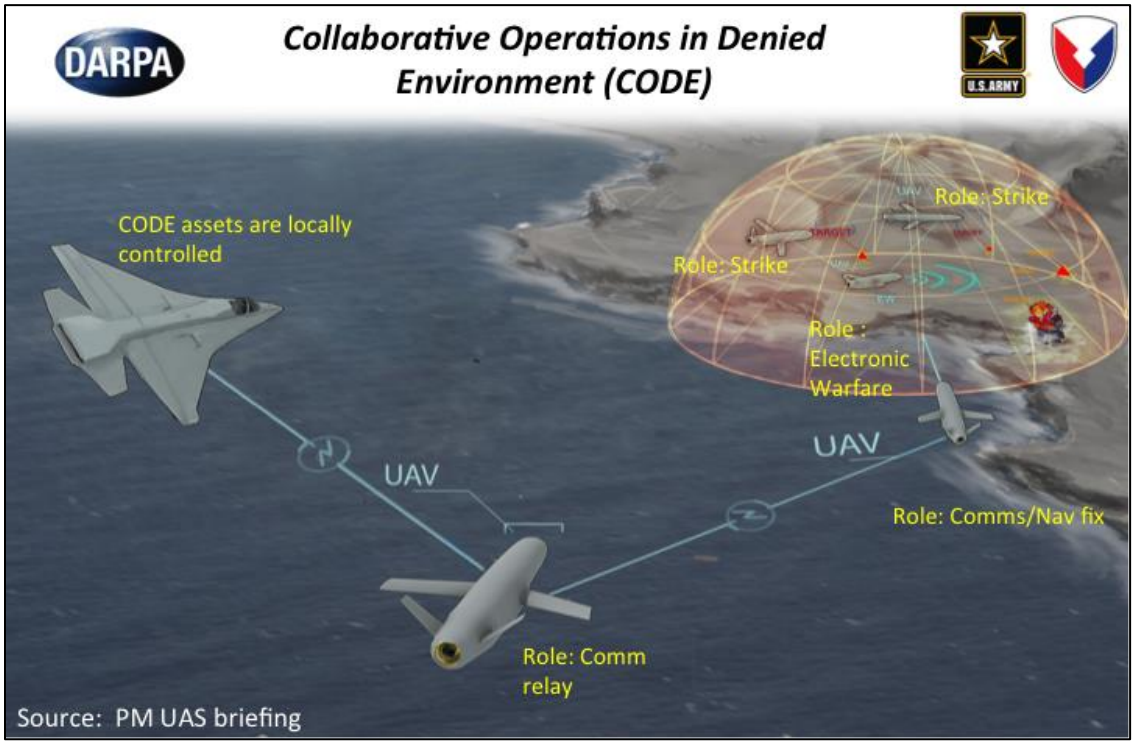


Figure 4-23. DARPA-RDECOM CODE Program

The ASB study team recommends that RDECOM develop advanced technologies for an integrated/ holistic manned/unmanned architecture/system to help ensure survivability and

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mission success. The team also recommends that ASA(ALT) include in its S&T portfolio appropriate leap-ahead technologies. The findings and recommendations on this topic are summarized in Figure 4-24.

Findings

- Army Aviation is at a crossroad of challenge and opportunity.
  - The challenge: threat sophistication will demand a transformation in the nature of warfare in 2025 and beyond (missiles, UAS, DE, Cyber).
  - The opportunity: technology is emerging that enables significant improvement in aviation capabilities.
- Advanced technology solutions are required, including: UAS, autonomy, manned-unmanned collaboration, communications, directed energy, sensors, condition-based and near-zero maintenance technology/concepts, and other discoveries from the S&T enterprise.
- There is relevant work in other Services, DARPA, and NASA that should be leveraged.

Recommendations

- RDECOM: To address expanding complex threats and opportunities develop advanced technologies for an integrated/holistic, manned/unmanned architecture/system to ensure survivability and mission success.
- ASA(ALT): Include in S&T portfolio leap-ahead technologies (counter-DE, counter-UAS, advanced materials)

Figure 4-24. Findings and Recommendations Set #8

4.9 S&T Investment Strategy

One of the most successful Army Aviation development efforts has focused on improved turboshaft engines. The ITEP and FATE programs have led to improved engines that can be transitioned from S&T to programs of record for legacy systems, but they can also be incorporated in designs for future vertical lift. Maintaining active participation in engine development programs is key to achieving further advances and program transitions.

Most of the current Army investment in aviation technologies is focused on manned rotary wing platforms. If the manned-unmanned formations described above are to be evaluated and potentially implemented, S&T funding must be made available to develop the needed unmanned platforms and control systems.

As is documented in Appendix I, the Army Total Funding request in the FY2016 Budget Request is $147B ($126B Base and $21B OCO). Within the base budget, $16.1B is allocated for Procurement, with $5.7B for aircraft (34% of the total). In contrast, the total Army S&T budget request for Applied Research (Budget Area 2) and Advanced Technology Development (Budget Area 3) is $1.77B, with only $144M (8%) committed to Aviation projects. Thus only 8% of the BA2/BA3 budget request is expected to support 34% of the procurement request. This is not sufficient to meet the challenges discussed above.

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According to data from the OSD Air Platforms Community of Interest (COI), the Army FY2016 request amounts to 64% of the DoD BA2/BA3 request for rotary wing aircraft. This is consistent with the Army's role as Lead Service for rotorcraft. The next largest contribution is from DARPA, largely for the VTOL X-Plane effort. NASA funding for rotorcraft is minimal ($20M). Thus the Army cannot rely on any other Government organization for significant rotorcraft development.

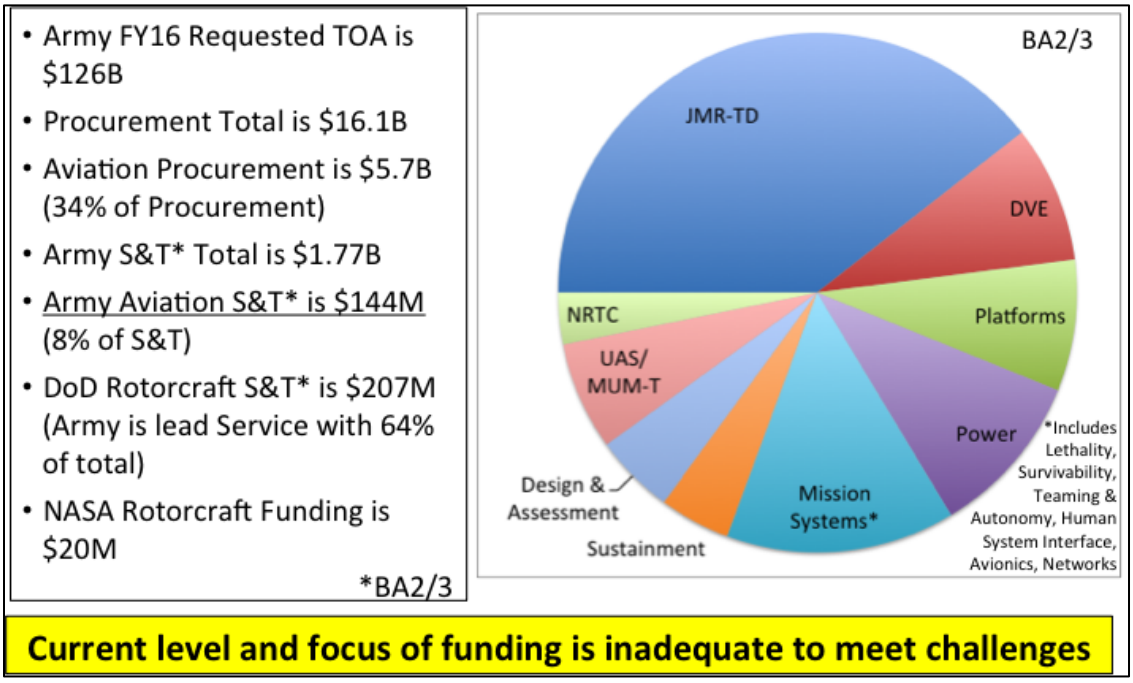


Figure 4-25. Meeting Future Challenges Demands a Robust Aviation Portfolio

One potential means to increase funding for aviation S&T is to employ innovative mechanisms for external collaboration with universities and industry. An example of such a mechanism is the DARPA Grand Challenge mechanism used to encourage development of autonomous ground vehicles. It is recommended that ASA(ALT) advocate for additional funding for Aviation S&T. Figure 4-26 provides a summary of findings and recommendations for this topic.

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Findings

- Based on findings in Sections 1-8, the capabilities of Army Aviation S&T must evolve rapidly (e.g., need to expand UAS and autonomy activity); thus the level of S&T activity must expand beyond the manned aviation S&T portfolio, which is currently well managed.
- Army S&T investment has led to successful ITEP and FATE engine developments; the transition of these S&T efforts to PORs is essential to both FVL and modernized legacy platforms.
- Current S&T investment is insufficient to achieve the needed transformation and to maintain overmatch in 2025 and beyond.

Recommendations

- AMRDEC/ADD: Continue active participation in VAATE and RAMPED engine development.
- RDECOM: Explore innovative mechanisms for external collaboration (university, industry, etc.), such as grand challenges (similar to DARPA construct).
- ASA(ALT): After exploring leveraging opportunities with other R&D activities, advocate more funding for Aviation S&T.

Figure 4-26. Findings and Recommendations Set #9

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5 CONCLUSION – THE FUTURE OF ARMY AVIATION

This Army Science Board study examined options for the Future of Army Aviation in the 2025-2040 time period that were informed by (1) clear trends in the rapid global growth of technology; (2) numerous serious, increasing, and evolving threats; (3) more than 30 visits to various Government and non-governments facilities and forums; and (4) a review of some 500 documents. Based on this work, the study team concluded that a context was critical to identifying these technical and operational options.

The rate of change of technology in the 21st century presents both challenges and opprtunities. The study team looked at an approach to this rapidly evolving and uncertain environment that requires the development of a new architecture able to adapt quickly, is cost-constrained, takes advantage of advancing technology, applies integrated systems thinking, and ultimately provides needed warfighting capability. This "System of Systems" construct (a way to describe different approaches that employ capabilities from the ground and air) provides for future capabilities, not only for airborne assests, but also for ground and air warfare. In this context, the study team's first and most important recommendation is that "Systems of Systems Operational Effectiveness Analyses" must be conducted to help identify the needs for Army Aviation. These analyses will inform many of the remaining recommendations.

The study team has strongly recommended increased emphasis on unmanned aircraft systems (UAS) with appropriate use of autonomy in conjunction with, and complementary to, human capabilities. The ISR focus of current UAS, with some limited attack capability, can and should be rapidly expanded. It is the human-machine system optimization that provides flexibility and affordable new capability in tomorrow's fight. Consistent with an evolving character of warfare and potential new roles for Army Aviation, our people in this Human-Machine System will need new systems operations/management skills and capabilities to deploy Army Aviation in the future Joint fight. For example, helicopter pilots would have a greater role in directing a "formation" of air assets, only some of which have soldiers in them.

Intellectual capital and innovation would be hallmarks of this adaptive system. Modularity of "system" design and deployment would allow increased speed of adaption and affordability. The potential exists to provide needed capability in a rapidly changing environment through the use of more, relatively inexpensive "parts" that are quickly integrated into increasingly dynamic and tailorable complex systems. Thus, Army Aviation capability is derived more from the "system of systems" rather than from the individual "parts" or platforms. The attributes of the "system" outlined in this report include implementing a "cost-imposing strategy" on the adversary, plus affordable speed of adaption to new and uncertain environments and to new technical and operational oportunities.

As presented in the study team's concluding briefing chart below, the threats are rapidly changing, the character of warfare is changing, and Army Aviation must change too. Thus, to win in a complex aviation world, the study team believes that an Aviation Systems of Systems approach is necessary. This approach must be pursued with urgency.

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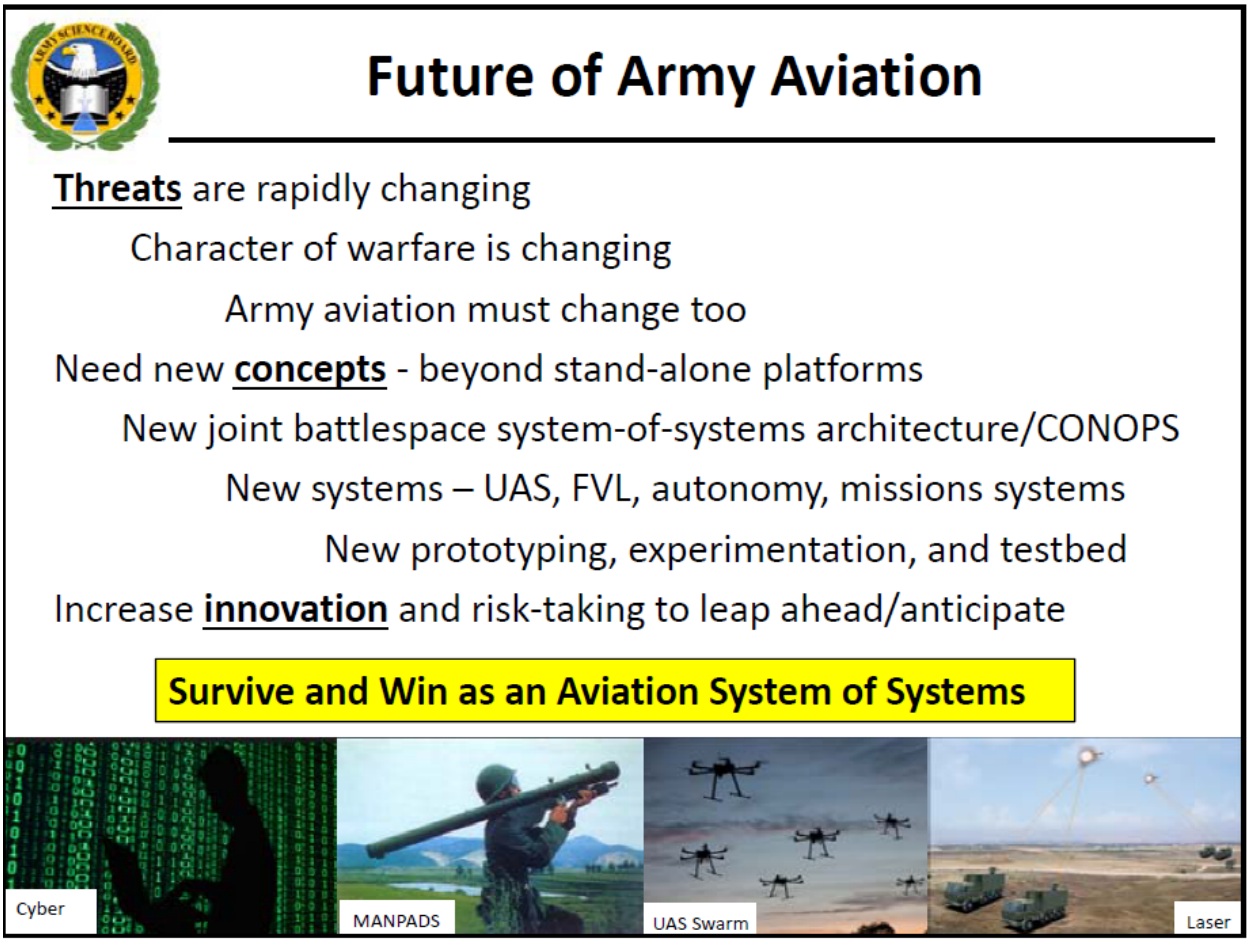


Figure 5-1. Future of Army Aviation

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APPENDICIES

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APPENDIX A TERMS OF REFERENCE

SECRETARY OF THE ARMY
WASHINGTON
JAN 0 6 2015

Dr. James Tegnelia
Chairman, Army Science Board
101 Army Pentagon
Washington, DC 20310

Dear Dr. Tegnelia:

I request that the Army Science Board (ASB) conduct a study entitled "Army Science and Technology for Army Aviation 2025-2040."

Analysis of the future Army operating environment suggests that under the current investment strategy, the Army will retain technology advantages to the end of this decade. After 2020 the Army will begin to experience erosion of overmatch, and between 2030 and 2040 the Army can expect to lose the edge in several key areas. To meet these challenges, aviation must address today's needs while balancing investments in innovation to enable next-generation aviation capabilities.

The objective of the study is to identify and assess Science and Technology (S&T) enhancements capable of being fielded during the 2025-2040 timeframe that will increase Army Aviation's expeditionary capabilities to support full-spectrum military operations and reduce its sustainment tails and logistics footprint. The study should:

a. Review current Army, Navy/USMC, Air Force, DARPA, OSD, NASA and industry aviation S&T plans, modernization plans and ongoing developments, as well as relevant Force 2025 and Beyond Campaign activities.

b. Address the use of innovative technologies that increase capabilities, overall mission effectiveness, survivability and lethality while reducing sustainment requirements, including logistics footprint and frequency of resupply.

c. Include, but not necessarily be limited to, the following key focus areas for improvement: (1) near-zero maintenance platforms and systems, (2) exploitation of unmanned aircraft systems, (3) meeting the challenges of emerging threats and (4) enhancing the ability to operate worldwide in a variety of stressing and degraded visual conditions.

d. Determine the feasibility and risks associated with each of the findings and recommendations.

The G-3/5/7 is the sponsor of this study and will assist the study team in accessing classified information up to Top Secret and including Sensitive Compartmented Information and Special Access Programs. The ASB shall present a comprehensive

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briefing that describes the study methodology and includes all findings and recommendations to the G-3/5/7 and me by September 30, 2015. The final written report shall be provided by October 31, 2015. All data supporting study findings and recommendations shall be available to Army senior leaders upon request.

The study will be conducted in accordance with the Federal Advisory Committee Act and DoD Directive 5104.4, "DoD Federal Advisory Committee Management Program." It is not anticipated that this study will need to go into any "particular matters" within the meaning of Title 18, United States Code Section 208, nor will it cause any member to be placed in the position of acting as a procurement official.

Sincerely,

John M. McHugh

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APPENDIX B STUDY TEAM MEMBERS

The 2015 ASB Army Science and Technology for Army Aviation 2025-2040 study consisted of the following members and support staff:

Dr. Ron Sega (Maj. Gen. - Ret) (Chair)

Dr. Mark Glauser (Vice Chair)

Dr. Nancy Chesser

Mike Heinz

Grant Hollett (RADM - Ret)

Tom Ramos

Teresa Smith

Dr. Bill Snowden

Dr. Alan Willner

Red Team Advisor: George Singley

Study Manager: Maj Andy Brown

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APPENDIX C SITE VISIT AND INTERVIEW LINES OF INQUIRY

Army Aviation S&T Home on Home / 22-23 January 2015 / Ft. Rucker, AL

- ASB Team members observed at meeting of Army organizations

Meetings of Future Vertical Lift IPTs / 17-19 February 2015, 28-29 April 2015, 23 June 2015 / WBB, Reston, VA

- ASB Team members observed at meetings of FVL IPTs

Aviation Development Directorate Industry Day / 3 March 2015 / AMRDEC, Huntsville, AL

- ASB Team members observed presentations to industry

Aviation Development Directorate / 16 March 2015 / NASA Langley Research Center, VA

- ASB provided TOR and asked for input on topics therein

Aviation Development Directorate / 17 March 2015 / Ft. Eustis, VA

- ASB provided TOR and asked for input on topics therein

Aviation Development Directorate / 19-20 March 2015 / NASA Ames, CA

- ASB provided TOR and asked for input on topics therein

Army Aviation Association of America – Army Aviation Mission Solutions Summit / 30-31 March 2015 / Nashville, TN

- ASB Team members attended the Quad-A Summit

Aviation Development Directorate / 1-2 April 2015 / Huntsville, AL

Specific Lines of Inquiry:

1. What do you consider to be ADD's core competencies?
2. Why was ADD's Advanced Systems and Concepts Office eliminated?
3. What is expected to be the next breakthrough in rotorcraft and why is it a game changer?
4. The 2007 DSB report on VSTOL aircraft supported by the SecDef cited a number of deficiencies in DoD rotorcraft programs, including in the areas of survivability, vulnerability, flight and crash safety, crew cognitive overload, and reliability. What actions has ADD taken and what progress has been made in response to the report? What remains to be done, and are the requisite resources and technological opportunities available?
5. How do ADD activities leverage technological developments of the Special Operations Aviation (SOA) community?
6. Does Army Aviation have a propulsion RDA roadmap? How important is ITEP? To what extent are ITEP and the JMR Tech Demo scalable for FVL?
7. How do ADD personnel and programs interface with ARL, PM ASE, PEO Aviation, PEO IEWS, PM UAS, NASA, and DARPA?

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8. What advanced/innovative concepts and technologies under development within ADD can be expected to contribute to the CSA's Force 2025 and Beyond Campaign being led by CG TRADOC?
9. What are ADD's principal contributions to the JMR Tech Demo and FVL programs?
10. What are the upper and lower limits of the scalability of JMR Tech Demo to smaller and larger rotorcraft?
11. Have design concept synthesis and assessment studies been conducted to evaluate alternative design options (e.g., tilt-rotor, compound or hybrid concepts) against the capability needs and performance goals of each class of the FVL FoS, as documented in the FVL FoS ICD (April 2013) and the JFTL ICD (October 2009)? What conclusions can be reached regarding the best fit of each concept to each class?
12. Has the robustness of each design concept to requirements creep or changes been studied? Robustness in this context means low sensitivity of the design gross weight and performance to requirements changes (e.g., payload weight/size, mission equipment SWAP, threat capability or countermeasures, etc.) during full scale development. What conclusions can be reached?
13. Has the life cycle cost for each FVL class (including Ultra) been evaluated? Please provide best LCC estimates at this time. What is the estimated cost savings for each class if designed from the outset as an unmanned system instead of a manned or optionally manned system?
14. Which performance objectives from the FVL FoS ICD and the JFTL ICD are the most challenging for each class of FVL? Which objectives, if tailored, would result in the greatest benefit from vehicle size, overall capability and cost standpoints? Which are the most challenging from a technology development standpoint for each class?
15. How applicable are the technologies to be embedded in the JMR Tech Demo to the other classes of FVL (other than Medium)? Which JMR technologies are also good candidates for transition to rotorcraft Programs of Record? What percentages of AMRDEC BA2 and BA3 R&D efforts are devoted to JMR?

PEO Aviation / 1-2 April 2015 / Huntsville, AL

Specific Lines of Inquiry:

1. The 2007 DSB report on VSTOL aircraft supported by the SecDef cited a number of deficiencies in DoD rotorcraft programs, including in the areas of survivability, vulnerability, flight and crash safety, crew cognitive overload, and reliability. What actions have been taken and what progress has been made in response to the report? What remains to be done, and are the requisite resources and technological opportunities available?
2. What specific technologies were inserted in the latest block upgrades to the AH-64, UH-60 and CH-47? What improved system and operational capabilities were fielded as a result of these block upgrades? What was the total investment associated with each of these upgrades?
3. Are any additional upgrades planned for these rotorcraft? If so, what technologies and capabilities advances are part of these plans? What funding is in the POM to initiate these upgrades?

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4. What is your assessment of the ability of the latest or planned upgrades of AH-64, UH-60 and CH-47 aircraft to effectively perform their missions against evolving threats over the next 20-30 years?
5. What additional unplanned and/or unbudgeted technology insertions and/or block upgrade improvements would have the greatest positive impact on mission effectiveness over the next 20-30 years?
6. Are there any technologies in development for the JMR Tech Demo program that would be good candidates for insertion into the AH-64, UH-60 or CH-47?
7. What is your assessment of the current Army Aviation portfolio and the VCSA portfolio review process? What were your top priorities not fully funded in the current Army Aviation portfolio?
8. Does the Army have an operational architecture, systems architecture, and technical architecture for its current and future fleet of unmanned aerial systems?
9. In the last 10 years, what technologies or advanced products developed/sponsored by DARPA have been incorporated in Army Aviation? What is your assessment of the current DARPA VTOL program?

USAACE, TCM Lift, TCM UAS, USAARL, Safety Center / 2-3 June 2015 / Ft Rucker, AL

- ASB provided TOR and asked for input on topics therein

Operational Support Airlift Agency / 5 June 2015 / Ft Belvoir, VA

- ASB provided TOR and asked for input on topics therein

National Aeronautics and Space Agency (NASA) / 9 June 2015 / NASA HQ, Washington DC

- ASB provided TOR and asked for input on topics therein

Night Vision and Electronic Sensors Directorate (NVESD) / 9 June 2015 / Ft Belvoir, VA

- ASB provided TOR and asked for input on topics therein

DARPA TTO / 10 June 2015 / Arlington, VA

- ASB provided TOR and asked for input on topics therein

Army Research Laboratory / 10-11 June 2015 / Adelphi, MD and Aberdeen Proving Ground, MD

- ASB provided TOR and asked for input on topics therein

Intelligence and Information Warfare Directorate (I2WD) / 11 June 2015 / Aberdeen Proving Ground, MD

- ASB provided TOR and asked for input on topics therein

Industry Representatives and Vertical Lift Consortium / 24 & 26 June 2015 / Arlington, VA

- ASB provided TOR and asked for input on topics therein

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Naval Air Systems Command and PM Aviation / 25 June 2015 / Naval Air Station, Patuxent River, MD

- ASB provided TOR and asked for input on topics therein

Air Force Research Laboratory / 7 July 2015 / US Air Force Academy (USAFA), Colorado Springs, CO

- ASB provided TOR and asked for input on topics therein

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APPENDIX D JOINT MULTI-ROLE TECH DEMO AND FUTURE VERTICAL LIFT INITIATIVE

Future Vertical Lift (FVL) Family of Systems (FoS) is an initiative (not yet a program) to develop a family of rotorcraft for the United States Armed Forces. Originally four different sizes of aircraft were to be developed. They are to share common hardware such as sensors, avionics, engines, and countermeasures. The precursor for FVL is the Joint Multi-Role (JMR) Technology Demonstration (TD) program, which plans to demonstrate relevant technologies in 2017.

D.1 Joint Multi-Role Technology Demonstration (JMR-TD)

The Joint Multi-Role Technology Demonstration (JMR-TD) is a 50/50 cost sharing initiative between the Army and vendors. JMR-TD is **NOT** a prototype for Future Vertical Lift – it is a technology demonstration. Four vendors were selected in October 2013 to begin designing a vehicle demonstrator:

1. AVX Aircraft Company – coaxial-rotor, ducted-fan compound helicopter
2. Bell Helicopter, a Textron Company – tilt rotor
3. Karem Aircraft Inc. - variable-speed tilt rotor
4. Sikorsky Aircraft – Boeing Company – coaxial rigid-rotor, pusher-propulsor design



Figure D-1 Phase 1 JMR-TD Designs

In August 2014 the competitors were down-selected to two, Bell and Sikorsky-Boeing, to build demonstrators for 2017 flight. Details of those designs are shown in Figure D-2 and Figure D-3. The remaining two competitors, AVX and Karem, have been funded for technology development.

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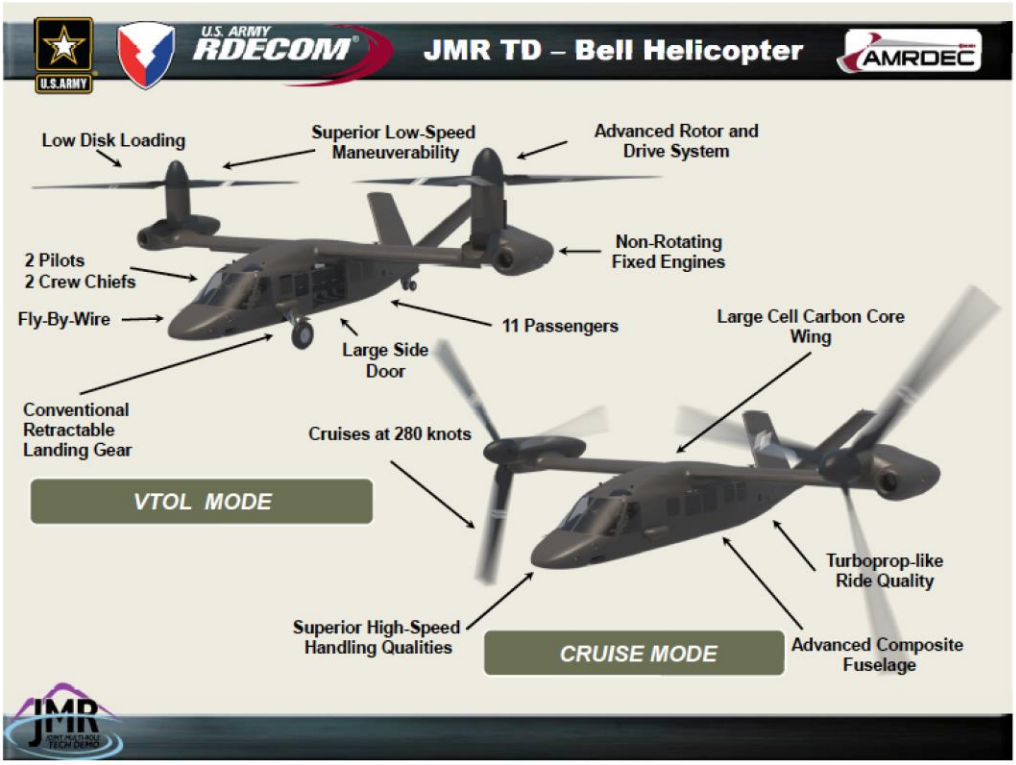


Figure D-2 Bell Helicopter JMR-TD Design

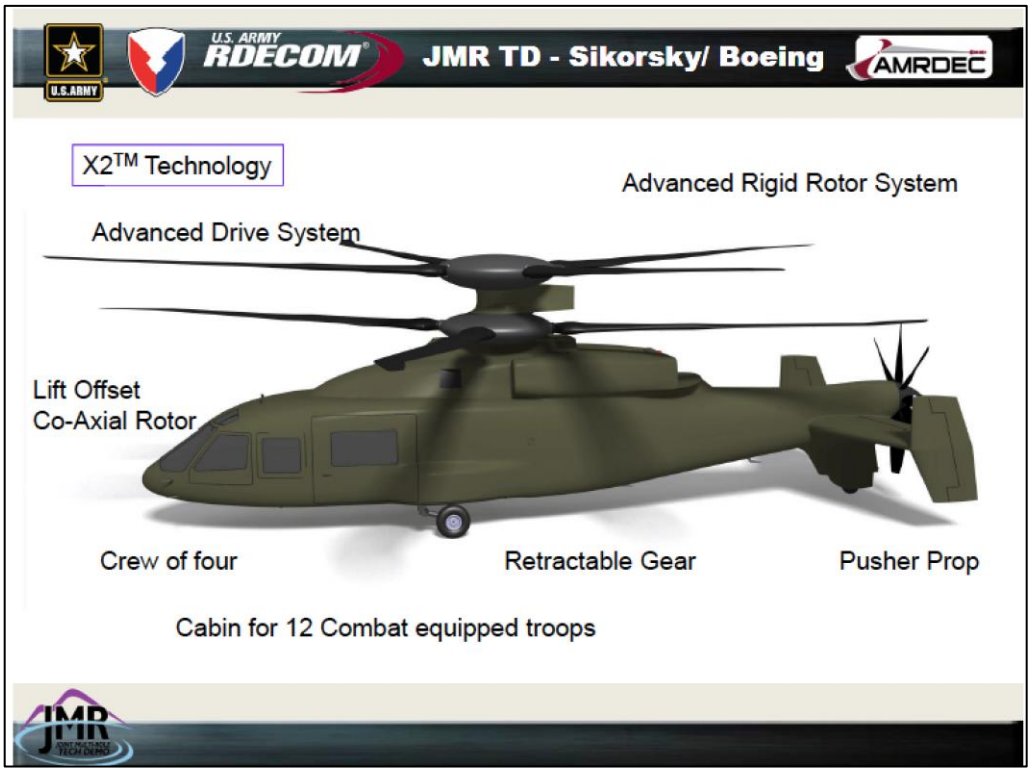


Figure D-3 Sikorsky/Boeing JMR-TD Design

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Both vehicles use existing engines (the CH-53 engine for Bell and the CH-47 engine for Sikorsky-Boeing).

The schedule for the JMR-TD is shown in Figure D-4. The Air Vehicle Demonstration (AVD) at the top of the figure will enable learning with regards to

- Advanced technology implementation on high speed air vehicle configurations
- The refinement of analytical methods for coaxial and tilt rotor configurations
- The collaboration of the rotary wing enterprise to provide an advanced, efficient, affordable aviation weapon system

Because it is too early to design a mission equipment package (MEP) or mission systems architecture for FVL, the Mission Systems Architecture Demo (MSAD) shown at the bottom of the figure will focus on standards, processes and tools to support the FVL.

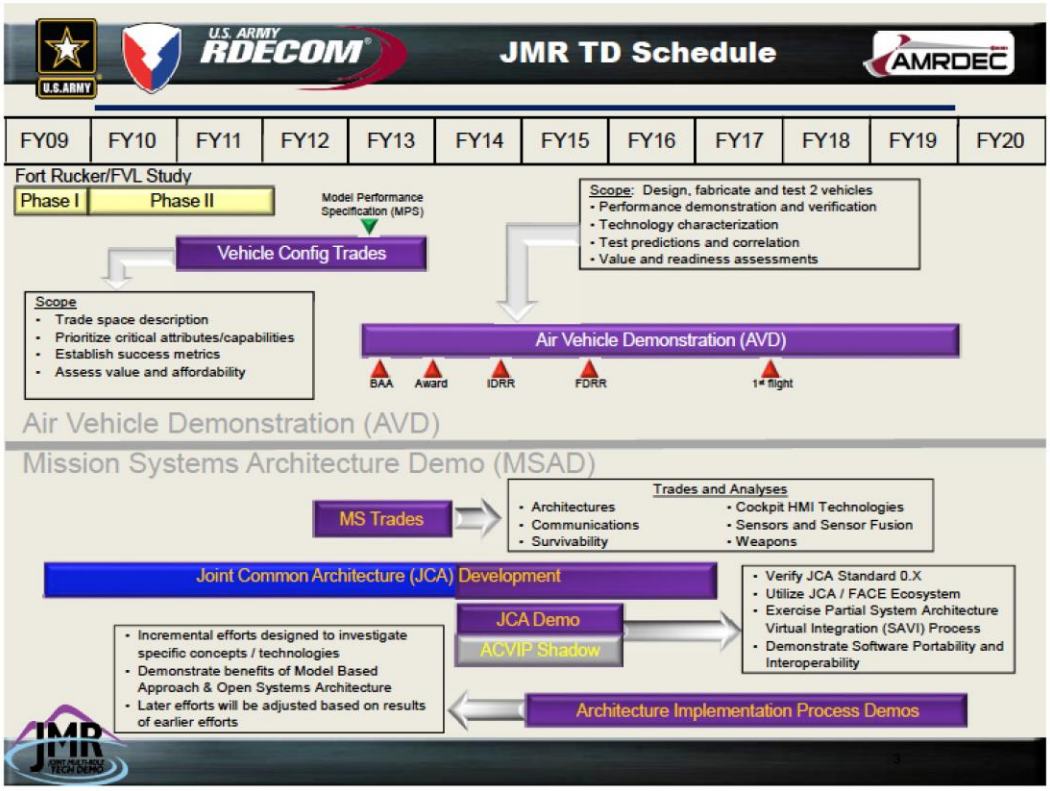


Figure D-4 JMR-TD Schedule

D.2 Future Vertical Lift (FVL) Family of Systems (FoS)

Because the current FVL initiative will presumably lead to a development effort, and perhaps a procurement effort, much of the information obtained by the study team is competition sensitive and will not be included here.

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The FVL FoS initiative is a multi-service effort led by the Army. To ensure coordination between the JMR-TD and FVL efforts, Dan Bailey at AMRDEC is the Program Director for both. The figure below shows the multiple Integrated Product Teams (IPTs) involved in scoping the FVL effort.

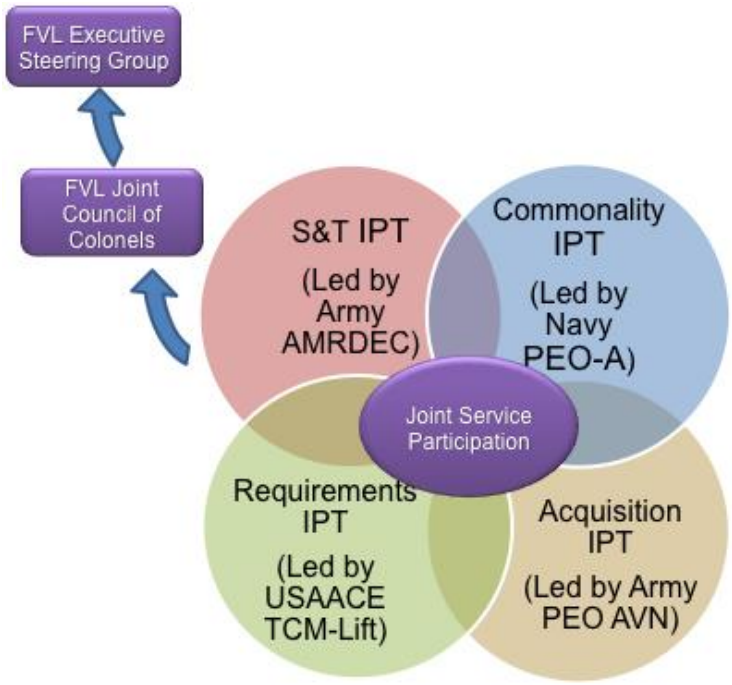


Figure D-5 Multiple IPTs Support the FVL Initiative

The duties of the individual IPTs are:

- Requirements IPT (RIPT) – will develop official requirements documents
- Acquisition IPT (AIPT) – will develop documents to support the acquisition process
- Commonality IPT (CIPT) – addresses use of common systems across FVL
- S&T Overarching IPT (SOIPT) – will develop S&T strategy for FVL (has 12 Working IPTs)
    - Air Vehicle Platform
    - Propulsion
    - Communications & Navigation
    - Weapons & Fire Control
    - Survivability & Vulnerability
    - Sensors: Pilotage & Targeting
    - Human System Integration
    - Mission Management
    - Vehicle Management / Flight Controls
    - Reliability & Maintenance
    - Subsystems
    - Training

The objective of the S&T OIPT is not to design an airplane but rather to identify technologies that might be available. FVL is NOT an airplane program – it is an initiative to develop an aviation weapon system (thus weapons WIPT etc. above).

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Although requirements are still being refined, the notional concept for a new aircraft must:

- Reach speeds of 230 knots (260 mph; 430 km/h)
- Carry up to 12 troops
- Operate in "high-hot" conditions at altitudes of 6,000 ft (1,800 m) and temperatures of 95-degrees Fahrenheit,
- Have a combat radius of 424 km (263 mi) with an overall unrefueled range of 848 km (527 mi).

As is shown in Figure D-6, technology assessment for FVL takes place in the JMR Technology Demonstration. Capabilities Assessment at the top of the figure shows the major documentation that must be developed for an acquisition program. Note the anticipated Materiel Development Decision is October 2016 and Milestone A is January 2019.

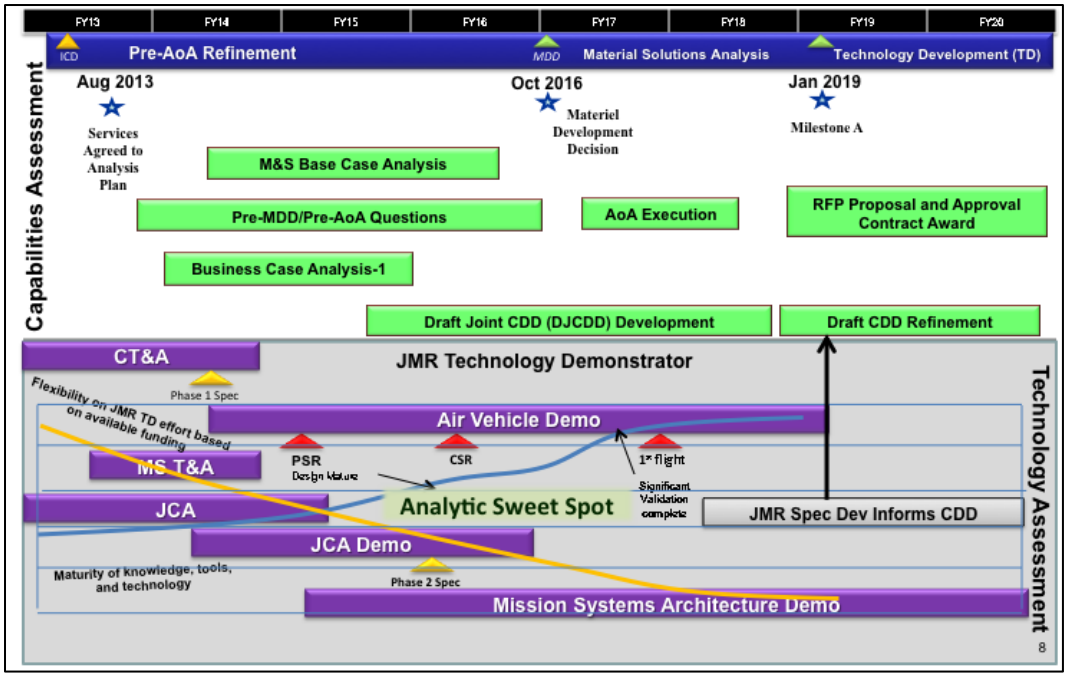


Figure D-6 Projected Road Ahead for FVL

Mission sets considered in the capabilities assessment include: cargo; utility; armed scout; attack; humanitarian assistance; medical evacuation; anti-submarine warfare; anti-surface warfare; land/sea search and rescue; special warfare support; vertical replenishment; airborne mine countermeasures; and others.

As is shown in Figure D-7, three sizes of aircraft are anticipated with one set of missions and potential Service customers for the light vehicle, three for the medium vehicle and one for the heavy vehicle. Additional details are competition sensitive.

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The FVL family of aircraft will be required to have either optionally piloted or autonomous flight capabilities.

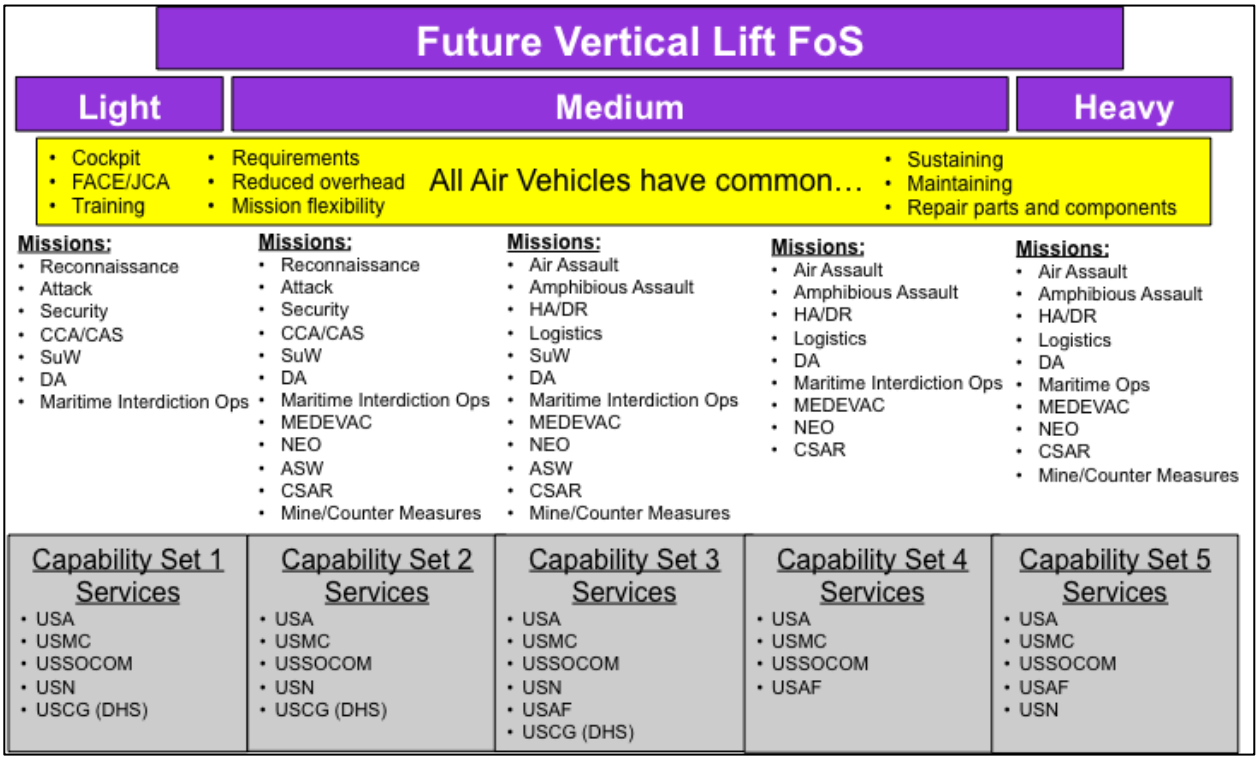


Figure D-7 The Future Vertical Lift Family

D.3 Findings Regarding JMR-TD and FVL FoS

The study team had several key findings with regard to JMR-TD and FVL FoS:

1. JMR-TD and FVL provide focus for Army Aviation S&T for next generation rotorcraft systems and provide a solid basis for much needed capability improvements (Ref. FVL ICD); however, there is no funding for FVL in the POM.
2. The JMR-TD vehicles are close in size and aerodynamic performance capability to the FVL medium class system.
3. The current FVL schedule leads to an IOC of the first system in the mid 2030s. It should be beneficial to accelerate this timeline through an evolutionary acquisition approach if funding allows.
4. The JMR-TD, DARPA X planes, USN/USMC prototyping efforts, and industry investment support talent development and retention in rotorcraft government and industry teams.

Based on these findings, the team recommended that ASA(ALT) develop an evolutionary acquisition approach for FVL to allow for earliest possible fielding consistent with funding constraints, as informed by the results of system of systems operational effectiveness analyses recommended elsewhere in this report.

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APPENDIX E ARMY AVIATION EFFORTS

The Aviation Development Directorate (ADD) is responsible for aviation S&T within the Aviation and Missile Research Development and Engineering Command (AMRDEC). Figure E-1 shows the organization of ADD. For the most part the Aviation Applied Technology Directorate (AATD) is located at Joint Base Langley-Eustis in Virginia, the Aeroflightdynamics Directorate (AFDD) is at NASA Ames Moffett Field in California, and the remainder of the organization is at headquarters at Redstone Arsenal in Alabama.

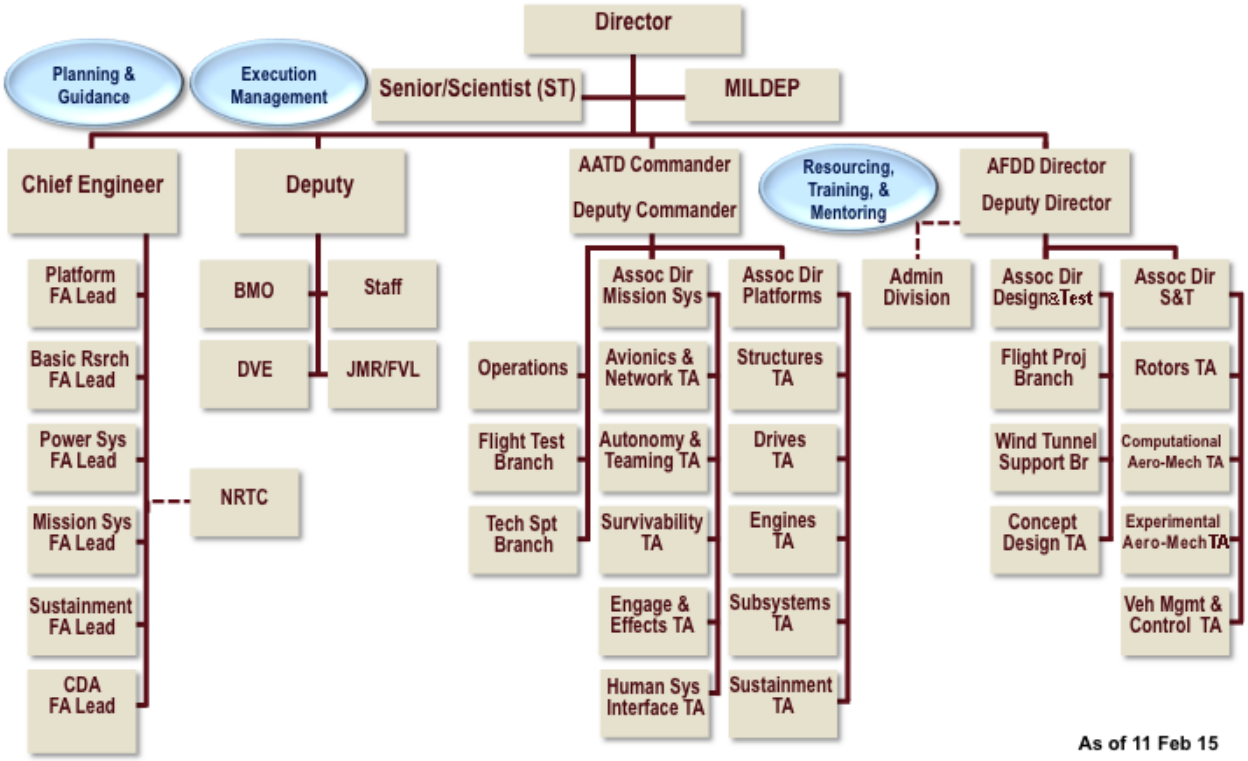


Figure E-1 Organization of the Aviation Development Directorate.

Figure E-2 shows the technology areas (TA) included in five of the ADD Focus Areas (FA). The sixth FA is Basic Research. Within these focus areas there are two major programs:

- Degraded Visual Environment Mitigation (DVE-M) in Mission Systems (see Section 3.1)
- Joint Multi-Role Technology Demonstrator (JMR-TD) in Platforms (see APPENDIX D)

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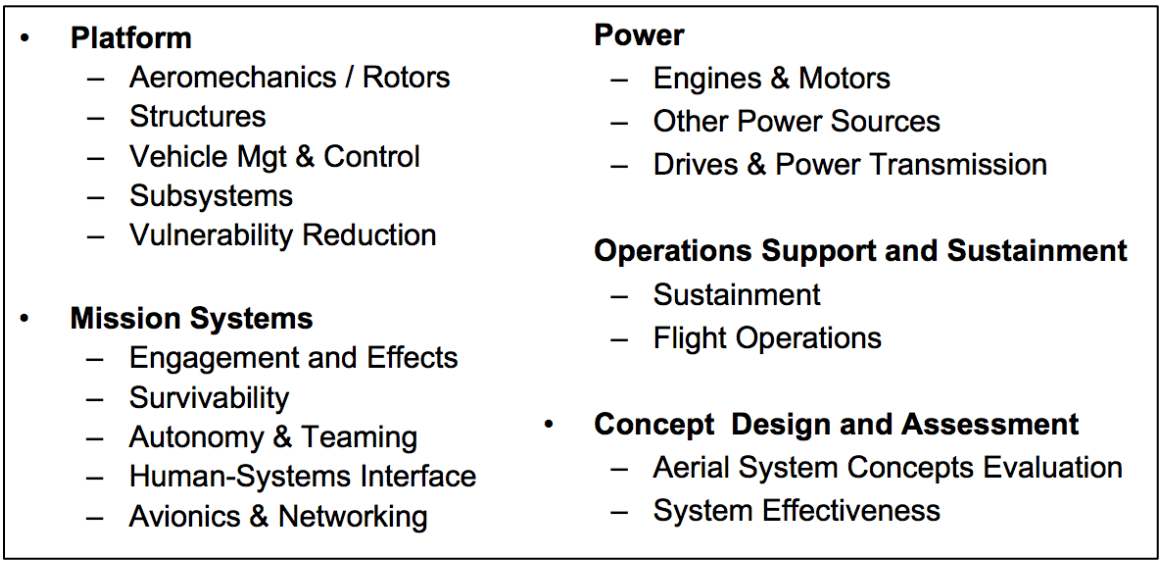


Figure E-2 ADD Focus Areas and Technology Areas

The Platform and Power Focus Areas were described in Section 3.5 in the Main Report. Mission Systems are described in Section 3.3 (manned-unmanned teaming) and Section 3.4 (lethality and survivability). The remaining focus areas are described below.

E.1 Operations Support and Sustainment

Programs in FY2016 Budget Documents

The Army's longstanding commitment to reducing maintenance costs and maximizing the performance and availability of aircraft, ground vehicles, and weapon systems is reflected in a wide range of RDT&E activities relevant to Condition-Based Maintenance (CBM) cited in the Fiscal Year 2016 Justification Book of Research, Development, Test & Evaluation, Army, Volumes 1-5.

For Budget Activity 1, Basic Research, specific efforts relevant to CBM involve research in the areas of advanced propulsion and structures. **Advanced Propulsion** efforts include work to develop thermal materials for advanced high-performance engines to reduce engine and transmission friction losses, improve performance, and reduce maintenance costs; on thermo-mechanical fatigue of materials; and on high-speed thermo-mechanical turbomachinery and mechanical energy transfer for future rotorcraft. It also includes development of advanced computational damage models and mechanical diagnostics experiments to improve the understanding of failure progression and diagnostics in drive train mechanical components, such as gears and bearings.

Advanced Structures basic research efforts include development of improved tools and methods to enable and enhance structural health monitoring capabilities and CBM for both rotorcraft and ground vehicles. It also includes work on composite structures able to meet the dynamic interaction requirements of future platforms identified by the Army Modernization Strategy. Overall, the research is intended to lead to safer and more affordable systems having

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extended service life, reduced maintenance costs, enhanced durability, and reduced logistics footprints. The work involves structural integrity analyses and development of failure criteria and inspection methods that address fundamental technology deficiencies in both metallic and composite Army rotorcraft structures. It addresses an urgent need for improved structural analysis and validation methods to predict durability and damage tolerance of composite and metallic rotorcraft structures, and the need for advanced structural dynamics modeling methods for both rotating and fixed system components important to future aircraft reliability. Specific efforts are focused on advanced fatigue assessment methodologies for metallic structures, improved composites technology, developing damage progression models, assessing the practicality of damage-detection sensing modes, failure mechanisms, integrated stress-strength-inspection, and advanced methods for predicting rotor system vehicle vibratory loads and aircraft stability.

Applied Research (Budget Activity 2) relevant to Condition Based Maintenance for aircraft builds on advances being recorded in ongoing basic research efforts. **Platform Design & Structures Technologies** efforts include the development and application of modeling and simulation tools to design and perform analysis of the Family of Systems (FoS) for Future Vertical Lift (FVL) to support "Zero Maintenance" helicopter concepts; physics of failure modeling to improve reliability of system components and enable damage-tolerant component design; and investigation of methods for monitoring component loads. Planned work for FY 2016 will include the development of improved damage initiation and propagation models, application of modeling and simulation tools to support design of FVL/novel concepts, and investigation of high-strain capable, multifunctional structures that offer improvements in structural efficiency and enable ultra-reliable, operationally durable designs.

Applied research in the area of **Maintainability & Sustainability Technologies** seeks to develop prognostic and system health assessment technologies to enable an enhanced CBM supportability structure applicable to an ultra-reliable, low-maintenance approach to aircraft design that significantly reduces unscheduled maintenance, inspections, and operations and sustainment costs. This work includes development of embedded multifunctional sensors with built-in processing and communications, health assessment systems to support adaptive controls, technologies for component self-assessment, and usage tracking and embedded history. Plans for FY 2016 call for investigating wireless communication technologies, integrating health assessment technologies into the Joint Common Architecture (JCA)/avionics/cockpit, developing fly-by-wire with CBM monitoring capability, developing miniaturized wireless sensors with on-component processing, history and parts tracking, and investigating technologies for in-flight transmission of condition/performance data to ground.

Applied research in the **Rotor and Structure Technology** area is directed toward the development of improved tools and methodologies enabling more accurate design for improved component reliability and durability. Specific efforts involve prognostic and diagnostic (P&D) inspection experiments aimed at improving structural risk assessment, development of self-sensing strategies for monitoring damage precursors, incorporating optimized sensing strategies into P&D systems, and investigating novel approaches for improving rotorcraft

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vehicle maintainability. FY 2016 plans call for the design and development of smart materials that can self-sense, self-heal, and self-reconfigure to facilitate damage/health assessment of aviation component structures, evaluation of material/component damage sensing strategies, modeling and simulation of damage detection, and investigation of data-fusion techniques for assessing material/component failure in aircraft.

Aviation Component Failure Modeling efforts include development of failure analysis and prediction models and techniques to support the Army's "zero maintenance helicopter" concept, including improved failure models to characterize and categorize specific material damage precursors relevant to aviation components, and a probabilistic framework for predicting remaining useful life of vehicle platforms. The work also includes investigation of advanced aviation component health monitoring techniques into health-usage monitoring systems (HUMS) and development of self-sensing structural material technologies that incorporate damage precursor detection philosophy. Planned FY 2016 work will develop the Virtual Risk-informed Agile Maneuver Sustainment (VRAMS) concept, which will evaluate technologies to autonomously provide state awareness at the material level and automate stress-reduction methods; investigate a "virtual reality" concept for self-diagnostics of real-time material state and automated solutions for self-directed maneuver alternatives in real-time; this effort will enable fatigue-free and zero-maintenance aircraft components. **Engine and Drive Train Technology** work includes development of high-temperature materials and improved methods for predicting propulsion system mechanical behavior.

Advanced Technology Development (Budget Activity 3) work relevant to Condition Based Maintenance for aircraft involves efforts in areas similar to those being pursued in basic and applied research projects. The **Advanced Rotary Wing Vehicle Technology** project includes activities intended to mature, demonstrate, and integrate components, subsystems and systems for vertical lift and unmanned air systems that provide reduced maintenance and sustainment costs and enable greater performance through improved rotors, drives, vehicle management systems and platform design and structures. Systems being demonstrated include rotors, drive trains, robust airframe structures, and integrated threat protection systems. This project includes the Joint Multi-Role (JMR) Technology Demonstrator in support of the Future Vertical Lift (FVL) family of aircraft.

Maintainability & Sustainability Systems work is focused on improving the operational availability of rotorcraft while reducing operating and support (maintenance) costs. Specific efforts include component sensing, diagnostics, prognostics, and control systems developments. The *far-term* objective of this work is to enable transition to an ultra-reliable, low-maintenance design approach that significantly reduces unscheduled maintenance, inspections and operating and sustainment costs. Recent and ongoing work has focused on advanced prognostic algorithms for failure modes for engines, structures, rotor systems and drives; the interfaces for health monitoring systems to communicate with Joint Common Architecture standards; integration of system health monitoring with electronic controls to enable adaptive control systems; engine adaptive controls to optimize performance, component life and maintenance schedule based on engine health; multifunctional aircraft

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sensor technology; demonstrating technologies for assessing the structural integrity of a primarily composite airframe; and verifying the integrity of composite repairs and predicting remaining useful life. FY 2016 plans include efforts to demonstrate wireless sensors for on-component processing of part health and usage history; evaluate methodologies enabling probability-of-failure predictions based on vehicle current state and anticipated missions; and mature and demonstrate technologies for component self-assessment, usage tracking and embedded history. Additional work will involve developmental testing of system health and fault recognition algorithms, sensors, and structural global health models. Advanced Technology Development work directed toward maturing integrated CBM technologies that reduce the operation and sustainment costs of vehicle electronics and electrical power devices is being conducted as part of the Army's **Combat Vehicle Electronics** project.

Ongoing RDT&E work in Budget Activities 4 and 5 is more limited than in the other categories, reflecting the fact that much work remains to be done before comprehensive CBM will become common practice for many Army systems. A search of ongoing activities in the Advanced Component Development and Prototypes (Budget Activity 4) category indicates only that the Aviation/Advanced Development program supports an **Advanced Maintenance Concepts and Equipment** project that includes work to develop diagnostics/prognostic monitoring systems. Activities supported in the System Development and Demonstration (Budget Activity 5) category include support under the **Aircraft Avionics** program for the Aircraft Notebook (ACN), an Army aviation automated information system program for streamlining the completion of aviation maintenance activities and the documentation required to maintain airworthiness for all Army aircraft. ACN reduces the information technology footprint within an aviation unit by integrating multiple software applications, including CBM+ tools, onto one hardware platform. The **Automatic Test Equipment** program includes a **Diagnostics/Expert Systems** project that supports the development of test and diagnostic systems and procedures, as well as integration of the Army's Maintenance Support Device (MSD), into the Brigade Combat Team information structure. The MSD serves as the at-platform data collection device for the Army's condition-based maintenance plus (CBM+) initiative and maintains compatibility with emerging aviation platform hardware bus technology, and ACN software interface requirements.

Revised Programs

Certain changes have been made to ARMY RDT&E activities involving CBM since publication of the Fiscal Year 2016 Justification Book of Research, Development, Test & Evaluation, Army, Volumes 1-5. The thrust of Applied Research (Budget Activity 2) involving **Maintainability & Sustainability Technologies** was changed in June 2015 to more accurately reflect work being done on the Autonomous Sustainment Technologies for Rotorcraft Operations (ASTRO) and Ultra Reliable Design programs. The work now involves continuing development of technologies and methodologies to enable more efficient designs and reduce the maintenance burden for future and current fleet vertical lift aircraft; development of on-engine, adaptive engine controls to optimize performance, component life and maintenance schedule based on engine health; development of in-flight, real-time, automated methods to adjust rotor system track and balance to reduce aircraft vibration and loads; development of improved failure

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detection capabilities within the planetary system; and reducing the size and weight impact of advanced sensor technologies. Additional work involves continuing development of methodology to allow operations above maximum continuous rating for limited periods of time; development of a level of autonomy for the condition assessment process for a composite airframe; decision support for repair decisions with a repair integrity assessment approach; and development of a comprehensive integrated aircraft-wide electrical system capability for diagnostics, fault isolation, and generating trendable health indicators. An assessment directed toward development of reliability criteria for design tools, methodologies, and materials to facilitate optimization of future rotorcraft designs is also being conducted.

Another change, one involving Advanced Technology Development (Budget Activity 3) in the area of **Maintainability & Sustainability Systems,** restates FY 2016 plans as emphasizing the development of technologies and methodologies to enable more efficient designs and reduce the maintenance burden for future and current fleet vertical lift aircraft. Specific planned activities include completion of developments of on-engine, adaptive engine controls to optimize performance, component life and maintenance schedule based on engine health; development of in-flight, real-time, automated methods for adjusting rotor system track and balance to reduce aircraft vibration and loads; development of improved failure detection within the planetary system; and reducing the size and weight impact of advanced sensor technologies. Additional planned FY 2016 work will develop methodology to allow operations above maximum continuous rating for limited periods of time; complete development of a level of autonomy for the condition assessment process for a composite airframe; and provide decision support for repair decisions with a repair integrity assessment approach. This change was also made to more accurately describe the work being done on the ASTRO program.

E.2 Concept Design and Assessment

The Concept Design and Assessment (CD&A) group focuses on

- Multi-disciplinary design analysis and optimization
- Development of design methods and tools
- Concept formulation and design
- Generation of conceptual design performance data to populate the evaluation trade space
- Evaluation of concepts' ability to meet user requirements
- Identification of technology impacts

Figure E-3 summarizes CD&A activities.

CD&A supports in-house AMRDEC efforts, JMR and FVL initiatives, next generation UAS efforts, and other efforts within the Aviation S&T community.

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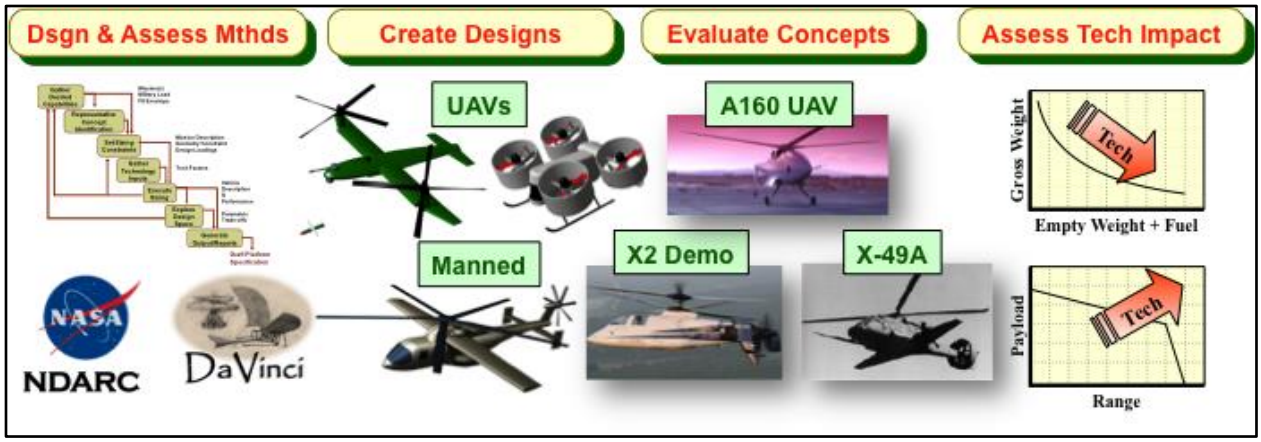


Figure E-3 CD&A Activities

For example, the group has performed extensive analysis for the Future Vertical Lift Initiative to explore the impact of various design choices on projected vehicle performance. These studies inform the requirements definition process to balance requirements across the family of systems. Assessments include aerodynamics, aeromechanics, performance, and flying qualities

In addition, in order to exercise current capabilities, develop new capabilities, and explore new concepts, the group also performs a "deep dive" on an advanced concept such as the tail sitter UAV configuration examined during FY15.

This is a small group (10-15 personnel) that acts as the "honest broker" for many efforts, comparing alternatives and independently assessing claims. Because many of these assessments are competition sensitive they cannot be discussed in this document.

E.3 Unmanned Aircraft Systems

Army Unmanned Aircraft System (UAS) efforts include Manned-Unmanned Teaming (described in Section 3.3) as well as development and modernization of UAS. This section focuses on the latter.

Legacy Army UAS include:

- Raven – hand-launched, 4 lb max takeoff
- Puma – hand-launched, 13.5 lb max takeoff
- Shadow – short range tactical ISR, 375 lb max takeoff
- Gray Eagle – Predator upgrade, 3,600 lb max takeoff

Figure E-4 lists the UAS challenges and concerns cited by the Deputy PM for UAS in July 2015.[37] Note that the first challenge/concern listed is that S&T investment is needed for Group 3 and

[37] John Beck, "Army UAS Update," briefing to Huntsville Aerospace Marketing Association, 15 July 2015, http://hamaweb.org/presentations/2015/july2015johnbeck.pdf

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above (such as Shadow and Gray Eagle) and that it is assumed that industry will drive the S&T for smaller platforms.

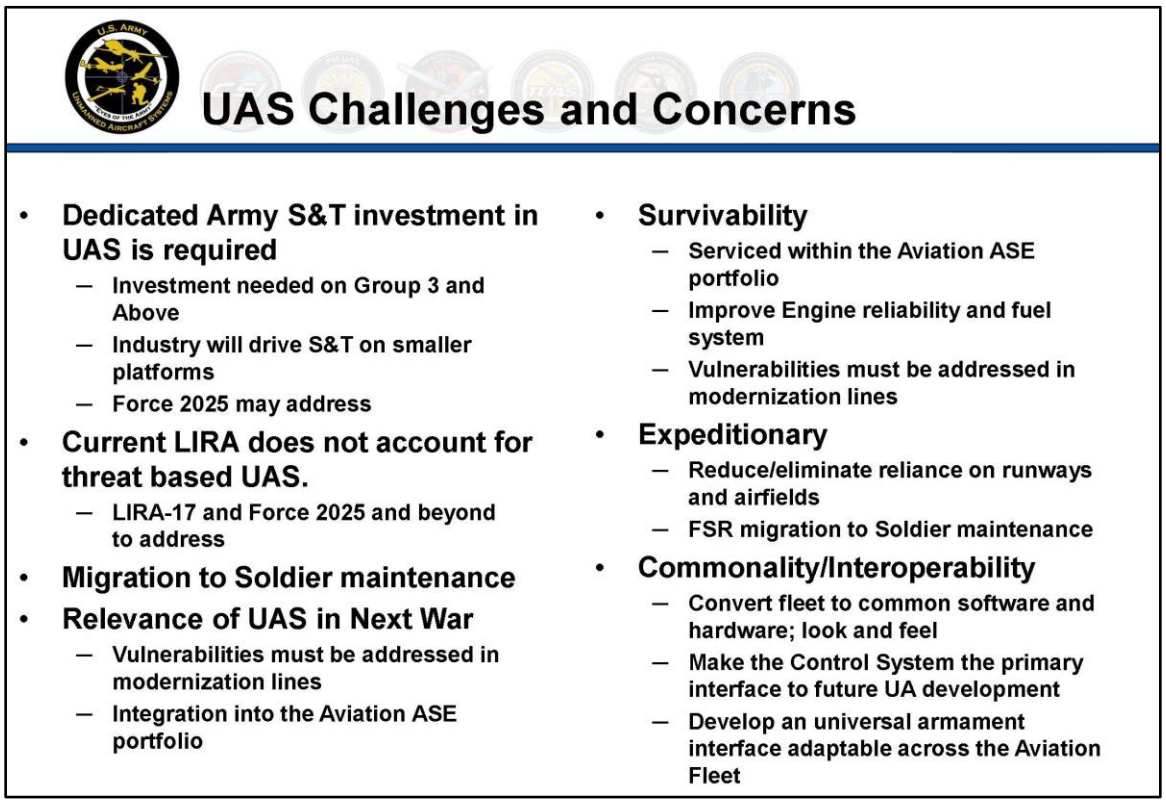
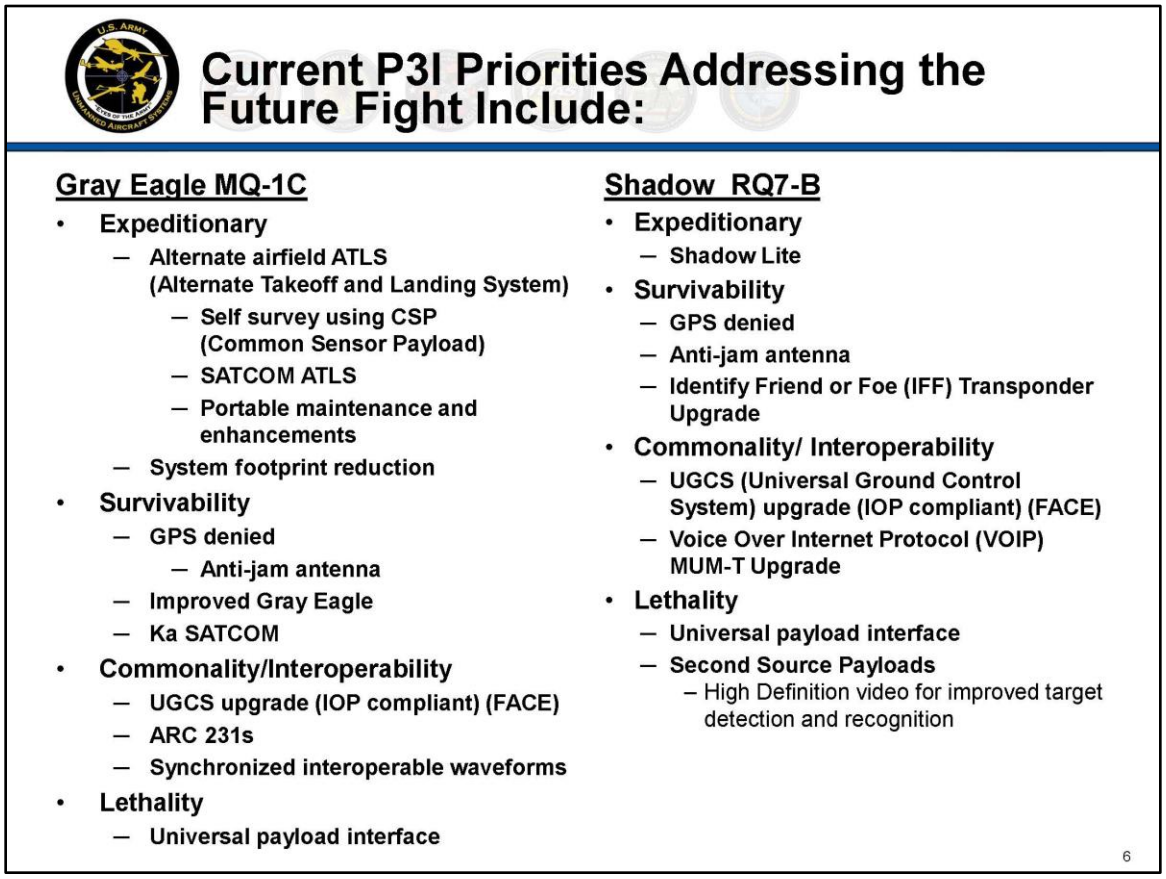


Figure E-4 UAS Challenges and Concerns

The Army P3I priorities to address these concerns for the larger UAS platforms are displayed in Figure E-5. Note that interoperability and commonality are cited for both platforms.

AMRDEC Aviation has been given the responsibility to develop UAS technology for both new systems and modernization of legacy systems, but they have generally not been given additional funds to do so. As a result, Army S&T has relied on industry to develop the UA vehicles. The tendency is for the development companies to build a package that includes both the vehicle and ground control system (GCS), inhibiting development of a common control system. For example, both Shadow and Gray Eagle have unique operating systems and mission packages. While the GCS for Shadow and Gray Eagle is called a Universal Ground Control System (UGCS), it is optimized for one or the other and cannot easily transition to a different vehicle. For example the Gray Eagle GCS has functions to control SATCOM and Link-16 communications, weapons and SAR payloads; the Shadow system does not. An additional complication is that the communications equipment is located in the GCS rather than in the vehicle.

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ATLS - Alternate Takeoff and Landing System
CSP - Common Sensor Payload
UGCS - Universal Ground Control System
VOIP – Voice over Internet Protocol

Figure E-5 P3I Priorities for Larger Legacy UAS

The US Army Roadmap for Unmanned Aircraft Systems[38] is subtitled "Eyes of the Army" reflecting the Army's current focus on using UAS for ISR. It is anticipated that cargo/sustainment UAS will be introduced in the mid-term (2016-2025). Improved networking will permit improved information distribution in the same timeframe. By the far-term (2026-2035) technology advances will permit operators to control multiple UAS from a common control system.

These considerations led to the ASB recommendation that ASA(ALT) should revise the UAS Roadmap to expand near-term and future UAS vehicle options, some of which should be compatible with speed, hover, and range of current and future manned aircraft, with attributes compatible with distributed functionality among UAS (ISR, Lethality, …).

[38] US Army UAS Center of Excellence, "*Eyes of the Army," U.S. Army Unmanned Aircraft Systems Roadmap 2010-2035*, 2010, http://www-rucker.army.mil/usaace/uas/us%20army%20uas%20roadmap%202010%202035.pdf .

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E.4 Basic Research

S&T is summarized by REDCOM as:[39]

- **Discovering, Maturing** and **Demonstrating** technologies that support the desired Army (in this case Army Aviation) capabilities and then **combining technologies** into **capabilities.**
- **There are three major types of S&T**
  - **6.1 Basic Research:** Fundamental Science, system non-specific
  - **6.2 Applied Research:** Component Level, Concept Development
  - **6.3 Advanced Technology Development:** System Level, Concept Field Demonstration
- **There are two major strategies**
  - Develop body of technical **knowledge** that supports decisions
  - Develop early versions of **"the system"**

S&T is **not** engineering work for existing platforms. Figure E-6 describes S&T in RDECOM; basic research is distributed between ARL/ARO and the RDECS (AMRDEC for Aviation).

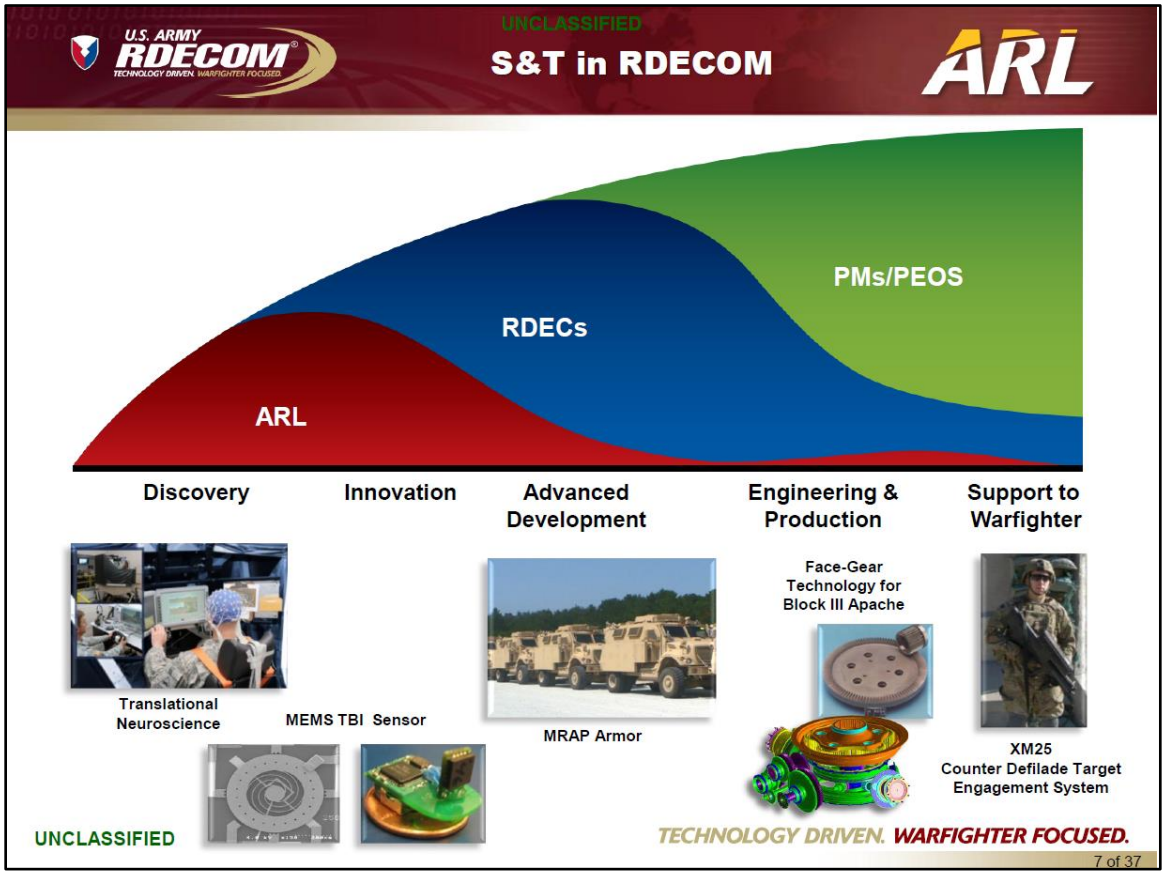


Figure E-6 S&T in RDECOM

[39] Army Aviation Technical Panel briefing to Army Aviation Home-on-Home, 22 January 2015.

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Figure E-7 shows Aviation S&T and how 6.1 basic research fits within the overall portfolio. The 6.2/6.3 elements shown are discussed in their respective sections within the main body of this report and/or the appendices.

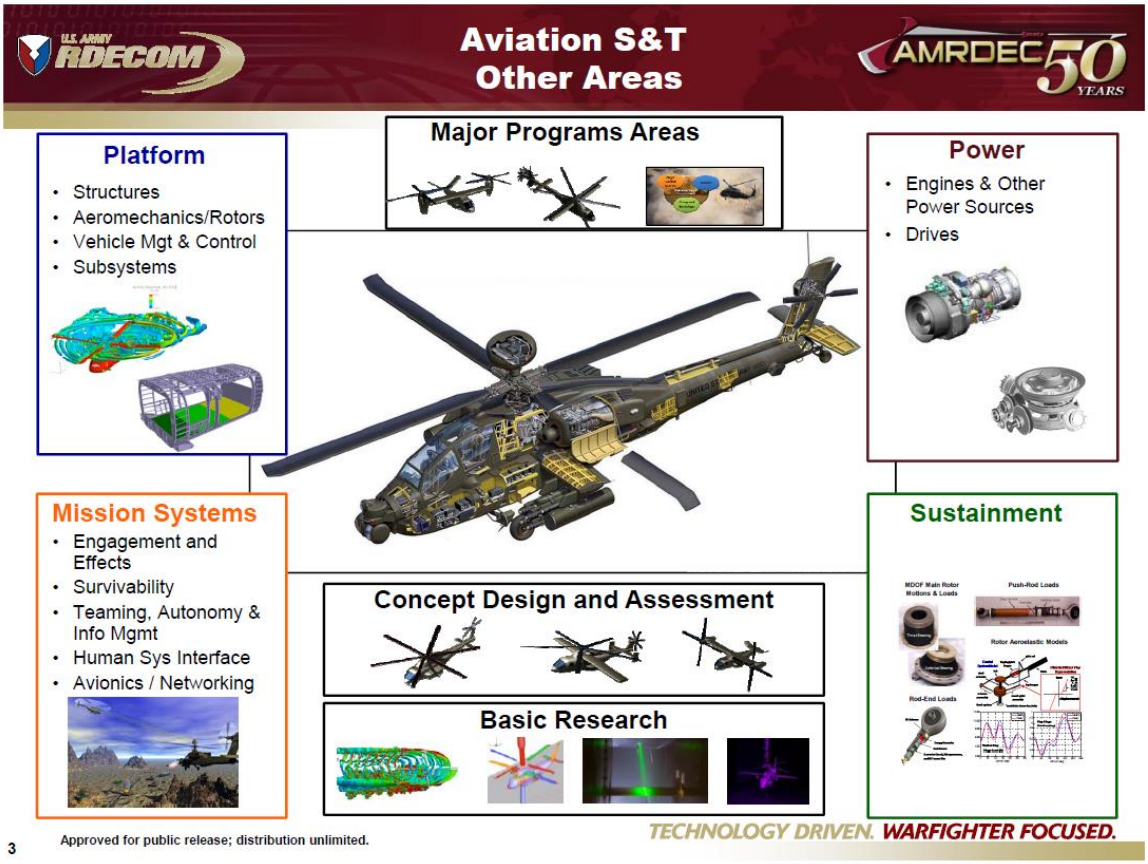


Figure E-7 Aviation S&T - 6.1 Basic Research Supports the Overall Portfolio

Figure E-8 presents an overview of the overall 6.1 Basic research portfolio supporting Army Aviation, distributed across ARL/ARO and AMRDEC including the University Centers of Excellence at Georgia Tech, University of Maryland and Penn State University that combine basic research with graduate education.

Figure E-9 shows a deeper dive into the Aeromechanics elements within the 6.1 basic research portfolio. Figure E-10 presents the aviation 6.1 basic research focus area road map that connects the 6.1 basic research to the 6.2 research areas out to FY 21.

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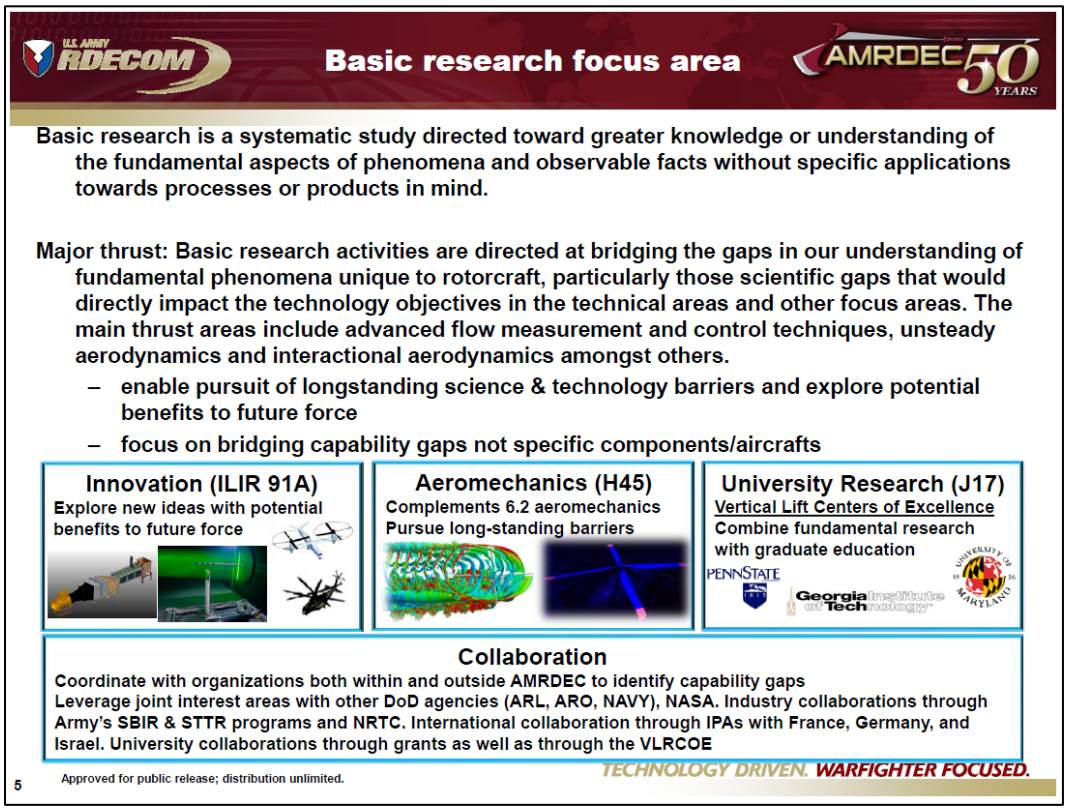


Figure E-8 Overview of the Basic Research portfolio to Support Army Aviation

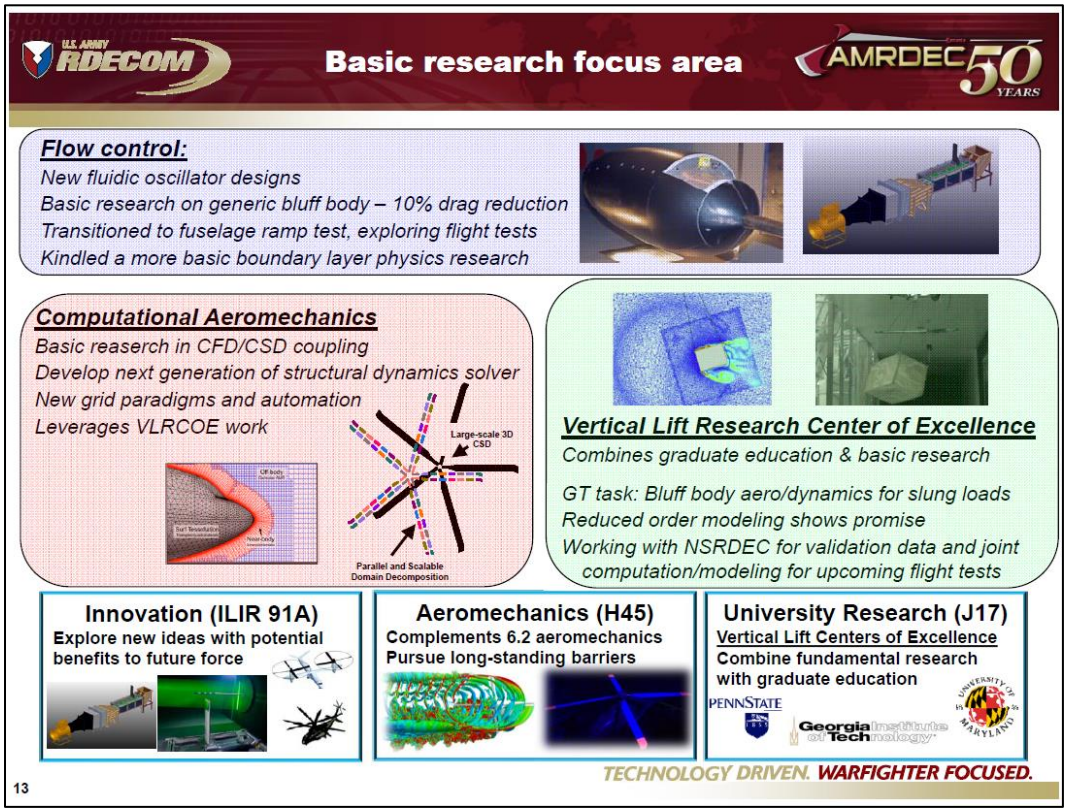


Figure E-9 A Deeper Dive into the Aeromechanical Elements Basic Research

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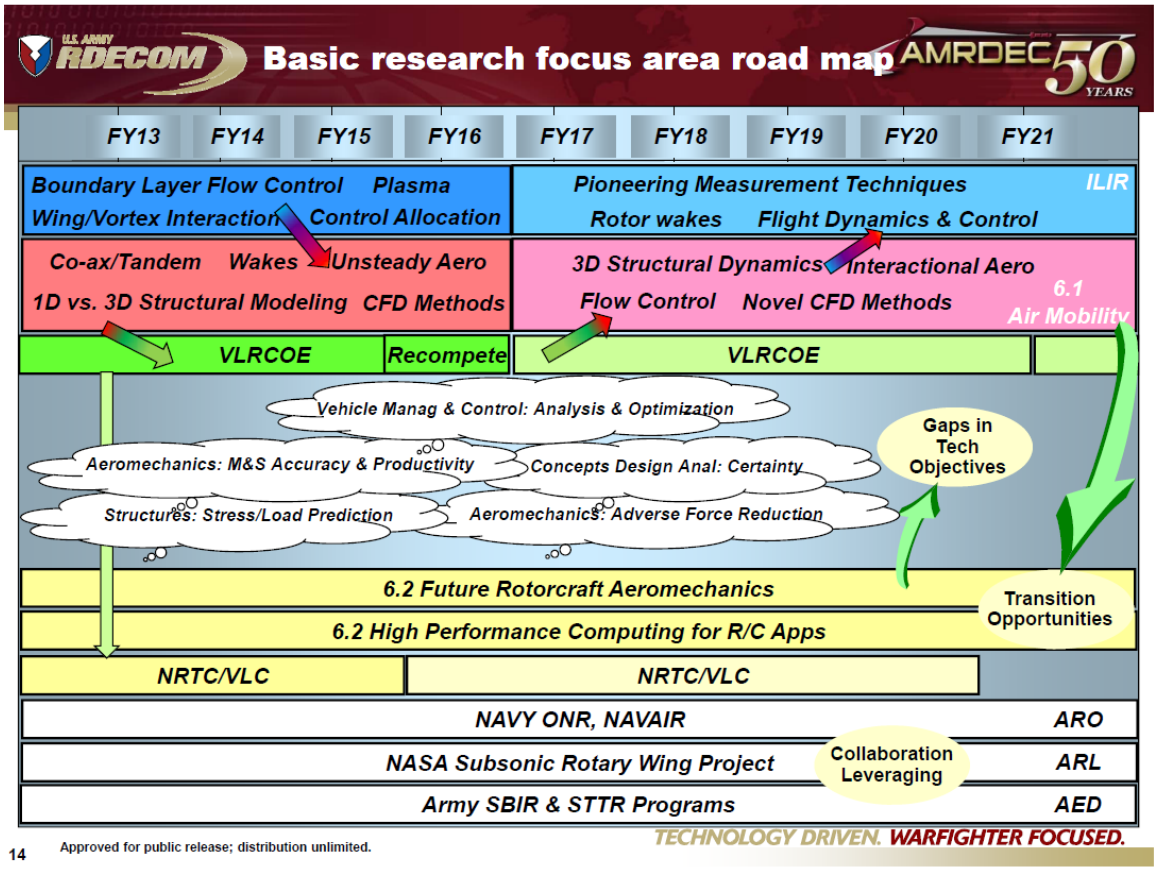


Figure E-10 Aviation Basic Research Focus Area Road Map

Finally, it is important to point out a new laboratory business model termed the "Open Campus Initiative" put forward by ARL. The concept for this ARL initiative is shown in Figure E-11. This innovative approach holds forth the promise of leading to breakthroughs by allowing university/industry researchers extensive access to ARL laboratory facilities and provides an opportunity to have ARL staff work closely with university researchers including faculty, Ph.D. students and post docs as well as industry researchers.

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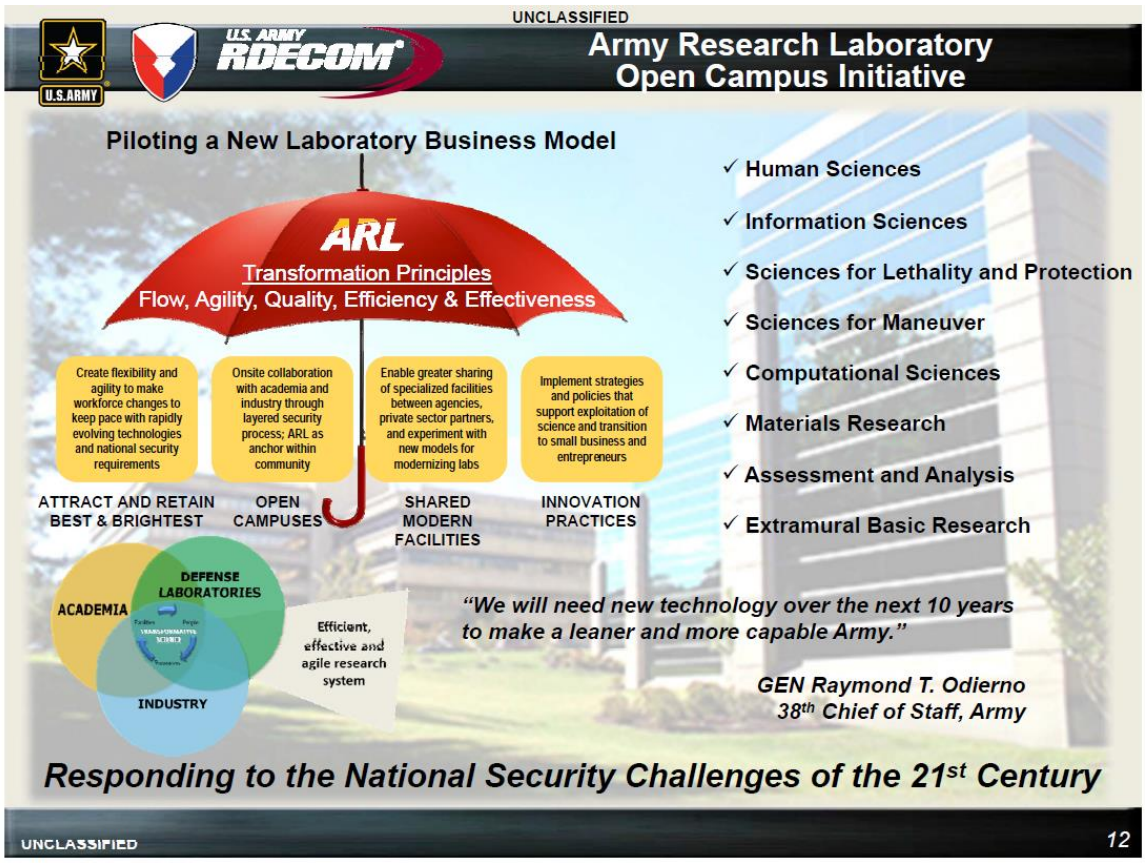


Figure E-11 The ARL Open Campus Initiative

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APPENDIX F OTHER EFFORTS IN MANNED AND OPTIONALLY MANNED ROTORCRAFT

Task 1 of the TOR directs the study team to review current government and industry aviation plans and programs. Army systems are described in the main part of the report and in Appendix E. The remainder of this section describes the information obtained regarding other efforts on manned and optionally manned rotorcraft.

Figure F-1 summarizes the characteristics of current and near-term DoD rotorcraft with the heaviest platforms at the top. Note that the largest, the King Stallion CH-53K, will be able to lift 35,000 lb and is expected to reach IOC with the Marine Corps in 2018. It is also noteworthy that only two of the remaining rotorcraft, the Osprey and Lakota, have an IOC within the last 25 years.

The Osprey has a cruise speed of 241 kt, the only rotorcraft to exceed 200 kt; it is also the only tilt-rotor on the list.

The Army is funding the only developmental rotorcraft effort in the Services, the Joint Multi-Role Technology Demonstrator (JMR-TD). Two demonstrators are funded for flight tests in 2017. The Bell demonstrator is a tilt-rotor that builds on Osprey technology. The Boeing-Sikorsky demonstrator is a coaxial rigid-rotor, pusher-propulsor design. Both industry teams have invested significant internal resources in the effort. The JMR-TD is described in detail in APPENDIX D.

DARPA is funding the VTOL X-Plane program. Flight demonstrations will take place in 2017-2018. This effort is described in detail in Section F.4

Industry is also funding development efforts in proprietary programs. On 22 May 2015 Sikorsky announced the successful first flight of the S-97 Raider helicopter.[40]

[40]Sikorsky press release, “Sikorsky S-97 RAIDER™ Helicopter Achieves Successful First Flight,” 22 May 2015, http://raider.sikorsky.com/raider-first-flight.asp.

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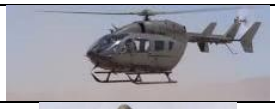
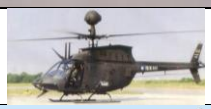
DoD Current and Near-Term Rotorcraft	Name / Designator	Role	IOC	Service	Max Takeoff (lb)	Max Load	Cruise Speed/ Range	Developer (inventory)
	King Stallion CH-53K	Cargo	2018	USMC	84,700	35,000 lb	170 kt / 460 nm	Sikorsky
	Super Stallion CH-53E & Sea Dragon MH-53	Cargo Multi-mission	1981	USMC & USN	73,500	30,000 lb int, 32,000 lb ext	150 kt / 540 nm	Sikorsky (176)
	Osprey C/MV-22	Cargo, Multi-mission	2006	USAF & USMC	52,870	10,000 lb	241 kt / 1,000 nm	Bell (231)
	Chinook CH-47D/F	Cargo	1962	USA	50,000	28,000 lb	130 kt / 400 nm	Boeing (503)
	Whitehawk VH-60N	VIP Trans-port	1988	USMC	23,501		159 kt max / 1200 nm	Sikorsky (8)
	Black Hawk UH-60	Utility	1979	USA	23,500	2,640 lb int, 9,000 lb ext	159 kt / 640 nm	Sikorsky (1,565)
	Pave Hawk/ Rescue Hawk HH-60	Search & Rescue	1981	USAF & USN	22,000	5,000 lb	159 kt / 324 nm	Sikorsky (149)
	Seahawk, M/SH-60	ASW, multi-mission	1984	USN	21,884	6,684 lb	146 kt max / 450 nm	Sikorsky (460)
	Apache AH-64	Attack	1986	USA	23,000		143 kt / 257 nm	Boeing (756)
	Sea King VH-3D	VIP Trans-port	1976	USMC	22,050		144 kt max / 540 nm	Sikorsky (11)
	Super Cobra, AH-1W & Viper AH-1Z	Attack	1986	USMC	14,750		190 kt max / 317 nm	Bell (161)
	Twin Huey, UH-1N & Venom, UH-1Y	Utility	1970	USAF & USMC	10,500	4,500 lb	110 kt / 248 nm	Bell (154)
	Lakota UH-72	Trainer, CONUS only	2007	USA	7,900	3,950 lb	133 kt / 370 nm	Eurocopter (307)
	Kiowa OH-58D	Observa-tion	1969	USA	5,500	1,700 lb	110 kt / 140 nm	Bell (618)
	Little Bird A/MH-6	SOF	1980	USA	3,100	1,500 lb (6 pax)	135 kt / 232 nm	McDonnell Douglas / Boeing (47)

Figure F-1 DoD Current and Near-Term Rotorcraft

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F.1 OSD Air Platforms Community of Interest

The Office of Secretary of Defense (OSD) has established 17 Communities of Interest (COIs) to encourage multi-agency coordination and collaboration:

1) Advanced Electronics
2) Air Platforms
3) Autonomy
4) Biomedical
5) CounterIED
6) CounterWMD
7) Cyber Security
8) Electronic Warfare
9) Energy & Power Technologies
10) Engineered Resilient Systems
11) Ground & Sea Platforms
12) Human Systems
13) Command, Control, Comms, Computers, and Intelligence (C4I)
14) Materials & Manufacturing Processes
15) Sensors
16) Space
17) Weapons Technologies

The Air Platforms COI is led by the Air Force. The Army principal is Bill Lewis of AMRDEC.

COIs develop technology roadmaps for the relevant technology areas and describe the cross-organization interactions in terms of four levels of coordination:

1) Information Sharing
2) Active Coordination (deconflicted, not joint)
3) Building Joint S&T Roadmaps
4) Delivering Joint S&T Roadmaps

The Air Platforms COI is primarily Level 2 (for technologies that are predominantly single-Service investment) and Level 3 (for technologies of common interest).

Air Platform Technology Sub-Areas are 1) Fixed Wing Vehicles, 2) Rotary Wing Vehicles, 3) High Speed/Hypersonics, and 4) Aircraft Propulsion, Power and Thermal. In the funding request for FY16 $207M is planned for S&T in rotary wing vehicles. The Army provides over 60% of the proposed S&T funding for rotary wing vehicles; DARPA plans to provide over 20% and the Navy/Marine Corps will provide over 10%. OSD plans to provide a small amount for rotary wing S&T (on the order of $350K). Specific OSD projects were not identified.

F.2 Navy/Marine

The USN and USMC operate a number of manned vertical lift platforms for a variety of missions. Among these are the AH-1, UH-1, VH-3, HH-60, M/SH-60, C/MV-22 and CH-53. Of most interest to potential Army aviation applications are the V-22 and CH-53K.

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The V-22 Osprey Tilt-Rotor, with a speed of approximately 250 knots, is the only deployed vertical lift platform within the DoD inventory with a speed that can satisfy the FVL requirement. In fact, the V-22 tilt-rotor technology provides the basis for one of the JMR-TD vehicles, which will demonstrate FVL aerodynamic capabilities, including speed. While V-22 does not satisfy other FVL requirements, it could serve as a back-up interim capability for the most speed-critical FVL missions (e.g., MEDEVAC) in the event of unanticipated programmatic delays to the FVL program. In addition, some of the V-22 technology efforts could be of benefit to Army aviation rotorcraft systems. These include material efforts, such as rotorcraft blade coatings, engine blade wear coatings and windscreen coatings. Relevant aerodynamic technology efforts include active flow control and external carry at high speeds. AMRDEC is tracking these S&T efforts to exploit advances relevant to Army aviation.

The Army CH-47F currently has the greatest vertical lift load capacity of Army deployed platforms, rated at 14 stons. However, at hot/high conditions, the external load is 6 stons at 20 nm. As is shown in Figure F-2, this load capacity can be greatly improved to 9 stons at 20 nm with a future upgrade to the Future Affordable Turbine Engine (FATE).

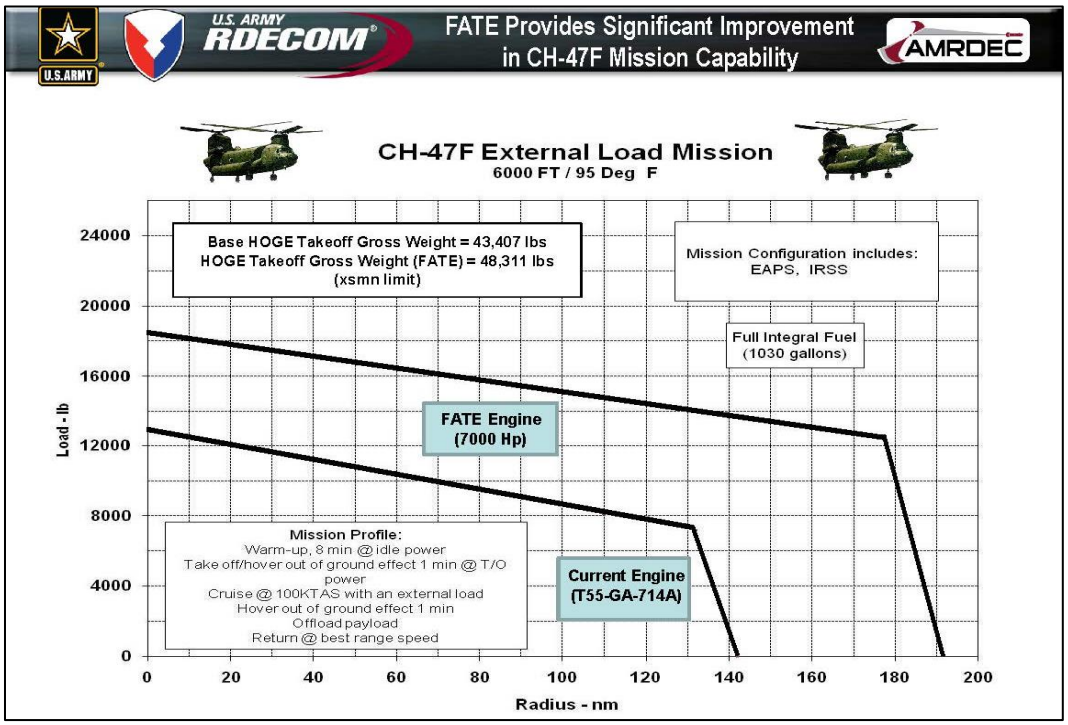


Figure F-2 Future Affordable Turbine Engine Improvement for CH-47

The latest version of the USN CH-53, the CH-53K, has an external load capacity of 18 stons. The requirement is for an external load capability of 15 stons at 110 nm (Figure F-3). While 18 stons is still shy of the Joint Heavy Lift (JHL) requirement of 20-30 stons, the CH-53K could provide the Army with a significant increase in heavy vertical lift capability if it becomes evident that a JHL

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program is unaffordable anytime in the foreseeable future. From an S&T perspective, the Army should benefit from technologies being developed for CH-53K (Figure F-4).

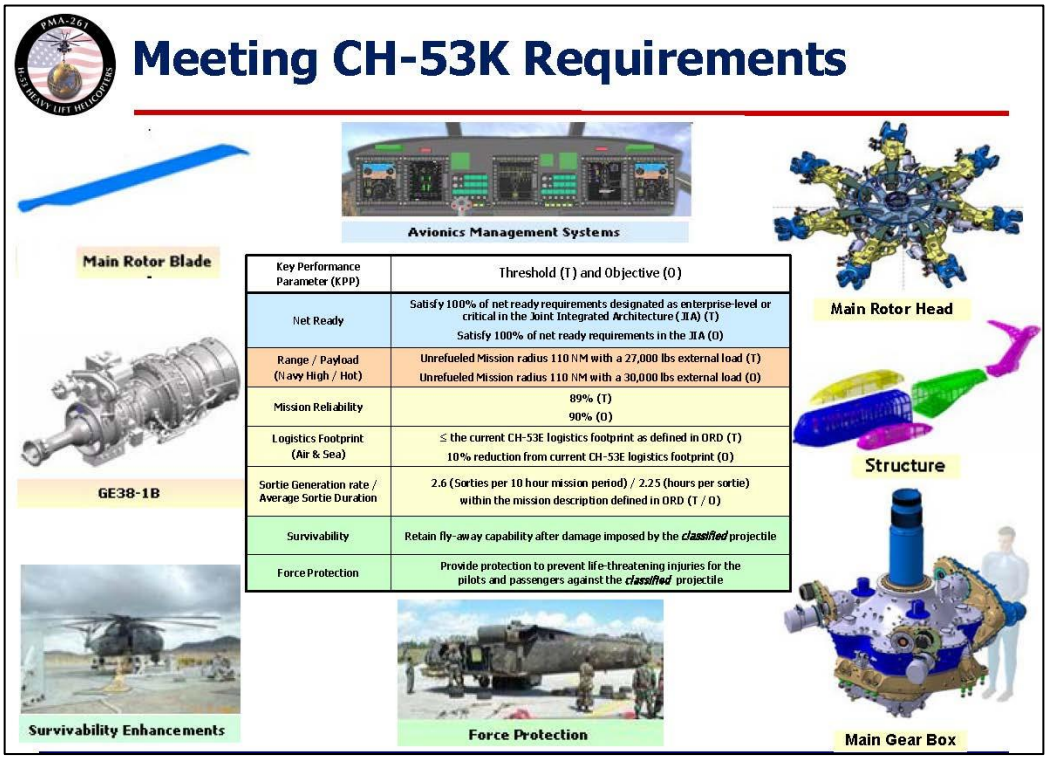


Figure F-3 CH-53 Requirements

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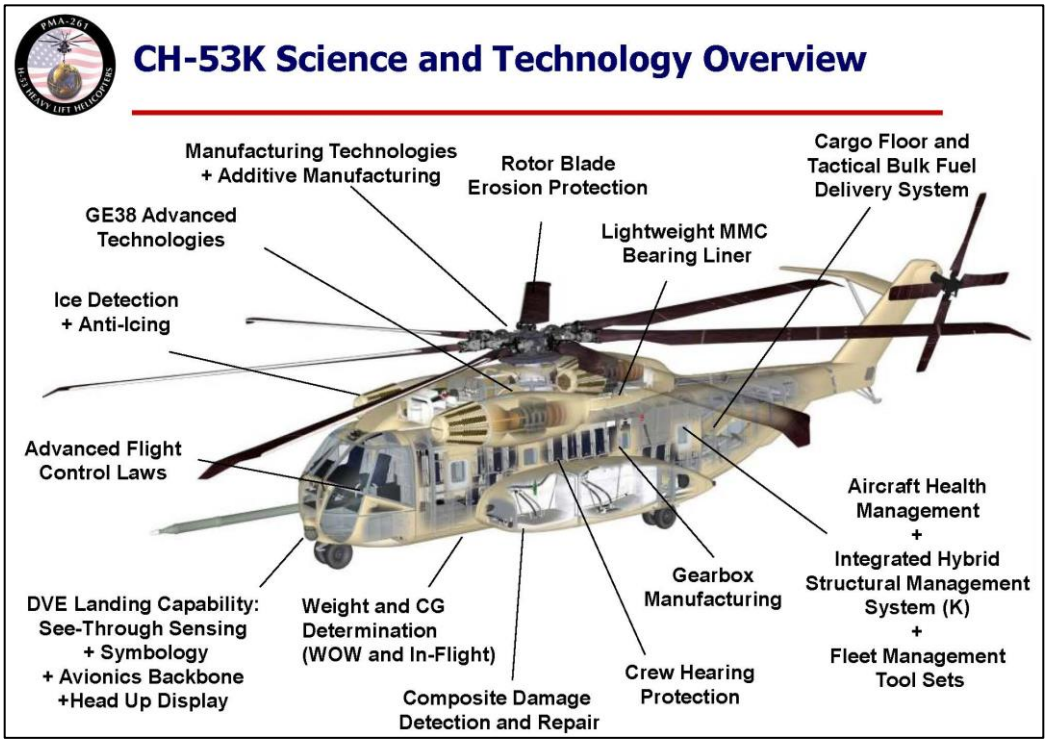


Figure F-4 CH-53K Science and Technology

F.3 Air Force

Beginning with the Key West Agreement[41] in 1948, there have been numerous documents that define the separate responsibilities of the Army and Air Force with respect to air transport. The Air Force has responsibility for longer-range transport and has chosen to use fixed wing aircraft for the purpose.

An Air Force presentation to the House Armed Services Committee on Air Force Rotorcraft Programs[42] stated:

> Air Force rotary wing assets are critical to the mission of the Air Force and provide worldwide support to Combatant Commanders. The HH-60G supports the Service's Core Function of Personnel Recovery. Additionally, the UH-1N provides security for Nuclear Operations while also ensuring continuity of government and continuity of operations in the National Capital Region. Another H-1 variant, the TH-1H, provides a modern platform for the rotary wing track of

[41] Richard Wolf, *The United States Air Force: Basic Documents on Roles and Missions*, 1987, http://www.afhso.af.mil/shared/media/document/AFD-100525-080.pdf

[42] Kane, Major General Robert and Major General Noel Jones, *Presentation to the House Armed Services Committee, Subcommittee on Tactical Air and Land Forces – Air Force Rotorcraft Programs*, 27 March 2012, http://armedservices.house.gov/index.cfm/files/serve?File_id=d305f5a9-ce63-4b12-b815-3a459128ea9e

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> Air Force undergraduate pilot training. Finally, the CV-22 provides US Special Operations Command with a unique long-range vertical lift capability.
> . . .
> The Air Force continues to participate in the DoD-wide Future Vertical Lift effort to ensure a joint roadmap informs future modernization efforts. While fiscal constraints may have required us to reassess the timing of some rotary wing modernization efforts, the Air Force's commitment to rotary wing modernization remains strong.

Thus there are several niche roles for rotary wing aircraft in the Air Force. In general the Air Force adapts aircraft developed by another Service.

F.4 DARPA

DARPA is currently funding the Vertical Takeoff and Landing (VTOL) Experimental Aircraft (X-Plane) effort. This $130 million project will cover 52 months, from 2013 to 2018, in three phases:

- Phase 1: develop a preliminary concept design for aircraft (4 primes)
- Phase 2: develop, construct, and integrate (1 prime)
- Phase 3: conducting flight test demonstrations by 2017-2018 (1 prime)

Conventional rotorcraft are limited to about 175 knots. Fixed wing aircraft achieve higher speeds but are not as agile as a helicopter. The DARPA effort has four specific goals:[43]

- Speed: Achieve a top sustained flight speed of 300 kt-400 kt
- Hover efficiency: Raise hover efficiency from 60 percent to at least 75 percent
- Cruise efficiency: Present a more favorable cruise lift-to-drag ratio of at least 10, up from 5-6
- Useful load capacity: Maintain the ability to perform useful work by carrying a useful load of at least 40% of the vehicle's projected gross weight of 10,000-12,000 pounds

The effort focuses on unmanned aircraft but technology developed is applicable to manned aircraft as well.

The four competing designs in Phase 1 are shown in Figure F-5: [44]

- Boeing Phantom Swift – Four ducted fans - 2 body lift fans fore and aft and 2 wingtip thrusters that tilt for forward flight
- Karem – tilt rotor with optimum speed rotor
- Sikorsky (w/ Lockheed Skunk Works) – tail-sitter aircraft using rotor blown wing

[43] Dr. Ashish Bagai, "Vertical Takeoff and Landing Experimental Plane (VTOL X-Plane)," http://www.darpa.mil/program/vertical-takeoff-and-landing-experimental-plane accessed 27 Oct 2015.

[44] Richard Whittle, "The Next X-Plane," *Air and Space Magazine*, October 2015.

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- Aurora Flight Sciences Lightning Strike – electric generators that drive 24 fans that tilt upward for lift and forward for horizontal flight, 18 are in a wing near the tail of the aircraft and 6 are on a canard near the nose

Downselect from four contractors to one is expected late 2015/early 2016.



Figure F-5 DARPA VTOL X-Plane Designs

F.5 Army Special Operations

In addition to Chinook and BlackHawk, Army Special Operations uses the AH-6/MH-6 Little Bird attack/utility helicopter shown in Figure F-6. Little Bird is used for close air support of ground troops, target destruction raids, and armed escort of other aircraft. It is a small (3,100 lb max takeoff) aircraft that is less detectable than the larger platforms.

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Figure F-6 Little Bird carrying Rangers strapped to benches along the fuselage.

F.6 NASA

The Revolutionary Vertical Lift Technology Project (RVLT) is part of the overall NASA Advanced Air Vechicles (AAV) which is shown in Figure F-7. Other projects within the AAV Program, including the Advanced Air Transport Project, the Advanced Composites Project and the Aeronautical Evaluation & Test Capabilities Project, provide some peripheral basic support for the RVLT project.

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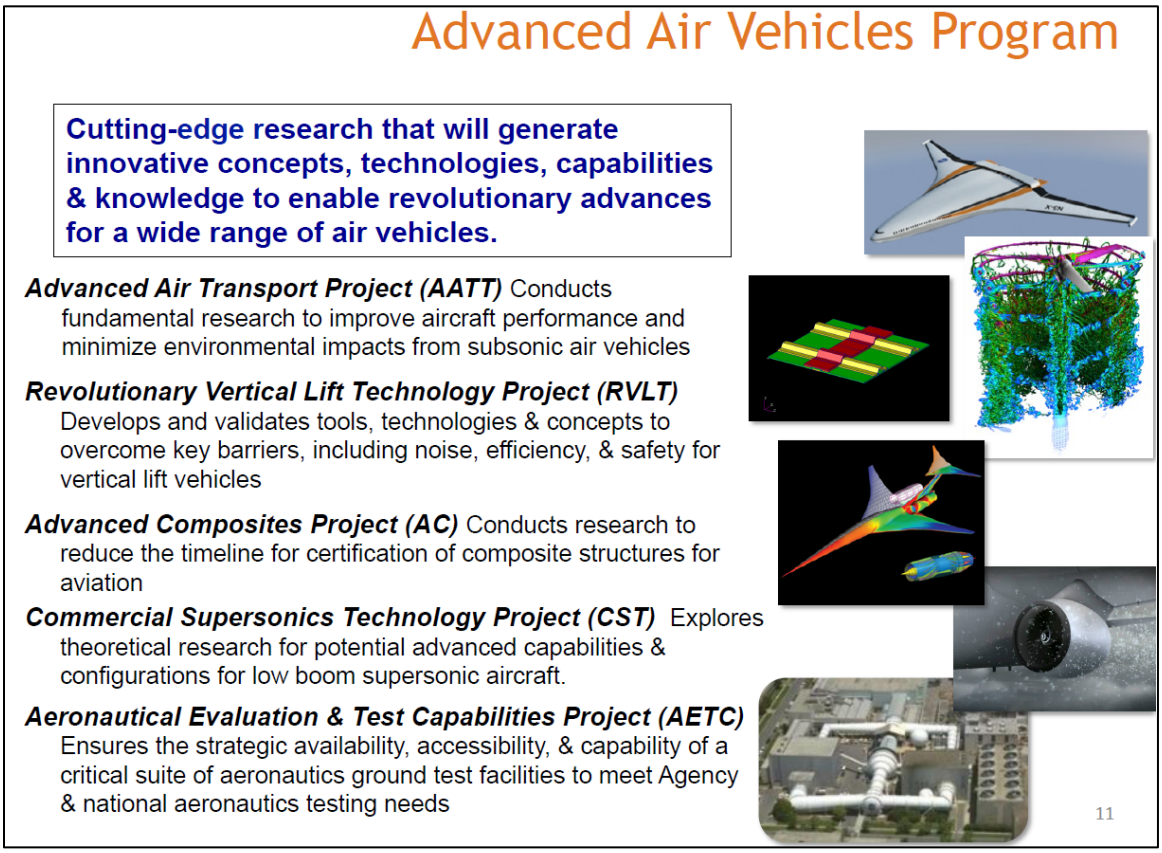


Figure F-7 NASA Advanced Air Vehicles Program

Figure F-8 shows the future capabilities that the RVLT project contains which supports the development and validation of tools, technologies and concepts to overcome key barriers for Vertical Lift Vehicles. These key challenges are shown in Figure F-9

The vision of the RVLT project is to enable the development of vertical lift vehicles with aggressive goals for efficiency, noise, and emissions to expand current capabilities and develop new commercial markets. The scope of the RVLT project is two-fold:[45]

1. Development of conventional and non-conventional very light, light, medium, heavy and ultra-heavy vertical lift configurations.
2. Development of technologies that address noise, performance, efficiency, safety, community acceptance and affordability. These include:
    a. Advanced Efficient Multi-speed Propulsion: Demonstrate and mature propulsion and drive system technologies to enable increased vehicle speeds while maximizing propulsive efficiency and minimizing weight penalty. Figure F-10 shows the development schedule through FY20 for this technology.

[45] NASA Aeronautics Research Mission Directorate, *AMRD Briefings to ASB,* 9 June 2015: 1) Jay Dyer, "ARMD and Advanced Air Vehicles Program Overview" and Susan A. Gorton, "Revolutionary Vertical Lift Technology Project Overview"

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b. Low-Noise Vertical-Lift Concepts and Configurations: Demonstrate and mature aeromechanics technologies to enable design, analysis, testing, and optimization of low-noise vertical lift concepts. Figure F-10 shows the development schedule through FY20 for these technologies.

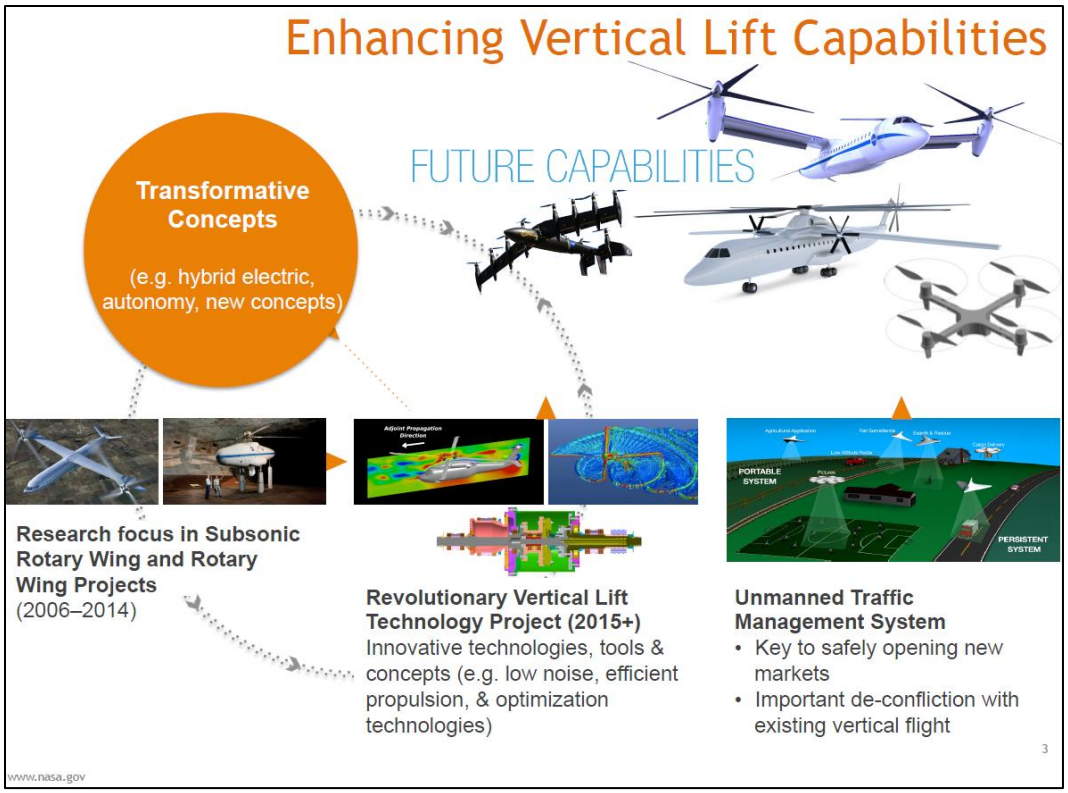


Figure F-8 Future Vertical Lift Capabilities supported by the NASA RVLT Program

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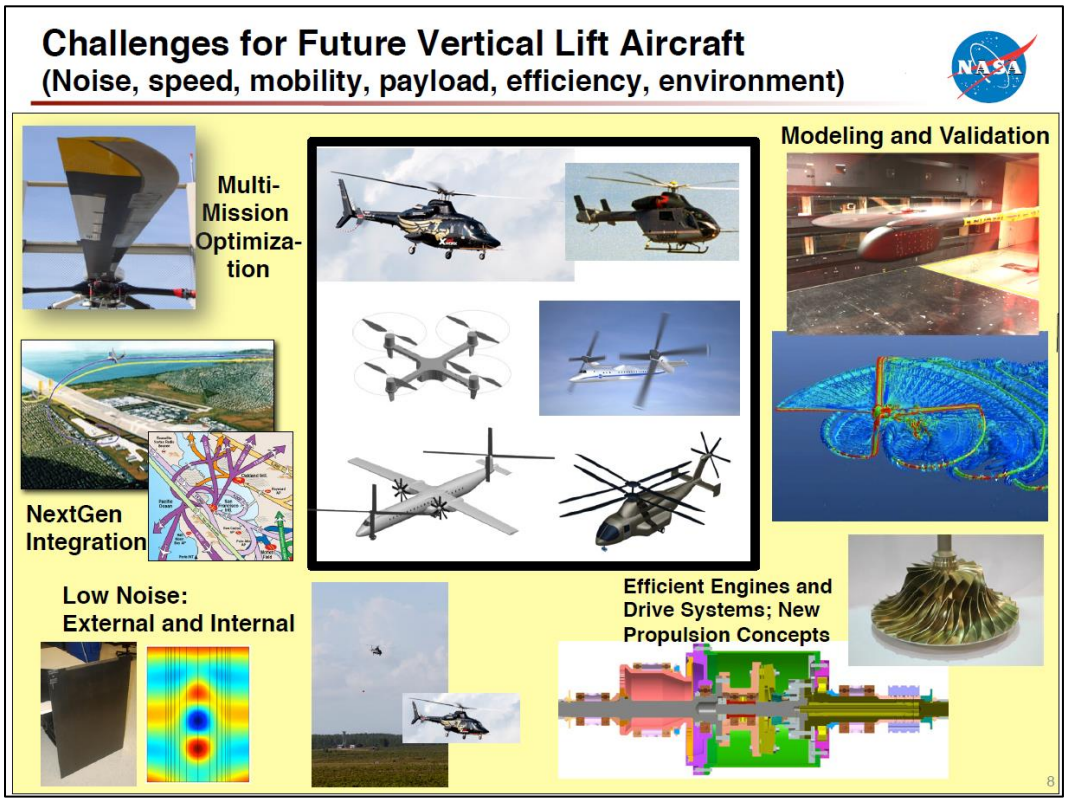


Figure F-9 Challenges for the future vertical lift aircraft

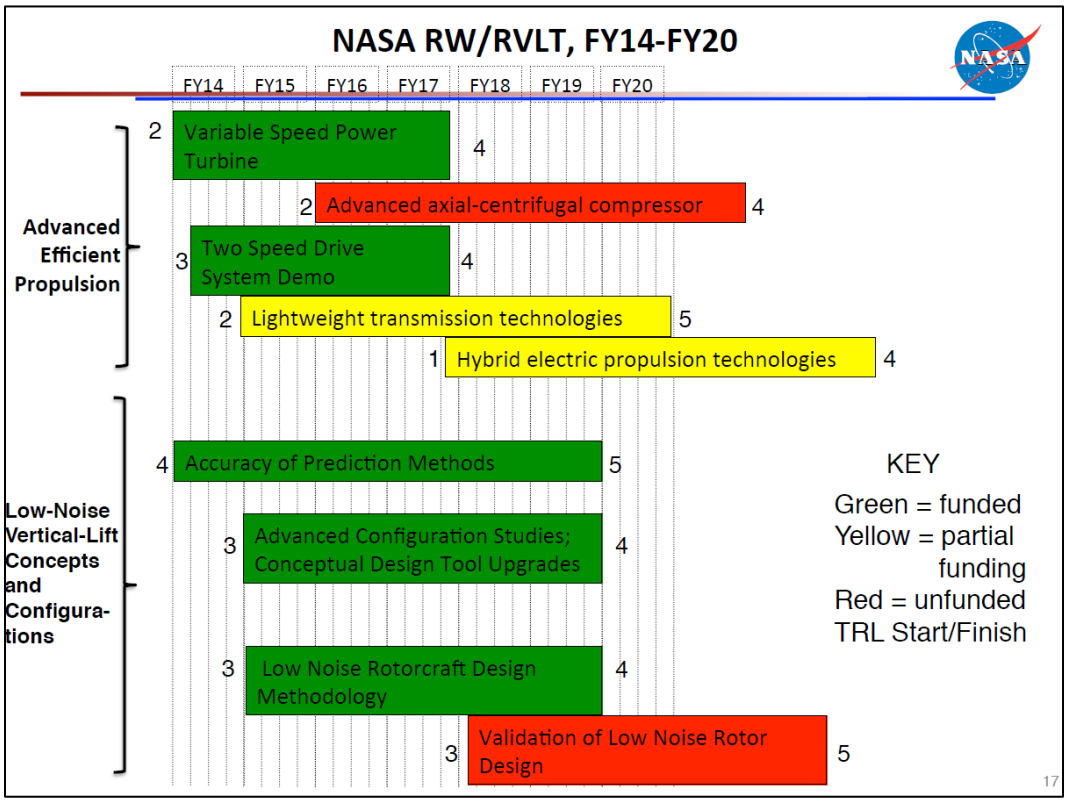


Figure F-10 Schedule for Development of RVLT technologies through FY20

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Figure F-11 provides an overview of the interaction between NASA and DoD. This has been a very effective relationship that has been ongoing for 50 years. The challenge for rotorcraft R&D is that NASA's funding levels are ~$20M per year (includes salary for ~65 Civil Service Workers) and similar levels of funding are anticipated for FY16-20. This relatively limited investment by NASA is already highly leveraged by the Army and supports the ASB Study Teams Recommendation 9, advocate more funding for Aviation S&T.

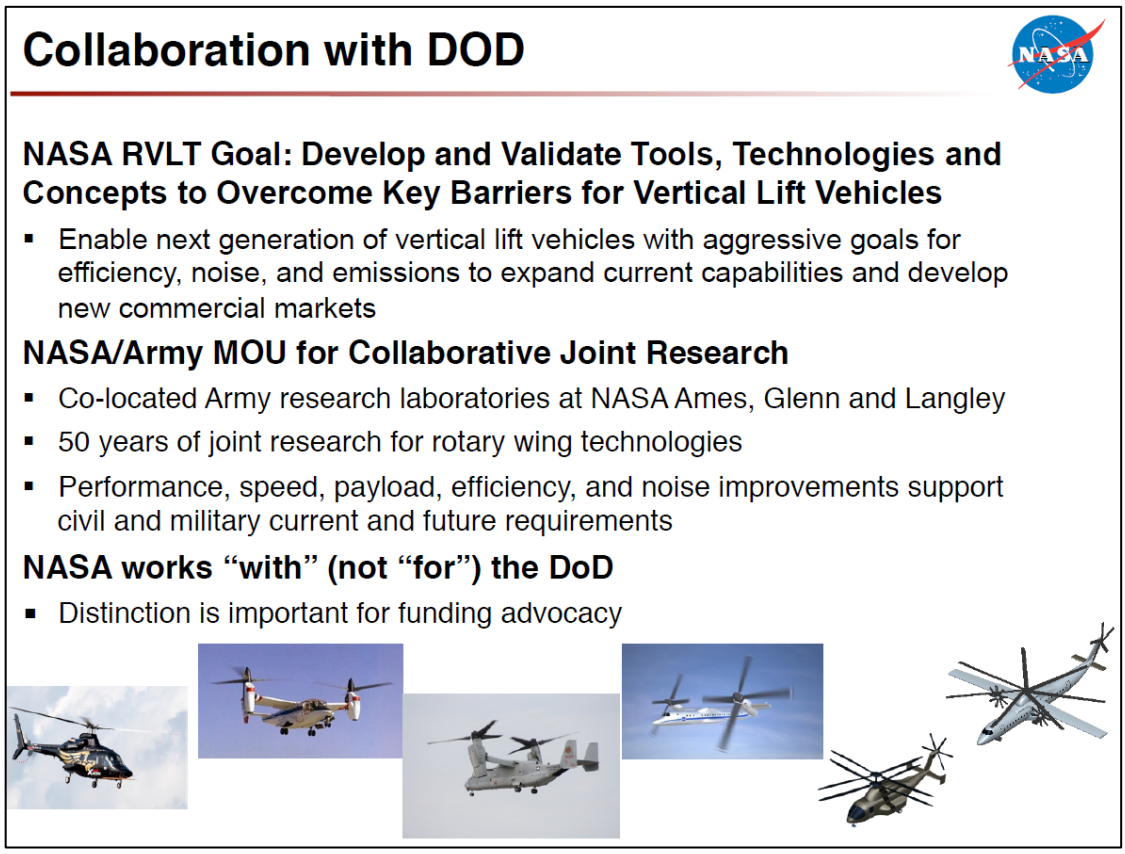


Figure F-11 Overview of the Interaction between NASA and DoD

F.7 Industry

Industry teams support Army aviation in the modernization of legacy rotorcraft systems and the development of new systems. For legacy systems, Sikorsky and its contractor team works closely with PEO-Aviation, AMRDEC and CERDEC in development of the UH-60 modernization roadmap and performs the development and production of upgrades under contract to PM UH-60. Likewise, the Boeing Company and its contractor team actively support the Army in modernization of AH-64 and CH-47. In both cases, the contractors work closely with RDECOM laboratories to develop technologies for insertion into the platforms. They also often invest company funds into technologies that may enable improved operational effectiveness or reduced operations and support costs for future upgrades of the systems.

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Industry also invests in the development of new aviation systems and capabilities that may lead to future Programs of Record (PORs). A perfect example is the JMR-TD, in which the industry teams are more than matching Army S&T investment. Likewise, several industry teams are investing in the DARPA X-plane program and in USN/USMC rotorcraft developments.

Rotorcraft prototyping programs are particularly important to the health of the US military rotorcraft industry because new PORs are too infrequent to maintain design and development skills. The decline of US market share in the commercial helicopter market provides evidence that US leadership in rotorcraft system design and development is eroding. As indicated in Figure F-12, the total share of US industry ***combined*** is only 25%, while the two European companies, Airbus Helicopters and Augusta Westland have almost 60% of the world market.

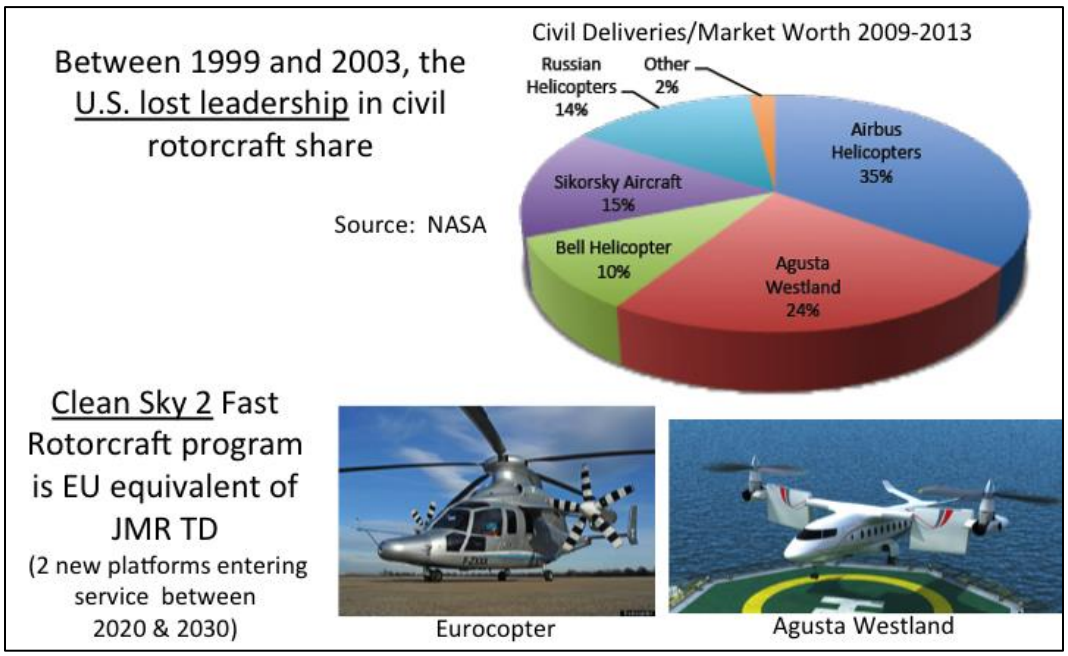


Figure F-12 Worldwide Competition

Concern regarding the health of the US rotorcraft industry has been voiced by the Vertical Lift Consortium (VLC). The VLC was established in 2009 in response to a memorandum from the Under Secretary of Defense AT&L that stated that the Future Vertical Lift initiative "will only be successful with the full support of, and partnership with, the vertical lift aircraft industry". The mission of the VLC is to "work collaboratively with the US Government to develop and transition innovative vertical lift technologies to rapidly and affordably meet warfighter needs." Its mission is to be a "cohesive national resource which various Government customers can efficiently access for innovative technologies to fulfill critical DoD vertical lift needs, which invigorates the US industrial base, drives innovation, and achieves an international competitive edge."

In its response to the FVL Executive Steering Group (ESG), the VLC indicated that the US has enjoyed global asymmetrical advantage from innovative technology that has been generated by a diverse, competitive research and industrial base and motivated by an engaged Government

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customer. However, continued advantage is not assured and Asia and Europe are at par and advancing.

Among the programs being sponsored by the European Union is the Clean Sky 2 Fast Rotorcraft Program, which has performance attributes similar to FVL and which is building two prototypes very similar to JMR-TD. A robust US rotorcraft industry is essential for the future of Army aviation, but that is certainly not assured in this global environment.

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APPENDIX G ONGOING AND PLANNED DEVELOPMENT FOR UAS (INLCUDING MUM-T)

Task 1 of the TOR directs the study team to review current government and industry aviation plans and programs. Army Unmanned Aircraft Systems (UAS) are described in APPENDIX E. The remainder of this section describes the information obtained regarding other unmanned aircraft systems, both fixed wing and rotary wing as well as efforts in manned-unmanned teaming (MUM-T).

Figure G-1 provides definitions of the grouping used to describe DoD UAS, primarily based on size. Group 1 systems are handheld, operate at low altitude, and used by small units; Group 5 systems are high altitude platforms.

	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Size	Small	Medium	Large	Larger	Largest
Max Gross Takeoff Wt (lbs)	0-20	21-55	<1,320	>1,320	>1,320
Normal Operating Altitude (ft)*	<1,200 AGL	<3,500 AGL	<18,000 MSL	<18,000 MSL	>18,000
Airspeed (kts)	<100	<250	<250	Any	Any

* AGL – Above Ground Level, MSL – Mean Sea Level

Figure G-1 Grouping of DoD Unmanned Aircraft Systems (UAS)

Figure G-2 and Figure G-3 describe the current and near-term DoD UAS in Groups 1 through 5. Figure G-4 describes developmental systems.

DoD Current and Near-term UAS - Grp 1	Name / Designator	Service	IOC	Payload	Max Takeoff	Cruise Spd/ Endurance	Developer (Inventory)
	Wasp III	USAF & USMC	2007	ISR	3 lb	20 kt / 45 min	Aero-Vironment
	Raven RQ-11A/B	USMC, SOCOM & USA	1999	ISR	4 lb	30 kt / 1-1.5 hrs	Aero-Vironment
	Switchblade	USMC & USA	2012	Warhead	5.5 lb (inc. launcher)	55-85 kt / 10 min	Aero-Vironment
	Puma RQ-20A	USMC, USAF & USA	2007	ISR	13.5 lb	45 kt max / 2 hrs	Aero-Vironment

Figure G-2 DoD Current and Near-term UAS – Group 1

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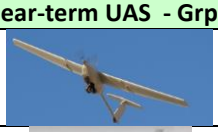
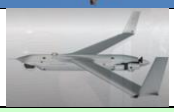
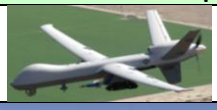
DoD Current and Near-term UAS - Grp 2	Name / Designator	Service	IOC	Payload	Max Takeoff	Cruise Spd/ Endurance	Developer (Inventory)
	Stalker	SOCOM	2006	5.5 lb	22.5 lb	43 kt max / 13 hr	Lockheed Martin
	ScanEagle	USN & USMC	2005	ISR	48.5 lb	60 kt / 24+ hrs	Boeing Insitu
DoD Current and Near-term UAS - Grp 3	Name / Designator	Service	IOC	Payload	Max Takeoff	Cruise Spd/ Endurance	Developer (Inventory)
	Blackjack RQ-21	USN	2014	ISR	135 lb	55 kt / 24 hrs	Boeing Insitu
	Shadow RQ-7	USMC & USA	2002	ISR	375 lb	70 kt / 9 hrs	AAI Corp (500)
DoD Current and Near-term UAS - Grp 4	Name / Designator	Service	IOC	Payload	Max Takeoff	Cruise Spd/ Endurance	Developer (Inventory)
	Snowgoose CQ-10B	SOCOM	2005	500 lb Cargo	1,400 lb	65 kt / 320 nm range	Mist Mobility Int Sys Tech (15)
	Predator MQ-1B	USAF	1995	ISR Pod / Hellfire	2,250 lb	70-90 kt / 24 hrs	General Atomics (154)
	Fire Scout MQ-8	USN	2009	ISR + weapons	3,150 lb	110 kt / 8 hrs	Northrup Grumman (27)
	Gray Eagle MQ-1C	USA	2009	ISR Pod / Hellfire	3,600 lb	150 kt max/ 30 hrs	General Atomics (75)
	Improved Gray Eagle	Gray Eagle Upgrade	2017	ISR Pod / Hellfire	4,200 lb	167 kt max / 48 hrs	General Atomics / Army
	Sentinel RQ-170	USAF	2005	Intel	Est >8,500 lb	UNK	Lockheed Martin
	K-MAX (originally manned)	USMC	2008	6,000 lb external	12,000 lb	80 kt / 267 nm range	Kaman (1)
DoD Current and Near-term UAS - Grp 5	Name / Designator	Service	IOC	Payload	Max Takeoff	Cruise Spd/ Endurance	Developer (Inventory)
	Reaper MQ-9	USAF & USN	2007	Hellfire or LGB	10,494 lb	169 kt / 14 hrs	General Atomics (104)
	Global Hawk / Triton R/MQ-4	USAF & USN	~2000	Intel	32,250 lb	310 kt / 32+ hrs	Northrup Grumman (37)

Figure G-3 DoD Current and Near-term UAS – Groups 2 through 5

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DoD Developmental UAS (Grp 4)	Name / Designator	Service	IOC	Payload	Max Takeoff	Cruise Spd/ Endurance	Developer (Inventory)
	UCAS X-47B	USN	2020s	4,500 lb in 2 weapon bays	44,567 lb	Mach 0.9+ / 2,100 nm range	Northrup Grumman / USN

Figure G-4 DoD Developmental UAS (Group 4)

G.1 DoD Unmanned Systems Integrated Roadmap

The Unmanned Systems Integrated Roadmap (FY2013-2038)[46] describes the role of unmanned systems to meet the mission and capability needs of Combatant Commanders as follows:

> There are no requirements for unmanned systems within the Joint force, but some capabilities are better fulfilled by unmanned systems. Unmanned systems provide persistence, versatility, survivability, and reduced risk to human life, and *in many cases are the preferred alternatives especially for missions that are characterized as dull, dirty, or dangerous.* With that mindset, unmanned systems are being optimized for these dull, dirty, or dangerous missions:
>
> - Dull missions are ideal for unmanned systems because they involve long-duration undertakings with mundane tasks that are ill suited for manned systems. Good examples are surveillance missions that involve prolonged observation. Unmanned systems currently fulfill a wide variety of "dull" mission sets, and the number will increase in all domains as unmanned systems capabilities improve.
> - Dirty missions have the potential to unnecessarily expose personnel to hazardous conditions. A primary example is chemical, biological, and nuclear detection missions. Unmanned systems can perform these dirty missions with less risk exposure to the operators.
> - Dangerous missions involve high risk. With advances in capabilities in performance and automation, unmanned systems will reduce the risk exposure to personnel by increasingly fulfilling capabilities that are inherently dangerous.

The roadmap summarizes mission and capability needs, technology areas of interest, operating environments, logistics and sustainment challenges, training challenges, and international issues for unmanned air, ground, and maritime systems.

G.2 Navy/Marine

Among the UAVs in the USN/USMC inventory are the RQ-11B Raven, the RQ-12A Wasp, the RQ-20A Puma, the RQ-7B Shadow, the RQ-21A Blackjack, the MQ-8 FireScout, and KMax.

The Raven, Wasp and Puma systems are small man-packable/portable systems used for organic, real-time Reconnaissance, Surveillance and Target Acquisition (RSTA) and Bomb

[46] Department of Defense, "Unmanned Systems Integrated Roadmap (FY2013-2038)," DOD-USRM-2-13, 2013, http://www.defense.gov/Portals/1/Documents/pubs/DOD-USRM-2013.pdf , p20.

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Damage Assessment (BDA) at the small unit (battalion and below) level. Among these, the Raven and Puma systems are also operated by the Army. The Shadow is also deployed by the Army, for ISR missions.

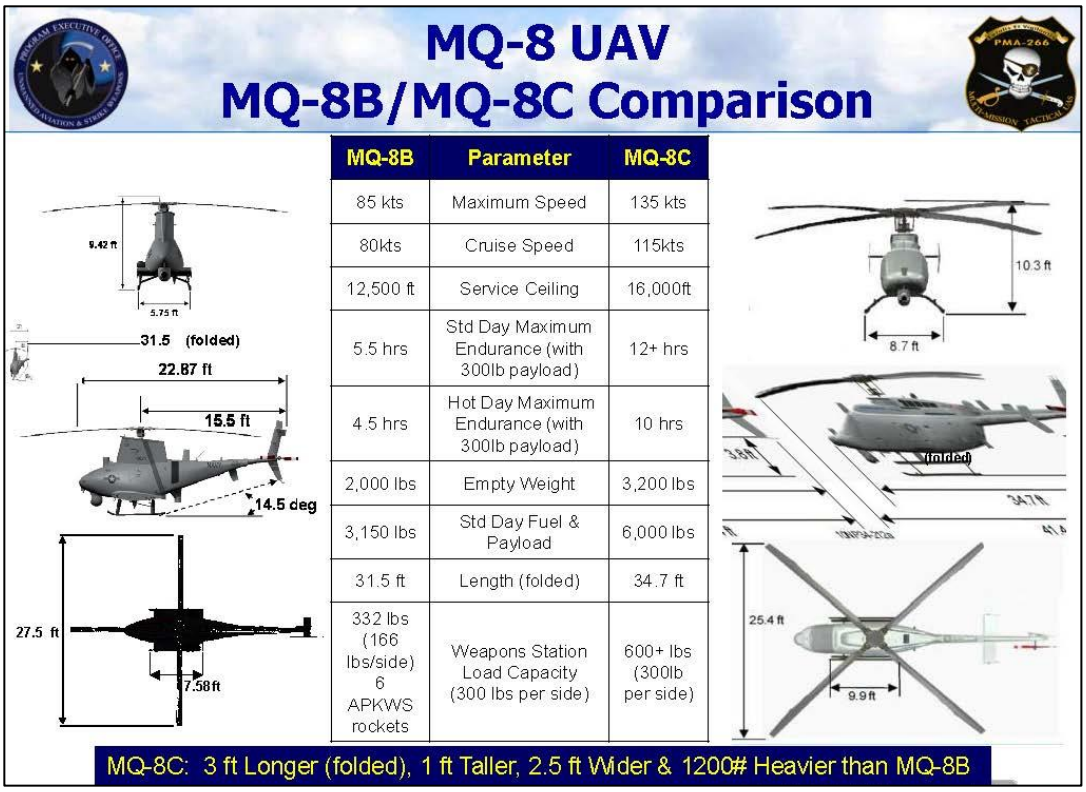
The RQ-21A Blackjack (Figure G-5) is a larger twin-tailed follow-on to the ScanEagle UAS, with a payload capacity of 39 lb. and an endurance of 16 hours. It is currently used for RSTA data collection and dissemination. Standard payloads include day/night full motion video; electro-optical/infrared cameras; mid-wave infrared imager; laser rangefinder; and communications relay. Mission flexibility is allowed by a modular payload bay for payload swap out and integration of advanced payloads. Among the mission system payloads in development for Blackjack are SIGINT, EW and SAR/GMTI. This modular payload feature and the types of modular mission payloads in use or in development are the types of capabilities for the UAVs that complement manned assets envisioned for the distributed functionality system-of-systems concept discussed in section 2.3 of the report.



Figure G-5 RQ-21A Blackjack and Launcher on the flight deck of USS Mesa Verde

The USN/USMC operates two unmanned rotorcraft systems, the MQ-8 FireScout and the CQ-24A KMAX. The MQ-8C is a 3000 lb. class unmanned rotorcraft capable of carrying a 300 lb. payload for up to 12 hours (Figure G-6). The KMAX was used by the USMC for unmanned cargo delivery in OEF. It is capable of carrying up to 4500 lb. of payload per sortie (Figure G.2-3). The Army currently lacks a vertical lift UAV for point-of-need sustainment to distributed forces. The KMAX might be able to provide an interim capability until the Army can afford a more tailored solution to this need.

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MQ-8B	Parameter	MQ-8C
85 kts	Maximum Speed	135 kts
80kts	Cruise Speed	115kts
12,500 ft	Service Ceiling	16,000ft
5.5 hrs	Std Day Maximum Endurance (with 300lb payload)	12+ hrs
4.5 hrs	Hot Day Maximum Endurance (with 300lb payload)	10 hrs
2,000 lbs	Empty Weight	3,200 lbs
3,150 lbs	Std Day Fuel & Payload	6,000 lbs
31.5 ft	Length (folded)	34.7 ft
332 lbs (166 lbs/side) 6 APKWS rockets	Weapons Station Load Capacity (300 lbs per side)	600+ lbs (300lb per side)

Figure G-6 MQ-8 Rotary-wing UAV

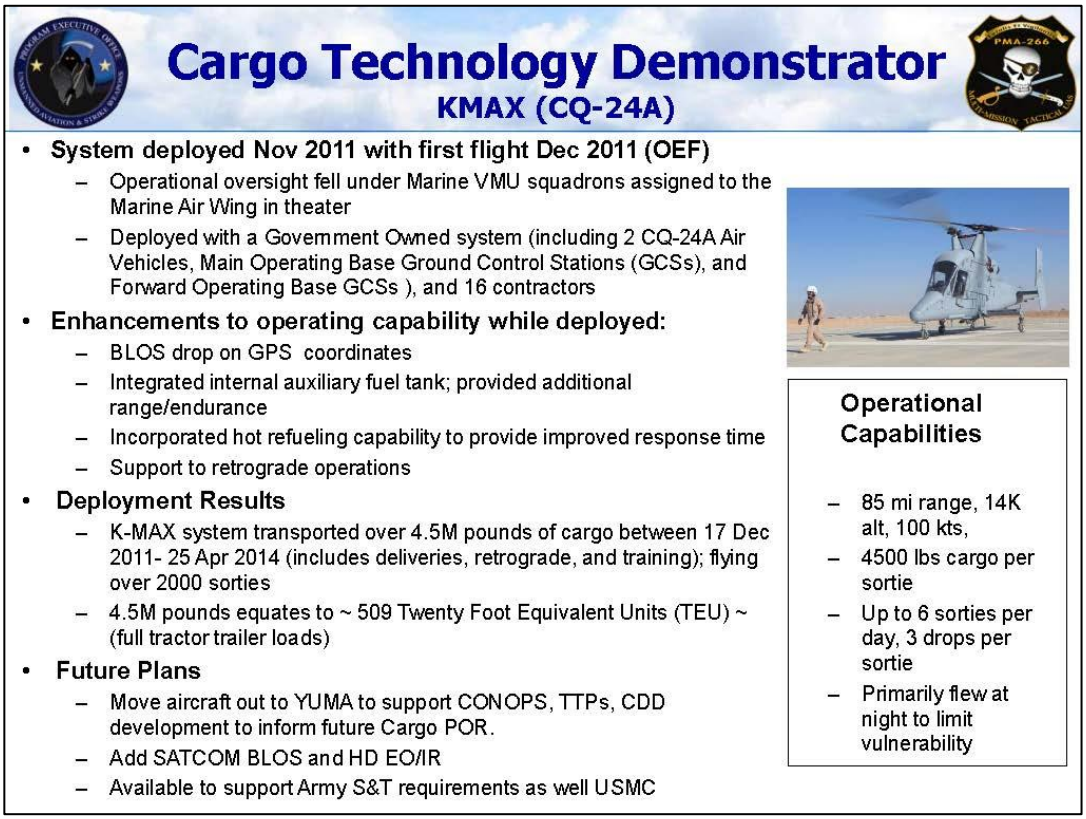


Figure G-7 KMax Cargo Technology Demonstrator

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G.3 Air Force

The Air Force vision depicted in Figure G-8 shows the Unmanned Combat Air Vehicle (UCAV) flying in close formation with the F-22, providing "wingman" capabilities utilizing autonomous operations under supervised control of the manned fighter.



Figure G-8 Air Force Vision

The Air Force UAS portfolio focuses on larger platforms (over 1320 lbs):

- MQ-1 Predator/Gray Eagle
- MQ-9 Reaper
- RQ-4A and RQ-4B Global Hawk

The objective of the Low-Cost Attritable Aircraft Program is to develop mission-capable low-cost aircraft concepts and prototypes to validate technologies required for rapid and agile production. The program is scheduled for spiral development with flight demonstrations by FY21.

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G.4 DARPA

DARPA has several UAS and/or MUM-T projects, including System of Systems Integration Technology and Experimentation (SoSITE), Collaborative Operations in Denied Environment (CODE), and Aerial Reconfigurable Embedded System (ARES).

Systems of systems aviation architectures, utilizing both manned and unmanned assets which are carefully networked with dispersed functionality, offer the potential to quickly and more effectively respond to a new world of complex mission threat scenarios. This hypothesis is currently being tested at DARPA in the SoSITE program depicted in Figure G-9.

DARPA, through its SoSITE innovative research program, is attempting to demonstrate that a system of systems (SoS) approach can:

1. Provide increased military effectiveness in complex environments,
2. Obtain cost leverage (i.e., the cost of the opponent to counter relative to the cost of the US to deploy), and
3. Enable adaptability necessary to maintain US air superiority in contested environments.

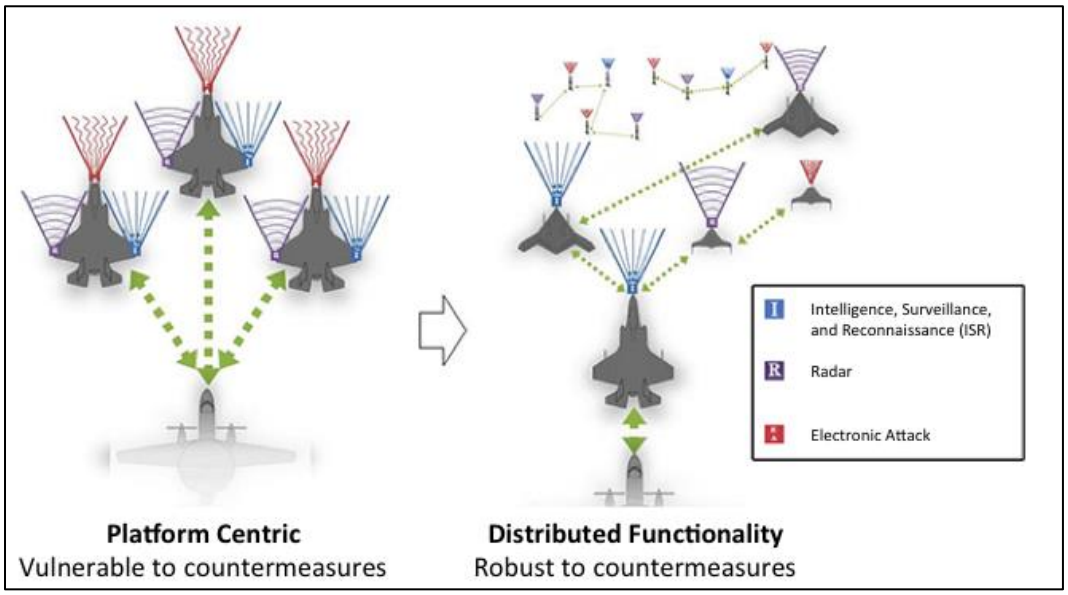


Figure G-9 System of Systems Integration Technology and Experimentation (SoSITE)

The objective of Phase 1 of this DARPA program is to develop architectures for distributing functionality across networks of manned and unmanned platforms for future experimentation, and to develop tools to enable this distribution to be done quickly and reliably. The second phase of the SoSITE program will focus on resolving risks through experiments.

Anti-access, aerial denial (A2/AD) scenarios developed by the DoD are being used as the bases for simulating and evaluating a host of solutions sets using existing, developing and next-generation technologies. Contracts with Boeing, General Dynamics, Lockheed Martin, Northrop Grumman, Apogee Systems, BAE Systems, and Rockwell Collins are experimenting with ways to spread capabilities across a number of manned and unmanned vehicles and weapons to

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address the future threat scenarios. The SoSITE project encompasses the integration of aircraft, weapons, sensors, and mission systems via the SoSITE open-systems architecture (OSA). The program OSA is based on the open mission systems (OMS) -- an Air Force effort which developed interfaces between mission systems and services connected through an avionics service bus. (The interfaces are based upon a set of open and standardized interface definitions.)

The DARPA Collaborative Operations in Denied Environment (CODE) program depicted in Figure G-10 is another example of research investigating system of system approaches for distributing capabilities among a team of UAVs. This effort is considering how to enable UAVs to work together in teams and take advantage of the relative strengths of each participating unmanned aircraft. The program is specifically looking at expanding the mission capabilities of existing UAVs through increased autonomy and inter-platform collaboration. DARPA's premise is that collaborative autonomy has the potential to increase capabilities and reduce costs of today's UAVs by composing heterogeneous teams of UAVs that can capitalize on the capabilities of each unmanned aircraft without the need to duplicate or integrate capabilities into each UAV.

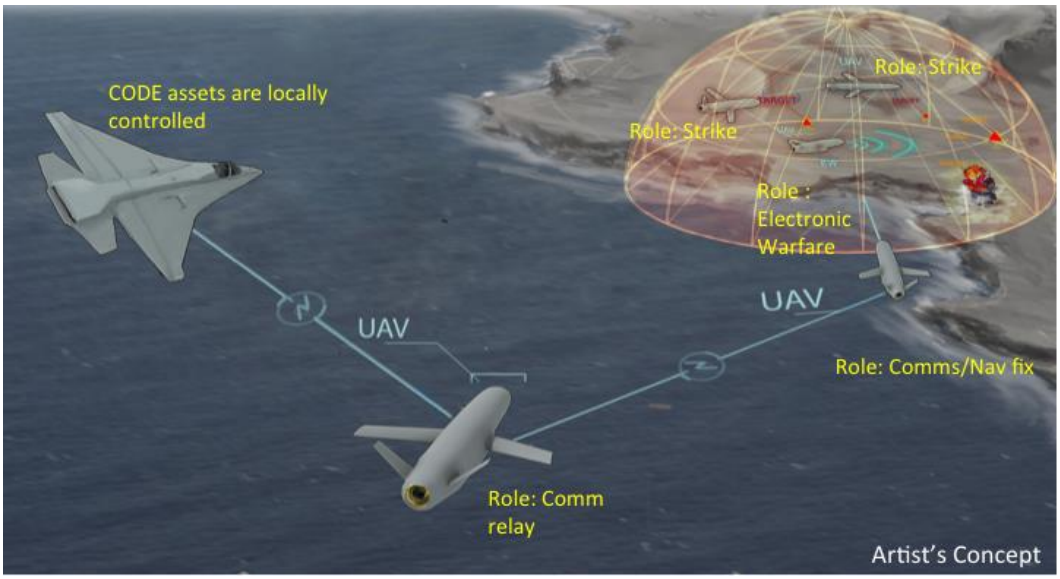


Figure G-10 Collaborative Operations in Denied Environment (CODE)

A SoSITE type approach could have significant utility in Army aviation mission planning. The threat environment for Army aviation is becoming much more complex with a host of different technology threats surfacing (as illustrated in Figure G-11) which include the potential of attack by: cyber, directed energy weapons, sophisticated MANPADS, swarms of UAVs, and the electromagnetic spectrum. A distributed platform/system approach rather than a platform centric design offers the potential of realizing higher survivability under these complex conditions and an increased potential for successful mission execution.

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Figure G-11 Complex Threats

The Army's Future Combat System (FCS) had a vision of creating a highly, integrated systems-of-systems network which could flexibly adapt to complex environments. However, after the program's cancellation, the vision of creating distributed system-of-system networks lost priority and a platform-centric approach has largely prevailed. This is evident in the Future Vertical Lift demonstrator programs. There is clearly some good work being done on this effort to reduce program risks associated with a new platform development; however, we see little discussion about how these future platforms can be teamed with other unmanned assets or how functions could be distributed among other platforms to achieve higher potentials of mission success, increased survivability and lower overall lifetime costs.

The panel believes that networked systems studies need to be intensified in the Army especially with regard to aviation mission planning. MUM-T (manned-unmanned teaming) exercises are a first step and are critical to demonstrating such things as interoperability among unmanned systems through the Universal Ground Control Stations and highlighting open architectural approaches that allows multiple control nodes and information access points via the Tactical Common Data Links (TCDL). However, research efforts similar to the SoSITE program at DARPA need to be increased using Army's common open architecture protocols to model and experiment with integration of different technologies and assets in different mission configurations. Other elements such as secure communications technologies, levels of autonomy, common ground controls and operating conditions (visually denied or GPS denied environments) need to be included in these modeling scenarios. The utility of employing unmanned assets used as attritables (Air Force/DARPA construct) should also be considered. While these attritable unmanned systems are not designed to be expendable, meaning that

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they are not intended to be lost every time they are sent out, they are "attritable," meaning that the operator can afford to "attrit" or lose them, especially when the alternative is the loss of a manned aircraft or an aircrew.

ARES is a vertical takeoff and landing (VTOL) flight module designed to operate as an unmanned cargo platform capable of transporting a variety of payloads. The ARES VTOL flight module is designed to have its own power system, fuel, digital flight controls and remote command-and-control interfaces. Twin tilting ducted fans would provide efficient hovering and landing capabilities in a compact configuration, with rapid conversion to high-speed cruise flight. Lockheed-Martin is the primary performer. The goal is a 7,500 lb vehicle that carries a 3,000 lb payload externally. It can land in a 50x50 ft area. It could be used for MEDEVAC if it is rated to carry humans. Flight test is scheduled for 4Q 2015.



Figure G-12 Aerial Reconfigurable Embedded System (ARES)

G.5 Army Special Operations

In a presentation to the Association of the US Army, BG Erik Peterson, Commanding General, United States Army Special Operations Aviation Command, indicated that the command has more than 300 unmanned air vehicles.[47] In addition to 12 Gray Eagles, 32 Shadows, 224 Ravens, and 7 Pumas, which are Army Programs of Record (PORs), the command uses other vehicles procured in response to joint urgent operational needs (JUONs) and other requests.

Going forward the Army Special Operations team would like fewer types of UAV with more capability, especially multiple sensors on one UAV. Improved processing, exploitation and dissemination is also needed to fully exploit such multi-sensor capabilities.

G.6 NASA

The NASA Aeronautics Six Strategic Thrusts[48] are shown in Figure G-13. The primary thrust for UAS is the Assured Autonomy for Aviation Transformation. In addition, the Real-Time System-Wide Safety Assurance and the Safe, Efficient Growth in Global Operations Thrusts play a role,

[47] Jen Judson, "Army Special Operations Want Multi-Intelligence UAVs," *Defense News*, 14 January 2016, http://www.defensenews.com/story/defense/land/army-aviation/2016/01/14/army-special-operations-want-multi-intelligence-uavs/78812140/

[48] NASA Aeronautics Research Mission Directorate, *AMRD Briefings to ASB,* 9 June 2015: Jay Dyer, "ARMD and Advanced Air Vehicles Program Overview"

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especially for the traffic management systems required for eventual integration of UAS into the civilian airspace. NASA's concept for the unmanned traffic management system is key to

- Safely opening new markets, and
- De-confliction with existing vertical flight.



Figure G-13 NASA Aeronautics Six Strategic Thrusts

In addition to the traffic management systems, NASA has created a design environment for the development of novel vertical lift vehicle platforms including significant focus on UAS as shown in Figure G-14.[49] In light of the capability gap identified by the ASB Study Team, Recommendation 3 - UAS Vehicles, these NASA resources should be leveraged as much as possible.

[49] NASA Aeronautics Research Mission Directorate, *AMRD Briefings to ASB,* 9 June 2015: Susan A. Gorton, "Revolutionary Vertical Lift Technology Project Overview"

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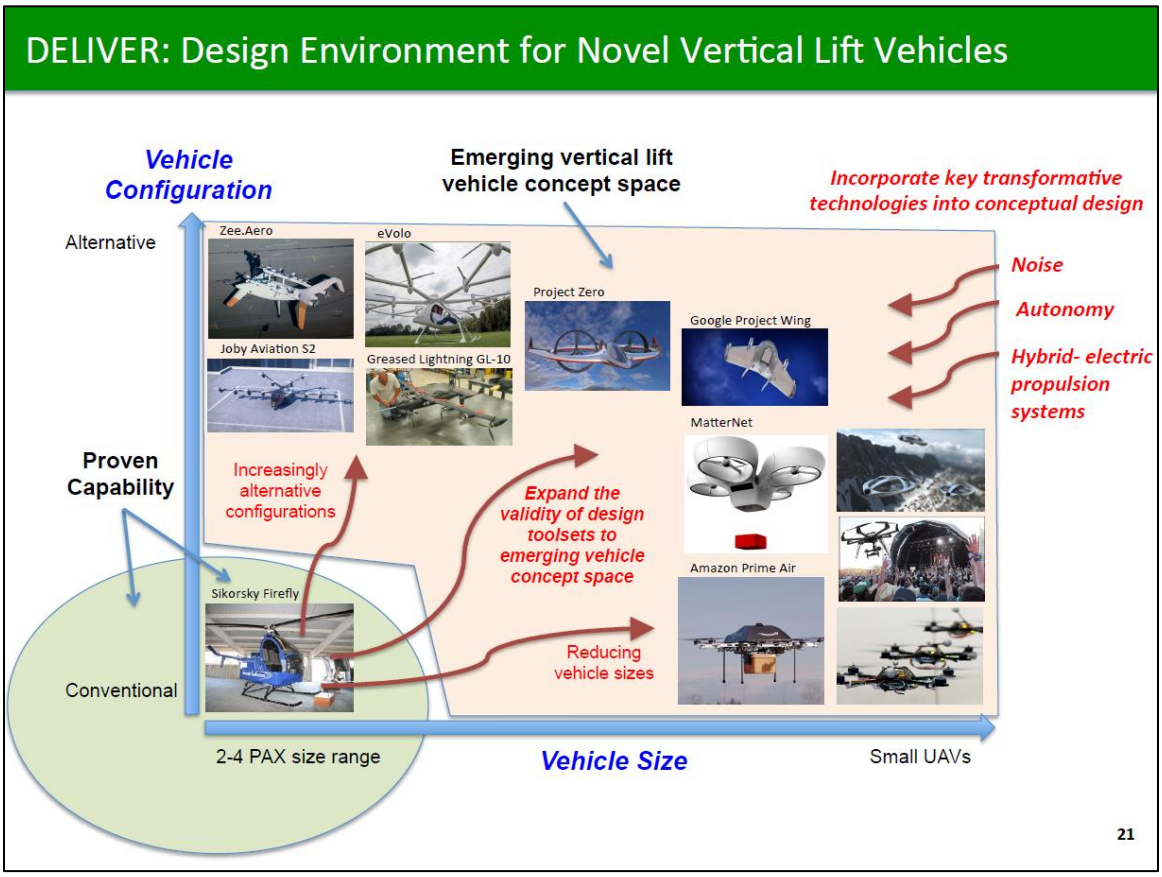


Figure G-14 Design Environment for Novel Vertical Lift Vehicles

G.7 Industry

The US has a healthy UAS industry that spans the gamut from major aircraft companies (i.e., Boeing, Lockheed, Northrop, Sikorsky and Textron) to medium sized companies that specialize in UAS (e.g., General Atomics, Aerovironment, Aurora Flight Sciences) to numerous small innovative companies that provide small UAS, primarily for the commercial market. The investment in UAS and advancement of capabilities through this US-based industrial complex is considerable. However, even with this plethora of activity, the US cannot be assured of asymmetric advantage in UAS systems and capabilities. The rest of the world is also investing in UAS and offer capable systems in the open market. Many of the foreign systems are inexpensive, easy to use, and available to any state or non-state adversary.

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APPENDIX H LARGE-SCALE TEST FACILITIES RELEVANT TO ARMY AVIATION

The Army Aviation RDECOM community (AMRDEC and ARL) has established numerous facilities at locations in Virginia and California in support of Army Aviation. Figure H-1 describes the large-scale AMRDEC facilities used for ballistics testing, aerodynamics, countermeasures, large rotor testing, structural testing, and transonic dynamics.



Figure H-1 Key Test Facilities Relevant to Army Aviation

These AMRDEC facilities are unique and provide important capabilities needed to further Army Aviation. These key test facilities, along with other relevant facilities, are described briefly below.

Wind Tunnels:

- National Full-Scale Aerodynamics Complex (NFAC), Moffett Field, CA: Advanced testing of full-scale rotorcraft; 40-by-80 foot wind tunnel circuit is capable of providing test velocities up to 300 knots. The 80-by-120 foot test section is the world's largest wind tunnel and is capable of testing a full-size Boeing 737 at velocities up to 100 knots.
- 7-by-10 foot Wind Tunnel, Moffett Field, CA: Scaled subsonic aerodynamic research.
- Transonic Dynamics Tunnel, Hampton, VA: Helicopter performance loads and stability testing; world's premier wind tunnel for testing large aeroelastically scaled models at transonic speeds.

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Other Major Facilities:

- Ballistics Test Facility, Ft. Eustis, VA: Fuel tank testing up to 30 mm ammunition.
- Countermeasures Test Facility, Ft. Eustis, VA: Acoustic/infrared radiation measurement of turbine engines and suppression devices.
- Structural Test Facility, Ft. Eustis, VA: Rotor-blade root end fixture for loads and fatigue testing; rotor-blade mid-span fixture for loads and fatigue testing; Rotor-Full Scale Dynamics Test Facility.
- Large Rotor Test Apparatus (in NFAC), Moffett Field, CA; Full scale rotorcraft component testing.

Other Key Facilities:

- Rapid Prototyping Facility (RPF), Ft. Eustis, VA: Rapid prototyping of aircraft modifications and developmental test hardware.
- Prototype Integration Facility (PIF), Redstone Arsenal, AL: Multi-discipline facility for fabricating and integrating developmental and operational test hardware and systems for AMRDEC and other customers.
- Advanced Prototype Experimentation (APEX), Redstone Arsenal, AL: Warfighter-in-the-loop simulation facilities for missile, aviation and unmanned systems.
- Aviation System Integration Facility (ASIF), Redstone Arsenal, AL: Avionics & software development integration & testing in a Common Avionics Architecture System (CAAS) and Future Airborne Capability Environment (FACE) based SIL.
- Rotorcraft Aircrew Systems Concepts Airborne Laboratory (RASCAL), Moffett Field, CA: Full-authority variable-stability JUH-60 Black Hawk.
- RASCAL Development Facility, Moffett Field, CA: Ground-based hardware-in-the-loop simulation facility to check out ``experimental'' code before flying on RASCAL.
- RMAX, Moffett Field, CA: two Yamaha RMAX helicopters used for OFN/SLAD autonomy research.

Figure H-2 shows the facilities key to the foundational science work conducted by ARL in the areas of rotorcraft survivability, scientific visualization, materials, robotics, electromagnetics, and propulsion.

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Figure H-2 Key ARL Facilities for foundational science and engineering work that support Aviation

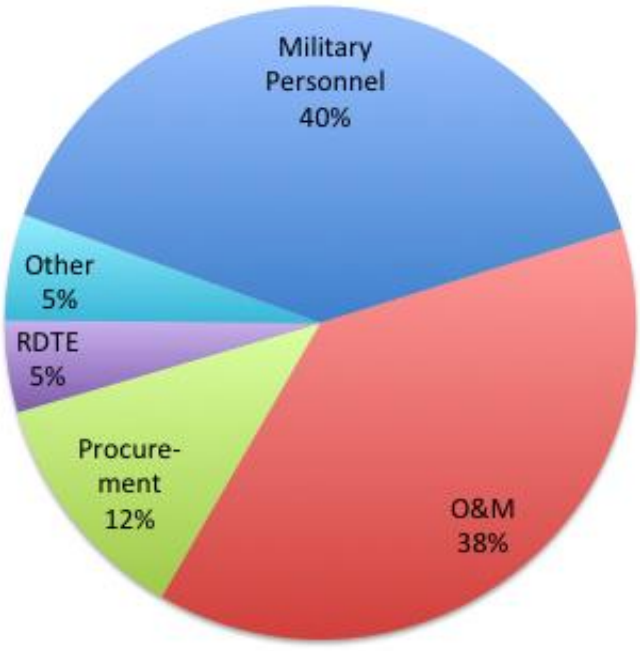
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APPENDIX I ARMY AVIATION FUNDING

Data in this Appendix is taken from FY16 budget justification documents at http://www.asafm.army.mil/offices/BU/BudgetMat.aspx?OfficeCode=1200 in Sept 2015.

I.1 Army Total Obligation Authority

The President's Budget funding request for FY16 includes $126.4B base funding plus $20.7B overseas contingency operations (OCO) funding. Those funds are distributed across major funding areas as shown in Figure I-1.



FY16 (B$)	Base	OCO	Total
Military Personnel	56.3	2.0	58.3
O&M	44.7	11.5	56.2
Procurement	16.1	1.6	17.7
RDTE	6.9	0.0	6.9
Other	2.4	5.6	8.0
Total	126.4	20.7	147.1

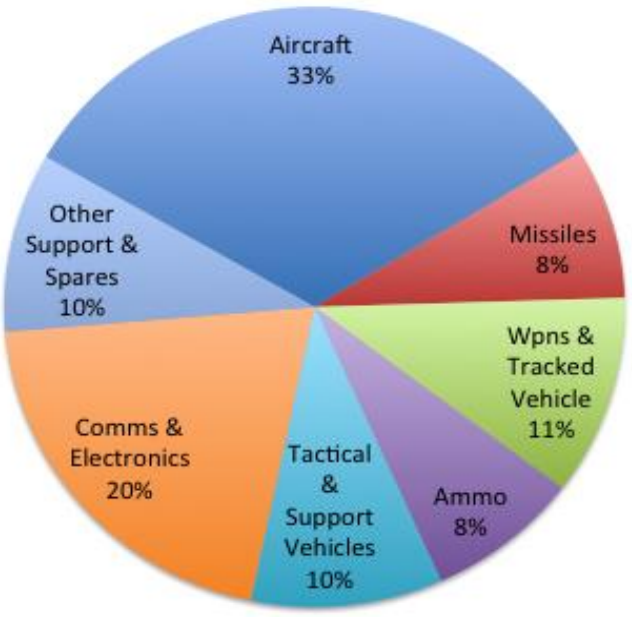
Figure I-1 Distribution of Army TOA Requested for FY16 ($147.1B)

While some of the funding for military personnel and operations & maintenance (O&M) supports Army aviation, the budget documents do not provide sufficient detail to identify those funds separately. The documents do identify procurement funds for aircraft. They also provide sufficient description of RDT&E efforts to estimate aviation funding. Other funding (military construction, family housing, BRAC, Chemical Agents and Munitions Destruction, Army Working Capital Fund, Arlington National Cemetery, and OCO passthrough/transfer) does not appear to directly support aviation.

I.2 Army Procurement Funding

Figure I-2 shows the distribution of Army procurement funding requested for FY16; $5.9B of the $17.8B (33% of the total) is allocated to aircraft systems. This includes funding for purchase of aircraft (fixed wing and rotary wing), modification of aircraft, and support equipment & facilities.

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FY16 (B$)	Base	OCO	Total
Aircraft	5.7	0.2	5.9
Missiles	1.4	0.0	1.5
Weapons & Tracked Combat Vehicle	1.9	0.0	1.9
Ammunition	1.2	0.2	1.4
Tactical & Support Vehicles	0.8	1.0	1.8
Communication & Electronics	3.5	0.1	3.6
Other Support Equipment & Spares	1.6	0.1	1.7
Total	16.1	1.6	17.8

Figure I-2 Distribution of Army Procurement Funding Requested for FY16 ($17.8B)

I.3 Army RDTE Funding

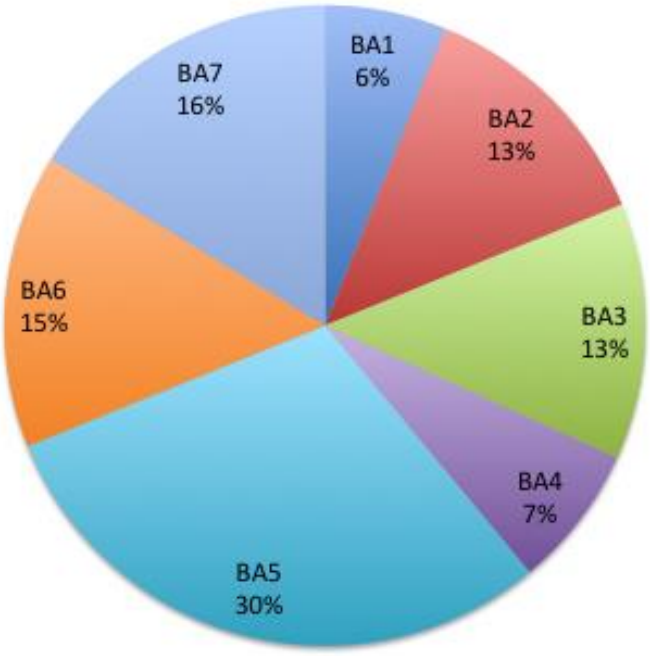
RDTE funds are allocated in program elements and projects within seven budget activities:

- Budget Activity 1, Basic Research: Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind.
- Budget Activity 2, Applied Research: Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met. It is a systematic application of knowledge toward the production of useful materials, devices, and systems or methods.
- Budget Activity 3, Advanced Technology Development: Includes all efforts that have moved into the development and integration of hardware for field experiments and tests. Projects in this category have a direct relevance to identified military needs.
- Budget Activity 4, Demonstration and Validation. Dem/Val includes all efforts necessary to evaluate integrated technologies in as realistic an operating environment as possible to assess the performance or cost reduction potential of advanced technology.
- Budget Activity 5, Engineering and Manufacturing Development: EMD includes those projects in engineering and manufacturing development for Service use but which have not received approval for full-rate production.
- Budget Activity 6, RDT&E Management Support: Includes R&D effort directed toward support of installations or operations required for general R&D use. Included would be test ranges, military construction, maintenance support of laboratories, O&M of test aircraft and ships, and studies and analyses in support of the R&D program.
- Budget Activity 7, Operational System Development. Includes those development projects in support of development acquisition programs or upgrades still in EMD, but

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which have received Defense Acquisition Board (DAB) or other approval for production, or production funds have been included in the DoD budget submission for the budget or subsequent fiscal year.

Figure I-3 shows the distribution of funds in the FY16 budget request. Only a very small amount of OCO funding is requested for the RDTE accounts.



FY16 (M$)	Base	OCO	Total
BA1	425.1	0.0	425.1
BA2	879.7	0.0	879.7
BA3	895.7	0.0	895.7
BA4	498.7	1.5	500.2
BA5	2,069.0	0.0	2,069.0
BA6	1,027.5	0.0	1,027.5
BA7	1,129.3	0.0	1,129.3
Total	6,925.0	1.5	6,926.5

Figure I-3 Distribution across Budget Activities of RDTE Funding Requested for FY16 ($6.9B)

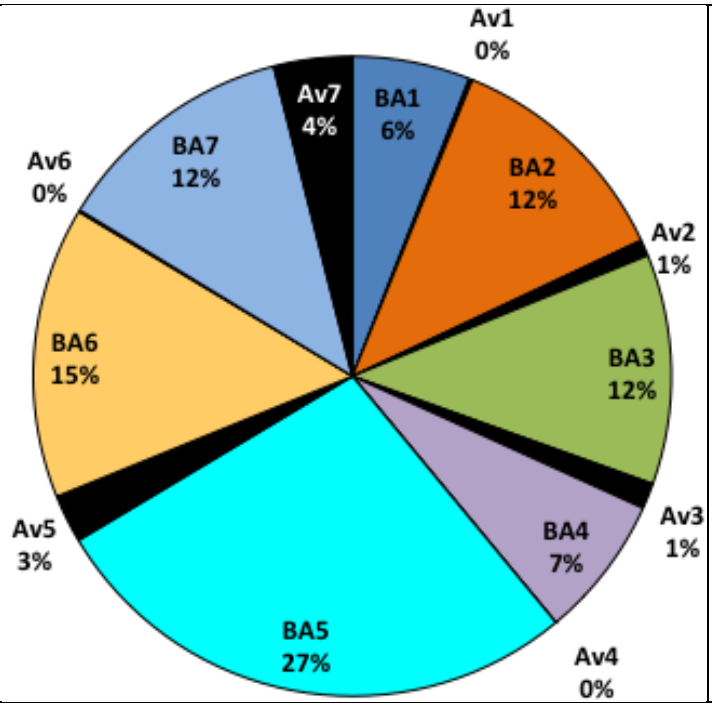
RDTE budget documents provide sufficiently detailed descriptions to permit estimating the funding allocated to aviation within each budget activity. Figure I-4 shows, for each Budget Activity, the estimated amount of funding supporting Army aviation. The black wedge shown clockwise from each budget activity represents the aviation funding, 8.8% of the Army RDTE total. Note that the aviation RDTE funding totals $609M, slightly more than 1/10 of the aviation Procurement funding.

The largest component of RDTE aviation funding is in BA7, Operational System Development. Over 80% of that funding is allocated to Apache, Blackhawk, and Chinook Product Improvement Programs and the Improved Engine Turbine Program (ITEP).

The next largest component is in BA5, Engineering and Manufacturing Development, with over half of that funding allocated to the Joint Air-to-Ground Missile (JAGM) designed to replace the Hellfire and LONGBOW aviation missiles.

The Science and Technology Budget Activities, BA1-BA3, include $158M for aviation, a little over 7% of the total. These activities are discussed further in the next section.

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FY16 (M$)	Non-Aviation	Aviation	% Aviation
BA1	413.5	11.6	2.7%
BA2	822.8	56.9	6.5%
BA3	806.0	89.7	10.0%
BA4	500.2	0.0	0.0%
BA5	1,900.0	168.9	8.2%
BA6	1,021.1	6.4	0.6%
BA7	853.9	275.4	24.4%
Total	6,317.5	608.9	8.8%

Figure I-4 RDTE Funds Requested for Aviation

I.4 Army S&T Funding

For Budget Activity 1, Basic Research, budget documents do not provide detailed breakdowns of the planned efforts. Some projects such as the Vertical Lift Research Centers of Excellence clearly support aviation. Others are more general and cannot be linked to specific technologies.

Budget Areas 2, Applied Research, and 3, Advanced Technology Development, support more specific projects that can be linked to aviation or other areas. Approximately 8.3% of Army BA2 and BA3 supports Army aviation. Estimates can also be made of which activities within aviation are supported. Figure I-5 shows estimates for FY16 BA2/3 requests. The largest portion supports the Joint Multi-Role Technology Demonstration. The Degraded Visual Environment (DVE) effort also receives significant support.

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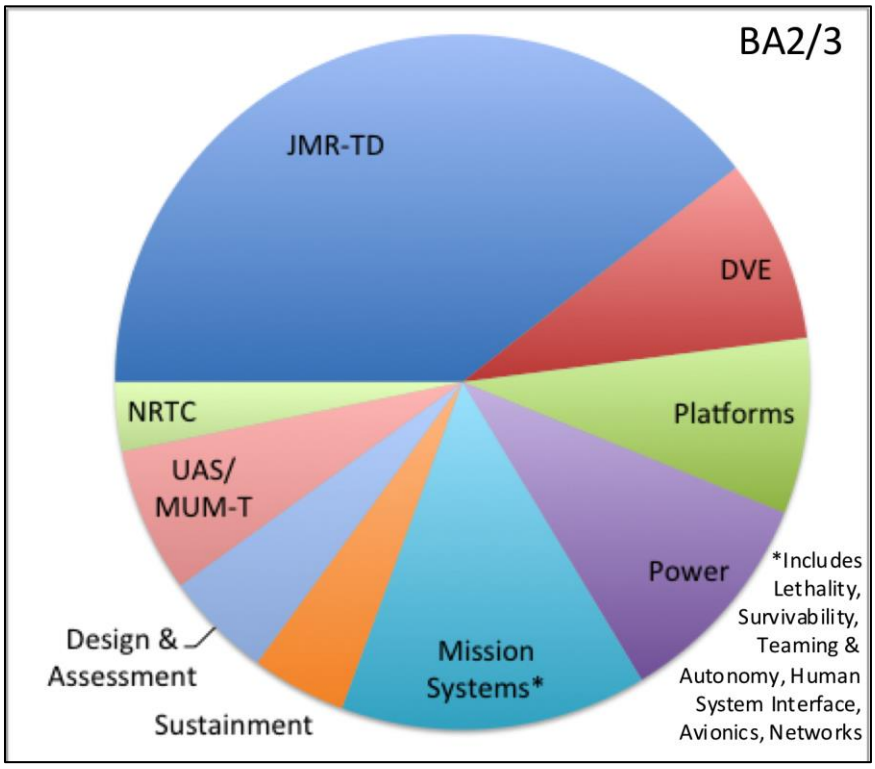


Figure I-5 Efforts Supported by Aviation BA2 and BA3 Funds

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APPENDIX J ASB APPROVED BRIEFING WITH FINDINGS AND RECOMMENDATIONS



Future of Army Aviation

Summer Study Outbrief

07/16/15



Agenda

- Introduction: Team, Terms of Reference (TOR)
- TOR Task 1: Review S&T, Modernization Plans, Developments and Force 2025 and Beyond Campaign
- TOR Task 2: Innovative Technologies & Focus Areas with Findings and Recommendations
- TOR Task 3: Feasibility & Risk Assessment

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Study Team

1. Dr. Ron Sega (MG-Ret) (Chair)
2. Dr. Mark Glauser (Vice Chair)
3. Dr. Nancy Chesser
4. Mike Heinz
5. Grant Hollett (RADM-Ret)
6. Tom Ramos
7. Teresa Smith
8. Dr. Bill Snowden
9. Dr. Alan Willner

Red Team Advisor: George Singley
Study Manager: Maj Andy Brown

Sponsor: G-3/5/7

Army Science and Technology for Army Aviation 2025-2040

TOR Objective

Identify and assess S&T enhancements capable of being fielded during the **2025-2040** timeframe that will:

- increase Army Aviation's expeditionary capabilities to support full-spectrum military operations, and
- reduce its sustainment tails and logistics footprint.

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TOR Has Three Tasks

1. **Review** current Army, Navy/USMC, Air Force, DARPA, OSD, NASA and industry aviation S&T **plans, modernization plans and ongoing developments**, as well as relevant Force 2025 and Beyond Campaign activities.
2. Address the use of **innovative technologies** that increase capabilities, overall mission effectiveness, survivability and lethality while reducing sustainment requirements, including logistics footprint and frequency of resupply.
   Include, but not necessarily be limited to, the following key focus areas for improvement:
   - near-zero maintenance platforms and systems,
   - exploitation of unmanned aircraft systems,
   - meeting the challenges of emerging threats,
   - enhancing the ability to operate worldwide in a variety of stressing and degraded visual conditions.
3. Determine the **feasibility and risks** associated with each of the findings and recommendations.

Army Science Board 5

Over 30 Team Visits

- **Army**
  - AMRDEC Aviation Development Directorate (ADD)
  - PEO Aviation and PMs
  - USA Aviation Center of Excellence (USAACE)
  - USA Aeromedical Research Laboratory (USAARL)
  - Combat Readiness/Safety Center
  - TRADOC Capability Managers (UAS, Lift)
  - CERDEC
  - Army Research Laboratory
  - Army Special Operations Aviation (ARSOA)
- **Other Services**
  - Navy - NAVAIR
  - Air Force - AFRL
- **Joint**
  - Future Vertical Lift IPTs
  - DARPA
- **Other**
  - NASA HQ
  - NASA Langley
  - NASA Ames
  - Army Aviation Association of America (Quad-A) Summit
  - Industry

Army Science Board 6

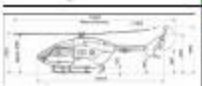
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Extensive Literature Survey (Partial List)

- **Army**
  - Army Equipment Program in support of Presidents Budget 2016
  - 2014 Army Aviation S&T Strategic Plan (ASSP)
  - 2014 Army Equipment Modernization Plan
  - ARCIC Executive Summary Unified Quest 2014
  - TRADOC Pamphlet 525-7-15 Army Aviation Operations 2015-2024
  - TRADOC Pamphlet 525-8-5 Army Functional Concept for Engagement
  - FM 3-04 Army Aviation
  - RDECOM Strategic Plan 2015-2040
  - Budget Documents FY01-FY16
  - Force 2025 and Beyond Oct 2014
  - UAS Roadmap 2010-2035
  - Army Vision: Strategic Advantage in a Complex World
  - Force 2025 Maneuvers White Paper, 2014
- **DoD**
  - 2015 National Security Strategy
- **JROC**
  - Future Vertical Lift (FVL) Capability Based Assessment (CBA), 21 Jun 10
  - FVL Family of Systems (FoS) Initial Capabilities Document (ICD), 8 Apr 13
  - Joint Future Vertical Lift (JFVL) ICD, Oct 09
  - Joint Heavy Lift (JHL) ICD, 12 Oct 07
  - Unmanned Systems ICD, 14 May 10
  - Aircraft Survivability CBA, 6 Jan 09
  - Degraded Visual Environment CBA, Jul 09
  - Aircraft Survivability ICD, 6 Oct 11
- **Navy/USMC**
  - 2015 Marine Aviation Plan
  - FY14 Navy Science and Technology Objectives
  - Naval Aviation Vision
  - Sea-Based Aviation – A National Naval Responsibility
- **DSB**
  - Future Needs for VTOL/STOL Aircraft, 2007

Army Science Board 7

Legacy Rotorcraft

Legacy Army Rotorcraft	Name / Designator	Role	IOC/ Retire?	Status	Max Takeoff	Max Load	Speed/ Range	Developer (# built)
	Chinook CH-47D/F	Cargo	1962 / 2060	Block II in 2020	50,000 lb	28,000 lb	170 kt / 400 nmi	Boeing (~1,200)
	Black Hawk UH-60	Utility	1979 / 2060	Upgrades + ARI transfer*	23,500 lb	2,640 lb int, 9,000 lb ext	159 kt /	Sikorsky (~4,000)
	Apache AH-64	Attack	1984 / 2060	Upgrades + ARI transfer*	23,000 lb		158 kt / 257 nmi	Hughes (~2,000)
	Lakota UH-72	Trainer, CONUS only	2006 / ???	ARI use for training	7,900 lb	3,950 lb	145 kt / 370 nmi	Eurocopter (~300)
	Kiowa OH-58D	Observa-tion	1969 / soon	ARI retire*	5,500 lb	1,700 lb	120 kt / 260 nmi	Bell (~2,200)
	Little Bird MH-6	SOF	1980 / ???		3,100 lb	1,500 lb (6 pax)	152 kt / 232 nmi	McDonnell Douglas / Boeing

*ARI = Aviation Restructuring Initiative proposed by Army

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Legacy UAS & Fixed WIng

Legacy Army UAS	Name / Designator	Role	IOC	Payload	Max Takeoff	Speed/ Endurance	Developer (# built)
	Raven RQ-11A/B	Small UAV, Hand launch	1999	ISR	4 lb	24-50 kt / 1-1.5 hrs	Aero-Vironment (19,000+)
	Puma RQ-20A		2007	ISR	13.5 lb	20-45 kt / 3.5 hrs	Aero-Vironment (1,000+)
	Shadow RQ-7A/B	Short Range Tactical	2002	ISR	375 lb	110 kt / 9 hrs	AAI Corp (~100+)
	Gray Eagle MQ-1C	Predator Upgrade	2009	ISR Pod / Hellfire	3,600 lb	150 kt / 30 hrs	General Atomics (~100)

Fixed Wing: Over 339 aircraft – all commercial derivative aircraft
Three categories: Special Electronic Mission Aircraft (SEMA), Transport Aircraft:, Mission Support Aircraft

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Agenda

- Introduction: Team, Terms of Reference (TOR)
- TOR Task 1: Review S&T, Modernization Plans, Developments and Force 2025 and Beyond Campaign
- TOR Task 2: Innovative Technologies & Focus Areas with Findings and Recommendations
- TOR Task 3: Feasibility & Risk Assessment

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FM 525-3-1 Army Operational Concept: Win In A Complex World

- Respond Globally: "When called upon, globally responsive combined arms teams ***maneuver from multiple locations*** and domains to present multiple dilemmas to the enemy..."
- Conduct Joint Combined Arms Operations: "Joint combined arms operations create multiple dilemmas for the enemy. Army forces ***achieve surprise*** through ***maneuver across strategic distances*** and arrival at unexpected locations. Army forces have the mobility, protection and firepower necessary to strike the enemy from unexpected directions. In high ***anti-access and area denial*** environments, ***dispersion*** allows future army forces to evade enemy attacks, deceive the enemy and achieve surprise."
- Sustain High Tempo Operations: "Army sustainment units integrate efforts with Joint Force to ensure unimpeded sustainment flows across land, air and maritime domains. These units provide supplies and services to the ***point of need...***"

Operational maneuver and sustainment to point of need of dispersed forces

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Complex Threats and Opportunities



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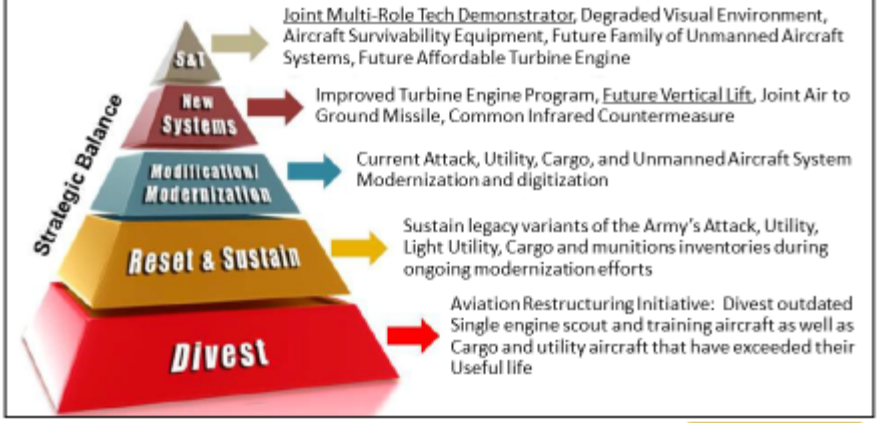
Unified Quest 2014 Conclusions

- "Self-deployable Army future **vertical lift** capabilities and joint shallow draft systems must be capability development options. These capabilities are **essential** to future strategic, operational, and tactical maneuver and enable dispersed forces to maintain mutually supportive functions."
- **"Unmanned** air and ground platforms that enhance soldier decision-making and action with self-planning, self-navigation, and mission execution capabilities will have significant potential to change the future battlefield. The Army must develop concepts of employment for future autonomous and unmanned systems in the near-term to integrate them efficiently into the force in the far-term (2030-2040)."

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Army Aviation Modernization Strategy

Invest in essential technologies that have a high likelihood of successful transition to Affordable programs, to help close capability gaps in a resource constrained environment. Incrementally upgrade Aviation platforms, divest old systems and invest in new platforms and technologies, in order to maintain modernized aircraft that can defeat **new and increasingly complex threats.**



Source: Army Equipment Modernization Strategy, March 2015 (Annex E – Aviation) - G8

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Joint Multi-Role Tech Demo (JMR-TD)

- JMR-TD is cost sharing effort between Army and Vendors. Four vendors selected Oct 2013 to begin design for vehicle demonstrator:
  - AVX – coaxial-rotor, ducted-fan compound helicopter
  - Bell – tilt rotor
  - Karem - variable-speed tilt rotor
  - Sikorsky Boeing – coaxial rigid-rotor, pusher-propulsor design



- Down-selected Aug 2014 to Bell "V-280 Valor" and Sikorsky-Boeing "Defiant" to build demonstrators for 2017 flight. AVX and Karem funded for tech development.
- Both JMR TD variants use existing engines (Bell – CH-53, Sikorsky – CH-47)

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Future Vertical Lift Family of Systems

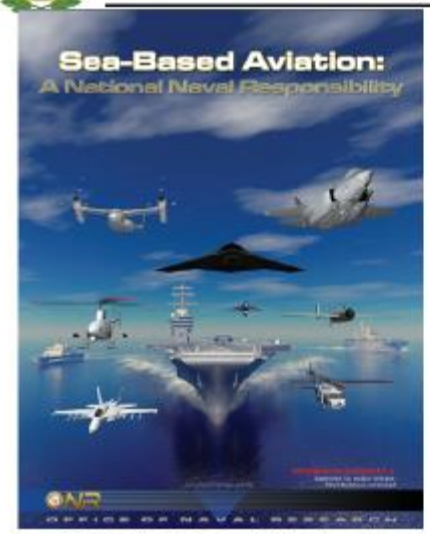
- FVL FoS is a Joint **initiative**, not yet a **program**, to develop a 5-class family of rotorcraft for DoD (light, medium, heavy).
- Although requirements are still being refined, the notional concept for a new aircraft must:*
  - reach speeds of 230 knots
  - carry up to 12 troops
  - Operate in "high-hot" conditions at altitudes of 6,000 ft and temperatures of 95-degrees Fahrenheit,
  - have a combat radius of 263 mi with an overall unrefueled range of 527 mi
  - have optionally piloted or supervised autonomous flight capabilities
- Mission sets include: cargo; utility; armed scout; attack; humanitarian assistance; medical evacuation; anti-submarine warfare; anti-surface warfare; land/sea search and rescue; special warfare support; vertical replenishment; airborne mine countermeasures.

Source: Army Propels Next Generation of Helicopter Program Forward, DefenseTech, Oct 2014 (http://defensetech.org/2014/10/08/army-propels-next-generation-helicopter-program-forward/)

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Navy and Air Force Have Visions for UAS





SECNAV: "F-35C should be Navy's last manned strike jet" 4/16/15

General Impressions Gained From Review

- **Army manned aviation S&T:** Generally well balanced (e.g. JMR-TD & FVL)
- **Outside investments:** NASA, USAF, USN/USMC, DARPA and industry have promising innovative technology and concepts that could be leveraged
- **Survivability**: Sophisticated threats place Army aviation assets at high risk. These threat capabilities are growing and proliferating.
- **Architecture**: Survivability against 2025+ threats will require system of systems (SoS) solutions that exploit the power of collaborative manned-unmanned teaming (MUM-T). The operational and system architectures and CONOPS for these SoS solutions have not been defined.
- **Unmanned Systems**: Army aviation requires a strong vision for the expanded use of UAS. Currently, there is neither the vision nor the funding to exploit the potential of UAS, autonomy and MUM-T
- **Manned Systems**: Legacy manned systems are 1970 vintage designs. Next generation systems (FVL) are scheduled for IOC in mid 2030s.
- **Maneuver**: Army CONOPS requires expeditionary and operational maneuver of dispersed mechanized forces. Army aviation assets cannot satisfy this need.
- **Army Aviation RDT&E Budget**: Inadequate to meet future aviation challenges. FVL is not funded; industrial base is eroding.

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Findings & Recommendations Overview

Context: Character of Warfare in 2025 and Role of Army Aviation

1. System of Systems Operational Effectiveness Analyses
2. Affordability of Heavy Vertical Lift

Addressing Capability Gaps: Development and Acquisition

3. UAS Vehicles
4. Modernization of Legacy Rotorcraft Systems
5. FVL Acquisition with Speed and Simplicity
6. Aviation Mission Systems
7. Aviation Systems Integration and Testbed

S&T Portfolio: Innovation and Game Changers

8. Advanced and Disruptive Systems S&T
9. S&T Investment Strategy

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1. System of Systems Operational Effectiveness Analyses

Findings

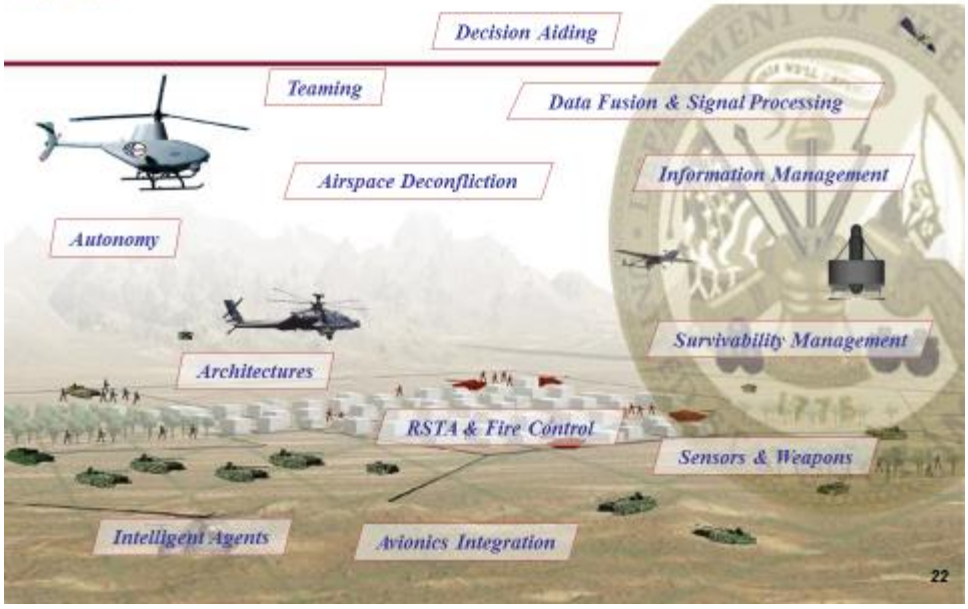
- Increasing threat sophistication and proliferation (e.g., missiles, UAS, cyber, and directed energy) pose critical concerns. (Classified annex provides additional details)
- Platform-centric survivability must evolve to a manned-unmanned system-centric approach with new CONOPS and TTPs.
- A system of systems architecture should include manned-unmanned teaming, supervised autonomous systems, and secure communications.

Recommendation

- TRADOC: Conduct operational effectiveness analyses of potential system of systems concepts in a cost-constrained environment that address capability gaps for Army aviation in 2025 and beyond in complex threat environments. Concepts should include holistic air-ground approaches, high/low mixes of collaborative manned/unmanned systems, FVL performance characteristics, higher levels of autonomy, PNT in denied GPS environments, attritable UAS assets and enhanced lethality of DE. Develop CONOPS and architectures for the most cost effective concepts.

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Integrated Battlespace



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2. Affordability of Heavy Vertical Lift (HVL)

Findings

- Heavy vertical lift (20-30 stons) is required by the Army CONOPS for expeditionary and operational maneuver, validated by JROC (documented in the FVL and JHL ICDs) and supported by Unified Quest 2014, and "2012 Gaining and Maintaining Access: An Army-Marine Corps Concept."
- However, development of a new system is cost prohibitive within likely future Army modernization (RDA) funding before 2040.
- Interim solutions able to provide more limited capability are available (e.g., CH-53K at 18 stons, and Joint Precision Air Drop System – JPADS) and could provide viable options.

Recommendation

- TRADOC: Assess interim and future HVL options for meeting Army CONOPS and documented JCIDS capability needs for expeditionary and operational maneuver and recommend road ahead
  - If development of HVL is cost prohibitive, consider alternatives.
  - If there are no plans for HVL, do not assume it is available in analyses, wargames, and exercises.

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Historical Heavy Vertical Lift Options









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Findings & Recommendations Overview

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7. Aviation Systems Integration and Testbed

S&T Portfolio: Innovation and Game Changers

8. Advanced and Disruptive Systems S&T
9. S&T Investment Strategy

3. UAS Vehicles

Findings

- The USN/USMC and USAF have strong visions for the expanding role of UAS and manned-unmanned teaming in aviation missions.
- DARPA, USN/USMC and USAF are investing in next generation UAS technology options that offer potential capability for Army aviation.
- New UAS are needed to fully exploit manned–unmanned synergy and collaboration of manned systems with supervised autonomous systems within a system-of-systems architecture.

Recommendation

- ASA(ALT): Revise UAS Roadmap to expand near-term and future UAS vehicle options, some of which should be compatible with speed, hover, and range of current and future manned aircraft, with attributes compatible with distributed functionality among UAS (ISR, Lethality, …) as informed by the results of system of systems operational effectiveness analyses (Recommendation 1)

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Distributed Functionality Collaborative System of Systems Concept



Low End Single Function Unmanned Systems
Complement and Expand Capability of High End System

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4. Modernization of Legacy Rotorcraft Systems

Findings

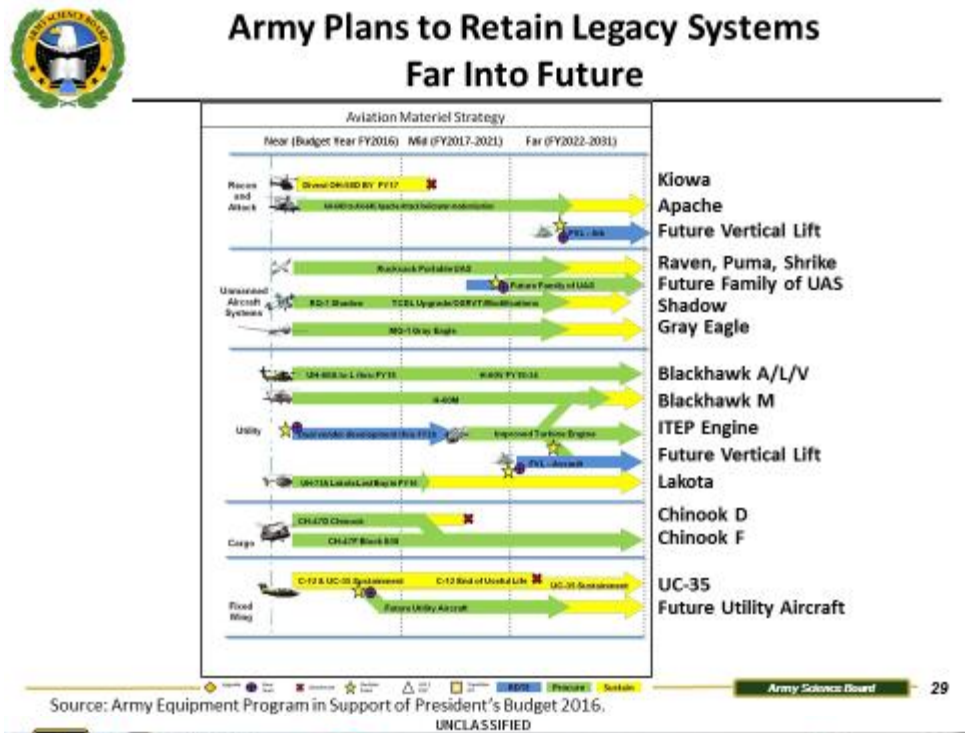
- Legacy rotorcraft systems (AH-64, CH-47 and UH-60) are expected to remain deployed until at least 2060, requiring modernization investment.
- Within the current limited budget, Army aviation S&T is investing in technologies that apply to both legacy and future manned systems.
- These technologies include: ITEP/FATE engine insertion, DVE capabilities, CBM/PHM capabilities, ASE improvements, and greater MUM-T.

Recommendation

- ASA(ALT): Continue S&T and road-mapping efforts for modernizing legacy systems with emphasis on those technologies that are also applicable to future vehicles, as informed by the results of system of systems operational effectiveness analysis (Recommendation 1).

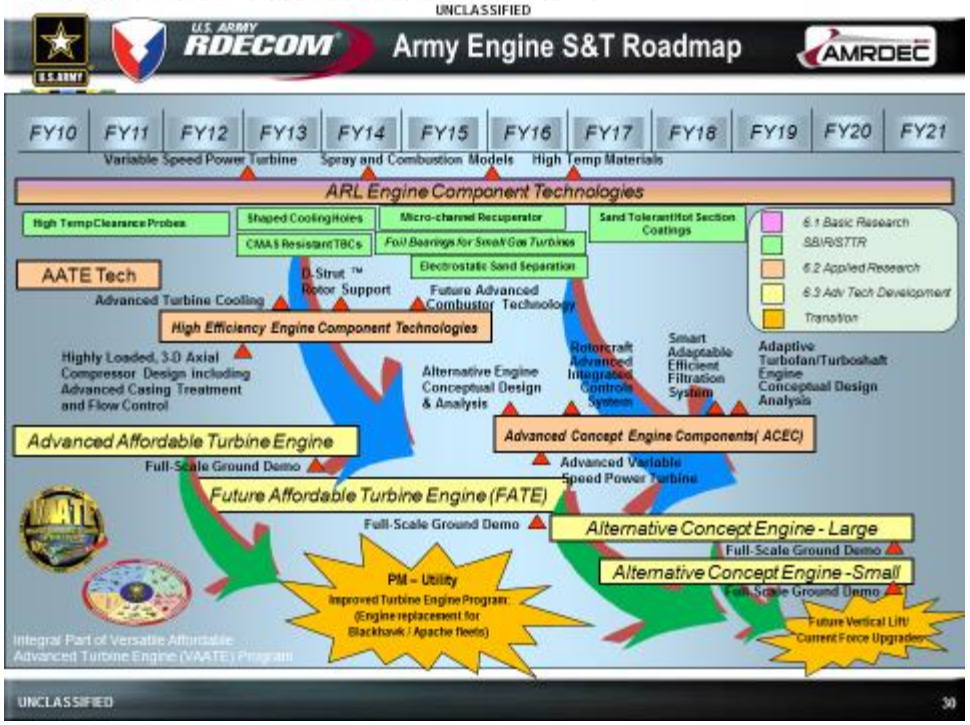
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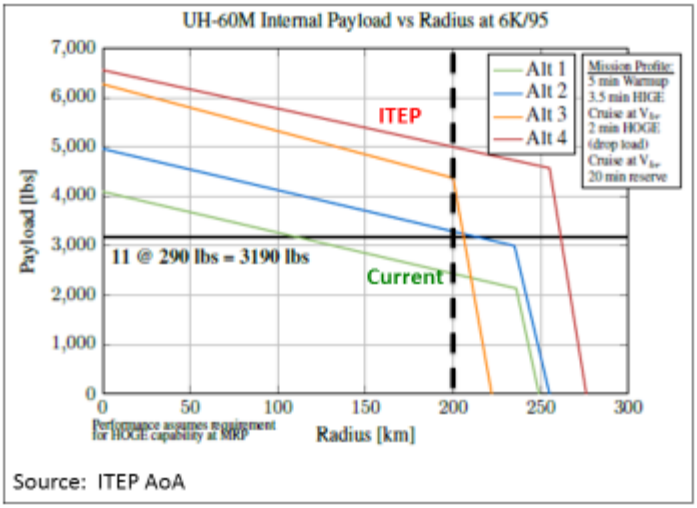
Source: Army Equipment Program in Support of President's Budget 2016.

UNCLASSIFIED



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ITEP Provides Significant Improvement in Performance of Legacy Platforms



5. FVL Acquisition with Speed and Simplicity

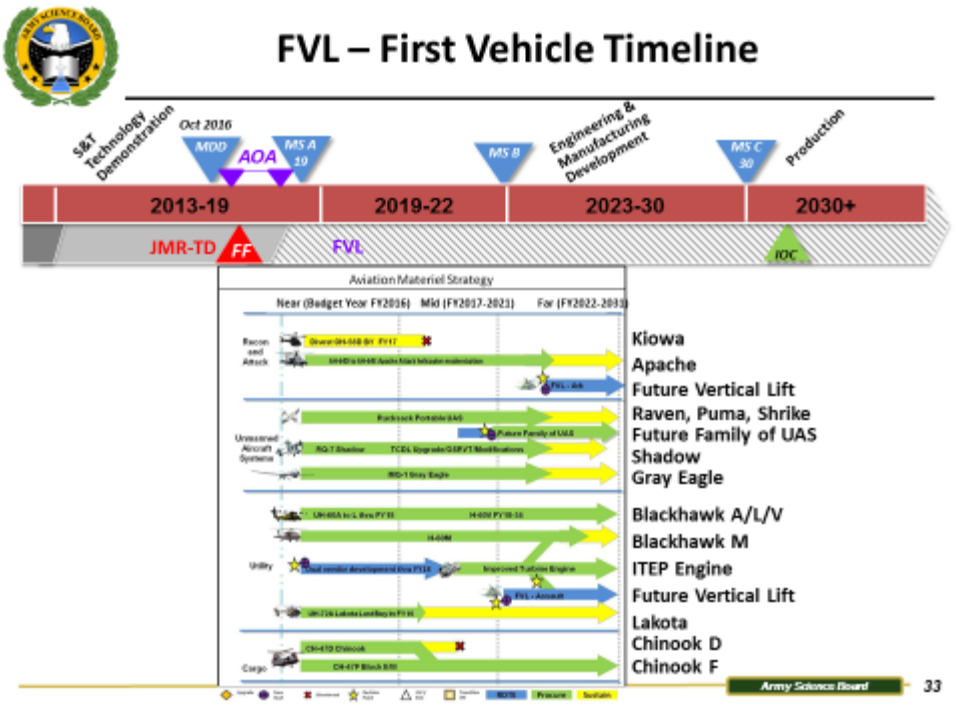
Findings

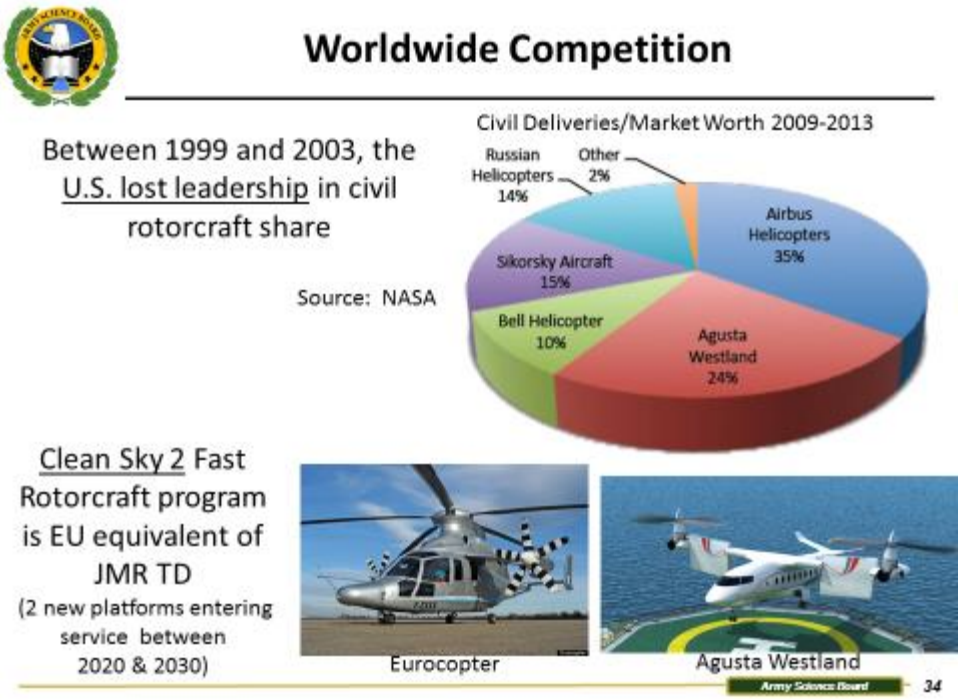
- JMR-TD and FVL provide focus for Army Aviation S&T for next generation rotorcraft systems and provide a solid basis for much needed capability improvements (Ref. FVL ICD); however, there is no funding for FVL in the POM.
- The JMR-TD vehicles are close in size and aerodynamic performance capability to the FVL medium class system.
- The current FVL schedule leads to an IOC of the first system in the mid 2030s. It should be beneficial to accelerate this timeline through an evolutionary acquisition approach if funding allows.
- The JMR-TD, DARPA X planes, USN/USMC prototyping efforts, and industry investment support talent development and retention in rotorcraft government and industry teams.

Recommendation

- ASA(ALT): Develop an evolutionary acquisition approach for FVL to allow for earliest possible fielding consistent with funding constraints, as informed by the results of system of systems operational effectiveness analyses (Recommendation 1).

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6. Aviation Mission Systems

Findings

- Army S&T mission system programs include Lethality, Survivability, Teaming & Autonomy, Human-System Interface, Avionics, and Networks.
- RDECOM DVE goals are appropriate and feasible - Progress at AMRDEC, CERDEC, and ARL in sensors, flight control, cueing, computing, and networking.
- Reduced pilot workload arising from DVE technologies should increase operational mission capacity (e.g., formations with UAS).
- Advanced sensors (e.g., IR, visible, and hyperspectral) are being developed.
- Additional advanced mission systems (e.g., offensive and defensive directed energy) and open system architectures are needed.
- DoD provides singular modeling and wind tunnel capabilities (NASA Ames)

Recommendation

- AMRDEC/ADD: Expand mission system technology development, currently focused on DVE, to enable advanced formation concepts in future manned and unmanned platforms, and legacy platforms as appropriate, as informed by the results of system of systems operational effectiveness analyses (Recommendation 1).

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The DVE Environments: 2 + 9

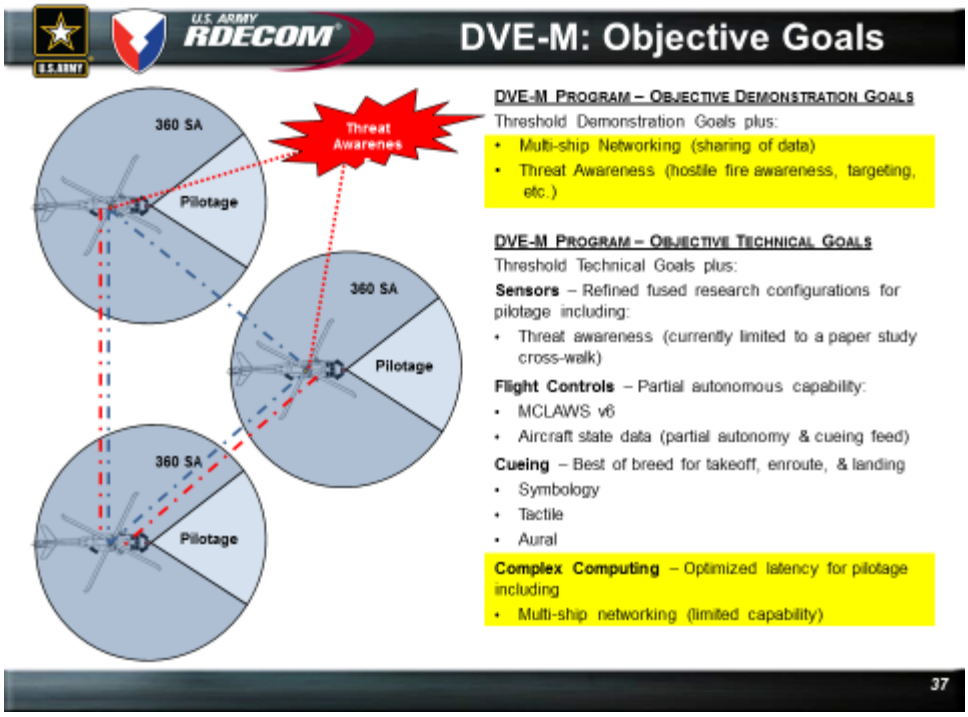


TRADOC DVE Definition (2011) – Reduced visibility of potentially varying degree, wherein situational awareness and aircraft control cannot be maintained as comprehensively as they are in normal visual meteorological conditions and can potentially be lost.

In the 1980's, IR technology allowed the US military to claim "We own the night!" . . . The RDECOM Rotorcraft DVE Mitigation Program overall goal is to "OWN THE WEATHER!".

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7. Aviation Systems Integration and Testbed

Findings

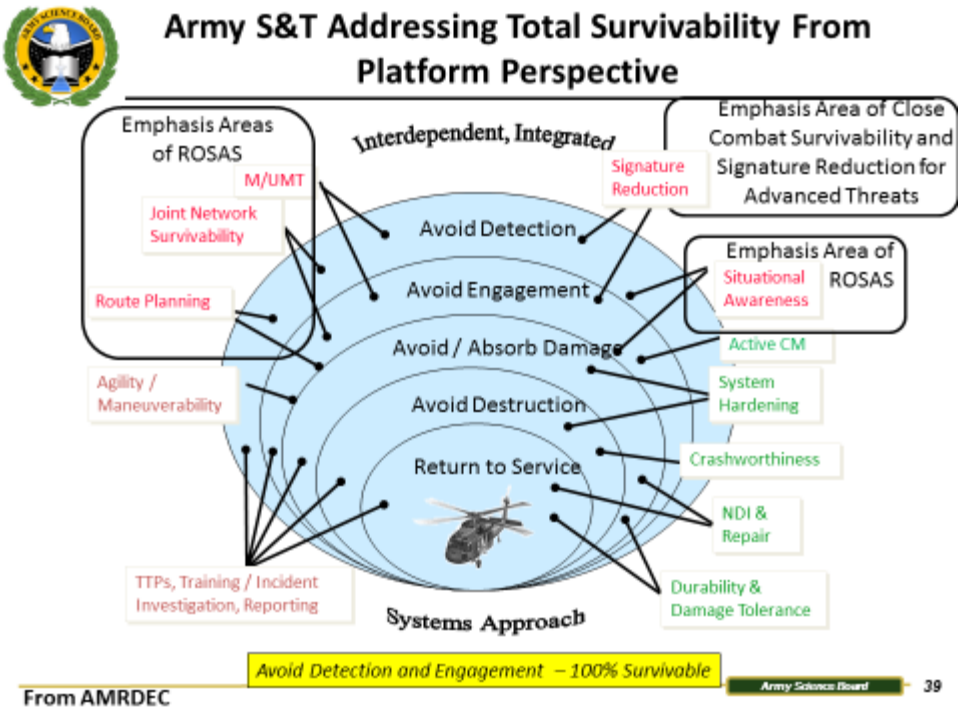
- Concepts developed in Recommendation 1 and new technical capabilities referenced in Sections 2-6 (individually and as integrated systems) will require extensive testing.
- Some initial work is found in CERDEC I2WD open systems efforts and DARPA's System of Systems Integration, Technology and Experimentation (SoSITE).
- Fully integrated joint vision for aviation in DoD is not evident. Coalition environment should be considered.

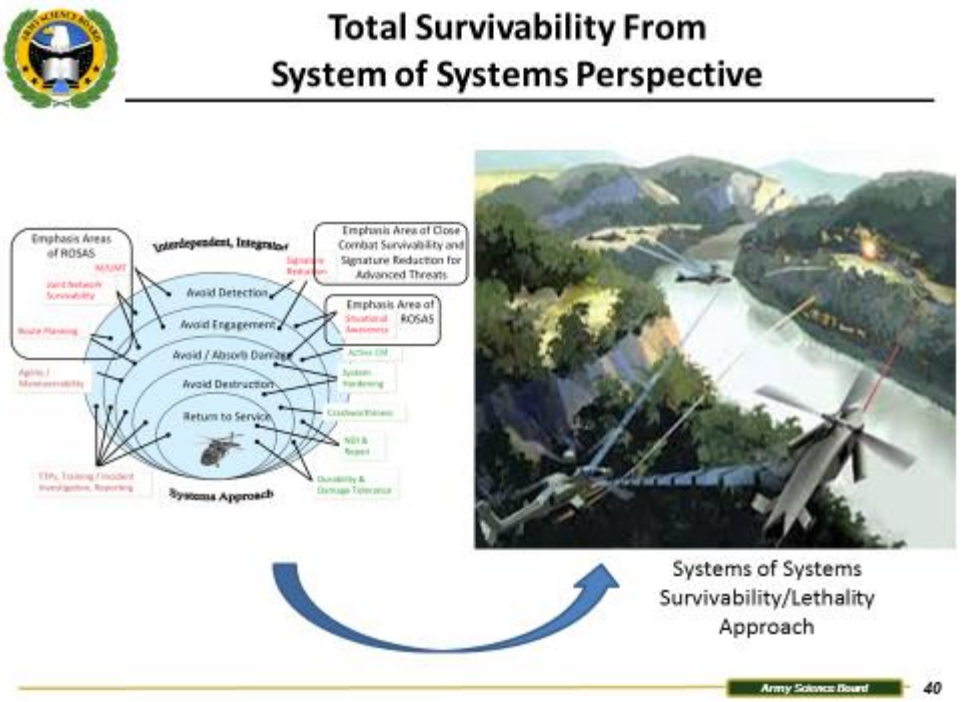
Recommendations

- RDECOM: Build the components of an integrated "survivable" system (MUM-T, attritable assets, secure comm, PNT, open operating systems, autonomy, high/low mix, distributed functions across future "formations").
- RDECOM: Building on Recommendation 1 and Sections 2-6, develop an aviation integration testbed for experimentation and validation of technology, prototypes, and concepts. Potentially include demonstration (such as JMR TD), prototype, surrogate, and operational systems.

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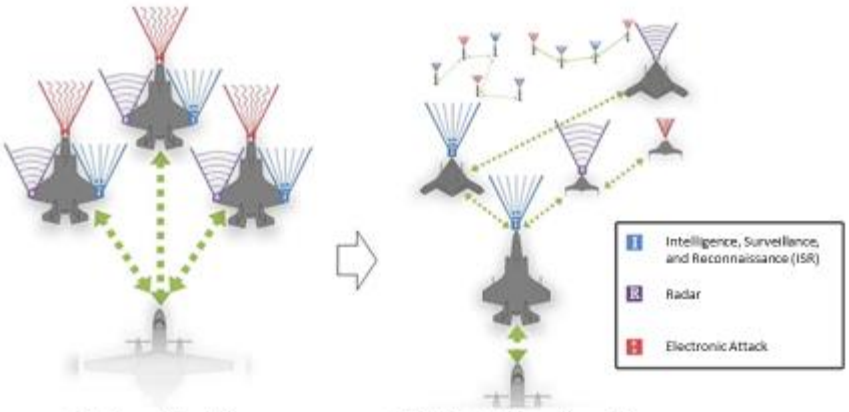
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SoSITE System of Systems Example



Platform Centric
Vulnerable to countermeasures

Distributed Functionality
Robust to countermeasures

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Source: DARPA SoSITE website

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8. Advanced and Disruptive Systems S&T

Findings

- Army aviation is at a crossroad of challenge and opportunity.
  - The challenge: threat sophistication will demand a transformation in the nature of warfare in 2025 and beyond (missiles, UAS, DE, Cyber).
  - The opportunity: technology is emerging that enables significant improvement in aviation capabilities.
- Advanced technology solutions are required, including: UAS, autonomy, manned-unmanned collaboration, communications, directed energy, sensors, condition-based and near-zero maintenance technology/concepts, and other discoveries from the S&T enterprise.
- There is relevant work in other Services, DARPA, and NASA that should be leveraged.

Recommendations

- RDECOM: To address expanding complex threats and opportunities develop advanced technologies for an integrated/holistic, manned/unmanned architecture/system to ensure survivability and mission success.
- ASA(ALT): Include in S&T portfolio leap-ahead technologies (counter-DE, counter-UAS, advanced materials)

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Aviation Innovation Examples





DARPA X-Plane







ARES (DARPA)





Great Horned Owl (Air Force)



Air Launch UAVs (Boeing)

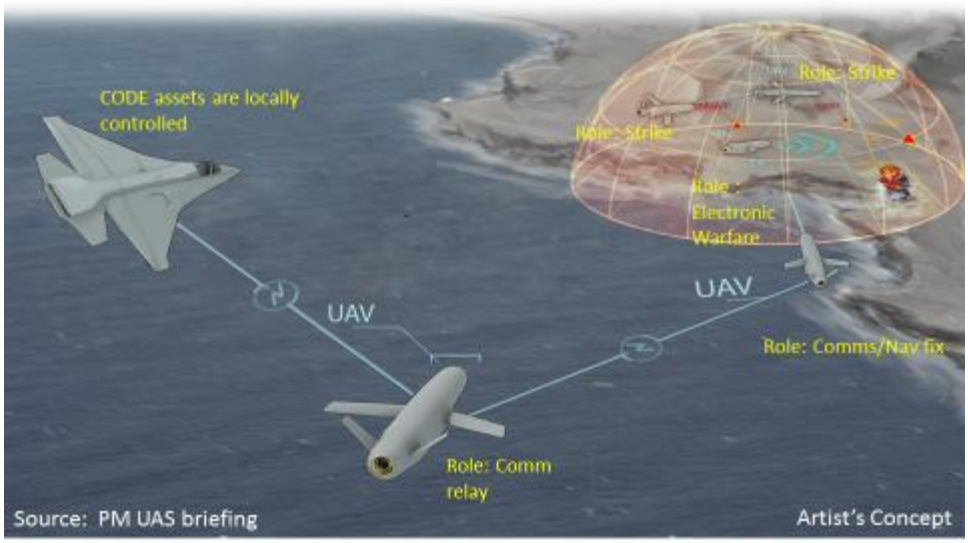




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Collaborative Operations in Denied Environment (CODE)



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9. S&T Investment

Findings

- Based on findings in Sections 1-8, the capabilities of Army Aviation S&T must evolve rapidly (e.g., need to expand UAS and autonomy activity); thus the level of S&T activity must expand beyond the manned aviation S&T portfolio, which is currently well managed.
- Army S&T investment has led to successful ITEP and FATE engine developments; the transition of these S&T efforts to PORs is essential to both FVL and modernized legacy platforms.
- Current S&T investment is insufficient to achieve the needed transformation and to maintain overmatch in 2025 and beyond.

Recommendations

- AMRDEC/ADD: Continue active participation in VAATE and RAMPED engine development.
- RDECOM: Explore innovative mechanisms for external collaboration (university, industry, etc.), such as grand challenges (similar to DARPA construct).
- ASA(ALT): After exploring leveraging opportunities with other R&D activities, advocate more funding for Aviation S&T.

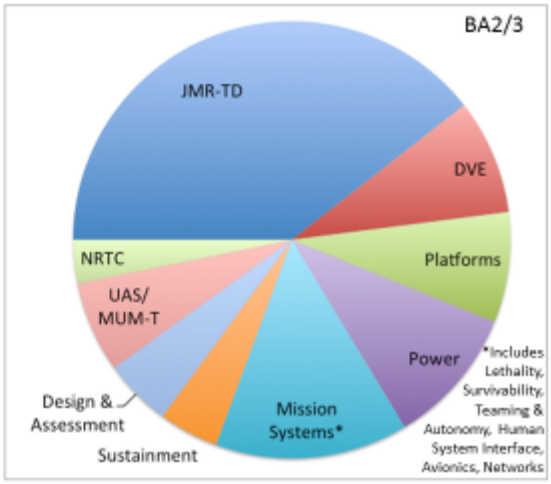
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Meeting Future Challenges Demands a Robust Aviation Portfolio

- Army FY16 Requested TOA is $126B
- Procurement Total is $16.1B
- Aviation Procurement is $5.7B (34% of Procurement)
- Army S&T* Total is $1.77B
- Army Aviation S&T* is $144M (8% of S&T)
- DoD Rotorcraft S&T* is $207M (Army is lead Service with 64% of total)
- NASA Rotorcraft Funding is $20M

*BA2/3



Current level and focus of funding is inadequate to meet challenges

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Findings & Recommendations Summary

Context: Character of Warfare in 2025 and Role of Army Aviation

1. System of Systems Operational Effectiveness Analyses
2. Affordability of Heavy Vertical Lift

Addressing Capability Gaps: Development and Acquisition

3. UAS Vehicles
4. Modernization of Legacy Rotorcraft Systems
5. FVL Acquisition with Speed and Simplicity
6. Aviation Mission Systems
7. Aviation Systems Integration and Testbed

S&T Portfolio: Innovation and Game Changers

8. Advanced and Disruptive Systems S&T
9. S&T Investment Strategy

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Future of Army Aviation

Threats are rapidly changing

Character of warfare is changing

Army aviation must change too

Need new **concepts** - beyond stand-alone platforms

New joint battlespace system-of-systems architecture/CONOPS

New systems – UAS, FVL, autonomy, missions systems

New prototyping, experimentation, and testbed

Increase **innovation** and risk-taking to leap ahead/anticipate

Survive and Win as an Aviation System of Systems



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APPENDIX K ABBREVIATIONS AND ACRONYMS

A2	Anti-Access
AATD	Aviation Applied Technological Directorate – merged with AFDD to form ADD – Ft Eustis, VA
ACAT I	Acquisition Category I (Major Defense Acquisition Programs)
AD	Area Denial
ADD	Aviation Development Directorate in AMRDEC – Merger of AATD and AFDD
AFDD	Aeroflight Dynamics Directorate – merged with AATD to form ADD – Moffett Field, CA
AFOSR	Air Force Office of Scientific Research – Arlington, VA (see also ARO and ONR)
AFRL	Air Force Research Laboratory (see also ARL and NRL)
AH	Attack Helicopter
AIPT	Acquisition IPT (FVL – Army PEO Aviation lead)
AMCOM	Aviation and Missile Command
AMRDEC	Aviation and Missile RDEC – Redstone Arsenal, Huntsville, AL
AO	Area of Operations
AoA	Analysis of Alternatives
APG	Aberdeen Proving Ground, MD
ARCIC	Army Capabilities Integration Center – subordinate to TRADOC
ARDEC	Armament RDEC – Picatinny Arsenal, NJ
ARES	Aerial Reconfigurable Embedded System (DARPA effort)
ARI	Aviation Restructuring Initiative proposed by Army
ARL	Army Research Laboratory – Adelphi, MD and APG, MD (see also AFRL and NRL)
ARO	Army Research Office, part of ARL – Raleigh-Durham, NC – Oversees external efforts in BA1 (see also AFOSR and ONR)
AS	Aviation Systems – a PM in PEO Aviation
ASA(ALT)	Assistant Secretary of the Army (Acquisition, Logistics, and Technology)
ASB	Army Science Board
ASD(R&E)	Assistant Secretary of Defense (Research & Engineering)
ASE	Aircraft Survivability Equipment
ASH	Armed Scout Helicopter – a PM in PEO Aviation
ASSP	Aviation S&T Strategic Plan (produced by ADD)
ASW	Anti-submarine Warfare
AUSA	Association of the US Army
BA1	Budget Activity 1 (DoD), Basic Research - directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs. Also called 6.1
BA2	Budget Activity 2 (DoD), Applied Research - systematic expansion and application of knowledge to develop useful materials, devices, and systems or methods. Also called 6.2
BA3	Budget Activity 3 (DoD), Advanced Technology Development (ATD) - development of subsystems and components and efforts to integrate subsystems and components

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	into system prototypes for field experiments and/or tests in a simulated environment. Also called 6.3
BA4	Budget Activity 4 (DoD): Demonstration and Validation - Dem/Val includes all efforts necessary to evaluate integrated technologies in as realistic an operating environment as possible to assess the performance or cost reduction potential of advanced technology.
BA5	Budget Activity 5 (DoD): Engineering and Manufacturing Development - EMD includes those projects in engineering and manufacturing development for Service use but which have not received approval for full-rate production..
BA6	Budget Activity 6 (DoD): RDT&E Management Support - Includes R&D effort directed toward support of installations or operations required for general R&D use. Included would be test ranges, military construction, maintenance support of laboratories, O&M of test aircraft and ships, and studies and analyses in support of the R&D program.
BA7	Budget Activity 7 (DoD): Operational Systems Development. - Includes those development projects in support of development acquisition programs or upgrades still in EMD, but which have received Defense Acquisition Board (DAB) or other approval for production, or production funds have been included in the DoD budget submission for the budget or subsequent fiscal year.
BDA	Battle Damage Assessment
BRAC	Base Realignment and Closure
C2	Command and Control
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CAPE	Cost Assessment and Program Evaluation (OSD)
CAS	Close Air Support
CBA	Cost-Benefit Analysis or Capabilities Based Assessment (part of JCIDs process)
CBM	Condition Based Maintenance
CCA	Close Combat Attack
CCS	Close Combat Survivability
CERDEC	Communications-Electronics RDEC – APG, MD
CG	Commanding General
CH	Cargo Helicopter
CIPT	Commonality IPT (FVL – Navy PEO Assault and ASW lead)
CM	Countermeasure
CODE	Collaborative Operations in Denied Environment (DARPA effort)
COE	Center of Excellence
COI	Community of Interest
CONOP	Concept of Operations
CONUS	Continental US
CSA	Chief of Staff of the Army
CSAR	Combat Search and Rescue
DA	Direct Attack
DAB	Defense Acquisition Board

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DARPA	Defense Advanced Research Projects Agency
DE	Directed Energy (includes high energy laser and high powered microwave)
DHS	Department of Homeland Security
DoD	Department of Defense
DSB	Defense Science Board
DTIC	Defense Technical Information Center (www.dtic.mil)
DVE	Degraded Visual Environment (includes brownouts, whiteouts, rain, snow, fog, sleet, mist, etc.)
DVE-M	DVE - Mitigation
ECBC	Edgewood Chemical and Biological Center – Edgewood, MD
EMD	Engineering and Manufacturing Development
EMI	Electromagnetic Interference
EO	Electro-Optic
ESD	Electrostatic Discharge
EW	Electronic Warfare
FA	Focus Area (at ADD)
FACE	Future Airborne Capability Environment
FATE	Future Affordable Turbine Engine
FCS	Future Combat System
FoS	Family of Systems
FOUO	For Official Use Only
FVL	Future Vertical Lift
FW	Fixed Wing – a PM in PEO Aviation
FY	Fiscal Year
GCS	Ground Control System
GMTI	Ground Moving Target Indicator
GPS	Global Positioning System
HA/DR	Human Assistance/Disaster Relief
HOGE	Hover Out of Ground Effect
HQDA	Headquarters Department of the Army
HSL	Helicopter Sling Load
HUMS	Health and Usage Monitoring System
HVL	Heavy Vertical Lift
I2WD	Intelligence and Information Warfare Directorate of CERDEC – APG, MD
ICD	Initial Capabilities Document
IED	Improvised Explosive Device
IEW&S	Intelligence, Electronic Warfare & Sensors
IHSMS	Integrated Hybrid Structures Management System (Navy)
ILIR	In-House Laboratory Innovative Research (BA1)
IOC	Initial Operational Capability
IPT	Integrated Product Team
IR	Infrared
ISR	Intelligence, Surveillance, and Reconnaissance
ITEP	Improved Turbine Engine Program

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IVSHM	Integrated Vehicle Self Health Monitoring
JAGM	Joint Air-to-Ground Missile
JCA	Joint Common Architecture
JCIDS	Joint Capabilities Integration and Development System, the formal United States DoD procedure that defines acquisition requirements and evaluation criteria for future defense programs
JF	Joint Force
JFTL	Joint Future Theater Lift – concept to lift 20-36 tons – USAF lead JFTL definition 2008-2012, canceled 2012
JFVL	Joint Future Vertical Lift
JHL	joint Heavy Lift – Army exploration of large tilt-rotor concept to lift ~30 tons over theater distances
JLTV	Joint Light Tactical Vehicle
JMR	Joint Multi-Role
JROC	Joint Requirements Oversight Council
kt	knot (1 nautical mile per hour = 1.852 km per hour)
LCC	Life Cycle Cost
LGB	Laser-Guided Bomb
LIRA	Long-Range Investment Requirements Analysis
M&S	Modeling & Simulation
MANPADS	Man-Portable Air Defense System
MCLAWS	Modernized Control Laws
MDD	Materiel Development Decision
MEDEVAC	Medical Evacuation
MEP	Mission Equipment Package
MFOP	Maintenance Free Operating Period
MSA	Milestone A – decision to move from Materiel Solution Analysis to Technology Development
MSB	Milestone B – decision to move from Technology Development to Engineering and Manufacturing Development
MSC	Milestone C – decision to move from Engineering and Manufacturing Development to Production and Deployment
MUM-T	Manned Unmanned Teaming
NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Systems Command
NDI	Non-Developmental Item
NDIA	National Defense Industrial Association
NEO	Noncombatant Evacuation Operations
NM	Nautical mile
NRL	Naval Research Laboratory – Washington, DC (see also AFRL and ARL)
NRTC	National Rotorcraft Technology Center at NASA Ames – an interagency team of NASA, Army, Navy, and FAA – focuses government, industry, and academic resources
NSRDEC	Natick Soldier RDEC - Natick MA

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NSRWA	Non-Standard Rotary Wing Aircraft – a PM in PEO Aviation
NVESD	Night Vision and Electronic Sensor Directorate of CERDEC – Ft. Belvoir, VA
O&M	Operations and Maintenance
O&S	Operations and Support
OCO	Overseas Contingency Operations
OEF	Operation Enduring Freedom
OMS	Open Mission Systems (USAF effort)
ONR	Office of Naval Research – Arlington, VA (see also AFOSR and ARO)
OSA	Open Systems Architecture
OSD	Office of the Secretary of Defense
OT&E	Operational Test and Evaluation
P3I	Pre-Planned Product Improvement
Pax	Passengers
PEO	Program Executive Office, e.g. PEO-Aviation at Redstone Arsenal, AL
PHM	Prognostic Health Management
PM	Program Manager in PEO, e.g., in PEO Aviation PMs are Apache, AS, ASH, Cargo, NSRWA, UH, UAS, FW
PNT	Positioning, Navigation and Timing
POD	Point of Departure or Point of Debarkation
POM	Program Objective Memorandum
POR	Program of Record – Acquisition program that has achieved MSB
R&D	Research and Development
RDA	Research Development and Acquisition
RDEC	Research, Development, and Engineering Center
RDECOM	Research, Development, and Engineering Command – RDECOM Organizations include ARDEC, AMRDEC, CERDEC, ECBC, NSRDEC, TARDEC and ARL – APG, MD
RDTE	Research Development Test & Evaluation (RDT&E funding includes BA1-BA7 budget areas)
RF	Radio Frequency
RIPT	Requirements IPT (FVL – TCM-Lift lead))
ROSAS	Route Optimization for Survivability Against Sensors (Army effort)
RSOI	Reception, Staging, Onward movement, and Integration
RSTA	Reconnaissance, Surveillance, and Target Acquisition
RVLT	Revolutionary Vertical Lift Technology (NASA project)
RW	Rotary Wing – a PM in PEO Aviation
S&T	Science & Technology – within DoD funded by BA1, BA2, and BA3
SA	Situational Awareness
SAM	Surface to Air Missile
SAR	Synthetic Aperture Radar
SBIR	Small Business Innovative Research
SEAD	Suppression of Enemy Air Defense
SIGINT	Signals Intelligence
SIL	Software Integration Laboratory
SLAD	Survivability/Lethality Analysis Directorate (ARL)

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SOCOM	Special Operations Command
SOF	Special Operations Force
SOIPT	S&T Overarching IPT (FVL – AMRDEC lead)
SoS	System of Systems
SoSITE	System of Systems Integration technology and Experimentation (DARPA effort)
SRAT	Signature Reduction Against Threats
STOL	Short Take-Off and Landing
SuW	Surface Warfare (Navy)
SWAP	Size, Weight, and Power
TA	Technical Area (at ADD)
TARDEC	Tank Automotive RDEC – Warren, MI
TCM	TRADOC Capability Manager
TD	Technology Demonstration
TOA	Total Obligation Authority
TOR	Terms of Reference
TRADOC	US Army Training and Doctrine Command – Ft Eustis, VA
TTO	Tactical Technology Office (DARPA)
TTP	Tactics, Techniques, and Procedures
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UH	Utility Helicopter – a PM in PEO Aviation
UNK	Unknown
UQ	Unified Quest (Army chief of staff annual future studies program, includes wargame)
USA	US Army
USAACE	US Army Aviation Center of Excellence – Ft. Rucker, AL
USAARL	US Army Aeromedical Research Laboratory – Ft. Rucker, AL
USAF	US Air Force
USCG	US Coast Guard
USMA	US Military Academy at West Point
USMC	US Marine Corps
USN	US Navy
V/STOL	Vertical/Short Take-Off and Landing
VAATE	Versatile Affordable Advanced Turbine Engine
VCSA	Vice Chief of Staff of the Army
VLC	Vertical Lift Consortium (Industry)
VLRCOE	Vertical Lift Research Center of Excellence (at Georgia Tech, Penn State, and U Md) – Funded with BA1
VRAMS	Virtual Risk-informed Agile Maneuver Sustainment
VTOL	Vertical Take-Off and Landing
WIPT	Working IPT under SOIPT (FVL)
WMD	Weapons of Mass Destruction
ZMA	Zero Maintenance Aircraft

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MONTEREY, CALIFORNIA

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FEASIBILITY AND UTILITY OF AIRBORNE SOLID-STATE LASERS AGAINST GROUND ORDNANCE

by

Joseph Fasone

June 2018

Thesis Advisor: Keith R. Cohn
Co-Advisor: Joseph A. Blau

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Explosive devices present a significant threat to civilian populations and are a severe counter-mobility obstacle for ground forces. With the proliferation of improvised explosive devices into potential U.S. military operating areas, a safer and more efficient method for eliminating the threat is required. U.S. Army forces operating at the brigade and above echelons are generally supported with a variety of unmanned aerial vehicle (UAV) airframes that are capable of conducting reconnaissance and surveillance. These UAVs are faster and more responsive to reports of ground-based explosive devices than explosive ordnance disposal (EOD) teams or route clearance patrols. If UAVs were equipped with a system capable of disarming or destroying explosive devices, the stress on EOD assets would be mitigated and the delaying effect of said explosives on ground forces would be reduced. This research explores the feasibility and utility of using a high-energy laser mounted onboard a UAV platform to defeat ground-based explosive devices. Specifically, this research defines an array of potential targets, characterizes the atmospheric effects in varied weather conditions and climates on such a laser system, and contrasts the size, weight, and power requirements of such a system with the operating capabilities of existing UAV platforms.

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FEASIBILITY AND UTILITY OF AIRBORNE SOLID-STATE LASERS AGAINST GROUND ORDNANCE

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Captain, United States Army
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Submitted in partial fulfillment of the
requirements for the degree of

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LIST OF ACRONYMS AND ABBREVIATIONS

ABL	Airborne Laser
ALL	Airborne Laser Lab
ATL	Advanced Tactical Laser
AV	anti-vehicle
BCT	brigade combat team
EFP	explosively formed penetrator
GADS	Global Aerosol Data Set
HEAT	high explosive anti-tank
HEL	high energy laser
HMX	high melting explosive
IED	improvised explosive device
LaWS	Laser Weapon System
LEEDR	Laser Environmental Effects Definition and Reference
MIRACL	Mid-IR Advanced Chemical Laser
MTHEL	Mobile Tactical High Energy Laser
NACL	Navy ARPA Chemical Laser
Nd:YAG	neodymium yttrium aluminum garnet
RDX	research department explosive
SBL	Space Based Laser
SWaP	size, weight, and power
THEL	Tactical High Energy Laser
TNT	trinitrotoluene
TOW	tube-launched optically-tracked wire-guided
UAV	unmanned aerial vehicle
UXO	unexploded ordnance

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I. INTRODUCTION

Explosive devices are among the most effective obstacles to ground maneuver in combat. Properly placed, these devices can inflict casualties, deny terrain, steal operational tempo, and threaten civilian populations. According to figures in 2008, approximately 70% of the then 4,163 U.S. combat deaths in Iraq since the start of the war in 2003 were due to roadside bombs [1]. Their proliferation and successes over the past decade ensure that improvised explosive devices (IEDs), land mines, and unexploded ordnance (UXO) remain a threat in future U.S. Army operating environments.

A. GROUND ORDNANCE THREATS

Relative to the weapons used in modern armed forces, IEDs are cheaply produced and readily available to insurgent or terrorist organizations. A bomb maker might expend less than $100 for an IED capable of destroying a light vehicle as compared to more than $100,000 for a conventional U.S. precision munition [2]. Simply put, organizations that employ IEDs are obtaining a comparable tactical effect for a fraction of what the U.S. government pays per application, and they are doing so without the billions of dollars poured into the acquisition and production of new weapon systems.

Land mines and UXO have a detrimental effect on both combat operations and civilian populations. Like IEDs, these munitions excel in the counter-mobility role against ground forces. However, once they have been bypassed, land mines and UXO still present a significant threat to civilian populations in the vicinity. As of 2003, Soviet land mines from the war in Afghanistan that ended in 1989 still inflicted approximately 300 civilian casualties per month [3]. Unfortunately, even modern armed forces continue to leave behind these dangerous explosives due to limited disposal assets and competing priorities. Apart from the broader humanitarian argument, this threat presents a more immediate challenge to the U.S. Army if the mission specifically entails protection of the civilian population.

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B. CURRENT REMOVAL METHODS

Ground-based explosive devices are undoubtedly a problem that the U.S. Army needs to solve safely, effectively, and cheaply in order to be successful on future battlefields. Current removal methods rely on the use of highly specialized units and equipment that may not always be available and are expensive to field. Directed energy is a potential solution to the threat posed by these devices. The Department of Defense recognized the utility of lasers on the battlefield as far back as the 1960s [2] and has since committed funding to multiple projects as a means of combatting a variety of threats to friendly forces.

C. POTENTIAL ADVANTAGES OF DIRECTED ENERGY EMPLOYMENT

In 2004 the U.S. Army demonstrated that in-flight mortar rounds can be destroyed using a ground-based high energy laser. The Mobile Tactical High Energy Laser (MTHEL) destroyed seven medium in-flight mortars during testing, which included a three-round salvo [4]. In 2008 the U.S. Special Operations Command mounted a 100 kW laser on an AC-130 gunship and dubbed it the Advanced Tactical Laser (ATL). The ATL was intended to function as a direct fire weapon against ground targets, which included a remotely controlled vehicle in one particularly successful test [5]. Finally, in 2010 the U.S. Air Force succeeded in destroying an in-flight ballistic missile using the Airborne Laser (ABL), a megawatt-class laser mounted inside a Boeing 747 [5] (Figure 1).

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Figure 1. YAL-1A Airborne Laser. Source: [6].

Although the MTHEL, ATL, and ABL were successful during testing in ideal conditions, all three projects were cancelled for the same general reasons. Each system utilized a large chemical laser that, aside from the massive size (the MTHEL required several oversized trailers to move across the battlefield [5]), required the transportation, storage, and handling of dangerous and expensive chemicals. Additionally, each project was built on the assumption that the laser would be in the right location at the right time to strike a fast moving target. In the case of the ABL, five to seven Boeing 747s would have to maintain a presence near a missile launch site for a successful interdiction [5]. Such a quantity of large, slow aircraft loitering over enemy controlled territory would be an irresistibly attractive target. In order for directed energy to be successful in tactical engagements, lasers must be smaller, logistically simple, and mobile.

This study models the use of solid-state lasers mounted on unmanned aerial vehicles (UAVs) against surface-laid ground ordnance. Solid-state lasers operate by electricity instead of chemical reactions and are generally much smaller than chemical lasers. Current solid-state lasers also produce much less optical output power than their chemical relatives, but this may be offset by the intended application. While the MTHEL, ATL, and ABL required high irradiance over a short dwell time to be successful, a solid-state laser that targets ground ordnance has the luxury of an extended engagement period

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since IEDs, land mines, and UXO don't move. Additionally, the explosives used in these potential targets self-ignite at temperatures of a few hundred kelvins; this is considerably lower than the temperatures needed for other target types (e.g., to melt through missile casings). Thus, the irradiance, and consequentially the output power, of the laser can be reduced while still achieving the desired effect.

UAVs are ideal platforms for destroying ground ordnance with solid-state lasers. Currently, a brigade combat team (BCT) in the U.S. Army fields four RQ-7B Shadow UAVs that are intended to provide 24-hour geographic coverage for that BCT's area of operations. The availability of UAVs only increases at each higher echelon, with the MQ-1C Gray Eagle (Figure 2) fielded at the division-level. This means that there is a persistent and flexible UAV presence within every area of operations that could potentially put a laser at the right location and time to be effective against the ground ordnance threat. Additionally, UAVs have a large stand-off distance from ground targets that eliminates the need to put soldiers or expensive equipment within the blast radius of said ground ordnance. The challenge for using UAVs in this intended application lies in the fact that all of these platforms have limited capacity for the size, weight, and power (SWaP) requirements inherent to solid-state lasers.



Figure 2. MQ-1C Gray Eagle. Source: [7].

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Aside from the engineering challenges associated with mounting lasers on UAVs, an air-to-ground directed energy system must consider atmospheric propagation effects such as diffraction, scattering, absorption, and turbulence [2]. Consequentially, the required beam output power must be designed to overcome these effects and cross the lethal fluence threshold at the target.

D. OVERVIEW OF STUDY

This study identifies the energetic compounds used in common IEDs, surface-laid land mines, and pieces of UXO in order to estimate the lethal fluence needed for these compounds. Based on this information, the study then estimates the laser power needed to achieve the lethal fluences over acceptable dwell times for various atmospheric conditions. Finally, the study discusses the feasibility of using solid-state lasers against ground ordnance based upon SWaP considerations and UAV platform availability.

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II. OVERVIEW OF DIRECTED ENERGY WEAPONS

As it is applied to weaponry, the term “directed energy” can have a multitude of meanings. For example, the deposition of energy on a target can be accomplished through the use of microwaves, particle beams, or high energy lasers (HELs). However, for directed energy weapons to be effective, the delivery method, target parameters, platform allowances, and propagation medium must be such that the desired result on the target is achieved. HELs are currently a highly active subject of study for defense applications and will be the focus for this research due to their relative advantages over other types of directed energy weapons.

A. HISTORY

The development of HELs as weapons began almost immediately following the invention of the first laser in 1960. The Soviet Union started researching the feasibility of HELs defeating intercontinental ballistic missiles during their reentry phase in 1965, going so far as establishing a town of 20,000 people at Raduga to conduct research and testing [8]. The United States followed when Ed Gerry created a gas dynamic CO2 laser with an output power of 100 kW in 1968 [8]. Each branch of the armed forces began funding their own projects tailored for their specific requirements.

The next major advancement came from the U.S. Navy with the creation of the Navy ARPA Chemical Laser (NACL), which was a multi-hundred kilowatt-class chemical laser. The NACL successfully destroyed tube-launched optically-tracked wire-guided (TOW) missiles in-flight in 1978 and led to the development of the Mid-IR Advanced Chemical Laser (MIRACL) in 1980, which was the world’s first megawatt-class laser [9]. However, chemical lasers are not ideal for ship-based applications due to the fuels required and exhaust they create. Additionally, the less-than-ideal output wavelength produced by these lasers were prone to atmospheric absorption, which resulted in decreased irradiance at the target and thermal blooming. These factors contributed to a hiatus in Navy HEL design until a suitable alternative with comparable power outputs could be developed. In 2014, the 30 kW AN/SEQ-3 Laser Weapon System (LaWS) (Figure 3) was installed on

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the USS *Ponce* and successfully demonstrated the ability to destroy small boats and UAVs [10]. The LaWS is a solid-state system that circumvents the challenges of chemical lasers at the expense of an output that is lower by at least an order of magnitude.



Figure 3. LaWS Onboard the USS *Ponce*. Source: [11].

The U.S. Air Force created the Airborne Laser Lab (ALL) with a 100 kW class gas dynamic laser mounted in a KC-135 aircraft, which succeeded in destroying AIM-9 missiles and BQM-34 drones during testing in 1983 [8]. Due to the relatively low electrical power requirements of chemical lasers, this type of system was the basis of the Space Based Laser (SBL) program that began in 1989 with the purpose of defeating ICBMs in their boost phase. The program intended to conduct a successful demonstration by 2012 [9], but was cancelled in 1991 [8]. Building on the successes of the ALL and prompted by the cancellation of the SBL, the Air Force began work on the ABL program in 1994, which incorporated a megawatt class laser in a Boeing 747 [8]. As mentioned in the previous chapter, the ABL was successful during testing in its intended purpose of destroying ballistic missiles in the boost phase, but the requirement of putting the laser within range of a target and program costs led to its cancellation.

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Meanwhile, the U.S. Army took an interest in using ground-based HELs to counter indirect fire. Research for the Tactical High Energy Laser (THEL) began in 1996 as a joint venture between the United States and Israel as a means to interdict Katyusha rockets [9]. The THEL achieved successes in testing against rockets in 2000 and against mortar rounds in 2004, but proved too expensive and unwieldy on the battlefield. The THEL and its offshoot, the MTHEL, were cancelled due to a lack of available funding. Although the Army lost interest in the THEL and MTHEL, it did not lose interest in ground-based HEL applications and by March 2003 deployed the Zeus HMMWV Laser Ordnance Neutralization System (Figure 4) to Afghanistan to assist with UXO removal [12]. That version of the Zeus incorporated a 500 W neodymium yttrium aluminum garnet (Nd:YAG) solid-state laser [9] with an effective range of 300 meters [12]. During its six-month deployment to Bagram Air Field, the Zeus negated over 200 pieces UXO, including a record-breaking 51 pieces of UXO in less than 100 minutes [12]. The performance of the Zeus demonstrated the feasibility of using a HEL to destroy ground ordnance.



Figure 4. Zeus HMMWV Laser Ordnance Neutralization System. Source: [13].

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Nearly 60 years of HEL design and testing revealed several lessons regarding their use as weapons. Although chemical and gas lasers are capable of achieving higher output powers at relatively better efficiencies, they are also unwieldy, if not downright dangerous to the user in battlefield applications. Solid-state lasers are currently receiving the most attention due to innovations that have increased their power output, their safer electrical "fuel," and their ideal wavelength for atmospheric propagation. This research will focus primarily on solid-state systems due to these reasons, especially considering the projected application of using them onboard UAVs. As the Zeus device demonstrated, only modest output power is needed to affect the desired result against ground ordnance.

B. ADVANTAGES AND DISADVANTAGES

Solid-state HELs have numerous advantages when compared to conventional ballistic weapons. Perhaps the most significant is that the beam propagates at the speed of light. The next major advantage of HELs is the cost per engagement associated with using the weapon. Ballistic munitions are expensive and only available in limited quantities; armored vehicles, aircraft, and ships can only carry a finite number of rounds, bombs, or missiles. On the other hand, lasers only cost the fuel required to generate electricity for each engagement; a typical cost of less than a dollar compared to thousands of dollars for conventional munitions. Finally, HELs can generally outrange conventional line-of-sight munitions if the laser is designed to overcome the effects of scattering and absorption that lead to beam extinction.

Solid-state HELs do come with some inherent disadvantages that have so far prevented their widespread deployment. Compared to ballistic munitions and chemical or gas lasers, solid-state HELs are inefficient. The typical "wall-plug" efficiency for solid-state systems is on the order of 20% to 30%, which necessitates an electrical power source capable of providing hundreds of kilowatts for each engagement. This inefficiency leads to heat generation in the lasing medium that must be actively removed. Cooling systems that can effectively dissipate the heat add additional power and weight requirements. Additionally, any HEL system is more susceptible to atmospheric effects, such as precipitation and haze, than conventional ballistic munitions. Since the defeat mechanism

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employed by HELs typically involves heating of the target, a laser must also overcome the energy loss resulting from light reflected by the target's surface.

Considering the objective of this research, airborne HELs are an attractive option for defeating explosive devices. If explosive ordnance disposal (EOD) personnel decide that a device can be rendered ineffective in-situ, there are a variety of methods available that include disruptors, anti-munition rifles, de-armers, explosives, fuze removal, or fuze immunization [14]. All of these options require deployment of EOD teams and potentially place these specially trained personnel at risk (Figure 5). Simply the loss of time incurred by friendly forces is often enough to justify the emplacement of explosive devices by the enemy. By requiring friendly forces to adjust from a proactive posture to a reactive one, an enemy that employs these devices steals the tactical initiative. Conversely, HELs (particularly airborne systems) enable the discoverer of an explosive device to act expeditiously and with pinpoint precision. Barring prohibitive weather conditions, UAVs continuously occupy the airspace of a U.S. Army unit's area of operations. The operational cost in time incurred by a friendly unit that encounters an explosive device could potentially be cut from hours (waiting on an EOD team or combat engineers to arrive) to minutes (the time it takes to direct an already airborne clearance asset to the location). This is not to say that using airborne HELs to dispose of explosive devices completely negates the need to have EOD assets available; weather occasionally grounds UAVs, disposing of a device in-situ is not always a possibility, and it is likely infeasible to use a HEL to defeat buried devices. However, it does provide another option for ground commanders to leverage based on the merits of the tactical situation.

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Figure 5. EOD Personnel Train to Dispose of an IED. Source: [15].

C. PROJECTED APPLICATIONS

HEL systems have demonstrated success in testing and limited field deployments, and the next generation of these weapons are currently in the design phase. The Navy established their Directed Energy Program Office within the Program Executive Office for Integrated Warfare Systems in August 2016 [16]. In a February 2017 Federal Business Opportunities posting, this office requested industry capabilities for a new program that consists of a 60 kW HEL with counter-ISR dazzling capability and is capable of operating on an Arleigh Burke-class guided missile destroyer [16]. The Air Force is currently funding a demonstration called SHIELD, which intends to integrate a solid-state HEL with an output power in the tens of kilowatts range on a fighter-size aircraft by 2020 [17]. The Army is investing in its High Energy Laser Mobile Demonstrator, a ground-based system primarily intended to counter indirect fire and UAVs and is capable of being transported by a relatively small armored vehicle such as a Stryker personnel carrier [18]. All of these projects underline the increased interest in HEL weapons, particularly solid-state systems, and the great advances that have been made in HELs since the first laser was invented in 1960.

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III. CHARACTERIZATION OF HIGH EXPLOSIVE TARGETS

Land mines, UXO, IEDs, and most other high explosive devices share the same basic components and principles of operation. It is this similarity that enables a single clearing system, such as a HEL, to be effective against a wide range of potential threats. Accordingly, three different explosive devices serve as target profiles for this research: the TM-83 anti-vehicle (AV) land mine, the PTAB-2.5M high explosive anti-tank (HEAT) sub-munition, and a Composition C-4 based IED. These devices were selected due to how well they characterize each category of munition (surface-laid land mine, UXO, and IED, respectively), current usage, and variety in construction and materials. This chapter will describe the fundamental components of high explosive devices and will detail the defeat mechanism selected for their removal using a HEL.

A. COMPOSITION

Explosive devices generally consist of four basic components; the detonator, the booster charge, the main charge, and the casing. The detonator is the component that triggers a detonation and can come in many forms. Conventional munitions such as bombs and artillery shells that are commonly found as UXO contain a fuze or a timer for this purpose. Land mines and IEDs make use of switches, sensors, wired detonators, or wireless receivers (Figure 6). Regardless of the form, the detonator is ultimately what initiates an explosive reaction in the booster charge.

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Figure 6. IEDs Captured in Afghanistan with Detonators Mounted on Top. Source: [19].

Booster charges are an intermediary material between the detonator and the main charge. Detonators usually do not provide enough energy to trigger an explosive reaction in the most common types of high explosives, so a less stable explosive is used to create a shock wave that will detonate the main charge. The main charge is what gives a device its explosive power and is usually the largest internal component (Figure 7). Common military-grade explosives used for main charges include trinitrotoluene (TNT), research department explosive (RDX), and high melting explosive (HMX). Perhaps the most commonly used combination of these explosives is Composition B-3, which is a 60% RDX and 40% TNT mixture [20].

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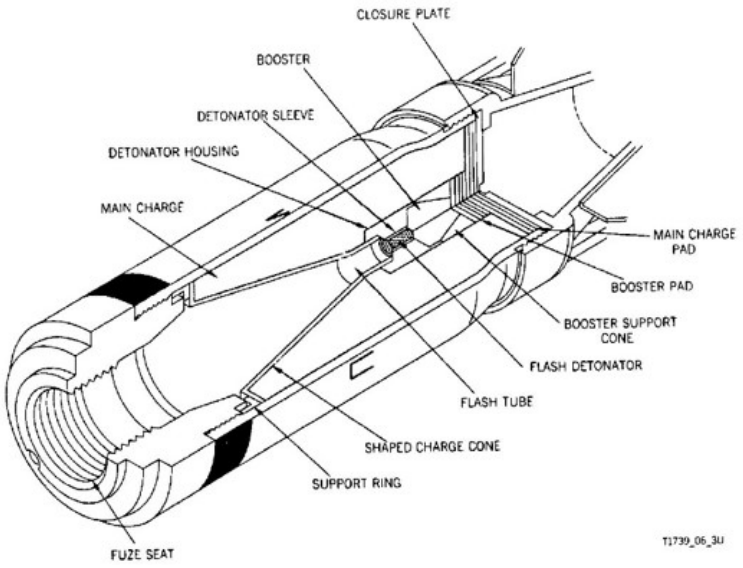


Figure 7. Cross-sectional Diagram of a PTAB-2.5M HEAT Sub-munition Depicting Booster and Main Charges. Source: [21].

The final basic component found in most explosive devices is the casing. The number of combinations of materials, shapes, and fragmentation patterns found in casings is effectively limitless. Metal casings provide durability and double as shrapnel when the device detonates, but are easier to detect with the magnetic scanners commonly employed by clearing assets. Conversely, plastic casings are difficult to detect, but require more care during handling and must be filled with some form of shrapnel to maximize effectiveness. Of particular note is the modern use of the explosively formed penetrator (EFP), which is a circular concave piece of malleable metal (usually copper) that is mounted over the main charge. Upon detonation, the explosive forces reshape the metal into a molten dart-like projectile capable of penetrating most types of armor. The TM-83 AV land mine is an example of a device that produces an EFP (Figure 8).

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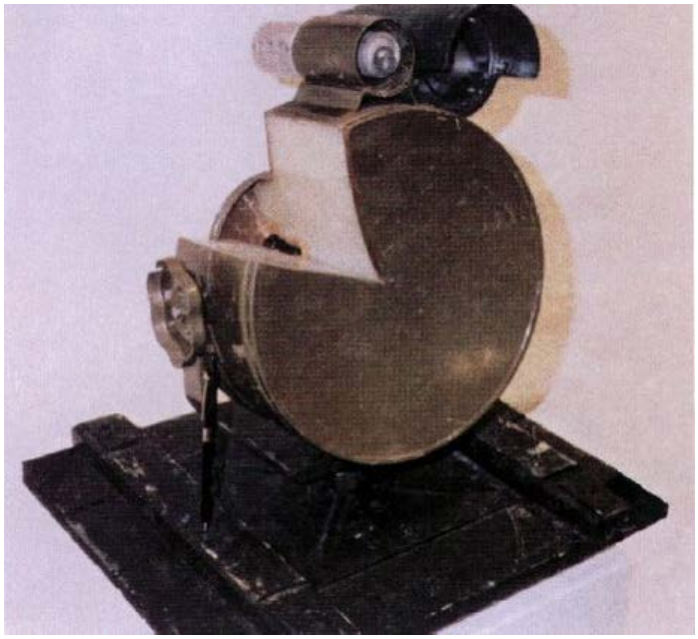


Figure 8. TM-83 AV Land Mine with Triangular Cutout Exposing Main Charge. Source: [22].

B. HIGH EXPLOSIVE PROPERTIES

The potential energy of an explosive material is analogous to a boulder resting on the edge of a cliff [23]. Initially, a great deal of energy is expended to move the boulder to this position. For explosives, this is referred to as the heat of formation. Once the boulder is at the edge, only a slight nudge is required to push it over and expend the high potential energy stored within. Accordingly, this nudge is known as the activation energy. The relatively rapid expenditure of energy during this detonation is what differentiates explosives from other high-energy materials such as wood, coal, or oil. In the case of coal versus HMX, the power output is a difference of nine orders of magnitude [23].

In this research, the "nudge" is the defeat mechanism used to destroy the designated targets. The HEL acts as an energy pump by depositing a portion of its energy in the form of heat on the surface of the target (the rest of its energy is reflected depending on the surface material). As the HEL deposits more energy over time, the temperature of the casing rises as heat diffuses through it and ultimately reaches the main charge contained

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within. The heat transfer in both the casing and main charge is easily modeled with the well-known heat diffusion equation:

$$\rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (\kappa \nabla T) \tag{1}$$

where ρ is the density of the casing or main charge, c_p is the specific heat capacity, T is the temperature, and κ is the thermal conductivity. Once the interface between the casing and main charge reaches an explosive property known as the autoignition temperature, the main charge will begin expending its potential energy in a manner similar to the falling boulder. While this mechanism will not produce a full detonation, it will render the explosive device ineffective by forcing the main charge to deflagrate [24]. This removal method can actually be more favorable than full detonation if the explosive device is located in close proximity to valuable infrastructure or populated areas.

C. EFFECT OF HEATING

As heat deposited by the laser beam accumulates at the interface between the casing and the main charge, the explosive material will undergo a chemical reaction and release its stored potential energy in the form of additional heat. The rate at which the explosive releases heat as it undergoes the chemical reaction is known as the thermal rate constant. While the constant is initially a relatively small value, it will grow exponentially as the heat deposited by the HEL combines with the accumulating heat emitted by the explosive. The empirical Arrhenius Law is probably the oldest yet best-known model for expressing this thermal rate constant *k(T)* [25]:

$$k(T) = Ae^{-\frac{E}{k_B T}} \tag{2}$$

where A is a pre-exponential constant, E is the activation energy, k_B is the Boltzmann constant, and T is the temperature of the explosive material. The pre-exponential constant is unique to a given chemical reaction and is often determined experimentally with units similar to the thermal rate constant (with magnitude typically on the order of 10^{10}) [26]. When the temperature is low, this pre-exponential factor is suppressed. However, as the temperature of the explosive rises relative to its activation energy, the extremely large pre-exponential factor causes the thermal rate constant to increase dramatically. The complete

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model for predicting heat transfer in an explosive material is a combination of both the heat diffusion equation (Equation 1) and the Arrhenius Law (Equation 2) and appears as:

$$\rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (\kappa \nabla T) + \rho Q Z e^{-\frac{E}{k_B T}} \tag{3}$$

where Q is the heat of decomposition and Z is the characteristic reaction rate of the explosive [27]. The product of the explosive's density, heat of decomposition, and characteristic reaction rate is the pre-exponential constant A annotated in Equation 2. The Arrhenius term acts as a heat source in the heat diffusion equation. Once the temperature T reaches the autoignition temperature, the Arrhenius term dominates and acts as a "positive feedback loop," producing a "run-away" reaction. The predicted autoignition temperature for Composition B-3 is approximately 800-K [20], while the predicted value for Composition C-4 is approximately 650-K [20].

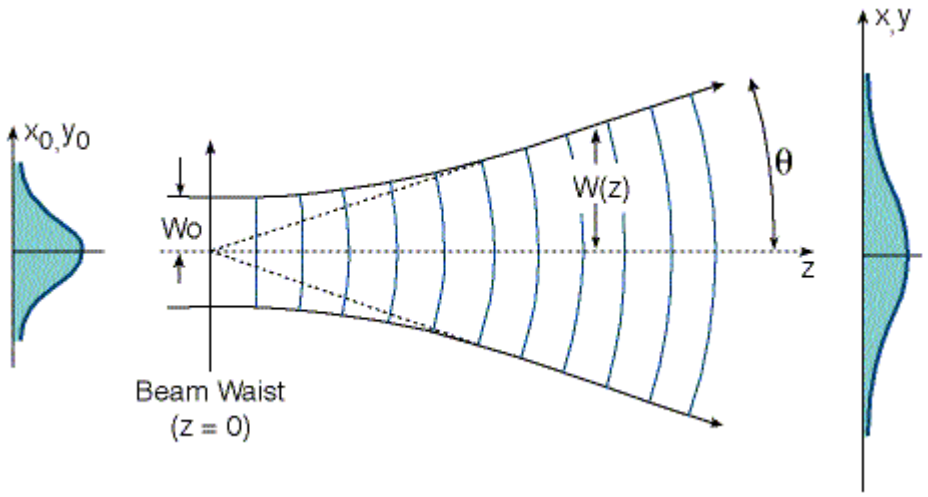
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IV. LASER BEAM PROPAGATION THROUGH THE ATMOSPHERE

The environment through which a laser beam propagates can dramatically affect the beam's properties from origin to termination. The Earth's atmosphere is full of molecules and particles that can influence a laser beam, and this fact must be accounted for in any system that intends to propagate over a meaningful distance. This chapter will describe those effects as well as their impact on an airborne laser system engaging ground-based targets.

A. VACUUM PROPAGATION

Before considering the effects of atmosphere on beam propagation, it is first necessary to understand how a beam propagates under ideal conditions. Due to the wave nature of light, any light source directed through an aperture will experience divergence. This will cause the radius of the beam, known as the beam waist, to increase in accordance with the divergence angle (Figure 9).



The divergence angle is represented by θ. Note the Gaussian profiles in the margins depicting the decrease in beam irradiance as propagation distance increases.

Figure 9. Beam Waist *w* as a Function of Propagation Distance *z*. Source: [28].

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The beam waist size, divergence angle, and beam wavelength determine the quality of the laser beam. This parameter is known as the beam quality factor and is calculated with the equation:

$$M^2 = \frac{w_0 \pi \theta}{4\lambda} \tag{4}$$

where M^2 is the beam quality factor, w_0 is the beam waist size, θ is the divergence angle, and λ is the beam wavelength [29]. A beam quality factor of 1 indicates an ideal Gaussian irradiance profile. However, current lasers are not perfect and will produce beams with a factor greater than 1. The greater the value of the beam quality factor, the less irradiant the laser beam will be at the target. For this research, a beam quality factor of 3 is used for simulations in order to produce more realistic results.

The size of the laser beam director itself can also significantly impact the qualities of the beam. The effect of beam director diameter on beam waist can be approximated with the equation:

$$w_0 \approx M^2 \left(\frac{2\lambda z}{\pi D} \right) \tag{5}$$

where w_0 is the beam waist size, M^2 is the beam quality factor, λ is the beam wavelength, z is the propagation distance, and D is the beam director diameter [30]. As the beam director diameter increases, the beam waist will decrease and produce a more irradiant beam profile at the target. However, regarding the use of lasers on airborne platforms, it is necessary to keep the beam director as small as possible due to limited space availability and payload capacity. In these simulations, the beam director diameter is set at 25 cm in order to accurately represent a system capable of being mounted to a UAV.

B. EXTINCTION

Atmospheric extinction of a laser beam is the result of two separate phenomena. The first of these is absorption, in which atmospheric molecules and aerosol particles absorb incoming photons and thereby decrease the irradiance of the laser beam. Absorption is dependent on the wavelength of the photons and the types of particles present. Since Earth's atmosphere is composed of numerous varieties of molecules and particles, there are only a few narrow wavelength bands that are favorable for beam propagation. Many

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solid-state lasers currently designed for directed energy applications have wavelengths near 1 μm, which is within a "window" in which light propagates with minimal absorption.

The second effect that causes beam extinction is scattering. Particles in the atmosphere with sizes comparable to the wavelength of light will deflect light rays in random directions. This effect is evident in white clouds, in which water vapor scatters incident light with wavelengths across the visible spectrum. Particles generated as dust or by pollution also scatter light, resulting in a hazy atmosphere (Figure 10).



Figure 10. Haze Created by Atmospheric Scattering of Light by Aerosol Particles. Source: [31].

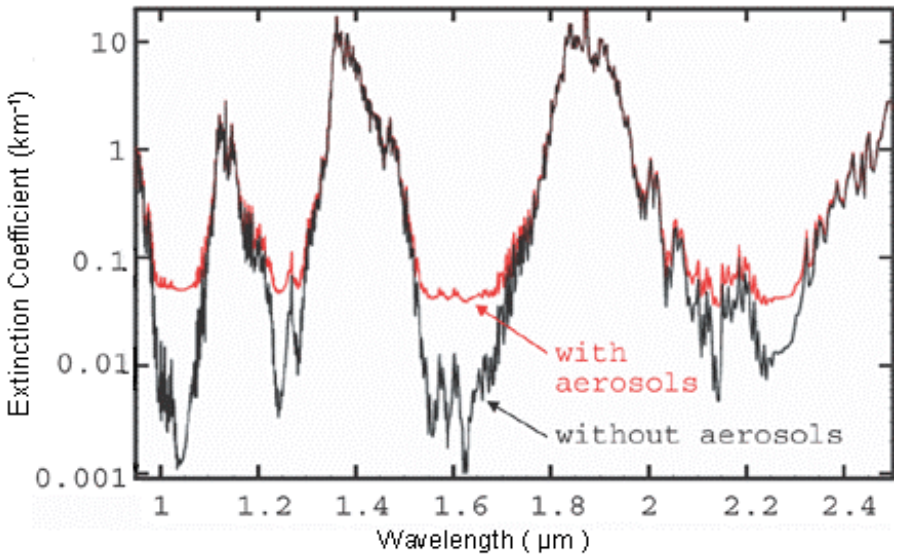
Laser beam extinction is modeled as an exponential decay. The Beer-Lambert Law provides the mathematical foundation with the function:

$$P(z) = P_0 e^{-\varepsilon z} \tag{6}$$

where *P(z)* is the beam's power as a function of propagation distance, *z* is the propagation distance, P_0 is the initial power, and ε is an extinction coefficient that accounts for wavelength-specific scattering and absorption information and also depends on location, time of day, aerosol concentration, etc. [32]. For the intended application of defeating explosive devices, the extinction coefficient must be as small as feasible, which is largely

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accomplished by selecting a beam wavelength of approximately 1 μm that tends to minimize extinction (Figure 11).



The red plot includes the presence of aerosols. Note the relatively low extinction coefficient values at approximately 1 μm and 1.6 μm.

Figure 11. Effect of Wavelength on Beam Extinction. Source: [33].

C. TURBULENCE

As the sun's radiation heats the atmosphere and Earth's surface, it creates differences in air temperature. Accordingly, these cells of air have different densities and pressure that alter their optical indices of refraction. When a light ray transmits between different cells, variations in the indices of refraction cause the light ray to deflect. In addition to this deflection, turbulent cells that are smaller than the laser beam's cross-sectional area will cause portions of the beam to diverge. This divergence results in a loss of coherence, as portions of the beam become out of phase and destructively interfere with each other. The ultimate consequence of turbulence is a distorted, larger, and less intense time-averaged beam spot on the target.

Turbulence is quantified by the refraction structure parameter C_n^2, which is a measure of the change in the air's index of refraction over distance:

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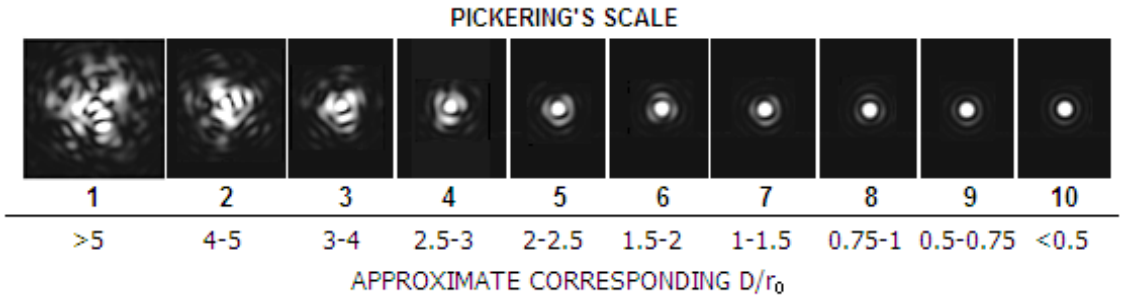
$$C_n^2 = \frac{\overline{[n(x) - n(x+r)]^2}}{r^{2/3}} \quad (7)$$

where *n(x)* is the index of refraction and *n(x+r)* is the index of refraction at range *r* [34]. A value of 10^{-14} $m^{-2/3}$ indicates stronger turbulence, while a value of 10^{-17} $m^{-2/3}$ indicates weaker turbulence.

The refraction structure parameter is of little analytical value by itself, but can be used to estimate the effect of turbulence on beam coherence at the target. The Fried parameter is an estimation of the diameter over which a laser beam maintains transverse coherence throughout a desired propagation distance:

$$r_0 = [0.423(2\pi / \lambda)^2 \int_0^z C_n^2(z)dz]^{-3/5} \quad (8)$$

where r_0 is the Fried parameter, λ is the wavelength, and z is the propagation distance [32]. This formula incorporates C_n^2 along the beam path. As the value of C_n^2 increases, the value of the Fried parameter decreases. For example, given a beam wavelength of 1 μm, a constant C_n^2 value of 10^{-14} $m^{-2/3}$, and a propagation distance of 3 km, the Fried parameter would be approximately 2.4 cm. Under these conditions, any laser beam that is greater than 2.4 cm at its source (established by the beam director diameter) will be significantly affected by turbulence (Figure 12).



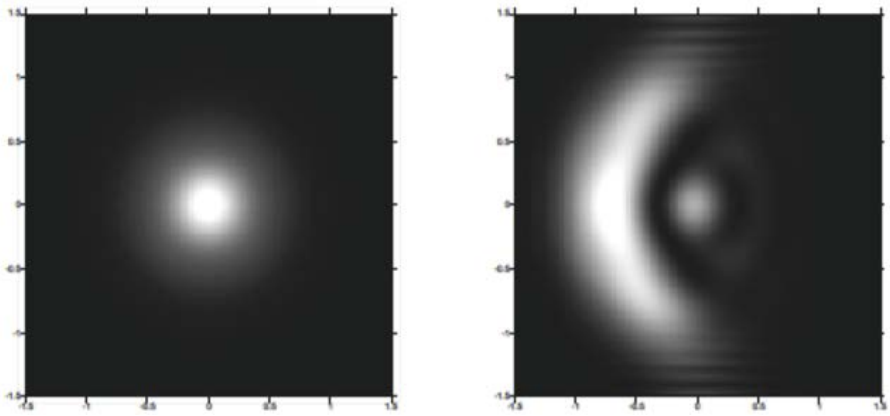
Pickering's scale provides a visual approximation of the relationship between the Fried parameter and beam director diameter (denoted as *D*). Each scale number corresponds to a representation of a beam cross-sectional area. As D/r_0 becomes greater than 1, the beam's area will increase and break apart.

Figure 12. Pickering's Scale. Source: [35].

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D. THERMAL BLOOMING

A laser beam itself can modify the properties of the air it is propagating through. As photons are absorbed by aerosols and molecules along the beam path, energy is released in the form of heat. This heat in turn alters the air's index of refraction by causing the air to expand and become less dense. As the beam continues to propagate through this modified air, it will begin to diverge more quickly than would otherwise be expected via this thermal blooming process [32]. This phenomenon is highly susceptible to temperature-altering effects such as wind. If wind blows across a beam path that is experiencing thermal blooming, it will cool the incident side of the beam and push heated air to the opposite side. The beam will then "bend" into the cooler, and therefore denser, side of the "lens" (Figure 13).



The image on the left depicts a beam profile without wind, while the image on the right depicts beam "bending" caused by a wind blowing from left to right.

Figure 13. Effect of Wind on Thermal Blooming. Source: [36].

Thermal blooming is roughly characterized through a dimensionless thermal distortion factor, N_t:

$$N_t = \frac{-(dn/dT)}{n\rho c_p} \times \frac{KIz^2}{vr} \tag{9}$$

where n is the air's index of refraction, (dn/dT) is the rate of change in the index of refraction as a result of temperature change, ρ is the air's density, c_p is the heat capacity of

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the air, *K* is the absorption coefficient of the air, *I* is the laser beam's irradiance without thermal blooming, *z* is the distance of propagation, *r* is the beam's radius, and *v* is the crosswind's speed [32]. A larger thermal distortion factor indicates greater beam distortion and decreased intensity at the target. If the crosswind speed or beam radius increase, the thermal distortion number will decrease. However, increasing beam irradiance or propagation distance has the unwanted effect of increasing the thermal distortion number. Figure 14 depicts the effect that the thermal distortion number has on the relative intensity of the laser beam.

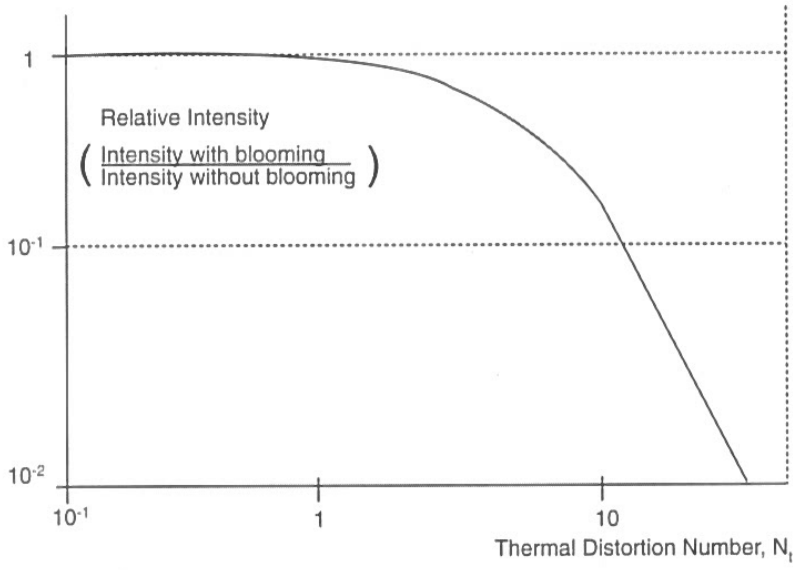


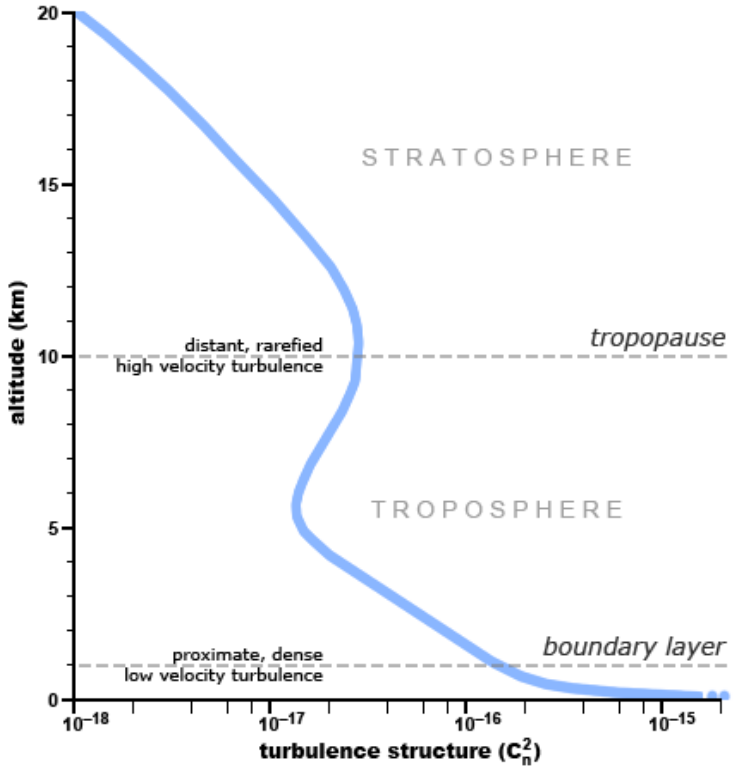
Figure 14. Relationship between Thermal Distortion Number and Relative Intensity. Source: [32].

E. ELEVATION EFFECTS

Using a HEL on an airborne platform to engage ground-based targets has several advantages relative to ground-based lasers. Turbulence is often dramatically reduced at elevation since the platform is further from the ground, and consequently, further from heat sources and surface effects (Figure 15). Although the laser beam is still required to propagate through low-altitude atmosphere as it nears the target, the path over which turbulence is a factor is greatly diminished and restricted to the terminal portion. A ground-

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based laser beam must suffer the effect over its entire path, including at the beam's origin where it has the greatest effect on the rest of propagation.



Smaller UAVs operate at lower altitude (approximately 2 km) while larger UAVs operate at higher altitude (between 15 km and 18 km).

Figure 15. Effect of Altitude on Atmospheric Turbulence. Source: [37].

Additionally, air density decreases with altitude, which exponentially decreases absorption and increases beam irradiance at the target. The desire to use UAVs as the airborne platform of choice in this research also introduces an advantage regarding thermal blooming. All UAVs currently employed by the U.S. Army are fixed wing aircraft that cannot remain stationary in flight. This means that any laser beam originating from a UAV platform will constantly be moving through unheated air and experience a relative wind proportional to the velocity of the UAV itself. These two factors effectively eliminate thermal blooming as a consideration for the intended application of this research.

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V. METHODOLOGY

This research simulates air-to-ground laser engagements of ground ordnance using computer-based MATLAB code with user-defined parameters. This chapter will address the variety of parameters used and the reasons for their selection. It will also identify existing simulations used, upon which this research is partially based.

A. TARGET PARAMETERS

Three different types of ground ordnance are modeled in this research: a land mine, IED, and piece of UXO. While it would be impossible to model every explosive device currently in use, the established target profiles emphasize generalized distinctions between the three types. The fundamental differences between these categories are target geometry, outer casing, and explosive material.

1. Geometry

All three types of target have myriad geometries available to choose from. However, the problem can be simplified when approached from the context of this research. Any laser beam intentionally aimed at an object of known range will be deliberately focused in order to reduce its effective area on the target. This focus spot acts as a source term for the heat diffusion equation previously mentioned in Chapter III (Equation 1). The profile of the laser beam is assumed to be a Gaussian distribution modeled by the equation:

$$S = I_{pk}(1-R)e^{-\frac{r^2}{w_{tot}^2}} \tag{10}$$

where S is the source term for the heat diffusion equation, I_{pk} is the peak irradiance of the laser beam, R is the reflectivity coefficient of the target's surface, r is the radial coordinate of the profile, and w_{tot} is the beam waist size. For these simulations, the reflectivity coefficient is assumed to have a value of 0.1, since most explosive devices are intentionally coated in dark non-reflective materials that conceal them within surroundings.

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Ideally, the beam waist is minimized at the target due to focusing (although this can be affected by atmospheric conditions). As a characteristic example, the circular face of the TM-83 AV land mine has a radius of 12.5 cm, with a surface area of approximately 490 cm^2 [22]. Assuming that a typical laser beam has a waist of 3 cm at the target and a cross-sectional area of approximately 28 cm^2, it is reasonable to neglect the effect of geometry on the target's heating since the beam area constitutes less than 6% of the total irradiated surface. Therefore, a standard geometry is used for all three target types during simulations, which consists of a right circular cylinder of 10 cm radius and 10 cm height, with one circular surface being irradiated by the laser beam at its center.

2. Outer Casing

There is a wide variety of casing materials used in explosive devices, which principally reduces to the distinction of plastic versus metal. As previously discussed, metal casings provide for safer handling of the device and have the added effect of increasing shrapnel upon detonation. Steel is a commonly used metal for this purpose and is the material used in many military-grade munitions. Due to this fact, it is appropriate to select steel as the outer casing for the land mine and UXO target profiles, since both are characteristically employed by military forces. Since the thickness of these casings is highly variable between specific devices, a generalized thickness of 5 mm is used for the land mine profile, while a thickness of 2.5 mm is used for the UXO profile. As the casing material is the same in both of these profiles, the simulation results illustrate the effect that casing thickness has on the required dwell times.

Plastic casings are more difficult to detect on the battlefield and are readily available to amateur explosives manufacturers, such as the insurgents and terrorists that employ IEDs. Although IEDs can and have been encased with metal, high density polyethylene is used in this research as the outer casing for the IED profile in order to demonstrate the effect that casing material has on required dwell times. A generalized thickness of 5 mm is used for the IED profile in order to make it comparable to the steel-encased land mine profile, also of 5 mm thickness. Table 1 includes a comprehensive listing of the all outer casing thermal property values used during actual simulations.

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Table 1. Outer Casing Thermal Properties. Source [38].

Material	Density, ρ [kg/m^3]	Thermal Conductivity, κ [W/(m*K)]	Heat Capacity, c_p [J/(kg*K)]
Steel (Plain)	7854	60.5	434
Polyethylene (High Density)	959	0.43	2000

3. Explosive Material

Since World War II, RDX is one of the most commonly used components in military-grade high explosives. It is a majority ingredient found in several Composition A, B, and C mixtures widely used by U.S. armed forces (up to 98.5% in Composition A-3, 60% in Composition B-3, and 95% in Composition C-3) [20]. Its thermochemical properties are widely studied and publicized, making it a reasonable assumption that most professional and amateur military forces employ it or its derivatives to some extent. This fact makes it an ideal material to include in generalized models of all three target types, and the thermal property values needed to do so are included in Table 2. These parameters are discussed in the context of the heat diffusion equation in Chapter III (Equation 3).

Table 2. RDX Thermochemical Properties. Source [39].

Density, ρ [kg/m^3]	Thermal Conductivity, κ [W/(m*K)]	Heat Capacity, c_p [J/(kg*K)]	Heat of Decomposition, Q [MJ/kg]	Activation Energy, E [kJ/mol]	Characteristic Reaction Rate, Z [s^{-1}]
1800	0.29	2093	2.09	199	$10^{18.5}$

B. ATMOSPHERIC PARAMETERS

In order to establish the atmospheric conditions under which to conduct simulations, it is necessary to consider climate type and weather. Since the combination of these two factors result in a countless number of geographic locations to model, it is necessary to also consider the likelihood that a particular region could become the home of

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an armed conflict within the near future. Seoul, South Korea and Kandahar, Afghanistan provide highly contrasting climatic conditions with potential for continuing and future military operations. Seoul possesses a temperate climate [40], which is well distinguished from the arid desert climate of Kandahar [41]. The contrast provided by these locations demonstrates the effect that climate has on the required target dwell times.

With climates established, it is also necessary to specify the exact weather conditions under which the simulations will be performed. In order to exemplify the extremes under which engagements could occur, clear and precipitous weather conditions are modeled. Clear weather enables ideal laser beam propagation, while the presence of large water droplets models the most non-ideal condition under which to engage ground ordnance with a laser. As an intermediary, hazy weather conditions are modeled in order to demonstrate the effect of aerosols on the engagements. All regional atmospheric properties are acquired from the Laser Environmental Effects Definition and Reference (LEEDR) database created at the Air Force Institute of Technology.

C. LASER AND PLATFORM PARAMETERS

Bearing the combined effect of target and atmospheric parameters in mind, the laser and platform configuration is critical in achieving a successful simulated engagement. The four most important parameters in this regard are the laser beam quality, laser beam wavelength, platform altitude, and laser power output.

1. Laser Beam Quality and Wavelength

As previously discussed, laser beam quality has a significant impact on the beam's irradiance at the target. A beam quality factor of 3 is used in these simulations to model a realistic laser. Atmospheric absorption of laser energy is highly dependent on the laser's frequency. In order to minimize absorption, a lasing wavelength of 1.0642 μm is used in these simulations. While other wavelength "windows" exist that minimize absorption, 1 μm is a commonly used wavelength in a multitude of existing solid-state systems.

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2. Platform Altitude

The capabilities of the UAV platform are the driving factor in determining the altitude at which the laser will engage the target. Generally, the greater the size and power of a UAV, the greater its maximum operating altitude, or service ceiling, will be. The RQ-7B Shadow, which is the smallest UAV currently used that could potentially carry a laser system, typically operates at an altitude of 2.4 km to 3 km during the day [42]. Conversely, the RQ-4 Global Hawk, which is likely the largest current UAV that could be used in this capacity, has a service ceiling of over 18 km [43].

Since increasing altitude also increases the amount of atmosphere through which the laser beam must propagate, a minimal altitude is ideal for these simulations. Three different altitudes of 1 km, 4 km, and 7 km are considered in this research to provide a reasonable range of values that could accommodate any tactical concerns. While 7 km is certainly not a limit imposed by existing UAV platform capabilities, it is within the upper limit of altitudes that enable engagement dwell times to remain minimal, which is kept within 60 seconds in this research.

3. Laser Power Output

In order to use an airborne platform for these engagements, the laser system must be kept as compact as possible with regard to SWaP design considerations. This is especially significant when the proposed airborne platform is a UAV, which are typically far smaller and less powerful than their manned counterparts or ground-based platforms. Considering the material properties of the proposed targets and the propagation distances of the laser beam, a power output less than 2.5 kW would likely be insufficient to achieve the desired effect, especially at higher altitude and in non-ideal weather conditions.

Fiber lasers are currently a viable solid-state laser option for producing outputs in the kilowatt range while maintaining beam quality and minimizing weight. For example, IPG Photonics, which specializes in producing industrial cutting lasers, manufactures a 1 μm continuous wave ytterbium fiber system with a scalable power output of 1 kW to 10 kW that weighs less than 380 pounds [44]. Such a system would be ideal for providing the necessary power output while minimizing size and weight. Accordingly, this research

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considers the effects of a 2.5 kW, 5 kW, and 10 kW power output in order to explore a range of powers likely to be mounted onboard a UAV platform.

D. SIMULATION TOOLS

This research relies on a pair of simulation tools developed at renowned defense research institutions. This section will briefly expound on both the inputs and outputs required to incorporate these tools into the simulated engagements.

1. LEEDR

As mentioned, LEEDR is a database of atmospheric conditions that generates regional approximations for the light propagation coefficients discussed in Chapter IV. LEEDR enables the user to control the weather conditions at specified locations using preset values or averages unique to that particular location. For these simulations, regional weather monitoring stations known as "ExPERT" sites in LEEDR will be used. Incheon International Airport is the ExPERT site representative of Seoul, while Kandahar Air Base is the ExPERT site used for the city of Kandahar. With one exception, all weather profiles used are representative of summer weather conditions (July), with the ambient temperature taken as the daily average for that location. The one exception is the precipitous weather profile for Kandahar since southern Afghanistan typically only receives rain during the winter months, which LEEDR bases on average conditions in the month of January. Clear and hazy profiles utilize a relative humidity percentile setting of 50% (i.e., more humid than 50% of measured days, and so represents a typical humidity for that location in January or July). Precipitous profiles utilize a relative humidity percentile setting of 99%. The widely known Hufnagel-Valley model for turbulence [45] was applied to all profiles as well.

Clear weather profiles utilize a Global Aerosol Data Set (GADS) multiplier of 1, which simulates a typical aerosol concentration for that location. The clear weather profiles do not include any cloud or rain effects. Precipitous weather profiles utilize a GADS multiplier of 0.2, the addition of "moderate rain" (a LEEDR setting that corresponds to 12.5 mm per hour), and a cloud layer at 10 km altitude. While a cloud layer at this height is unrealistic, it enables the simulation to demonstrate the effect of rain throughout the path

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of propagation. Otherwise the extinction effect generated by a cloud layer would completely disrupt a laser beam and prevent target autoignition (this effectively makes any simulations performed at 4 km and 7 km platform altitude under precipitous conditions unrealistic and therefore irrelevant). Finally, hazy weather profiles utilize a GADS multiplier of 3, which simulates high aerosol concentration, and do not include any cloud or rain effects. See Table 3 and Table 4 for a complete listing of settings used to generate the LEEDR weather profiles.

Table 3. Seoul Weather Profile Settings.

Weather	Aerosol Model	Aerosol Multiplier	Rain	Season	Temp.	Relative Humidity Percentile
Clear	GADS	1	-	Summer	Daily Avg.	50%
Precipitation	GADS	0.2	12.5 mm per hour	Summer	Daily Avg.	99%
Haze	GADS	3	-	Summer	Daily Avg.	50%

Table 4. Kandahar Weather Profile Settings.

Weather	Aerosol Model	Aerosol Multiplier	Rain	Season	Temp.	Relative Humidity Percentile
Clear	GADS	1	-	Summer	Daily Avg.	50%
Precipitation	GADS	0.2	12.5 mm per hour	Winter	Daily Avg.	99%
Haze	GADS	3	-	Summer	Daily Avg.	50%

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2. ANCHOR

Developed at the Naval Postgraduate School, ANCHOR is a scaling code that simulates the effect of atmospheric propagation on a laser beam. Its inputs include the LEEDR weather profile, laser parameters, and platform conditions. Its outputs include the beam waist size and beam irradiance over an array of cross ranges defined by the user. ANCHOR is capable of modeling the effects of extinction, turbulence, and thermal blooming, although the thermal blooming capability is not used in these simulations for the reasons discussed in Chapter IV. For this research, ANCHOR is used as a preliminary simulation for each test case that provides the laser beam parameters at the target prior to and during heat diffusion.

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VI. RESULTS AND CONCLUSIONS

This chapter discusses the effect that each independent variable has on required dwell times based on results obtained through simulation. The chapter concludes by determining the capabilities of laser systems with different output powers and the potential for mounting them onboard different UAVs based on SWaP requirements.

A. EXTINCTION PROFILES

Climate and weather conditions dramatically alter the atmospheric effects on laser beam propagation. Specifically, the effects of beam extinction are increased from clear to hazy weather, and even further increased when accounting for the presence of precipitation. See Figure 16, Figure 17, and Figure 18 for LEEDR-generated data regarding the extinction coefficient of various weather types in Seoul, South Korea. For reference, see Table 3 and Table 4 for the settings used to generate these figures.

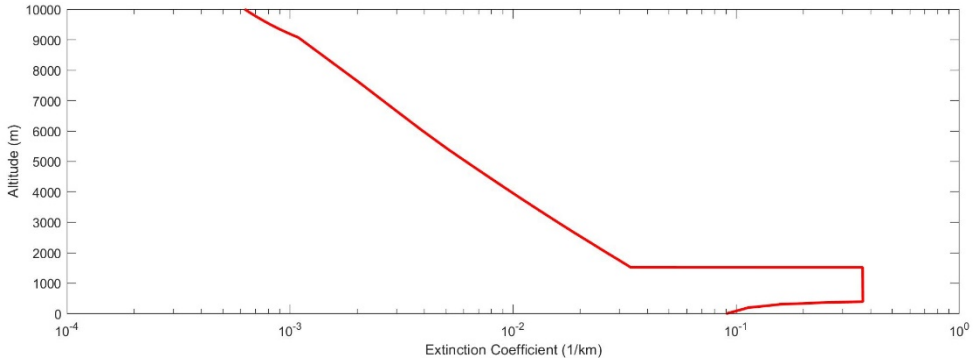
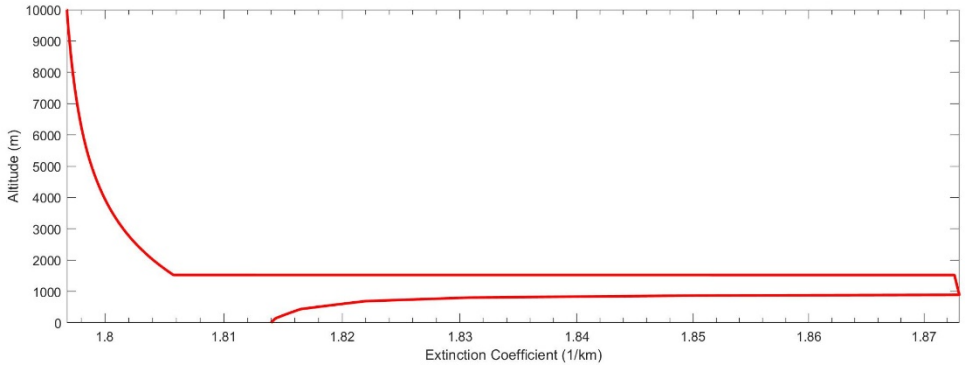


Figure 16. Extinction Coefficient for Clear Seoul Weather Conditions.

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Note the scale used for the extinction coefficient in this figure is linear (unlike the logarithmic scales used Figure 16 and Figure 18).

Figure 17. Extinction Coefficient for Precipitous Seoul Weather Conditions.

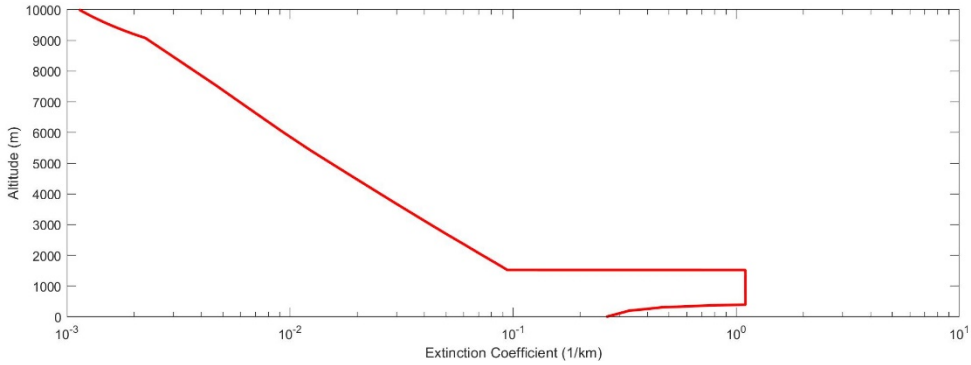


Figure 18. Extinction Coefficient for Hazy Seoul Weather Conditions.

The plots for extinction coefficient share the same general characteristics across both climates and all three weather profiles. From ground-level to an altitude of approximately 1 km (the atmospheric boundary layer), the coefficient value increases. However, just above the boundary layer at approximately 2 km altitude, the coefficient value decreases dramatically and then steadily declines even further with increased altitude. An increase in extinction coefficient value corresponds with a decrease in the amount of laser output power that actually reaches the target in accordance with the Beer-Lambert Law (Equation 6). Of note, the extinction coefficient data for Kandahar, Afghanistan indicates that, for similar weather types, the coefficient value generally remains less than that in Seoul across the platform altitudes simulated. The difference in

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extinction coefficient profiles can be explained by the relative abundance of atmospheric moisture near Seoul and the absence thereof near Kandahar. The extinction coefficient is inversely related to the surface visibility generated by LEEDR for each profile. Table 5 displays the effects that climate and weather type have on surface visibility.

Table 5. Effects of Climate and Weather on Surface Visibility.

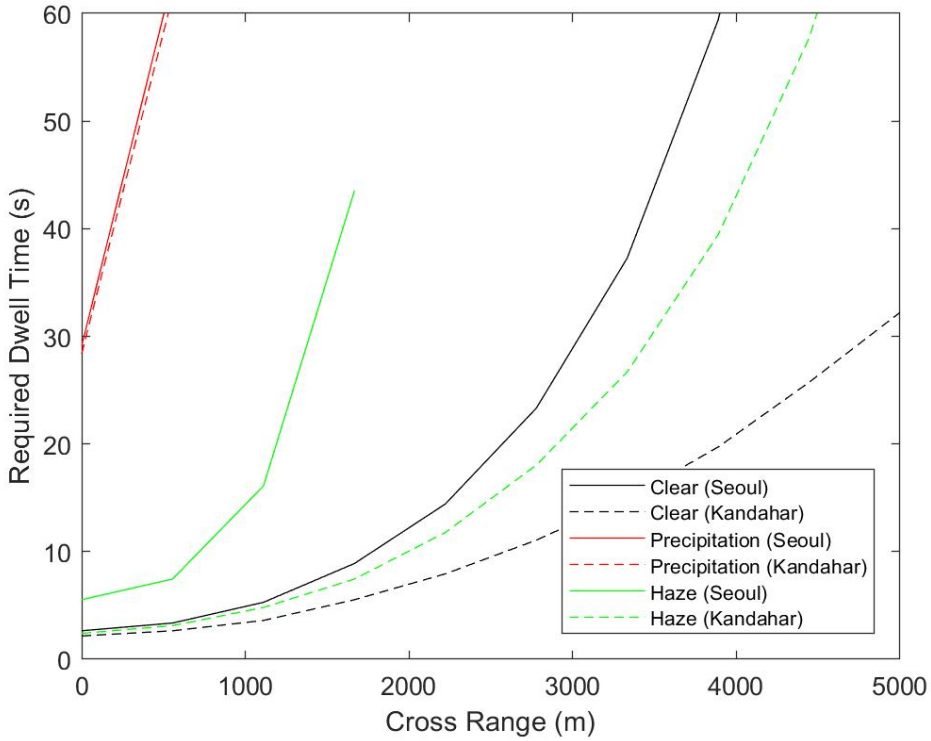
	Seoul, South Korea			Kandahar, Afghanistan		
	Clear	Precipitation	Haze	Clear	Precipitation	Haze
Surface Visibility (km)	23.7	1.64	8.50	33.3	1.64	12.0

The key conclusion to draw with regard to climate type is that, based on the data for these two locations, drier climates will produce more favorable atmospheric conditions for laser beam propagation (not considering the effects of sand storms). This effect is manifested in universally reduced dwell times for targets engaged in an arid desert environment, even when other independent variables are adjusted. In later sections, the Seoul climate profiles will be used to identify the extreme limits under which target autoignition can occur.

B. EFFECT OF WEATHER

To illustrate the effect of weather type on required dwell time, platform altitude, output power, and target type are kept constant. The comparison in Figure 19 displays data taken from 1 km platform altitude, 2.5 kW output power, and land mine target engagements.

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Note that the plot for hazy Seoul weather conditions stops at a cross range of approximately 1.75 km. This is due to the fact that the simulation is unable to achieve autoignition in the target within 60 seconds of dwell time at greater cross ranges.

Figure 19. Simulation Results for 1 km Platform Altitude, 2.5 kW Output Power, Land Mine Target Engagements.

Predictably, clear weather conditions produce the most favorable dwell times. The reduced presence of atmospheric particles corresponds with reduced beam extinction. Hazy weather conditions produce the next lowest dwell times, since the high concentration of aerosols results in increased beam scattering and absorption. Finally, precipitous weather produces the highest dwell times since the presence of large water droplets effectively extinguishes the beam at greater cross ranges.

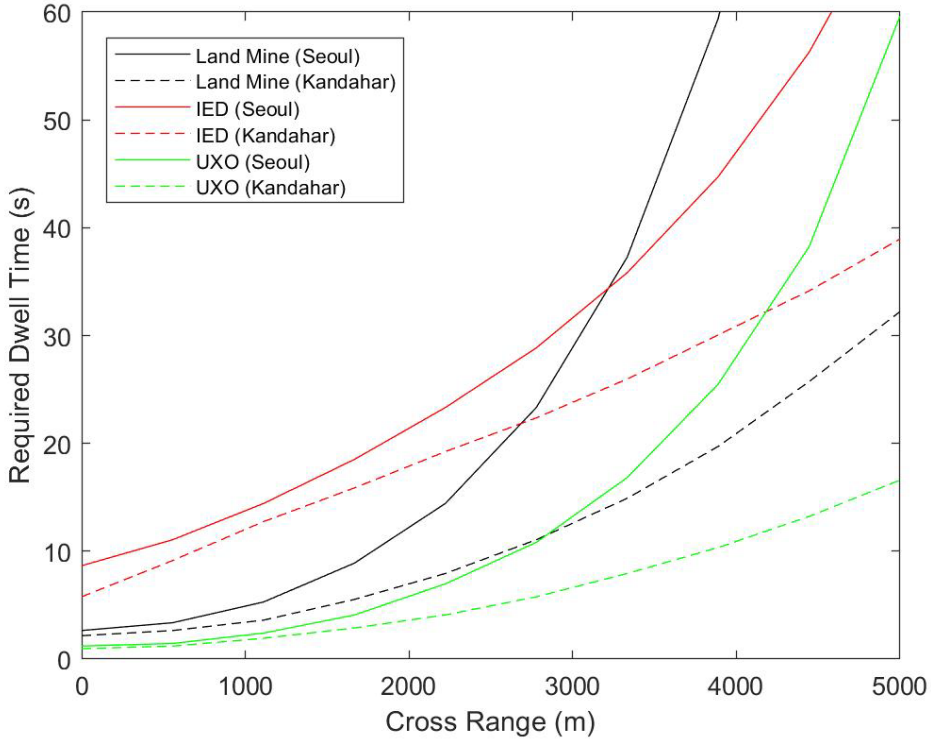
This data supports the conclusion that, although required dwell times are severely degraded, a low-power 2.5 kW laser is still capable of successfully engaging ground ordnance across all three weather types simulated. In precipitous conditions, the cross range is reduced to approximately 500 m for a 2.5 kW laser system. However, in clear

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conditions, the same system can achieve autoignition conditions in the target at a cross range in excess of 5 km.

C. EFFECT OF TARGET TYPE

To illustrate the effect of target type on required dwell times, engagements in clear weather, at 1 km platform altitude, and with 2.5kW output power are considered. See Figure 20 for simulation results.



The plots for land mine and IED targets engaged under similar climate conditions (Seoul) intersect at a cross range of approximately 3.25 km, which indicates that the land mine is a more difficult target to defeat at greater cross ranges under these simulation parameters.

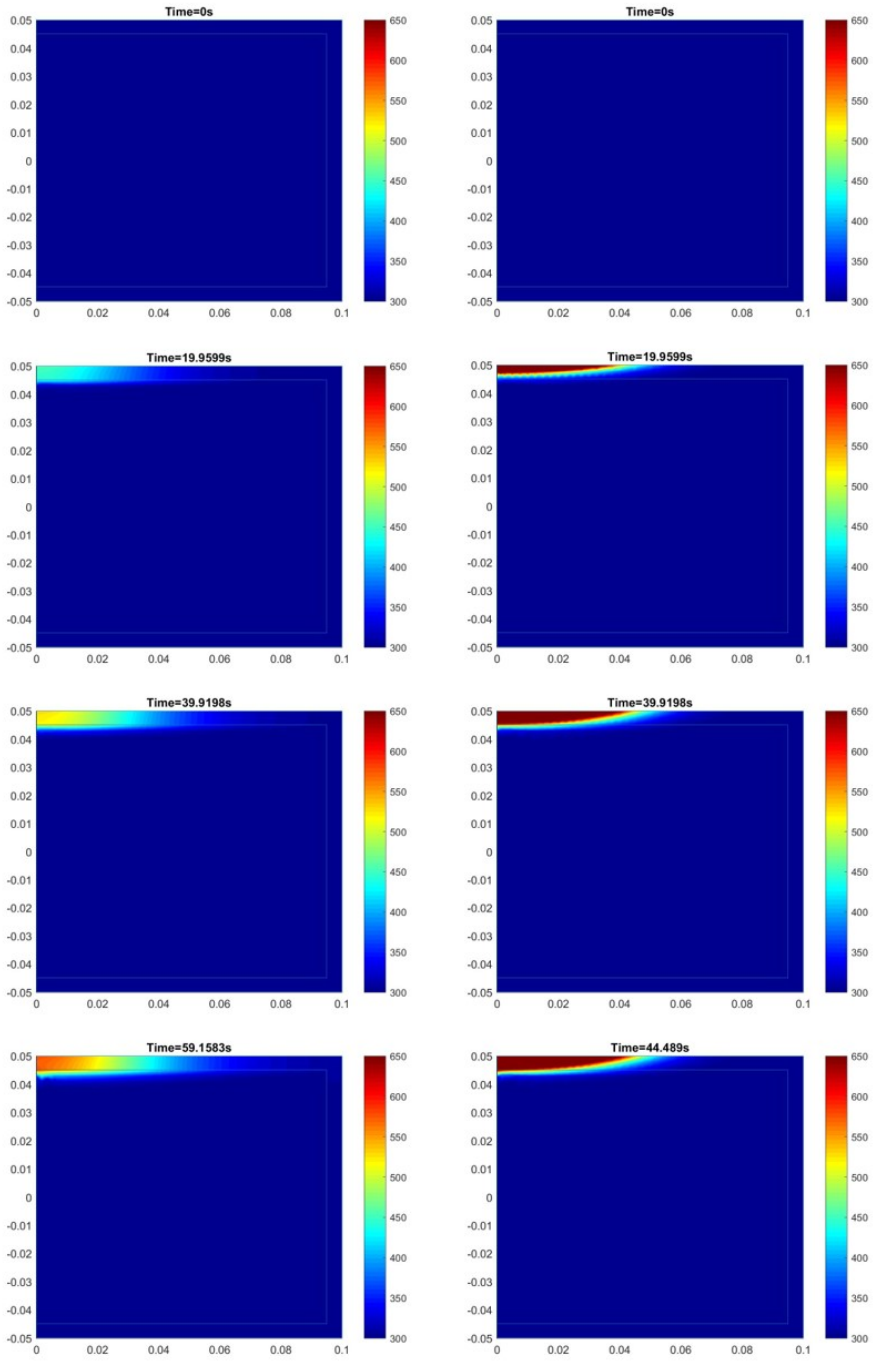
Figure 20. Simulation Results for Clear Weather, 1 km Platform Altitude, 2.5 kW Output Power Engagements.

Outer casing thickness has a significant effect on required dwell time. When comparing the two steel-encased targets, the UXO target profile (2.5 mm of casing) universally produces lower dwell times than the land mine target profile (5 mm of casing).

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Casing material has an even more dramatic effect on dwell times. The dwell times for the IED target profile, with its 5 mm of high density polyethylene casing, increase exponentially with respect to increasing cross range similarly to the steel-encased targets. However, the rate of this exponential increase is noticeably less than that for the steel profiles. Even though the IED target requires greater dwell times at lower cross ranges, the IED target data intersects the land mine target data at a cross range of approximately 3.25 km in Figure 20, after which the IED profile for Seoul actually requires lower dwell times than the land mine profile (also for Seoul). This intersection is indicative of different heating behaviors for both materials as beam irradiance is affected by increases in the propagation path (Figure 21).

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The figures on the left represent heating of a land mine target while the figures on the right represent heating of an IED target. For reference, the axes are in units of meters while the color scale is in units of kelvins. The bottom figure of each target is a depiction of the heating profile immediately prior to autoignition.

Figure 21. Target Cross-sectional Heating in Seoul Climate, Clear Weather, 1 km Platform Altitude, 2.5 kW Output Power, 3.89 km Cross Range Engagements.

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Due to the insulating nature of polyethylene, heat deposited by the laser beam remains relatively local to the beam spot on the surface of the target, where it accumulates and diffuses at a faster rate towards the explosive interface than it does radially outward. However, being a conductive material, steel casing diffuses more heat radially outward from the beam spot. When the beam irradiance is high (i.e., when the spot size is small at shorter cross ranges), the heat diffuses rapidly enough in both directions (towards the explosive interface and radially outward) that the target autoignites. When beam irradiance is low (i.e., when the spot size is larger at longer cross ranges), the radial diffusion prevents enough heat from reaching the explosive interface and autoigniting the RDX in a reasonable amount of time.

Since the melt temperature of high density polyethylene ranges between 383 K and 408 K [46], there is concern that the amount of heat deposited by the laser beam will melt the IED target's outer casing prior to explosive autoignition. However, it is possible to approximate the amount of total energy deposited by the laser beam that would be required to achieve such a state transition. The energy required to melt a material that is being irradiated by a laser beam can be approximated using the equation:

$$E_m \approx H_f \rho \pi w_{tot}^2 l \tag{11}$$

where E_m is the required melt energy, H_f is the heat of fusion (245 kJ/kg for high density polyethylene [46]), w_{tot} is the beam waist size, and l is the material thickness. Conversely, the total energy deposited by the laser beam can be approximated as:

$$E_b \approx I_{pk} \pi w_{tot}^2 t_d (1-R) \tag{12}$$

where E_b is the energy deposited by the beam, I_{pk} is the peak irradiance of the beam, t_d is the required dwell time for autoignition, and R is the reflectivity coefficient of the material. Relating Equation 11 and Equation 12 produces the equation:

$$G \approx \frac{H_f \rho l}{I_{pk} t_d (1-R)} \tag{13}$$

where G is the fraction that relates the energy required to melt the casing material to the total energy deposited by the laser beam. Upon conducting this calculation for a sample of simulations, the percentage is approximated to remain below 10% of the total energy deposited by the laser beam. It is therefore a reasonable assumption to neglect the energy

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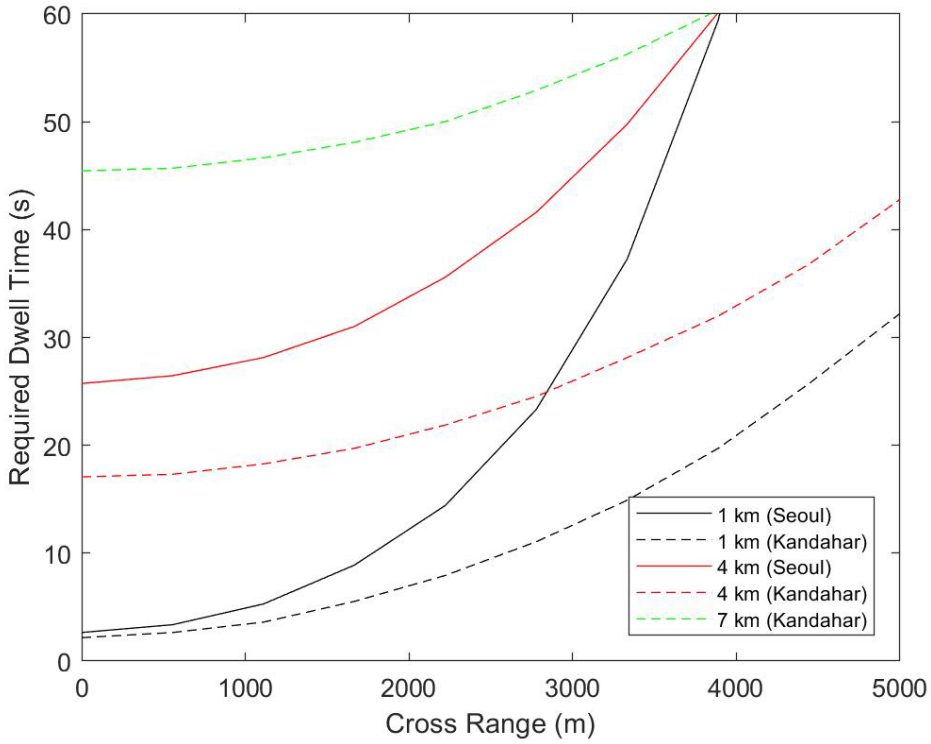
consumed by melting with regard to the time scales and polyethylene casing thickness modeled in these simulations.

In addition to melting, there is concern over the effect imposed by the removal of polyethylene casing while the target is irradiated (either by burning or gravity). In either case, the removal of mass would reduce the time required for the heat front to diffuse in accordance with the heat diffusion equation mentioned in Chapter III (Equation 1). In the case of burning (high density polyethylene itself has an autoignition temperature of approximately 613 K [46]), the energy released by burning the casing would actually contribute to the heat front diffusion. The ultimate effect of casing removal in either situation would be a reduction in the dwell time required to achieve autoignition in the target. Therefore, by not considering the effect of casing removal in this research, the simulation results are likely to be conservative (i.e., higher dwell times) than those that would be achieved through experimentation. Having established that the land mine and IED target types are the most difficult with which to achieve autoignition conditions, they are used as the standards by which to establish the requirements of a laser system intended to defeat ground ordnance.

D. EFFECT OF PLATFORM ALTITUDE

Simulated engagements performed in clear weather, with 2.5 kW output power, and against land mine targets are used to compare the effect of platform altitude on required dwell time (Figure 22).

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The plot for an engagement in Seoul at 7 km platform altitude is not available since the simulated laser beam is unable to achieve autoignition conditions in the target within 60 seconds of dwell time.

Figure 22. Simulation Results for Clear Weather, 2.5 kW Output Power, Land Mine Target Engagements.

There is a universally strong relationship between platform altitude and the required dwell time to achieve autoignition conditions. This can be explained by the increased effects of scattering, absorption, and turbulence as the propagation path of the laser beam increases. Although lower altitudes result in reduced engagement dwell times, they are also disadvantageous for UAV operations. An aircraft operating at low altitude is more vulnerable to anti-aircraft defenses, and relatively slow-moving UAVs are particularly vulnerable. Since low-level cloud layers typically exist below 2 km altitude [47], the only tactical reason for a UAV to operate below this altitude would be the presence of rain clouds (hence why precipitous weather simulations are relevant at 1 km altitude, but not 4 km or 7 km) or in overcast conditions. However, conducting engagements at high altitude places a tax on the laser system's requirements. Of note, the plots for the 1 km platform altitude and 4 km platform altitude engagements in Seoul converge at a cross range of

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approximately 4 km. This can be attributed to the effect of increased extinction coefficient in the atmospheric boundary layer. While the simulation performed at 1 km platform altitude must propagate almost the entire distance with a very large coefficient value, the simulation performed at 4 km platform altitude only propagates through the boundary layer for approximately half of the distance to the target.

E. EFFECT OF OUTPUT POWER

Engagements performed in clear weather, at 1 km platform altitude, and against land mine targets are used to determine the effect of laser output power on required dwell times. See Figure 23 for a visual comparison of the data.

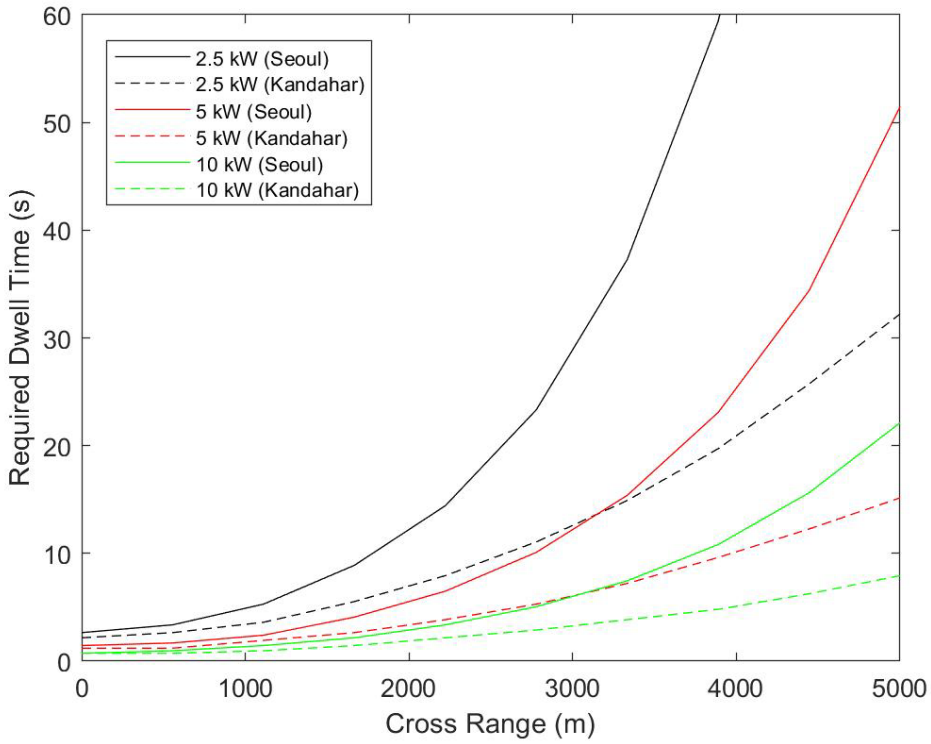


Figure 23. Simulation Results for Clear Weather, 1 km Platform Altitude, Land Mine Target Engagements.

As expected, laser output power plays a significant role in determining the required dwell time. Greater output power means that more energy is deposited at the surface of the

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target and consequentially increases the diffusion speed of the heat front through the outer casing. Of all the independent variables tested in this research, laser output power is the most significant with regard to designing a system capable of achieving target autoignition across all conditions.

As identified in previous sections of this chapter, engagements that occur in a temperate climate (Seoul) are non-ideal relative to those that occur in a drier climate (Kandahar). Additionally, depending on the platform altitude, precipitous and hazy weather are the most disruptive weather conditions regarding laser beam propagation. Finally, land mine and IED target types are the most difficult to defeat. These conclusions enable identification of the maximum capabilities of the three simulated output powers. A temperate climate with precipitous weather at 1 km platform altitude is the most non-ideal situation under which a 2.5 kW output power can achieve autoignition in the two most difficult target types (Figure 24).

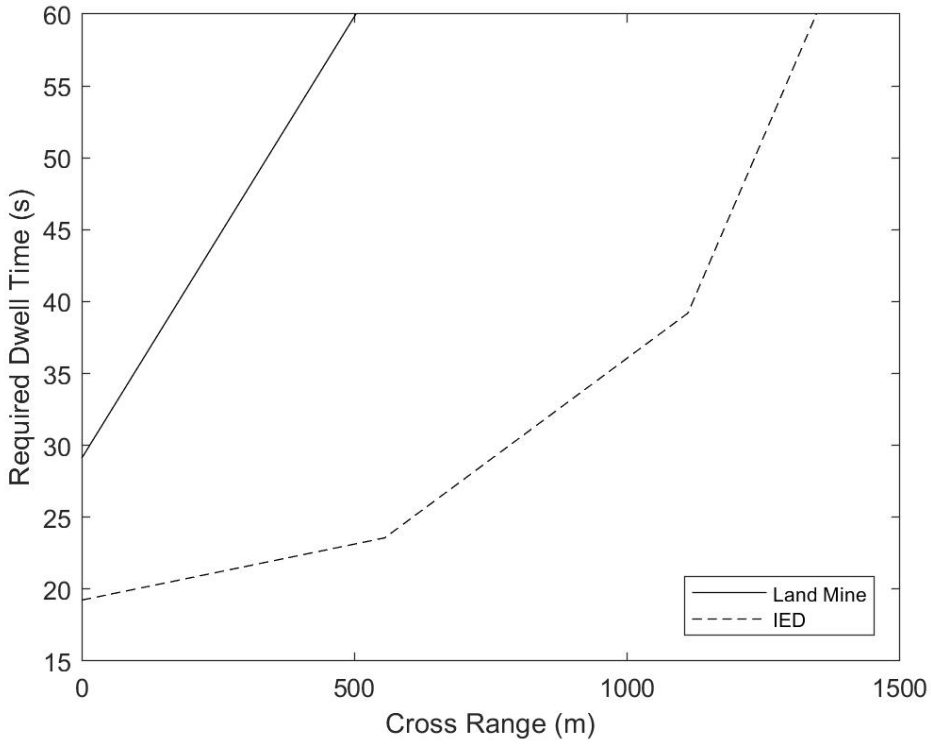


Figure 24. Simulation Results for a Seoul Climate, Precipitous Weather, 1 km Platform Altitude, 2.5 kW Output Power Engagement.

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Increasing the output power of the laser to 5 kW enables target autoignition at a platform altitude of 4 km in hazy weather conditions (Figure 25).

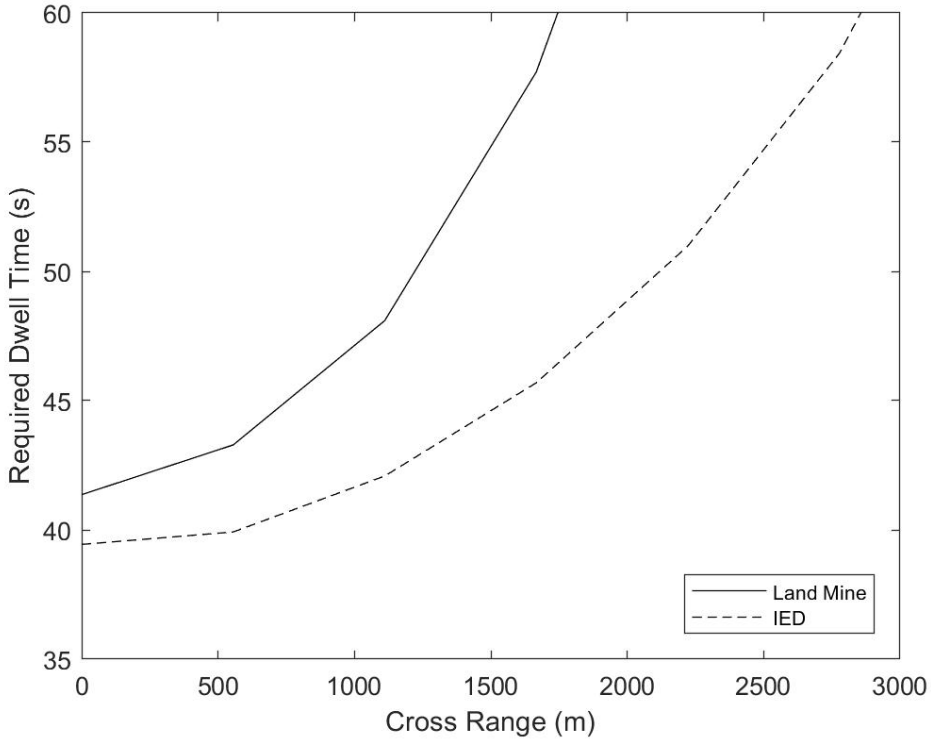


Figure 25. Simulation Results for a Seoul Climate, Hazy Weather, 4 km Platform Altitude, 5 kW Output Power Engagement.

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Finally, the maximum simulated output power of 10 kW enables target defeat at a platform altitude of 7 km in hazy weather conditions (Figure 26).

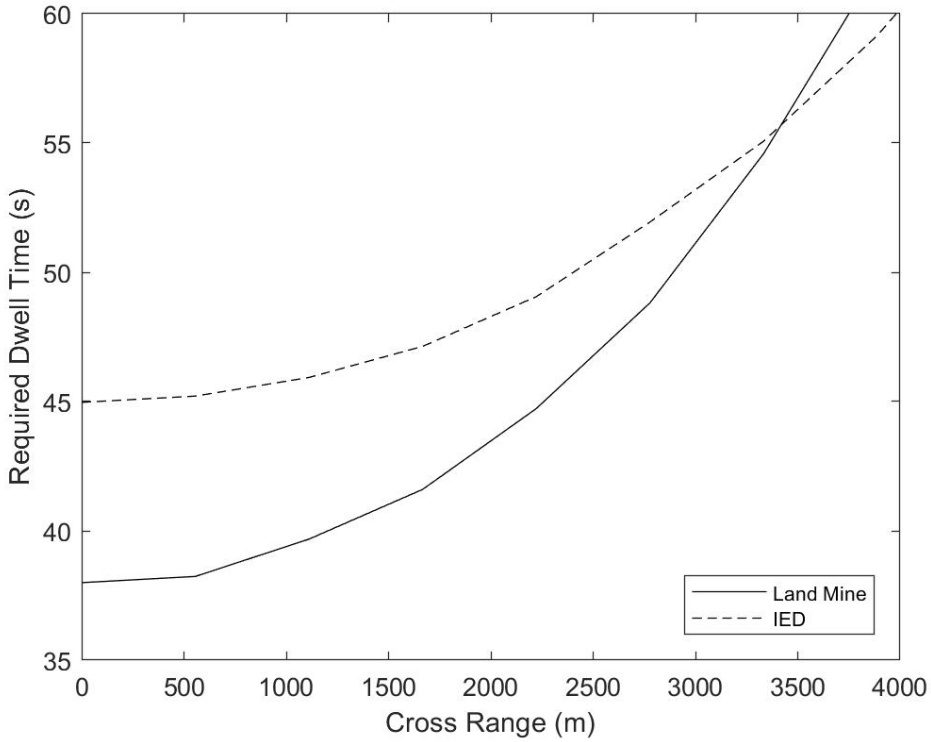


Figure 26. Simulation Results for a Seoul Climate, Hazy Weather, 7 km Platform Altitude, 10 kW Output Power Engagement.

F. CONCLUSIONS

It is feasible to engage and defeat ground ordnance using an airborne solid-state laser. At a platform altitude of 1 km, these simulations indicate that all three tested output powers are capable of achieving autoignition conditions in both climates, across all weather profiles, and against each target type. The most restrictive variable is weather, which effectively limits the platform altitude to the cloud layer during precipitous weather. Additionally, in order to defeat all three target types in clear or hazy weather and in either climate, the minimum required output power increases to 5 kW for 4 km platform altitude engagements and 10 kW for 7 km platform altitude engagements.

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The concept of using UAV-mounted solid-state lasers to defeat ground ordnance bears utility. As an example, the IPG Photonics YLS-3000-SM system produces a similar beam to the one simulated in this research with an output power of 10 kW and contained in a compact 0.95 m^3 package [48]. A similar model listed by the company weighs less than 380 pounds and has a published wall-plug efficiency greater than 50% [44]. This means that the system could be operated with a power source that outputs an average of 20 kW. While these SWaP requirements are too large for smaller UAVs such as the RQ-7B Shadow, they do not supersede the capabilities of mid-size UAVs such as the MQ-1C Gray Eagle, which has a payload capacity of 1,075 pounds [49]. This would enable current U.S. Army forces to maintain a responsive airborne ordnance-clearing asset at the division echelon.

There are many opportunities for expansion of this research. The diffusion of heat to achieve autoignition is just one defeat mechanism particular to a specific target type. Different target types with other defeat mechanisms should be studied in order to grasp the full utility of airborne laser systems. Additionally, expanding the selection of platforms beyond UAVs could create possibilities with regard to increased SWaP availability. Rotary and fixed-wing aircraft could theoretically carry laser systems with greater output power, which in turn increases the feasibility of defeating different target types. As solid-state laser systems continue to become more compact and powerful, it is highly likely that airborne laser weapons will become a fixture on future battlefields.

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APPENDIX. MATLAB CODE

A. HEAT DIFFUSION SIMULATION

```
close all;
% overall properties (cylindrical symmetry)
radius = 0.1;          % [m]
height = 0.1;          % [m]
T0 = 300;              % initial (ambient) temperature [K]
Texplode = 1e5;        % explosion threshold temperature [K]

% outer casing properties
thickness = 0.005;     % [m]
rho1 = 959;            % density [kg/m^3]
k1 = 0.43;             % thermal conductivity [W/(m*K)]
cp1 = 2000;            % heat capacity [J/(kg*K)]

% explosive properties
rho2 = 1800;           % density [kg/m^3]
k2 = 0.29;             % thermal conductivity [W/(m*K)]
cp2 = 2093;            % heat capacity [J/(kg*K)]
Qd = 2.09e6;           % heat of decomposition [J/kg]
Ea = 1.99e5;           % activation energy [J/mol]
Ze = 10^18.5;          % characteristic reaction rate [1/s]

% numerical properties
Hmax = 0.005;          % max mesh size [m]
nt = 500;              % number of time steps to save
RelTol = 0.01;         % relative tolerance (larger = faster but less accurate)
trun = 120;            % total time simulation will run [s]
tengage = trun;        % maximum desired engagement time (must equal trun) [s]

% create model object
thermalModelT = createpde('thermal','transient');
thermalModelT.SolverOptions.RelativeTolerance = RelTol;

% define geometry
r1 = [3, 4, 0, radius, radius, 0, -0.5*height, -0.5*height, 0.5*height, 0.5*height];
r2 = [3, 4, 0, radius-thickness, radius-thickness, 0, -0.5*height+thickness,...
    -0.5*height+thickness, 0.5*height-thickness, 0.5*height-thickness];
g = decsg([r1; r2]','R1+R2',['R1'; 'R2']');
geometryFromEdges(thermalModelT,g);

% plot geometry (for edge, face labeling)
%figure
%pdegplot(thermalModelT,'EdgeLabels','on','FaceLabels','on');

% mesh generation
generateMesh(thermalModelT,'Hmax',Hmax);

%pnodes = thermalModelT.Mesh.Nodes;
%indices = pnodes(2,:) < 0;%0.5*height-thickness;

% plot mesh (for diagnostics)
%figure
%pdeplot(thermalModelT);

% assign material properties (outer casing)
k1Func = @(region,state) k1*region.x;
cp1Func = @(region,state) cp1*region.x;
thermalProperties(thermalModelT,'Face',1,'ThermalConductivity',k1Func,...
                                'MassDensity',rho1,...
                                'SpecificHeat',cp1Func);
```


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```
% assign material properties (explosive)
k2Func = @(region,state) k2*region.x;
cp2Func = @(region,state) cp2*region.x;
q2Func = @(region,state) Qdot(state,region,Ea,rho2,Qd,Ze);
thermalProperties(thermalModelT,'Face',2,'ThermalConductivity',k2Func,...
                                'MassDensity',rho2,...
                                'SpecificHeat',cp2Func);
internalHeatSource(thermalModelT,q2Func,'Face',2);

% initial conditions
thermalIC(thermalModelT,T0);

clear range;
clear tdwell;
q = 1;
while q <= gridRt

    % laser properties
    Ipk = ANCHOROutput.IrrLinearArray(q,1);          % peak irradiance from ANCHOR [W/m^2]
    wtot = ANCHOROutput.Waist_total_longterm(q,1);   % rms width from ANCHOR [m]
    Reflect = 0.1;                                   % surface reflection coefficient

    % boundary condition(s)
    heatFluxFunc = @(region,state) Ipk*(1-Reflect)*exp(-(region.x).^2./wtot^2).*region.x;
    thermalBC(thermalModelT,'Edge',3,'HeatFlux',heatFluxFunc);

    % run model
    tlist = linspace(0,trun,nt);
    S = solve(thermalModelT,tlist);

    % plot final results
    if max(S.Temperature(:))> Texplode
        Tmax = 0;
        it = 1;
        while Tmax < Texplode
            it = it+1;
            Tmax = interpolateTemperature(S,0,0,it);
            Tmax = max(Tmax(:));
        end

        %figure
        %pdeplot(thermalModelT,'XYData',S.Temperature(:,it),'Contour','off');
        %hold on;
        %pdegplot(thermalModelT);
        %title(strcat('time=',num2str(tlist(it)), 's'));
        %hold off;

        %figure
        %pdeplot(thermalModelT,'XYData',S.Temperature(:,it-1),'Contour','off');
        %hold on;
        %pdegplot(thermalModelT);
        %title(strcat('time=',num2str(tlist(it-1)), 's'));
        %caxis([0 2500]);

        %figure
        %pdeplot(thermalModelT,'XYData',S.Temperature(:,end),'Contour','off');
        %hold on;
        %pdegplot(thermalModelT);
        %title(strcat('time=',num2str(tlist(end)), 's'));

    else
        disp('Time limit exceeded...increasing time step');
        if tlist(end) > 60
            break;
        end
        trun = 2*tlist(end);
        continue;
```


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```
    end
    range(1,q) = (q-1)*((Rtmax-Rtmin)/(gridRt-1));
    tdwell(1,q) = tlist(it);
    if tlist(it) > 60
        break;
    end
    q = q+1;
end

% plot cross range versus required dwell time
figure
plot(range,tdwell,'k');
hold on;
xlabel('Cross Range (m)');
ylabel('Required Dwell Time (s)');
```

B. ARRHENIUS HEAT SOURCE FUNCTION

```
function [qdot] = Qdot(state,region,Ea,Rho,Q,Ze)
% QDOT Calculates temperature dependent heat source

R = 8.314;     % ideal gas constant [J/(mol*K)]

if isnan(state.u)
    qdot = NaN(size(region.x));
    return;
else
    qdot = Rho*Q*Ze*exp(-Ea./(R*state.u));
end

maxQ = 1e15;
if max(qdot(:))>maxQ
    qdot = maxQ*ones(size(region.x));
end

qdot = qdot.*region.x;
end
```


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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

FEASIBILITY AND UTILITY OF AIRBORNE SOLID-STATE LASERS AGAINST GROUND ORDNANCE

by

Joseph Fasone

June 2018

Thesis Advisor: Keith R. Cohn
Co-Advisor: Joseph A. Blau

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Explosive devices present a significant threat to civilian populations and are a severe counter-mobility obstacle for ground forces. With the proliferation of improvised explosive devices into potential U.S. military operating areas, a safer and more efficient method for eliminating the threat is required. U.S. Army forces operating at the brigade and above echelons are generally supported with a variety of unmanned aerial vehicle (UAV) airframes that are capable of conducting reconnaissance and surveillance. These UAVs are faster and more responsive to reports of ground-based explosive devices than explosive ordnance disposal (EOD) teams or route clearance patrols. If UAVs were equipped with a system capable of disarming or destroying explosive devices, the stress on EOD assets would be mitigated and the delaying effect of said explosives on ground forces would be reduced. This research explores the feasibility and utility of using a high-energy laser mounted onboard a UAV platform to defeat ground-based explosive devices. Specifically, this research defines an array of potential targets, characterizes the atmospheric effects in varied weather conditions and climates on such a laser system, and contrasts the size, weight, and power requirements of such a system with the operating capabilities of existing UAV platforms.

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FEASIBILITY AND UTILITY OF AIRBORNE SOLID-STATE LASERS AGAINST GROUND ORDNANCE

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Captain, United States Army
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN APPLIED PHYSICS

from the

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

ABL	Airborne Laser
ALL	Airborne Laser Lab
ATL	Advanced Tactical Laser
AV	anti-vehicle
BCT	brigade combat team
EFP	explosively formed penetrator
GADS	Global Aerosol Data Set
HEAT	high explosive anti-tank
HEL	high energy laser
HMX	high melting explosive
IED	improvised explosive device
LaWS	Laser Weapon System
LEEDR	Laser Environmental Effects Definition and Reference
MIRACL	Mid-IR Advanced Chemical Laser
MTHEL	Mobile Tactical High Energy Laser
NACL	Navy ARPA Chemical Laser
Nd:YAG	neodymium yttrium aluminum garnet
RDX	research department explosive
SBL	Space Based Laser
SWaP	size, weight, and power
THEL	Tactical High Energy Laser
TNT	trinitrotoluene
TOW	tube-launched optically-tracked wire-guided
UAV	unmanned aerial vehicle
UXO	unexploded ordnance

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I. INTRODUCTION

Explosive devices are among the most effective obstacles to ground maneuver in combat. Properly placed, these devices can inflict casualties, deny terrain, steal operational tempo, and threaten civilian populations. According to figures in 2008, approximately 70% of the then 4,163 U.S. combat deaths in Iraq since the start of the war in 2003 were due to roadside bombs [1]. Their proliferation and successes over the past decade ensure that improvised explosive devices (IEDs), land mines, and unexploded ordnance (UXO) remain a threat in future U.S. Army operating environments.

A. GROUND ORDNANCE THREATS

Relative to the weapons used in modern armed forces, IEDs are cheaply produced and readily available to insurgent or terrorist organizations. A bomb maker might expend less than $100 for an IED capable of destroying a light vehicle as compared to more than $100,000 for a conventional U.S. precision munition [2]. Simply put, organizations that employ IEDs are obtaining a comparable tactical effect for a fraction of what the U.S. government pays per application, and they are doing so without the billions of dollars poured into the acquisition and production of new weapon systems.

Land mines and UXO have a detrimental effect on both combat operations and civilian populations. Like IEDs, these munitions excel in the counter-mobility role against ground forces. However, once they have been bypassed, land mines and UXO still present a significant threat to civilian populations in the vicinity. As of 2003, Soviet land mines from the war in Afghanistan that ended in 1989 still inflicted approximately 300 civilian casualties per month [3]. Unfortunately, even modern armed forces continue to leave behind these dangerous explosives due to limited disposal assets and competing priorities. Apart from the broader humanitarian argument, this threat presents a more immediate challenge to the U.S. Army if the mission specifically entails protection of the civilian population.

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B. CURRENT REMOVAL METHODS

Ground-based explosive devices are undoubtedly a problem that the U.S. Army needs to solve safely, effectively, and cheaply in order to be successful on future battlefields. Current removal methods rely on the use of highly specialized units and equipment that may not always be available and are expensive to field. Directed energy is a potential solution to the threat posed by these devices. The Department of Defense recognized the utility of lasers on the battlefield as far back as the 1960s [2] and has since committed funding to multiple projects as a means of combatting a variety of threats to friendly forces.

C. POTENTIAL ADVANTAGES OF DIRECTED ENERGY EMPLOYMENT

In 2004 the U.S. Army demonstrated that in-flight mortar rounds can be destroyed using a ground-based high energy laser. The Mobile Tactical High Energy Laser (MTHEL) destroyed seven medium in-flight mortars during testing, which included a three-round salvo [4]. In 2008 the U.S. Special Operations Command mounted a 100 kW laser on an AC-130 gunship and dubbed it the Advanced Tactical Laser (ATL). The ATL was intended to function as a direct fire weapon against ground targets, which included a remotely controlled vehicle in one particularly successful test [5]. Finally, in 2010 the U.S. Air Force succeeded in destroying an in-flight ballistic missile using the Airborne Laser (ABL), a megawatt-class laser mounted inside a Boeing 747 [5] (Figure 1).

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Figure 1. YAL-1A Airborne Laser. Source: [6].

Although the MTHEL, ATL, and ABL were successful during testing in ideal conditions, all three projects were cancelled for the same general reasons. Each system utilized a large chemical laser that, aside from the massive size (the MTHEL required several oversized trailers to move across the battlefield [5]), required the transportation, storage, and handling of dangerous and expensive chemicals. Additionally, each project was built on the assumption that the laser would be in the right location at the right time to strike a fast moving target. In the case of the ABL, five to seven Boeing 747s would have to maintain a presence near a missile launch site for a successful interdiction [5]. Such a quantity of large, slow aircraft loitering over enemy controlled territory would be an irresistibly attractive target. In order for directed energy to be successful in tactical engagements, lasers must be smaller, logistically simple, and mobile.

This study models the use of solid-state lasers mounted on unmanned aerial vehicles (UAVs) against surface-laid ground ordnance. Solid-state lasers operate by electricity instead of chemical reactions and are generally much smaller than chemical lasers. Current solid-state lasers also produce much less optical output power than their chemical relatives, but this may be offset by the intended application. While the MTHEL, ATL, and ABL required high irradiance over a short dwell time to be successful, a solid-state laser that targets ground ordnance has the luxury of an extended engagement period

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since IEDs, land mines, and UXO don't move. Additionally, the explosives used in these potential targets self-ignite at temperatures of a few hundred kelvins; this is considerably lower than the temperatures needed for other target types (e.g., to melt through missile casings). Thus, the irradiance, and consequentially the output power, of the laser can be reduced while still achieving the desired effect.

UAVs are ideal platforms for destroying ground ordnance with solid-state lasers. Currently, a brigade combat team (BCT) in the U.S. Army fields four RQ-7B Shadow UAVs that are intended to provide 24-hour geographic coverage for that BCT's area of operations. The availability of UAVs only increases at each higher echelon, with the MQ-1C Gray Eagle (Figure 2) fielded at the division-level. This means that there is a persistent and flexible UAV presence within every area of operations that could potentially put a laser at the right location and time to be effective against the ground ordnance threat. Additionally, UAVs have a large stand-off distance from ground targets that eliminates the need to put soldiers or expensive equipment within the blast radius of said ground ordnance. The challenge for using UAVs in this intended application lies in the fact that all of these platforms have limited capacity for the size, weight, and power (SWaP) requirements inherent to solid-state lasers.



Figure 2. MQ-1C Gray Eagle. Source: [7].

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Aside from the engineering challenges associated with mounting lasers on UAVs, an air-to-ground directed energy system must consider atmospheric propagation effects such as diffraction, scattering, absorption, and turbulence [2]. Consequentially, the required beam output power must be designed to overcome these effects and cross the lethal fluence threshold at the target.

D. OVERVIEW OF STUDY

This study identifies the energetic compounds used in common IEDs, surface-laid land mines, and pieces of UXO in order to estimate the lethal fluence needed for these compounds. Based on this information, the study then estimates the laser power needed to achieve the lethal fluences over acceptable dwell times for various atmospheric conditions. Finally, the study discusses the feasibility of using solid-state lasers against ground ordnance based upon SWaP considerations and UAV platform availability.

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II. OVERVIEW OF DIRECTED ENERGY WEAPONS

As it is applied to weaponry, the term “directed energy” can have a multitude of meanings. For example, the deposition of energy on a target can be accomplished through the use of microwaves, particle beams, or high energy lasers (HELs). However, for directed energy weapons to be effective, the delivery method, target parameters, platform allowances, and propagation medium must be such that the desired result on the target is achieved. HELs are currently a highly active subject of study for defense applications and will be the focus for this research due to their relative advantages over other types of directed energy weapons.

A. HISTORY

The development of HELs as weapons began almost immediately following the invention of the first laser in 1960. The Soviet Union started researching the feasibility of HELs defeating intercontinental ballistic missiles during their reentry phase in 1965, going so far as establishing a town of 20,000 people at Raduga to conduct research and testing [8]. The United States followed when Ed Gerry created a gas dynamic CO2 laser with an output power of 100 kW in 1968 [8]. Each branch of the armed forces began funding their own projects tailored for their specific requirements.

The next major advancement came from the U.S. Navy with the creation of the Navy ARPA Chemical Laser (NACL), which was a multi-hundred kilowatt-class chemical laser. The NACL successfully destroyed tube-launched optically-tracked wire-guided (TOW) missiles in-flight in 1978 and led to the development of the Mid-IR Advanced Chemical Laser (MIRACL) in 1980, which was the world’s first megawatt-class laser [9]. However, chemical lasers are not ideal for ship-based applications due to the fuels required and exhaust they create. Additionally, the less-than-ideal output wavelength produced by these lasers were prone to atmospheric absorption, which resulted in decreased irradiance at the target and thermal blooming. These factors contributed to a hiatus in Navy HEL design until a suitable alternative with comparable power outputs could be developed. In 2014, the 30 kW AN/SEQ-3 Laser Weapon System (LaWS) (Figure 3) was installed on

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the USS *Ponce* and successfully demonstrated the ability to destroy small boats and UAVs [10]. The LaWS is a solid-state system that circumvents the challenges of chemical lasers at the expense of an output that is lower by at least an order of magnitude.



Figure 3. LaWS Onboard the USS *Ponce*. Source: [11].

The U.S. Air Force created the Airborne Laser Lab (ALL) with a 100 kW class gas dynamic laser mounted in a KC-135 aircraft, which succeeded in destroying AIM-9 missiles and BQM-34 drones during testing in 1983 [8]. Due to the relatively low electrical power requirements of chemical lasers, this type of system was the basis of the Space Based Laser (SBL) program that began in 1989 with the purpose of defeating ICBMs in their boost phase. The program intended to conduct a successful demonstration by 2012 [9], but was cancelled in 1991 [8]. Building on the successes of the ALL and prompted by the cancellation of the SBL, the Air Force began work on the ABL program in 1994, which incorporated a megawatt class laser in a Boeing 747 [8]. As mentioned in the previous chapter, the ABL was successful during testing in its intended purpose of destroying ballistic missiles in the boost phase, but the requirement of putting the laser within range of a target and program costs led to its cancellation.

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Meanwhile, the U.S. Army took an interest in using ground-based HELs to counter indirect fire. Research for the Tactical High Energy Laser (THEL) began in 1996 as a joint venture between the United States and Israel as a means to interdict Katyusha rockets [9]. The THEL achieved successes in testing against rockets in 2000 and against mortar rounds in 2004, but proved too expensive and unwieldy on the battlefield. The THEL and its offshoot, the MTHEL, were cancelled due to a lack of available funding. Although the Army lost interest in the THEL and MTHEL, it did not lose interest in ground-based HEL applications and by March 2003 deployed the Zeus HMMWV Laser Ordnance Neutralization System (Figure 4) to Afghanistan to assist with UXO removal [12]. That version of the Zeus incorporated a 500 W neodymium yttrium aluminum garnet (Nd:YAG) solid-state laser [9] with an effective range of 300 meters [12]. During its six-month deployment to Bagram Air Field, the Zeus negated over 200 pieces UXO, including a record-breaking 51 pieces of UXO in less than 100 minutes [12]. The performance of the Zeus demonstrated the feasibility of using a HEL to destroy ground ordnance.



Figure 4. Zeus HMMWV Laser Ordnance Neutralization System. Source: [13].

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Nearly 60 years of HEL design and testing revealed several lessons regarding their use as weapons. Although chemical and gas lasers are capable of achieving higher output powers at relatively better efficiencies, they are also unwieldy, if not downright dangerous to the user in battlefield applications. Solid-state lasers are currently receiving the most attention due to innovations that have increased their power output, their safer electrical "fuel," and their ideal wavelength for atmospheric propagation. This research will focus primarily on solid-state systems due to these reasons, especially considering the projected application of using them onboard UAVs. As the Zeus device demonstrated, only modest output power is needed to affect the desired result against ground ordnance.

B. ADVANTAGES AND DISADVANTAGES

Solid-state HELs have numerous advantages when compared to conventional ballistic weapons. Perhaps the most significant is that the beam propagates at the speed of light. The next major advantage of HELs is the cost per engagement associated with using the weapon. Ballistic munitions are expensive and only available in limited quantities; armored vehicles, aircraft, and ships can only carry a finite number of rounds, bombs, or missiles. On the other hand, lasers only cost the fuel required to generate electricity for each engagement; a typical cost of less than a dollar compared to thousands of dollars for conventional munitions. Finally, HELs can generally outrange conventional line-of-sight munitions if the laser is designed to overcome the effects of scattering and absorption that lead to beam extinction.

Solid-state HELs do come with some inherent disadvantages that have so far prevented their widespread deployment. Compared to ballistic munitions and chemical or gas lasers, solid-state HELs are inefficient. The typical "wall-plug" efficiency for solid-state systems is on the order of 20% to 30%, which necessitates an electrical power source capable of providing hundreds of kilowatts for each engagement. This inefficiency leads to heat generation in the lasing medium that must be actively removed. Cooling systems that can effectively dissipate the heat add additional power and weight requirements. Additionally, any HEL system is more susceptible to atmospheric effects, such as precipitation and haze, than conventional ballistic munitions. Since the defeat mechanism

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employed by HELs typically involves heating of the target, a laser must also overcome the energy loss resulting from light reflected by the target's surface.

Considering the objective of this research, airborne HELs are an attractive option for defeating explosive devices. If explosive ordnance disposal (EOD) personnel decide that a device can be rendered ineffective in-situ, there are a variety of methods available that include disruptors, anti-munition rifles, de-armers, explosives, fuze removal, or fuze immunization [14]. All of these options require deployment of EOD teams and potentially place these specially trained personnel at risk (Figure 5). Simply the loss of time incurred by friendly forces is often enough to justify the emplacement of explosive devices by the enemy. By requiring friendly forces to adjust from a proactive posture to a reactive one, an enemy that employs these devices steals the tactical initiative. Conversely, HELs (particularly airborne systems) enable the discoverer of an explosive device to act expeditiously and with pinpoint precision. Barring prohibitive weather conditions, UAVs continuously occupy the airspace of a U.S. Army unit's area of operations. The operational cost in time incurred by a friendly unit that encounters an explosive device could potentially be cut from hours (waiting on an EOD team or combat engineers to arrive) to minutes (the time it takes to direct an already airborne clearance asset to the location). This is not to say that using airborne HELs to dispose of explosive devices completely negates the need to have EOD assets available; weather occasionally grounds UAVs, disposing of a device in-situ is not always a possibility, and it is likely infeasible to use a HEL to defeat buried devices. However, it does provide another option for ground commanders to leverage based on the merits of the tactical situation.

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Figure 5. EOD Personnel Train to Dispose of an IED. Source: [15].

C. PROJECTED APPLICATIONS

HEL systems have demonstrated success in testing and limited field deployments, and the next generation of these weapons are currently in the design phase. The Navy established their Directed Energy Program Office within the Program Executive Office for Integrated Warfare Systems in August 2016 [16]. In a February 2017 Federal Business Opportunities posting, this office requested industry capabilities for a new program that consists of a 60 kW HEL with counter-ISR dazzling capability and is capable of operating on an Arleigh Burke-class guided missile destroyer [16]. The Air Force is currently funding a demonstration called SHIELD, which intends to integrate a solid-state HEL with an output power in the tens of kilowatts range on a fighter-size aircraft by 2020 [17]. The Army is investing in its High Energy Laser Mobile Demonstrator, a ground-based system primarily intended to counter indirect fire and UAVs and is capable of being transported by a relatively small armored vehicle such as a Stryker personnel carrier [18]. All of these projects underline the increased interest in HEL weapons, particularly solid-state systems, and the great advances that have been made in HELs since the first laser was invented in 1960.

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III. CHARACTERIZATION OF HIGH EXPLOSIVE TARGETS

Land mines, UXO, IEDs, and most other high explosive devices share the same basic components and principles of operation. It is this similarity that enables a single clearing system, such as a HEL, to be effective against a wide range of potential threats. Accordingly, three different explosive devices serve as target profiles for this research: the TM-83 anti-vehicle (AV) land mine, the PTAB-2.5M high explosive anti-tank (HEAT) sub-munition, and a Composition C-4 based IED. These devices were selected due to how well they characterize each category of munition (surface-laid land mine, UXO, and IED, respectively), current usage, and variety in construction and materials. This chapter will describe the fundamental components of high explosive devices and will detail the defeat mechanism selected for their removal using a HEL.

A. COMPOSITION

Explosive devices generally consist of four basic components; the detonator, the booster charge, the main charge, and the casing. The detonator is the component that triggers a detonation and can come in many forms. Conventional munitions such as bombs and artillery shells that are commonly found as UXO contain a fuze or a timer for this purpose. Land mines and IEDs make use of switches, sensors, wired detonators, or wireless receivers (Figure 6). Regardless of the form, the detonator is ultimately what initiates an explosive reaction in the booster charge.

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Figure 6. IEDs Captured in Afghanistan with Detonators Mounted on Top. Source: [19].

Booster charges are an intermediary material between the detonator and the main charge. Detonators usually do not provide enough energy to trigger an explosive reaction in the most common types of high explosives, so a less stable explosive is used to create a shock wave that will detonate the main charge. The main charge is what gives a device its explosive power and is usually the largest internal component (Figure 7). Common military-grade explosives used for main charges include trinitrotoluene (TNT), research department explosive (RDX), and high melting explosive (HMX). Perhaps the most commonly used combination of these explosives is Composition B-3, which is a 60% RDX and 40% TNT mixture [20].

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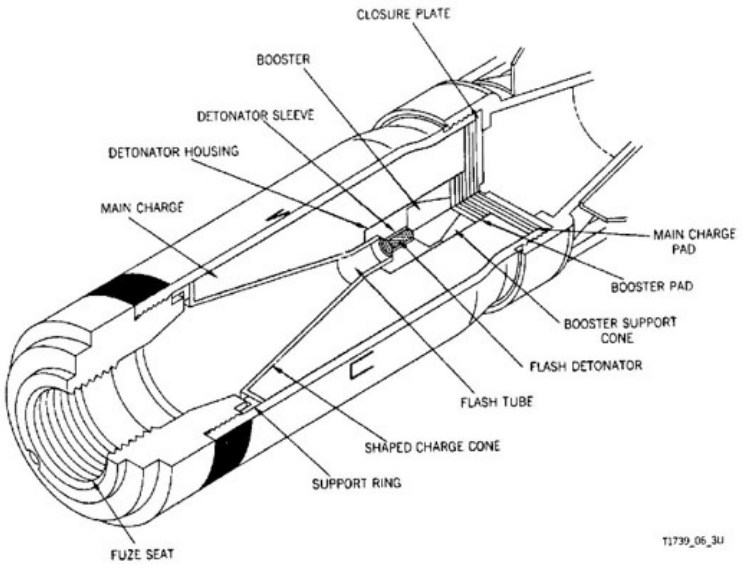


Figure 7. Cross-sectional Diagram of a PTAB-2.5M HEAT Sub-munition Depicting Booster and Main Charges. Source: [21].

The final basic component found in most explosive devices is the casing. The number of combinations of materials, shapes, and fragmentation patterns found in casings is effectively limitless. Metal casings provide durability and double as shrapnel when the device detonates, but are easier to detect with the magnetic scanners commonly employed by clearing assets. Conversely, plastic casings are difficult to detect, but require more care during handling and must be filled with some form of shrapnel to maximize effectiveness. Of particular note is the modern use of the explosively formed penetrator (EFP), which is a circular concave piece of malleable metal (usually copper) that is mounted over the main charge. Upon detonation, the explosive forces reshape the metal into a molten dart-like projectile capable of penetrating most types of armor. The TM-83 AV land mine is an example of a device that produces an EFP (Figure 8).

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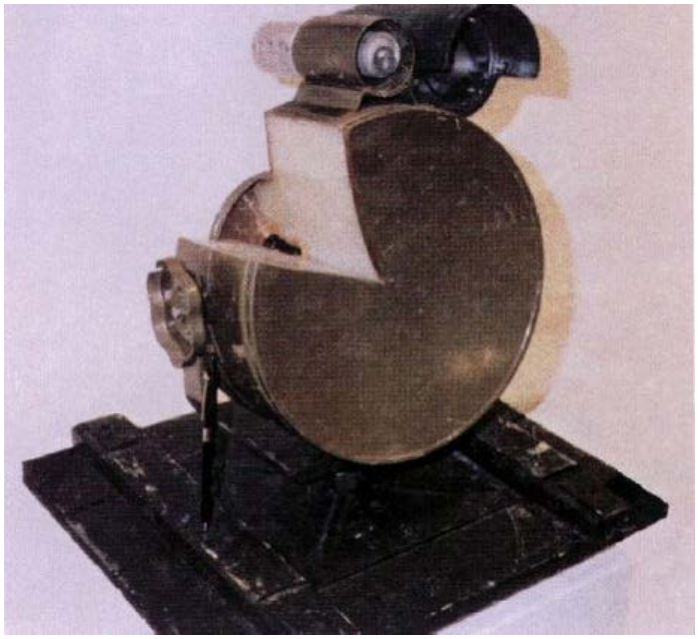


Figure 8. TM-83 AV Land Mine with Triangular Cutout Exposing Main Charge. Source: [22].

B. HIGH EXPLOSIVE PROPERTIES

The potential energy of an explosive material is analogous to a boulder resting on the edge of a cliff [23]. Initially, a great deal of energy is expended to move the boulder to this position. For explosives, this is referred to as the heat of formation. Once the boulder is at the edge, only a slight nudge is required to push it over and expend the high potential energy stored within. Accordingly, this nudge is known as the activation energy. The relatively rapid expenditure of energy during this detonation is what differentiates explosives from other high-energy materials such as wood, coal, or oil. In the case of coal versus HMX, the power output is a difference of nine orders of magnitude [23].

In this research, the "nudge" is the defeat mechanism used to destroy the designated targets. The HEL acts as an energy pump by depositing a portion of its energy in the form of heat on the surface of the target (the rest of its energy is reflected depending on the surface material). As the HEL deposits more energy over time, the temperature of the casing rises as heat diffuses through it and ultimately reaches the main charge contained

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within. The heat transfer in both the casing and main charge is easily modeled with the well-known heat diffusion equation:

$$\rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (\kappa \nabla T) \tag{1}$$

where ρ is the density of the casing or main charge, c_p is the specific heat capacity, T is the temperature, and κ is the thermal conductivity. Once the interface between the casing and main charge reaches an explosive property known as the autoignition temperature, the main charge will begin expending its potential energy in a manner similar to the falling boulder. While this mechanism will not produce a full detonation, it will render the explosive device ineffective by forcing the main charge to deflagrate [24]. This removal method can actually be more favorable than full detonation if the explosive device is located in close proximity to valuable infrastructure or populated areas.

C. EFFECT OF HEATING

As heat deposited by the laser beam accumulates at the interface between the casing and the main charge, the explosive material will undergo a chemical reaction and release its stored potential energy in the form of additional heat. The rate at which the explosive releases heat as it undergoes the chemical reaction is known as the thermal rate constant. While the constant is initially a relatively small value, it will grow exponentially as the heat deposited by the HEL combines with the accumulating heat emitted by the explosive. The empirical Arrhenius Law is probably the oldest yet best-known model for expressing this thermal rate constant *k(T)* [25]:

$$k(T) = Ae^{-\frac{E}{k_B T}} \tag{2}$$

where A is a pre-exponential constant, E is the activation energy, k_B is the Boltzmann constant, and T is the temperature of the explosive material. The pre-exponential constant is unique to a given chemical reaction and is often determined experimentally with units similar to the thermal rate constant (with magnitude typically on the order of 10^{10}) [26]. When the temperature is low, this pre-exponential factor is suppressed. However, as the temperature of the explosive rises relative to its activation energy, the extremely large pre-exponential factor causes the thermal rate constant to increase dramatically. The complete

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model for predicting heat transfer in an explosive material is a combination of both the heat diffusion equation (Equation 1) and the Arrhenius Law (Equation 2) and appears as:

$$\rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (\kappa \nabla T) + \rho Q Z e^{-\frac{E}{k_B T}} \tag{3}$$

where Q is the heat of decomposition and Z is the characteristic reaction rate of the explosive [27]. The product of the explosive's density, heat of decomposition, and characteristic reaction rate is the pre-exponential constant A annotated in Equation 2. The Arrhenius term acts as a heat source in the heat diffusion equation. Once the temperature T reaches the autoignition temperature, the Arrhenius term dominates and acts as a "positive feedback loop," producing a "run-away" reaction. The predicted autoignition temperature for Composition B-3 is approximately 800-K [20], while the predicted value for Composition C-4 is approximately 650-K [20].

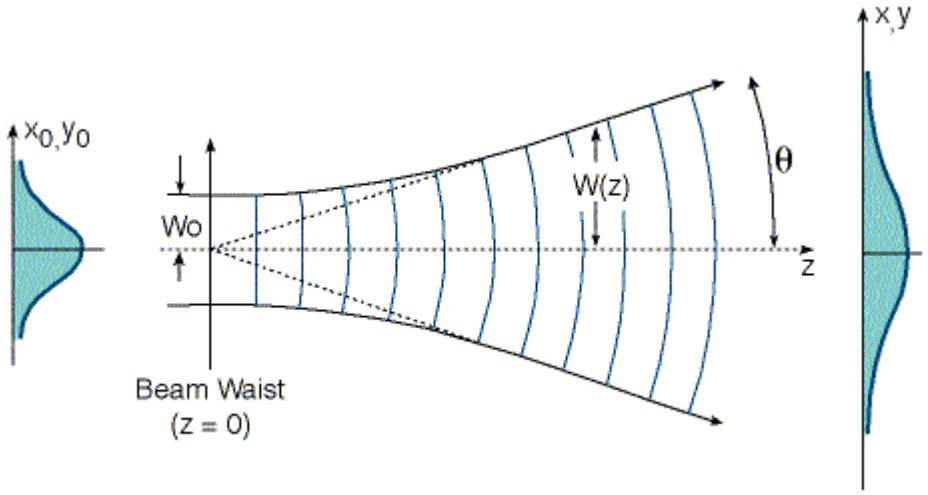
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IV. LASER BEAM PROPAGATION THROUGH THE ATMOSPHERE

The environment through which a laser beam propagates can dramatically affect the beam's properties from origin to termination. The Earth's atmosphere is full of molecules and particles that can influence a laser beam, and this fact must be accounted for in any system that intends to propagate over a meaningful distance. This chapter will describe those effects as well as their impact on an airborne laser system engaging ground-based targets.

A. VACUUM PROPAGATION

Before considering the effects of atmosphere on beam propagation, it is first necessary to understand how a beam propagates under ideal conditions. Due to the wave nature of light, any light source directed through an aperture will experience divergence. This will cause the radius of the beam, known as the beam waist, to increase in accordance with the divergence angle (Figure 9).



The divergence angle is represented by θ. Note the Gaussian profiles in the margins depicting the decrease in beam irradiance as propagation distance increases.

Figure 9. Beam Waist *w* as a Function of Propagation Distance *z*. Source: [28].

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The beam waist size, divergence angle, and beam wavelength determine the quality of the laser beam. This parameter is known as the beam quality factor and is calculated with the equation:

$$M^2 = \frac{w_0 \pi \theta}{4\lambda} \tag{4}$$

where M^2 is the beam quality factor, w_0 is the beam waist size, θ is the divergence angle, and λ is the beam wavelength [29]. A beam quality factor of 1 indicates an ideal Gaussian irradiance profile. However, current lasers are not perfect and will produce beams with a factor greater than 1. The greater the value of the beam quality factor, the less irradiant the laser beam will be at the target. For this research, a beam quality factor of 3 is used for simulations in order to produce more realistic results.

The size of the laser beam director itself can also significantly impact the qualities of the beam. The effect of beam director diameter on beam waist can be approximated with the equation:

$$w_0 \approx M^2 \left(\frac{2\lambda z}{\pi D} \right) \tag{5}$$

where w_0 is the beam waist size, M^2 is the beam quality factor, λ is the beam wavelength, z is the propagation distance, and D is the beam director diameter [30]. As the beam director diameter increases, the beam waist will decrease and produce a more irradiant beam profile at the target. However, regarding the use of lasers on airborne platforms, it is necessary to keep the beam director as small as possible due to limited space availability and payload capacity. In these simulations, the beam director diameter is set at 25 cm in order to accurately represent a system capable of being mounted to a UAV.

B. EXTINCTION

Atmospheric extinction of a laser beam is the result of two separate phenomena. The first of these is absorption, in which atmospheric molecules and aerosol particles absorb incoming photons and thereby decrease the irradiance of the laser beam. Absorption is dependent on the wavelength of the photons and the types of particles present. Since Earth's atmosphere is composed of numerous varieties of molecules and particles, there are only a few narrow wavelength bands that are favorable for beam propagation. Many

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solid-state lasers currently designed for directed energy applications have wavelengths near 1 μm, which is within a "window" in which light propagates with minimal absorption.

The second effect that causes beam extinction is scattering. Particles in the atmosphere with sizes comparable to the wavelength of light will deflect light rays in random directions. This effect is evident in white clouds, in which water vapor scatters incident light with wavelengths across the visible spectrum. Particles generated as dust or by pollution also scatter light, resulting in a hazy atmosphere (Figure 10).



Figure 10. Haze Created by Atmospheric Scattering of Light by Aerosol Particles. Source: [31].

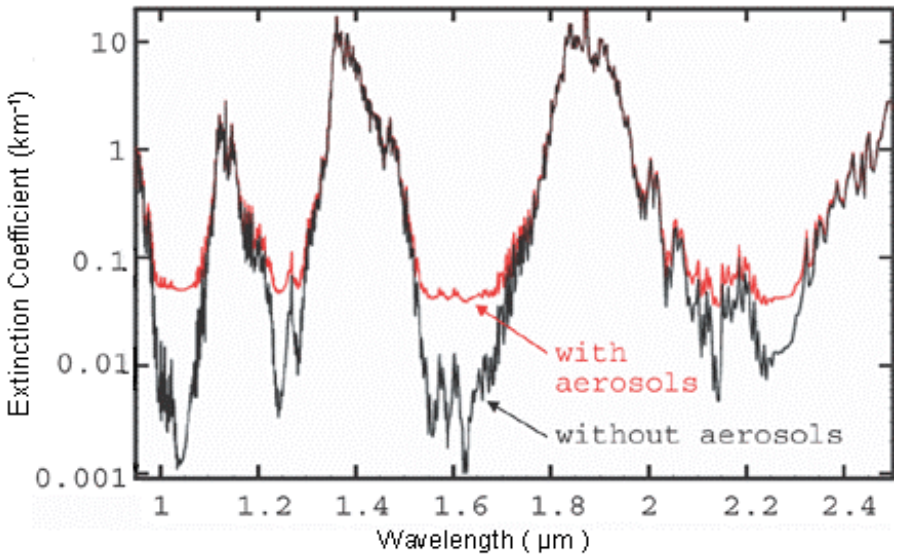
Laser beam extinction is modeled as an exponential decay. The Beer-Lambert Law provides the mathematical foundation with the function:

$$P(z) = P_0 e^{-\varepsilon z} \tag{6}$$

where *P(z)* is the beam's power as a function of propagation distance, *z* is the propagation distance, P_0 is the initial power, and ε is an extinction coefficient that accounts for wavelength-specific scattering and absorption information and also depends on location, time of day, aerosol concentration, etc. [32]. For the intended application of defeating explosive devices, the extinction coefficient must be as small as feasible, which is largely

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accomplished by selecting a beam wavelength of approximately 1 μm that tends to minimize extinction (Figure 11).



The red plot includes the presence of aerosols. Note the relatively low extinction coefficient values at approximately 1 μm and 1.6 μm.

Figure 11. Effect of Wavelength on Beam Extinction. Source: [33].

C. TURBULENCE

As the sun's radiation heats the atmosphere and Earth's surface, it creates differences in air temperature. Accordingly, these cells of air have different densities and pressure that alter their optical indices of refraction. When a light ray transmits between different cells, variations in the indices of refraction cause the light ray to deflect. In addition to this deflection, turbulent cells that are smaller than the laser beam's cross-sectional area will cause portions of the beam to diverge. This divergence results in a loss of coherence, as portions of the beam become out of phase and destructively interfere with each other. The ultimate consequence of turbulence is a distorted, larger, and less intense time-averaged beam spot on the target.

Turbulence is quantified by the refraction structure parameter C_n^2, which is a measure of the change in the air's index of refraction over distance:

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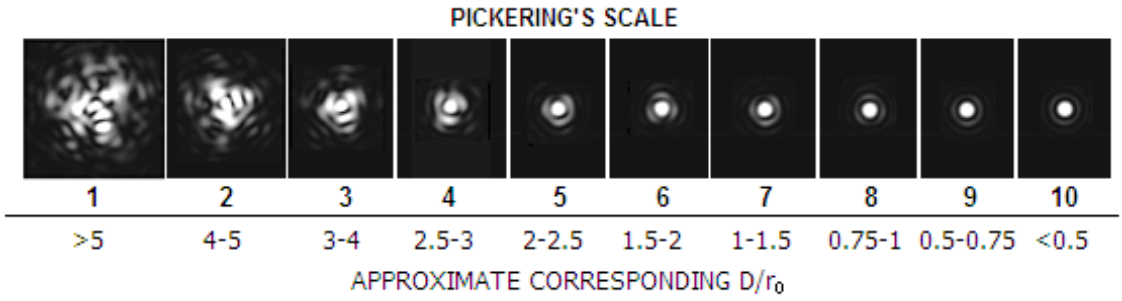
$$C_n^2 = \frac{\overline{[n(x) - n(x+r)]^2}}{r^{2/3}} \quad (7)$$

where *n(x)* is the index of refraction and *n(x+r)* is the index of refraction at range *r* [34]. A value of 10^{-14} $m^{-2/3}$ indicates stronger turbulence, while a value of 10^{-17} $m^{-2/3}$ indicates weaker turbulence.

The refraction structure parameter is of little analytical value by itself, but can be used to estimate the effect of turbulence on beam coherence at the target. The Fried parameter is an estimation of the diameter over which a laser beam maintains transverse coherence throughout a desired propagation distance:

$$r_0 = [0.423(2\pi / \lambda)^2 \int_0^z C_n^2(z)dz]^{-3/5} \quad (8)$$

where r_0 is the Fried parameter, λ is the wavelength, and z is the propagation distance [32]. This formula incorporates C_n^2 along the beam path. As the value of C_n^2 increases, the value of the Fried parameter decreases. For example, given a beam wavelength of 1 μm, a constant C_n^2 value of 10^{-14} $m^{-2/3}$, and a propagation distance of 3 km, the Fried parameter would be approximately 2.4 cm. Under these conditions, any laser beam that is greater than 2.4 cm at its source (established by the beam director diameter) will be significantly affected by turbulence (Figure 12).



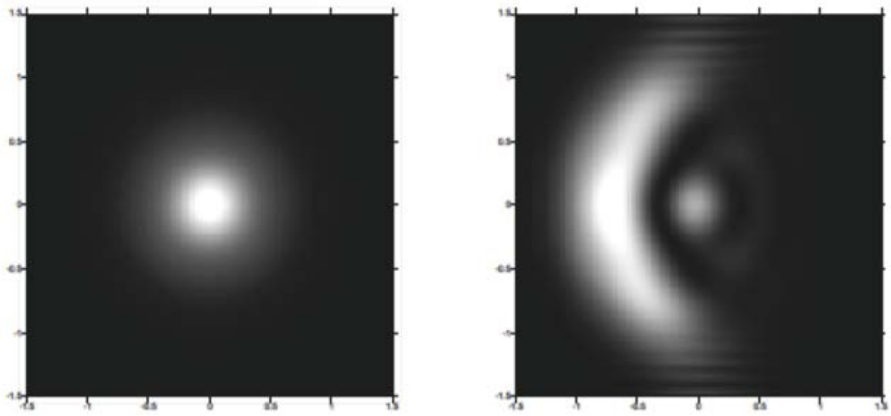
Pickering's scale provides a visual approximation of the relationship between the Fried parameter and beam director diameter (denoted as *D*). Each scale number corresponds to a representation of a beam cross-sectional area. As D/r_0 becomes greater than 1, the beam's area will increase and break apart.

Figure 12. Pickering's Scale. Source: [35].

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D. THERMAL BLOOMING

A laser beam itself can modify the properties of the air it is propagating through. As photons are absorbed by aerosols and molecules along the beam path, energy is released in the form of heat. This heat in turn alters the air's index of refraction by causing the air to expand and become less dense. As the beam continues to propagate through this modified air, it will begin to diverge more quickly than would otherwise be expected via this thermal blooming process [32]. This phenomenon is highly susceptible to temperature-altering effects such as wind. If wind blows across a beam path that is experiencing thermal blooming, it will cool the incident side of the beam and push heated air to the opposite side. The beam will then "bend" into the cooler, and therefore denser, side of the "lens" (Figure 13).



The image on the left depicts a beam profile without wind, while the image on the right depicts beam "bending" caused by a wind blowing from left to right.

Figure 13. Effect of Wind on Thermal Blooming. Source: [36].

Thermal blooming is roughly characterized through a dimensionless thermal distortion factor, N_t:

$$N_t = \frac{-(dn/dT)}{n\rho c_p} \times \frac{KIz^2}{vr} \tag{9}$$

where n is the air's index of refraction, (dn/dT) is the rate of change in the index of refraction as a result of temperature change, ρ is the air's density, c_p is the heat capacity of

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the air, *K* is the absorption coefficient of the air, *I* is the laser beam's irradiance without thermal blooming, *z* is the distance of propagation, *r* is the beam's radius, and *v* is the crosswind's speed [32]. A larger thermal distortion factor indicates greater beam distortion and decreased intensity at the target. If the crosswind speed or beam radius increase, the thermal distortion number will decrease. However, increasing beam irradiance or propagation distance has the unwanted effect of increasing the thermal distortion number. Figure 14 depicts the effect that the thermal distortion number has on the relative intensity of the laser beam.

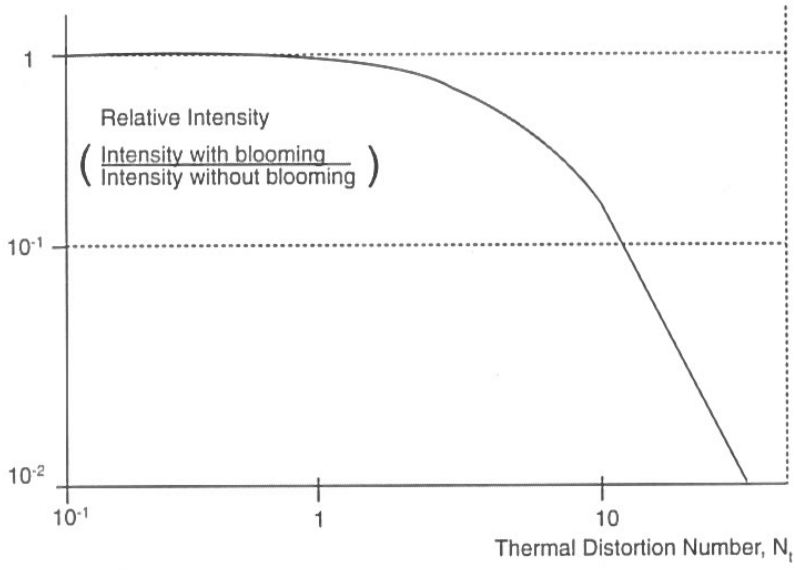


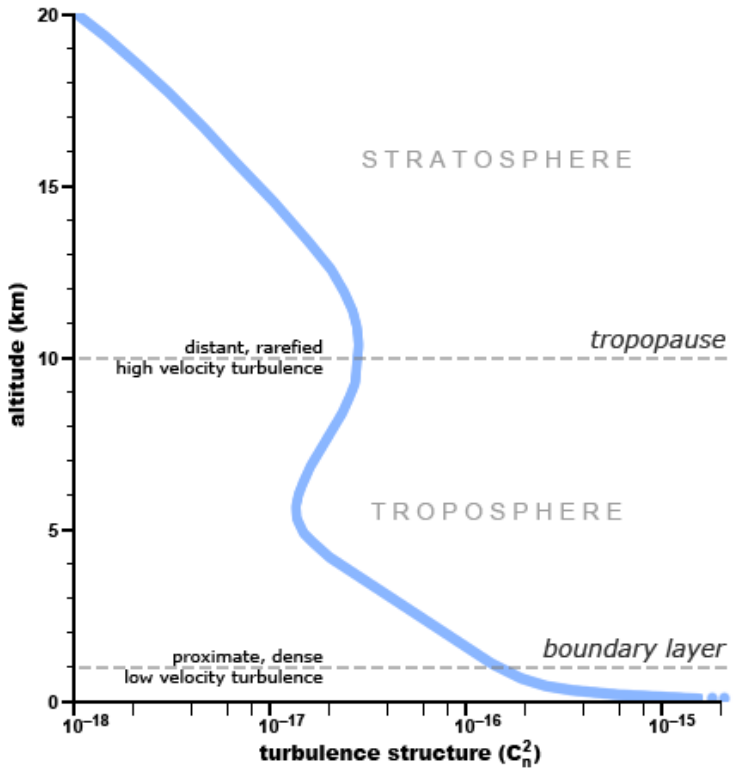
Figure 14. Relationship between Thermal Distortion Number and Relative Intensity. Source: [32].

E. ELEVATION EFFECTS

Using a HEL on an airborne platform to engage ground-based targets has several advantages relative to ground-based lasers. Turbulence is often dramatically reduced at elevation since the platform is further from the ground, and consequently, further from heat sources and surface effects (Figure 15). Although the laser beam is still required to propagate through low-altitude atmosphere as it nears the target, the path over which turbulence is a factor is greatly diminished and restricted to the terminal portion. A ground-

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based laser beam must suffer the effect over its entire path, including at the beam's origin where it has the greatest effect on the rest of propagation.



Smaller UAVs operate at lower altitude (approximately 2 km) while larger UAVs operate at higher altitude (between 15 km and 18 km).

Figure 15. Effect of Altitude on Atmospheric Turbulence. Source: [37].

Additionally, air density decreases with altitude, which exponentially decreases absorption and increases beam irradiance at the target. The desire to use UAVs as the airborne platform of choice in this research also introduces an advantage regarding thermal blooming. All UAVs currently employed by the U.S. Army are fixed wing aircraft that cannot remain stationary in flight. This means that any laser beam originating from a UAV platform will constantly be moving through unheated air and experience a relative wind proportional to the velocity of the UAV itself. These two factors effectively eliminate thermal blooming as a consideration for the intended application of this research.

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V. METHODOLOGY

This research simulates air-to-ground laser engagements of ground ordnance using computer-based MATLAB code with user-defined parameters. This chapter will address the variety of parameters used and the reasons for their selection. It will also identify existing simulations used, upon which this research is partially based.

A. TARGET PARAMETERS

Three different types of ground ordnance are modeled in this research: a land mine, IED, and piece of UXO. While it would be impossible to model every explosive device currently in use, the established target profiles emphasize generalized distinctions between the three types. The fundamental differences between these categories are target geometry, outer casing, and explosive material.

1. Geometry

All three types of target have myriad geometries available to choose from. However, the problem can be simplified when approached from the context of this research. Any laser beam intentionally aimed at an object of known range will be deliberately focused in order to reduce its effective area on the target. This focus spot acts as a source term for the heat diffusion equation previously mentioned in Chapter III (Equation 1). The profile of the laser beam is assumed to be a Gaussian distribution modeled by the equation:

$$S = I_{pk}(1-R)e^{-\frac{r^2}{w_{tot}^2}} \tag{10}$$

where S is the source term for the heat diffusion equation, I_{pk} is the peak irradiance of the laser beam, R is the reflectivity coefficient of the target's surface, r is the radial coordinate of the profile, and w_{tot} is the beam waist size. For these simulations, the reflectivity coefficient is assumed to have a value of 0.1, since most explosive devices are intentionally coated in dark non-reflective materials that conceal them within surroundings.

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Ideally, the beam waist is minimized at the target due to focusing (although this can be affected by atmospheric conditions). As a characteristic example, the circular face of the TM-83 AV land mine has a radius of 12.5 cm, with a surface area of approximately 490 cm^2 [22]. Assuming that a typical laser beam has a waist of 3 cm at the target and a cross-sectional area of approximately 28 cm^2, it is reasonable to neglect the effect of geometry on the target's heating since the beam area constitutes less than 6% of the total irradiated surface. Therefore, a standard geometry is used for all three target types during simulations, which consists of a right circular cylinder of 10 cm radius and 10 cm height, with one circular surface being irradiated by the laser beam at its center.

2. Outer Casing

There is a wide variety of casing materials used in explosive devices, which principally reduces to the distinction of plastic versus metal. As previously discussed, metal casings provide for safer handling of the device and have the added effect of increasing shrapnel upon detonation. Steel is a commonly used metal for this purpose and is the material used in many military-grade munitions. Due to this fact, it is appropriate to select steel as the outer casing for the land mine and UXO target profiles, since both are characteristically employed by military forces. Since the thickness of these casings is highly variable between specific devices, a generalized thickness of 5 mm is used for the land mine profile, while a thickness of 2.5 mm is used for the UXO profile. As the casing material is the same in both of these profiles, the simulation results illustrate the effect that casing thickness has on the required dwell times.

Plastic casings are more difficult to detect on the battlefield and are readily available to amateur explosives manufacturers, such as the insurgents and terrorists that employ IEDs. Although IEDs can and have been encased with metal, high density polyethylene is used in this research as the outer casing for the IED profile in order to demonstrate the effect that casing material has on required dwell times. A generalized thickness of 5 mm is used for the IED profile in order to make it comparable to the steel-encased land mine profile, also of 5 mm thickness. Table 1 includes a comprehensive listing of the all outer casing thermal property values used during actual simulations.

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Table 1. Outer Casing Thermal Properties. Source [38].

Material	Density, ρ [kg/m^3]	Thermal Conductivity, κ [W/(m*K)]	Heat Capacity, c_p [J/(kg*K)]
Steel (Plain)	7854	60.5	434
Polyethylene (High Density)	959	0.43	2000

3. Explosive Material

Since World War II, RDX is one of the most commonly used components in military-grade high explosives. It is a majority ingredient found in several Composition A, B, and C mixtures widely used by U.S. armed forces (up to 98.5% in Composition A-3, 60% in Composition B-3, and 95% in Composition C-3) [20]. Its thermochemical properties are widely studied and publicized, making it a reasonable assumption that most professional and amateur military forces employ it or its derivatives to some extent. This fact makes it an ideal material to include in generalized models of all three target types, and the thermal property values needed to do so are included in Table 2. These parameters are discussed in the context of the heat diffusion equation in Chapter III (Equation 3).

Table 2. RDX Thermochemical Properties. Source [39].

Density, ρ [kg/m^3]	Thermal Conductivity, κ [W/(m*K)]	Heat Capacity, c_p [J/(kg*K)]	Heat of Decomposition, Q [MJ/kg]	Activation Energy, E [kJ/mol]	Characteristic Reaction Rate, Z [s^{-1}]
1800	0.29	2093	2.09	199	$10^{18.5}$

B. ATMOSPHERIC PARAMETERS

In order to establish the atmospheric conditions under which to conduct simulations, it is necessary to consider climate type and weather. Since the combination of these two factors result in a countless number of geographic locations to model, it is necessary to also consider the likelihood that a particular region could become the home of

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an armed conflict within the near future. Seoul, South Korea and Kandahar, Afghanistan provide highly contrasting climatic conditions with potential for continuing and future military operations. Seoul possesses a temperate climate [40], which is well distinguished from the arid desert climate of Kandahar [41]. The contrast provided by these locations demonstrates the effect that climate has on the required target dwell times.

With climates established, it is also necessary to specify the exact weather conditions under which the simulations will be performed. In order to exemplify the extremes under which engagements could occur, clear and precipitous weather conditions are modeled. Clear weather enables ideal laser beam propagation, while the presence of large water droplets models the most non-ideal condition under which to engage ground ordnance with a laser. As an intermediary, hazy weather conditions are modeled in order to demonstrate the effect of aerosols on the engagements. All regional atmospheric properties are acquired from the Laser Environmental Effects Definition and Reference (LEEDR) database created at the Air Force Institute of Technology.

C. LASER AND PLATFORM PARAMETERS

Bearing the combined effect of target and atmospheric parameters in mind, the laser and platform configuration is critical in achieving a successful simulated engagement. The four most important parameters in this regard are the laser beam quality, laser beam wavelength, platform altitude, and laser power output.

1. Laser Beam Quality and Wavelength

As previously discussed, laser beam quality has a significant impact on the beam's irradiance at the target. A beam quality factor of 3 is used in these simulations to model a realistic laser. Atmospheric absorption of laser energy is highly dependent on the laser's frequency. In order to minimize absorption, a lasing wavelength of 1.0642 μm is used in these simulations. While other wavelength "windows" exist that minimize absorption, 1 μm is a commonly used wavelength in a multitude of existing solid-state systems.

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2. Platform Altitude

The capabilities of the UAV platform are the driving factor in determining the altitude at which the laser will engage the target. Generally, the greater the size and power of a UAV, the greater its maximum operating altitude, or service ceiling, will be. The RQ-7B Shadow, which is the smallest UAV currently used that could potentially carry a laser system, typically operates at an altitude of 2.4 km to 3 km during the day [42]. Conversely, the RQ-4 Global Hawk, which is likely the largest current UAV that could be used in this capacity, has a service ceiling of over 18 km [43].

Since increasing altitude also increases the amount of atmosphere through which the laser beam must propagate, a minimal altitude is ideal for these simulations. Three different altitudes of 1 km, 4 km, and 7 km are considered in this research to provide a reasonable range of values that could accommodate any tactical concerns. While 7 km is certainly not a limit imposed by existing UAV platform capabilities, it is within the upper limit of altitudes that enable engagement dwell times to remain minimal, which is kept within 60 seconds in this research.

3. Laser Power Output

In order to use an airborne platform for these engagements, the laser system must be kept as compact as possible with regard to SWaP design considerations. This is especially significant when the proposed airborne platform is a UAV, which are typically far smaller and less powerful than their manned counterparts or ground-based platforms. Considering the material properties of the proposed targets and the propagation distances of the laser beam, a power output less than 2.5 kW would likely be insufficient to achieve the desired effect, especially at higher altitude and in non-ideal weather conditions.

Fiber lasers are currently a viable solid-state laser option for producing outputs in the kilowatt range while maintaining beam quality and minimizing weight. For example, IPG Photonics, which specializes in producing industrial cutting lasers, manufactures a 1 μm continuous wave ytterbium fiber system with a scalable power output of 1 kW to 10 kW that weighs less than 380 pounds [44]. Such a system would be ideal for providing the necessary power output while minimizing size and weight. Accordingly, this research

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considers the effects of a 2.5 kW, 5 kW, and 10 kW power output in order to explore a range of powers likely to be mounted onboard a UAV platform.

D. SIMULATION TOOLS

This research relies on a pair of simulation tools developed at renowned defense research institutions. This section will briefly expound on both the inputs and outputs required to incorporate these tools into the simulated engagements.

1. LEEDR

As mentioned, LEEDR is a database of atmospheric conditions that generates regional approximations for the light propagation coefficients discussed in Chapter IV. LEEDR enables the user to control the weather conditions at specified locations using preset values or averages unique to that particular location. For these simulations, regional weather monitoring stations known as "ExPERT" sites in LEEDR will be used. Incheon International Airport is the ExPERT site representative of Seoul, while Kandahar Air Base is the ExPERT site used for the city of Kandahar. With one exception, all weather profiles used are representative of summer weather conditions (July), with the ambient temperature taken as the daily average for that location. The one exception is the precipitous weather profile for Kandahar since southern Afghanistan typically only receives rain during the winter months, which LEEDR bases on average conditions in the month of January. Clear and hazy profiles utilize a relative humidity percentile setting of 50% (i.e., more humid than 50% of measured days, and so represents a typical humidity for that location in January or July). Precipitous profiles utilize a relative humidity percentile setting of 99%. The widely known Hufnagel-Valley model for turbulence [45] was applied to all profiles as well.

Clear weather profiles utilize a Global Aerosol Data Set (GADS) multiplier of 1, which simulates a typical aerosol concentration for that location. The clear weather profiles do not include any cloud or rain effects. Precipitous weather profiles utilize a GADS multiplier of 0.2, the addition of "moderate rain" (a LEEDR setting that corresponds to 12.5 mm per hour), and a cloud layer at 10 km altitude. While a cloud layer at this height is unrealistic, it enables the simulation to demonstrate the effect of rain throughout the path

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of propagation. Otherwise the extinction effect generated by a cloud layer would completely disrupt a laser beam and prevent target autoignition (this effectively makes any simulations performed at 4 km and 7 km platform altitude under precipitous conditions unrealistic and therefore irrelevant). Finally, hazy weather profiles utilize a GADS multiplier of 3, which simulates high aerosol concentration, and do not include any cloud or rain effects. See Table 3 and Table 4 for a complete listing of settings used to generate the LEEDR weather profiles.

Table 3. Seoul Weather Profile Settings.

Weather	Aerosol Model	Aerosol Multiplier	Rain	Season	Temp.	Relative Humidity Percentile
Clear	GADS	1	-	Summer	Daily Avg.	50%
Precipitation	GADS	0.2	12.5 mm per hour	Summer	Daily Avg.	99%
Haze	GADS	3	-	Summer	Daily Avg.	50%

Table 4. Kandahar Weather Profile Settings.

Weather	Aerosol Model	Aerosol Multiplier	Rain	Season	Temp.	Relative Humidity Percentile
Clear	GADS	1	-	Summer	Daily Avg.	50%
Precipitation	GADS	0.2	12.5 mm per hour	Winter	Daily Avg.	99%
Haze	GADS	3	-	Summer	Daily Avg.	50%

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2. ANCHOR

Developed at the Naval Postgraduate School, ANCHOR is a scaling code that simulates the effect of atmospheric propagation on a laser beam. Its inputs include the LEEDR weather profile, laser parameters, and platform conditions. Its outputs include the beam waist size and beam irradiance over an array of cross ranges defined by the user. ANCHOR is capable of modeling the effects of extinction, turbulence, and thermal blooming, although the thermal blooming capability is not used in these simulations for the reasons discussed in Chapter IV. For this research, ANCHOR is used as a preliminary simulation for each test case that provides the laser beam parameters at the target prior to and during heat diffusion.

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VI. RESULTS AND CONCLUSIONS

This chapter discusses the effect that each independent variable has on required dwell times based on results obtained through simulation. The chapter concludes by determining the capabilities of laser systems with different output powers and the potential for mounting them onboard different UAVs based on SWaP requirements.

A. EXTINCTION PROFILES

Climate and weather conditions dramatically alter the atmospheric effects on laser beam propagation. Specifically, the effects of beam extinction are increased from clear to hazy weather, and even further increased when accounting for the presence of precipitation. See Figure 16, Figure 17, and Figure 18 for LEEDR-generated data regarding the extinction coefficient of various weather types in Seoul, South Korea. For reference, see Table 3 and Table 4 for the settings used to generate these figures.

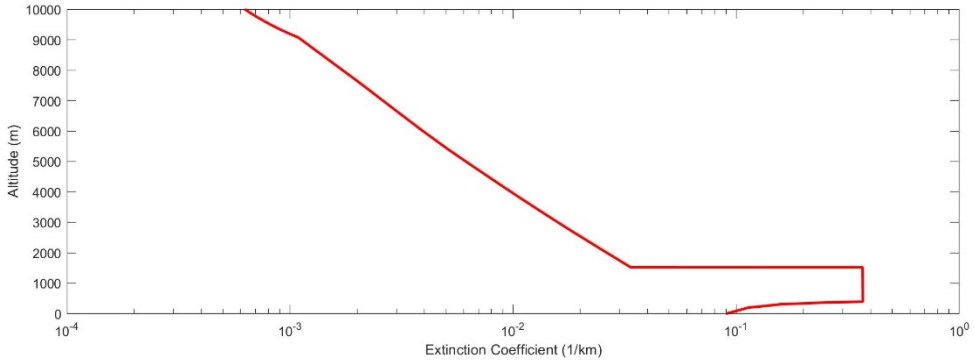
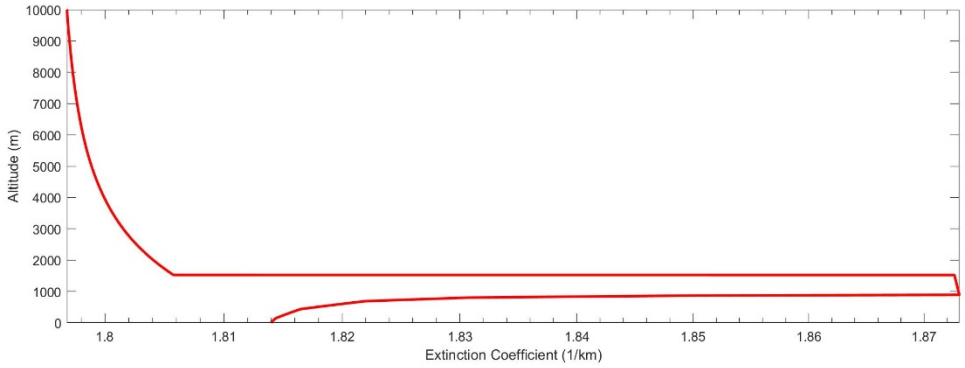


Figure 16. Extinction Coefficient for Clear Seoul Weather Conditions.

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Note the scale used for the extinction coefficient in this figure is linear (unlike the logarithmic scales used Figure 16 and Figure 18).

Figure 17. Extinction Coefficient for Precipitous Seoul Weather Conditions.

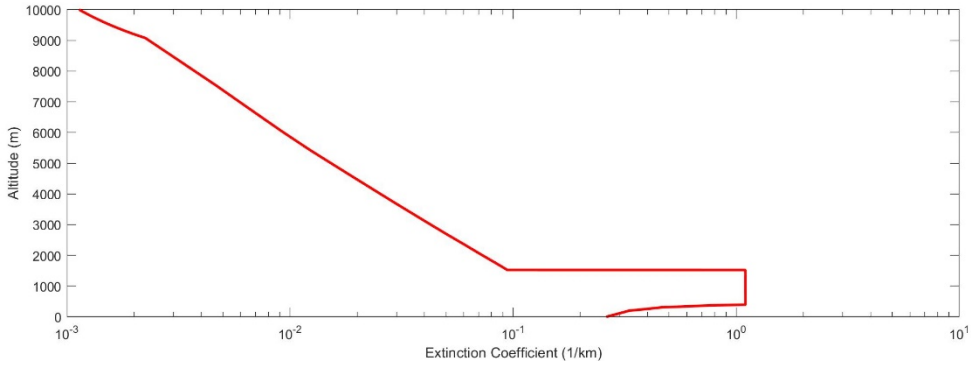


Figure 18. Extinction Coefficient for Hazy Seoul Weather Conditions.

The plots for extinction coefficient share the same general characteristics across both climates and all three weather profiles. From ground-level to an altitude of approximately 1 km (the atmospheric boundary layer), the coefficient value increases. However, just above the boundary layer at approximately 2 km altitude, the coefficient value decreases dramatically and then steadily declines even further with increased altitude. An increase in extinction coefficient value corresponds with a decrease in the amount of laser output power that actually reaches the target in accordance with the Beer-Lambert Law (Equation 6). Of note, the extinction coefficient data for Kandahar, Afghanistan indicates that, for similar weather types, the coefficient value generally remains less than that in Seoul across the platform altitudes simulated. The difference in

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extinction coefficient profiles can be explained by the relative abundance of atmospheric moisture near Seoul and the absence thereof near Kandahar. The extinction coefficient is inversely related to the surface visibility generated by LEEDR for each profile. Table 5 displays the effects that climate and weather type have on surface visibility.

Table 5. Effects of Climate and Weather on Surface Visibility.

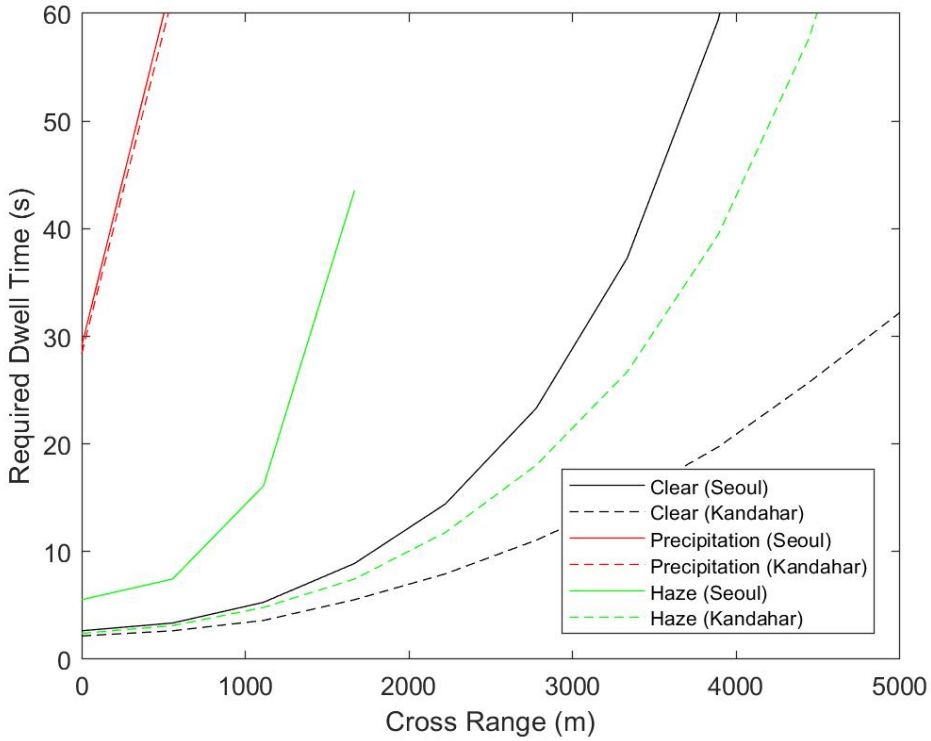
	Seoul, South Korea			Kandahar, Afghanistan		
	Clear	Precipitation	Haze	Clear	Precipitation	Haze
Surface Visibility (km)	23.7	1.64	8.50	33.3	1.64	12.0

The key conclusion to draw with regard to climate type is that, based on the data for these two locations, drier climates will produce more favorable atmospheric conditions for laser beam propagation (not considering the effects of sand storms). This effect is manifested in universally reduced dwell times for targets engaged in an arid desert environment, even when other independent variables are adjusted. In later sections, the Seoul climate profiles will be used to identify the extreme limits under which target autoignition can occur.

B. EFFECT OF WEATHER

To illustrate the effect of weather type on required dwell time, platform altitude, output power, and target type are kept constant. The comparison in Figure 19 displays data taken from 1 km platform altitude, 2.5 kW output power, and land mine target engagements.

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Note that the plot for hazy Seoul weather conditions stops at a cross range of approximately 1.75 km. This is due to the fact that the simulation is unable to achieve autoignition in the target within 60 seconds of dwell time at greater cross ranges.

Figure 19. Simulation Results for 1 km Platform Altitude, 2.5 kW Output Power, Land Mine Target Engagements.

Predictably, clear weather conditions produce the most favorable dwell times. The reduced presence of atmospheric particles corresponds with reduced beam extinction. Hazy weather conditions produce the next lowest dwell times, since the high concentration of aerosols results in increased beam scattering and absorption. Finally, precipitous weather produces the highest dwell times since the presence of large water droplets effectively extinguishes the beam at greater cross ranges.

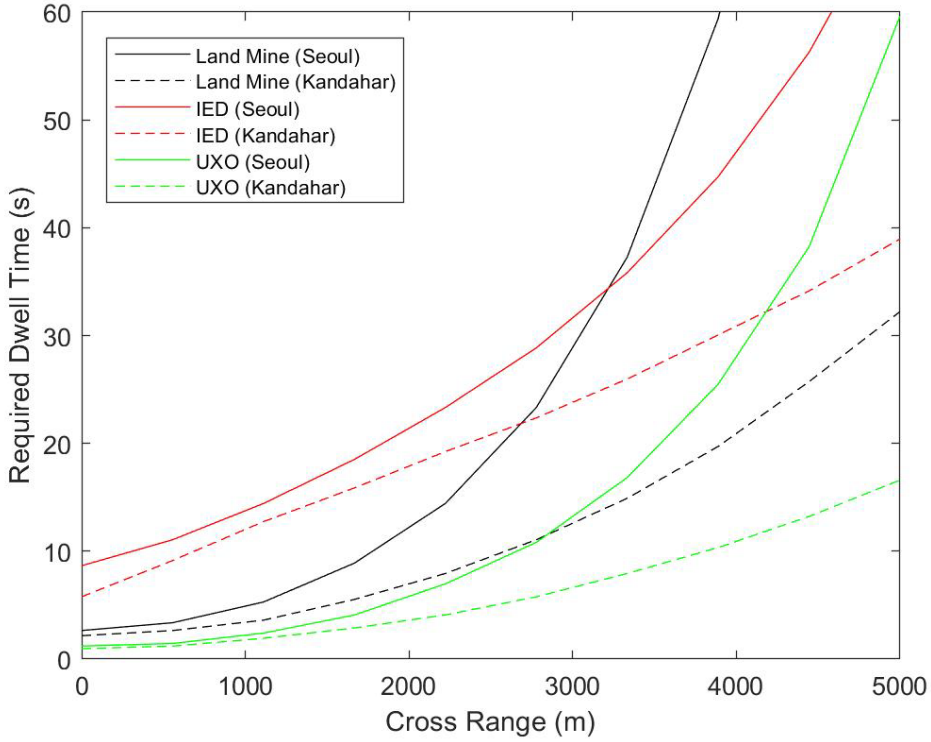
This data supports the conclusion that, although required dwell times are severely degraded, a low-power 2.5 kW laser is still capable of successfully engaging ground ordnance across all three weather types simulated. In precipitous conditions, the cross range is reduced to approximately 500 m for a 2.5 kW laser system. However, in clear

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conditions, the same system can achieve autoignition conditions in the target at a cross range in excess of 5 km.

C. EFFECT OF TARGET TYPE

To illustrate the effect of target type on required dwell times, engagements in clear weather, at 1 km platform altitude, and with 2.5kW output power are considered. See Figure 20 for simulation results.



The plots for land mine and IED targets engaged under similar climate conditions (Seoul) intersect at a cross range of approximately 3.25 km, which indicates that the land mine is a more difficult target to defeat at greater cross ranges under these simulation parameters.

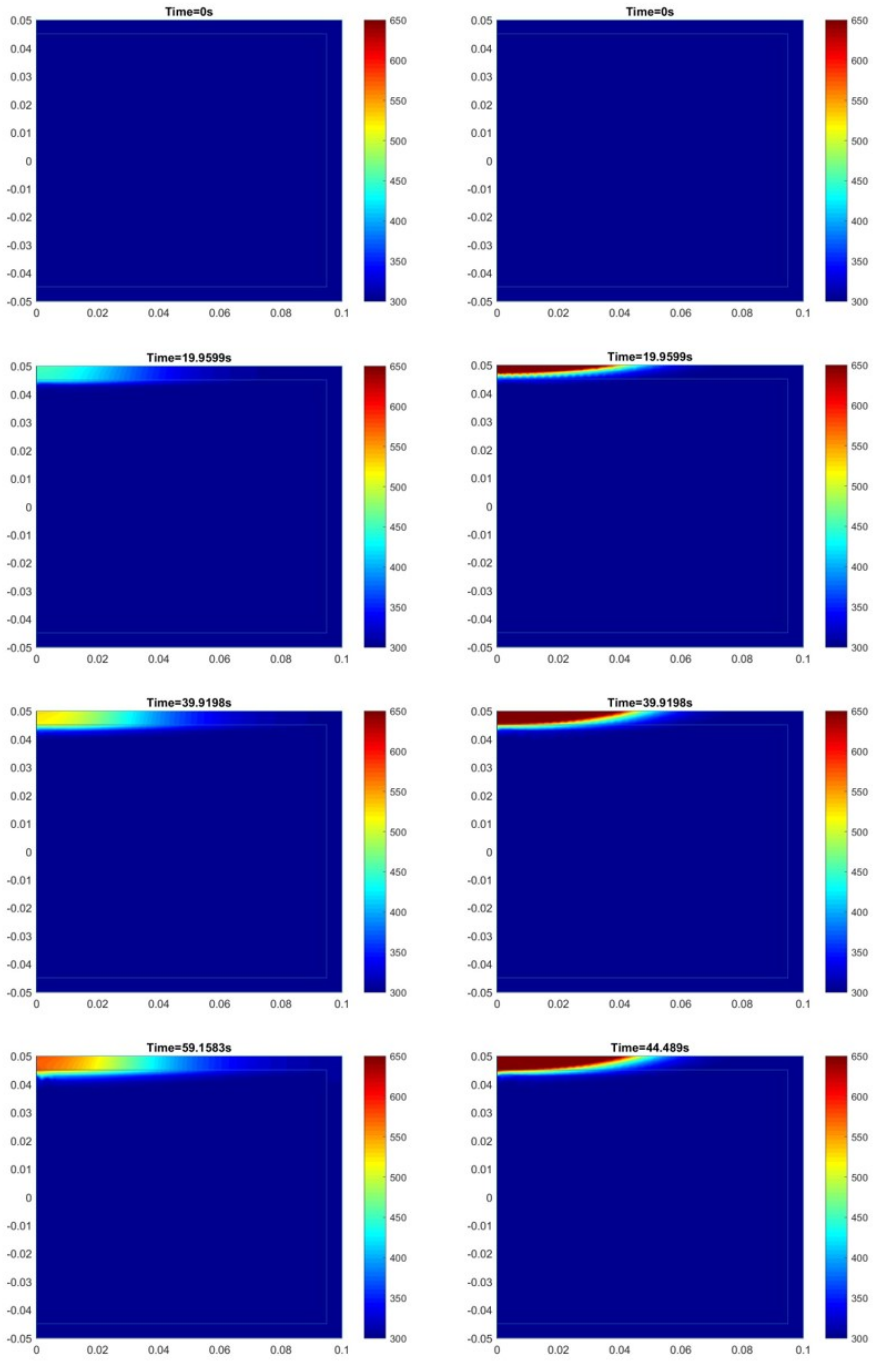
Figure 20. Simulation Results for Clear Weather, 1 km Platform Altitude, 2.5 kW Output Power Engagements.

Outer casing thickness has a significant effect on required dwell time. When comparing the two steel-encased targets, the UXO target profile (2.5 mm of casing) universally produces lower dwell times than the land mine target profile (5 mm of casing).

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Casing material has an even more dramatic effect on dwell times. The dwell times for the IED target profile, with its 5 mm of high density polyethylene casing, increase exponentially with respect to increasing cross range similarly to the steel-encased targets. However, the rate of this exponential increase is noticeably less than that for the steel profiles. Even though the IED target requires greater dwell times at lower cross ranges, the IED target data intersects the land mine target data at a cross range of approximately 3.25 km in Figure 20, after which the IED profile for Seoul actually requires lower dwell times than the land mine profile (also for Seoul). This intersection is indicative of different heating behaviors for both materials as beam irradiance is affected by increases in the propagation path (Figure 21).

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The figures on the left represent heating of a land mine target while the figures on the right represent heating of an IED target. For reference, the axes are in units of meters while the color scale is in units of kelvins. The bottom figure of each target is a depiction of the heating profile immediately prior to autoignition.

Figure 21. Target Cross-sectional Heating in Seoul Climate, Clear Weather, 1 km Platform Altitude, 2.5 kW Output Power, 3.89 km Cross Range Engagements.

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Due to the insulating nature of polyethylene, heat deposited by the laser beam remains relatively local to the beam spot on the surface of the target, where it accumulates and diffuses at a faster rate towards the explosive interface than it does radially outward. However, being a conductive material, steel casing diffuses more heat radially outward from the beam spot. When the beam irradiance is high (i.e., when the spot size is small at shorter cross ranges), the heat diffuses rapidly enough in both directions (towards the explosive interface and radially outward) that the target autoignites. When beam irradiance is low (i.e., when the spot size is larger at longer cross ranges), the radial diffusion prevents enough heat from reaching the explosive interface and autoigniting the RDX in a reasonable amount of time.

Since the melt temperature of high density polyethylene ranges between 383 K and 408 K [46], there is concern that the amount of heat deposited by the laser beam will melt the IED target's outer casing prior to explosive autoignition. However, it is possible to approximate the amount of total energy deposited by the laser beam that would be required to achieve such a state transition. The energy required to melt a material that is being irradiated by a laser beam can be approximated using the equation:

$$E_m \approx H_f \rho \pi w_{tot}^2 l \tag{11}$$

where E_m is the required melt energy, H_f is the heat of fusion (245 kJ/kg for high density polyethylene [46]), w_{tot} is the beam waist size, and l is the material thickness. Conversely, the total energy deposited by the laser beam can be approximated as:

$$E_b \approx I_{pk} \pi w_{tot}^2 t_d (1-R) \tag{12}$$

where E_b is the energy deposited by the beam, I_{pk} is the peak irradiance of the beam, t_d is the required dwell time for autoignition, and R is the reflectivity coefficient of the material. Relating Equation 11 and Equation 12 produces the equation:

$$G \approx \frac{H_f \rho l}{I_{pk} t_d (1-R)} \tag{13}$$

where G is the fraction that relates the energy required to melt the casing material to the total energy deposited by the laser beam. Upon conducting this calculation for a sample of simulations, the percentage is approximated to remain below 10% of the total energy deposited by the laser beam. It is therefore a reasonable assumption to neglect the energy

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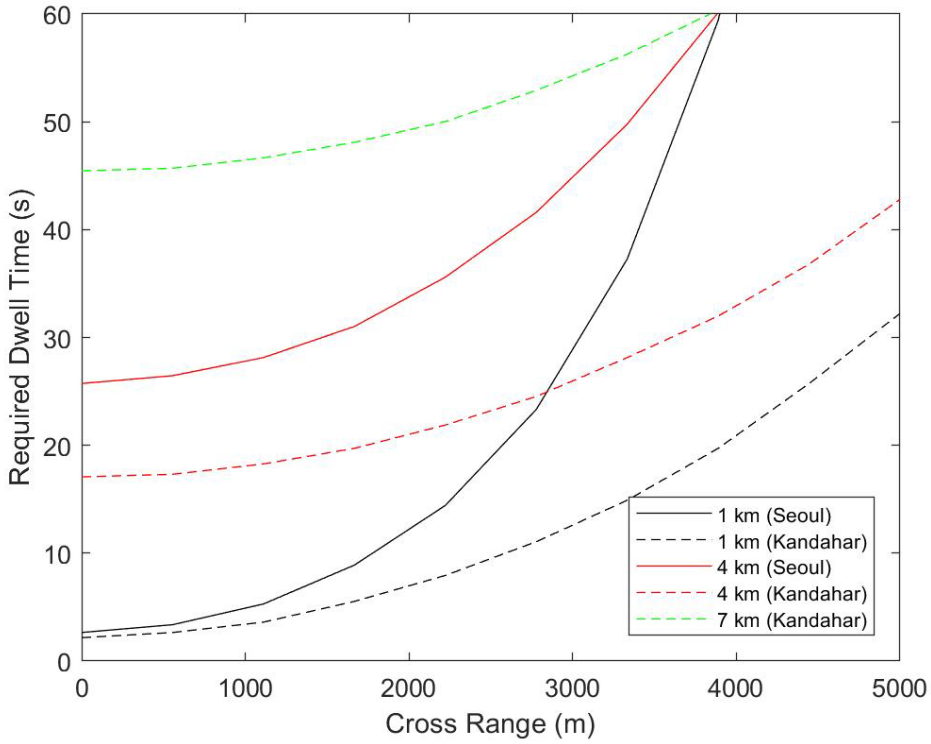
consumed by melting with regard to the time scales and polyethylene casing thickness modeled in these simulations.

In addition to melting, there is concern over the effect imposed by the removal of polyethylene casing while the target is irradiated (either by burning or gravity). In either case, the removal of mass would reduce the time required for the heat front to diffuse in accordance with the heat diffusion equation mentioned in Chapter III (Equation 1). In the case of burning (high density polyethylene itself has an autoignition temperature of approximately 613 K [46]), the energy released by burning the casing would actually contribute to the heat front diffusion. The ultimate effect of casing removal in either situation would be a reduction in the dwell time required to achieve autoignition in the target. Therefore, by not considering the effect of casing removal in this research, the simulation results are likely to be conservative (i.e., higher dwell times) than those that would be achieved through experimentation. Having established that the land mine and IED target types are the most difficult with which to achieve autoignition conditions, they are used as the standards by which to establish the requirements of a laser system intended to defeat ground ordnance.

D. EFFECT OF PLATFORM ALTITUDE

Simulated engagements performed in clear weather, with 2.5 kW output power, and against land mine targets are used to compare the effect of platform altitude on required dwell time (Figure 22).

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The plot for an engagement in Seoul at 7 km platform altitude is not available since the simulated laser beam is unable to achieve autoignition conditions in the target within 60 seconds of dwell time.

Figure 22. Simulation Results for Clear Weather, 2.5 kW Output Power, Land Mine Target Engagements.

There is a universally strong relationship between platform altitude and the required dwell time to achieve autoignition conditions. This can be explained by the increased effects of scattering, absorption, and turbulence as the propagation path of the laser beam increases. Although lower altitudes result in reduced engagement dwell times, they are also disadvantageous for UAV operations. An aircraft operating at low altitude is more vulnerable to anti-aircraft defenses, and relatively slow-moving UAVs are particularly vulnerable. Since low-level cloud layers typically exist below 2 km altitude [47], the only tactical reason for a UAV to operate below this altitude would be the presence of rain clouds (hence why precipitous weather simulations are relevant at 1 km altitude, but not 4 km or 7 km) or in overcast conditions. However, conducting engagements at high altitude places a tax on the laser system's requirements. Of note, the plots for the 1 km platform altitude and 4 km platform altitude engagements in Seoul converge at a cross range of

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approximately 4 km. This can be attributed to the effect of increased extinction coefficient in the atmospheric boundary layer. While the simulation performed at 1 km platform altitude must propagate almost the entire distance with a very large coefficient value, the simulation performed at 4 km platform altitude only propagates through the boundary layer for approximately half of the distance to the target.

E. EFFECT OF OUTPUT POWER

Engagements performed in clear weather, at 1 km platform altitude, and against land mine targets are used to determine the effect of laser output power on required dwell times. See Figure 23 for a visual comparison of the data.

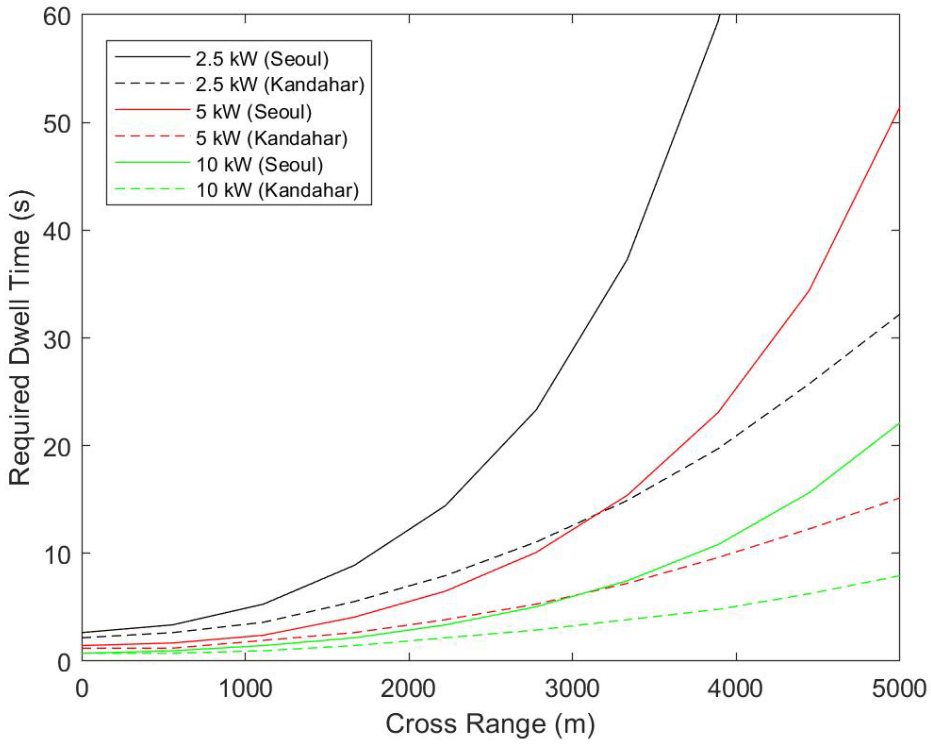


Figure 23. Simulation Results for Clear Weather, 1 km Platform Altitude, Land Mine Target Engagements.

As expected, laser output power plays a significant role in determining the required dwell time. Greater output power means that more energy is deposited at the surface of the

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target and consequentially increases the diffusion speed of the heat front through the outer casing. Of all the independent variables tested in this research, laser output power is the most significant with regard to designing a system capable of achieving target autoignition across all conditions.

As identified in previous sections of this chapter, engagements that occur in a temperate climate (Seoul) are non-ideal relative to those that occur in a drier climate (Kandahar). Additionally, depending on the platform altitude, precipitous and hazy weather are the most disruptive weather conditions regarding laser beam propagation. Finally, land mine and IED target types are the most difficult to defeat. These conclusions enable identification of the maximum capabilities of the three simulated output powers. A temperate climate with precipitous weather at 1 km platform altitude is the most non-ideal situation under which a 2.5 kW output power can achieve autoignition in the two most difficult target types (Figure 24).

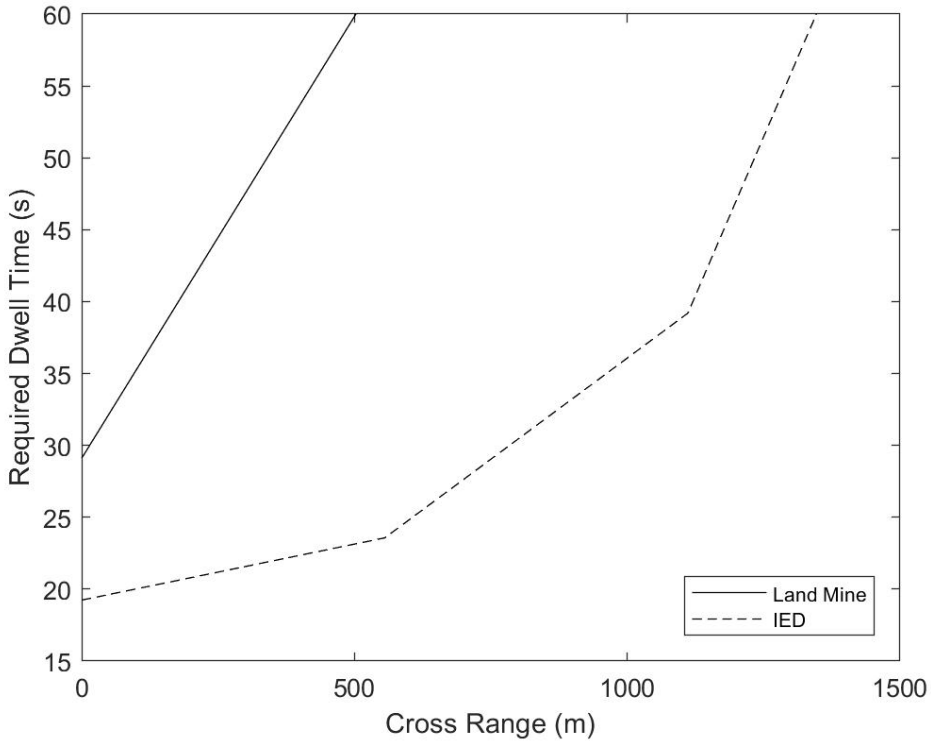


Figure 24. Simulation Results for a Seoul Climate, Precipitous Weather, 1 km Platform Altitude, 2.5 kW Output Power Engagement.

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Increasing the output power of the laser to 5 kW enables target autoignition at a platform altitude of 4 km in hazy weather conditions (Figure 25).

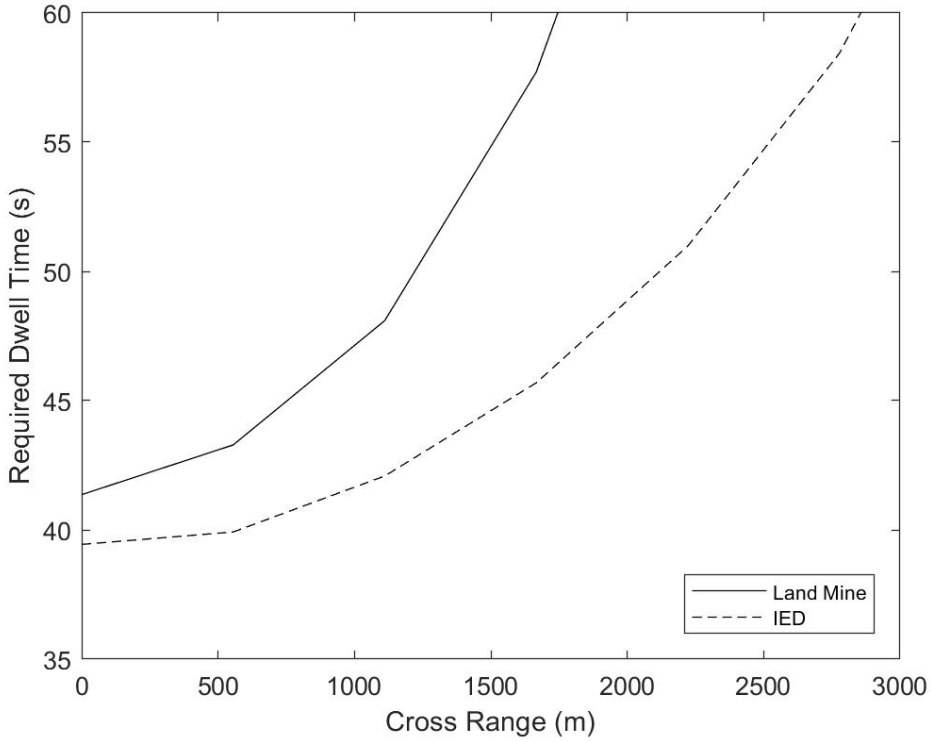


Figure 25. Simulation Results for a Seoul Climate, Hazy Weather, 4 km Platform Altitude, 5 kW Output Power Engagement.

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Finally, the maximum simulated output power of 10 kW enables target defeat at a platform altitude of 7 km in hazy weather conditions (Figure 26).

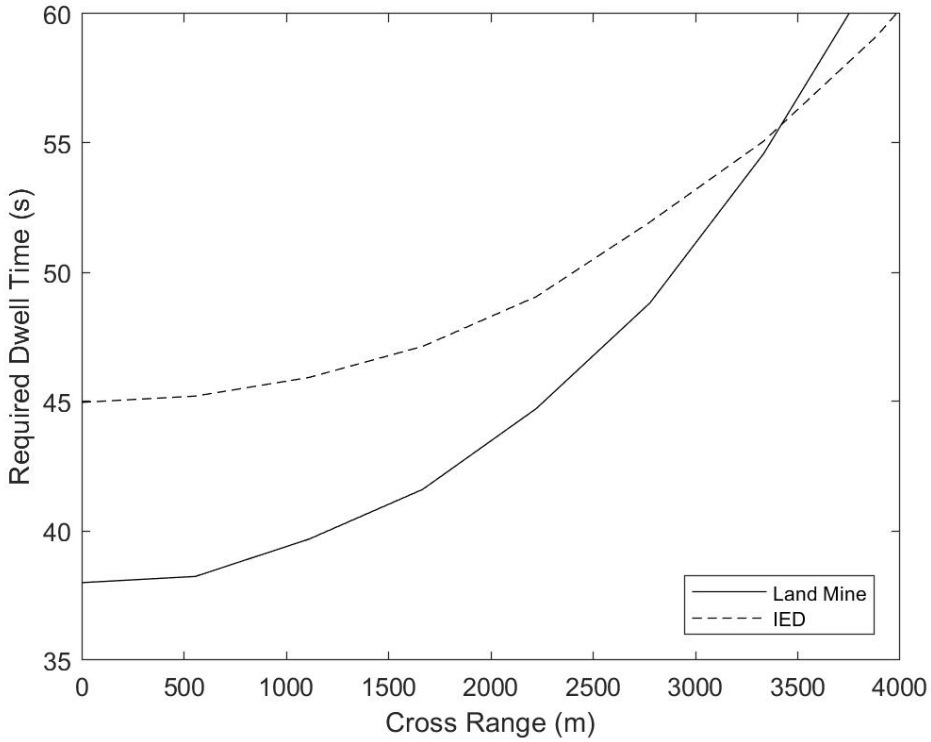


Figure 26. Simulation Results for a Seoul Climate, Hazy Weather, 7 km Platform Altitude, 10 kW Output Power Engagement.

F. CONCLUSIONS

It is feasible to engage and defeat ground ordnance using an airborne solid-state laser. At a platform altitude of 1 km, these simulations indicate that all three tested output powers are capable of achieving autoignition conditions in both climates, across all weather profiles, and against each target type. The most restrictive variable is weather, which effectively limits the platform altitude to the cloud layer during precipitous weather. Additionally, in order to defeat all three target types in clear or hazy weather and in either climate, the minimum required output power increases to 5 kW for 4 km platform altitude engagements and 10 kW for 7 km platform altitude engagements.

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The concept of using UAV-mounted solid-state lasers to defeat ground ordnance bears utility. As an example, the IPG Photonics YLS-3000-SM system produces a similar beam to the one simulated in this research with an output power of 10 kW and contained in a compact 0.95 m^3 package [48]. A similar model listed by the company weighs less than 380 pounds and has a published wall-plug efficiency greater than 50% [44]. This means that the system could be operated with a power source that outputs an average of 20 kW. While these SWaP requirements are too large for smaller UAVs such as the RQ-7B Shadow, they do not supersede the capabilities of mid-size UAVs such as the MQ-1C Gray Eagle, which has a payload capacity of 1,075 pounds [49]. This would enable current U.S. Army forces to maintain a responsive airborne ordnance-clearing asset at the division echelon.

There are many opportunities for expansion of this research. The diffusion of heat to achieve autoignition is just one defeat mechanism particular to a specific target type. Different target types with other defeat mechanisms should be studied in order to grasp the full utility of airborne laser systems. Additionally, expanding the selection of platforms beyond UAVs could create possibilities with regard to increased SWaP availability. Rotary and fixed-wing aircraft could theoretically carry laser systems with greater output power, which in turn increases the feasibility of defeating different target types. As solid-state laser systems continue to become more compact and powerful, it is highly likely that airborne laser weapons will become a fixture on future battlefields.

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APPENDIX. MATLAB CODE

A. HEAT DIFFUSION SIMULATION

```
close all;
% overall properties (cylindrical symmetry)
radius = 0.1;          % [m]
height = 0.1;          % [m]
T0 = 300;              % initial (ambient) temperature [K]
Texplode = 1e5;        % explosion threshold temperature [K]

% outer casing properties
thickness = 0.005;     % [m]
rho1 = 959;            % density [kg/m^3]
k1 = 0.43;             % thermal conductivity [W/(m*K)]
cp1 = 2000;            % heat capacity [J/(kg*K)]

% explosive properties
rho2 = 1800;           % density [kg/m^3]
k2 = 0.29;             % thermal conductivity [W/(m*K)]
cp2 = 2093;            % heat capacity [J/(kg*K)]
Qd = 2.09e6;           % heat of decomposition [J/kg]
Ea = 1.99e5;           % activation energy [J/mol]
Ze = 10^18.5;          % characteristic reaction rate [1/s]

% numerical properties
Hmax = 0.005;          % max mesh size [m]
nt = 500;              % number of time steps to save
RelTol = 0.01;         % relative tolerance (larger = faster but less accurate)
trun = 120;            % total time simulation will run [s]
tengage = trun;        % maximum desired engagement time (must equal trun) [s]

% create model object
thermalModelT = createpde('thermal','transient');
thermalModelT.SolverOptions.RelativeTolerance = RelTol;

% define geometry
r1 = [3, 4, 0, radius, radius, 0, -0.5*height, -0.5*height, 0.5*height, 0.5*height];
r2 = [3, 4, 0, radius-thickness, radius-thickness, 0, -0.5*height+thickness,...
    -0.5*height+thickness, 0.5*height-thickness, 0.5*height-thickness];
g = decsg([r1; r2]','R1+R2',['R1'; 'R2']');
geometryFromEdges(thermalModelT,g);

% plot geometry (for edge, face labeling)
%figure
%pdegplot(thermalModelT,'EdgeLabels','on','FaceLabels','on');

% mesh generation
generateMesh(thermalModelT,'Hmax',Hmax);

%pnodes = thermalModelT.Mesh.Nodes;
%indices = pnodes(2,:) < 0;%0.5*height-thickness;

% plot mesh (for diagnostics)
%figure
%pdeplot(thermalModelT);

% assign material properties (outer casing)
k1Func = @(region,state) k1*region.x;
cp1Func = @(region,state) cp1*region.x;
thermalProperties(thermalModelT,'Face',1,'ThermalConductivity',k1Func,...
                                'MassDensity',rho1,...
                                'SpecificHeat',cp1Func);
```


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```
% assign material properties (explosive)
k2Func = @(region,state) k2*region.x;
cp2Func = @(region,state) cp2*region.x;
q2Func = @(region,state) Qdot(state,region,Ea,rho2,Qd,Ze);
thermalProperties(thermalModelT,'Face',2,'ThermalConductivity',k2Func,...
                                'MassDensity',rho2,...
                                'SpecificHeat',cp2Func);
internalHeatSource(thermalModelT,q2Func,'Face',2);

% initial conditions
thermalIC(thermalModelT,T0);

clear range;
clear tdwell;
q = 1;
while q <= gridRt

    % laser properties
    Ipk = ANCHOROutput.IrrLinearArray(q,1);          % peak irradiance from ANCHOR [W/m^2]
    wtot = ANCHOROutput.Waist_total_longterm(q,1);   % rms width from ANCHOR [m]
    Reflect = 0.1;                                   % surface reflection coefficient

    % boundary condition(s)
    heatFluxFunc = @(region,state) Ipk*(1-Reflect)*exp(-(region.x).^2./wtot^2).*region.x;
    thermalBC(thermalModelT,'Edge',3,'HeatFlux',heatFluxFunc);

    % run model
    tlist = linspace(0,trun,nt);
    S = solve(thermalModelT,tlist);

    % plot final results
    if max(S.Temperature(:))> Texplode
        Tmax = 0;
        it = 1;
        while Tmax < Texplode
            it = it+1;
            Tmax = interpolateTemperature(S,0,0,it);
            Tmax = max(Tmax(:));
        end

        %figure
        %pdeplot(thermalModelT,'XYData',S.Temperature(:,it),'Contour','off');
        %hold on;
        %pdegplot(thermalModelT);
        %title(strcat('time=',num2str(tlist(it)), 's'));
        %hold off;

        %figure
        %pdeplot(thermalModelT,'XYData',S.Temperature(:,it-1),'Contour','off');
        %hold on;
        %pdegplot(thermalModelT);
        %title(strcat('time=',num2str(tlist(it-1)), 's'));
        %caxis([0 2500]);

        %figure
        %pdeplot(thermalModelT,'XYData',S.Temperature(:,end),'Contour','off');
        %hold on;
        %pdegplot(thermalModelT);
        %title(strcat('time=',num2str(tlist(end)), 's'));

    else
        disp('Time limit exceeded...increasing time step');
        if tlist(end) > 60
            break;
        end
        trun = 2*tlist(end);
        continue;
```


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```
    end
    range(1,q) = (q-1)*((Rtmax-Rtmin)/(gridRt-1));
    tdwell(1,q) = tlist(it);
    if tlist(it) > 60
        break;
    end
    q = q+1;
end

% plot cross range versus required dwell time
figure
plot(range,tdwell,'k');
hold on;
xlabel('Cross Range (m)');
ylabel('Required Dwell Time (s)');
```

B. ARRHENIUS HEAT SOURCE FUNCTION

```
function [qdot] = Qdot(state,region,Ea,Rho,Q,Ze)
% QDOT Calculates temperature dependent heat source

R = 8.314;     % ideal gas constant [J/(mol*K)]

if isnan(state.u)
    qdot = NaN(size(region.x));
    return;
else
    qdot = Rho*Q*Ze*exp(-Ea./(R*state.u));
end

maxQ = 1e15;
if max(qdot(:))>maxQ
    qdot = maxQ*ones(size(region.x));
end

qdot = qdot.*region.x;
end
```


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Future Roles of Army Aviation in Large Scale Combat Operations

A Monograph

by

MAJ Kenneth R. Dougher II
US Army



School of Advanced Military Studies
US Army Command and General Staff College
Fort Leavenworth, KS

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14. ABSTRACT
The US Army is experiencing a cultural shift away from years of low intensity, counter-insurgency operations toward large scale combat operations with a near-peer or peer threat. The shift includes a major change from brigade-centric operations to divisions and corps serving as the primary warfighting headquarters. Headquarters must now not only provide resources, but simultaneously direct the conflict in multiple domains, including space and cyber-space. US Army Aviation can be a significant force multiplier, but only when used effectively. Army Aviation continues to gain ground through lessons learned from the readiness training centers on how best to reach deep in multi-domain operations. Army Aviation faces many obstacles to continue to be a force multiplier. The 2015 *Field Manual 3-04, Army Aviation*, set new expectations for large scale combat operations, but improvements in training, equipment, and doctrine are necessary to achieve what *FM 3-04* demands conceptually. The complex battlefield set by near-peer and peer threats restricts Army Aviation's freedom of maneuver with anti-access and area-denial systems. To respond to such threats, Army Aviation currently fields upgrades to its legacy fleet of helicopters, but this approach consumes resources that could go towards the future vertical lift fleet. For Army Aviation to be ready to fight today, they must continue to improve the legacy fleet. However, the more Army Aviation spends on updating the legacy fleet, the less it is investing in the future airframes. Additionally, the current fleet has limited potential for further modifications. The key question is whether such modifications to the legacy fleet will be enough to combat the challenges faced in the complex and lethal battlefield of large scale combat operations against a near-peer or peer threat. This monograph addresses those questions surrounding the shift from counter-insurgency to large scale combat operations for Army Aviation.

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Abstract

Future Roles of Army Aviation in Large Scale Combat Operations, by MAJ Kenneth R. Dougher II, US Army, 47 pages.

The US Army is experiencing a cultural shift away from years of low intensity, counter-insurgency operations toward large scale combat operations with a near-peer or peer threat. The shift includes a major change from brigade-centric operations to divisions and corps serving as the primary warfighting headquarters. Headquarters must now not only provide resources, but simultaneously direct the conflict in multiple domains, including space and cyber-space. US Army Aviation can be a significant force multiplier, but only when used effectively. Army Aviation continues to gain ground through lessons learned from the readiness training centers on how best to reach deep in multi-domain operations. Army Aviation faces many obstacles to continue to be a force multiplier. The 2015 *Field Manual 3-04, Army Aviation*, set new expectations for large scale combat operations, but improvements in training, equipment, and doctrine are necessary to achieve what *FM 3-04* demands conceptually. The complex battlefield set by near-peer and peer threats restricts Army Aviation's freedom of maneuver with anti-access and area-denial systems. To respond to such threats, Army Aviation currently fields upgrades to its legacy fleet of helicopters, but this approach consumes resources that could go towards the future vertical lift fleet. For Army Aviation to be ready to fight today, they must continue to improve the legacy fleet. However, the more Army Aviation spends on updating the legacy fleet, the less it is investing in the future airframes. Additionally, the current fleet has limited potential for further modifications. The key question is whether such modifications to the legacy fleet will be enough to combat the challenges faced in the complex and lethal battlefield of large scale combat operations against a near-peer or peer threat. This monograph addresses those questions surrounding the shift from counter-insurgency to large scale combat operations for Army Aviation.

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Acronyms

A2/AD	Anti-Access/Area Denial
AGO	Air Ground Operations
AH	Attack Helicopter
AMCOM	Army Aviation and Missile Command
AMSO	Army Aviation Mission Survivability Officer
CAB	Combat Aviation Brigade
CH	Cargo Helicopter
COIN	Counter-Insurgency
CSAR	Combat Search and Rescue
EAB	Echelons Above Brigade
FM	Field Manual
FOB	Forward Operating Base
FVL	Future Vertical Lift
HA	Holding Area
HMMWV	High Mobility Multipurpose Wheeled Vehicle
JRTC	Joint Readiness Training Center
LCMC	Life Cycle Management Command
LSCO	Large Scale Combat Operations
MANPAD	Man Portable Air Defense System
MCTP	Mission Command Training Program
MDO	Multi-Domain Operations
MUM-T	Manned Unmanned Team
NTC	National Training Center
OH	Observation Helicopter
PIR	Priority Intelligence Requirement
PMO ASE	Project Management Office for Aircraft Survivability Equipment

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SERE	Survival, Evasion, Resistance, and Escape
SOAR	Special Operations Aviation Regiment (Airborne)
SOCCENT	Special Operations Command-Central
SOF	Special Operations Forces
TF	Task Force
UA	Unmanned Aircraft
UAS	Unmanned Aerial Systems
UH	Utility Helicopter

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Introduction

> Large-scale ground combat is more likely today than at any point since the end of the Cold War. And the risk of great power conflict will likely persist into the distant future. While the last 17 years of limited contingency and counterinsurgency operations were necessarily brigade-centric, conflict with a peer and near-peer threats requires a continued culture shift as well as the optimization of EABs (echelons above brigade) into highly capable divisions, corps, field armies, and theater armies.
>
> — Lieutenant General Michael D. Lundy, Commanding General, US Army Combined Arms Center

Background

Since the American Civil War, Army Aviation has played a role in US warfare. Army Aviation has continually adapted and strived to provide the ground force commander additional options, from deep attacks to reconnaissance, air assaults, medical evacuations, and more. In the most recent war on terrorism, Army Aviation provided these capabilities to the ground force commander which enabled numerous options, saving thousands of lives. While Army Aviation has proven itself as a combat multiplier in the current fight, past results may not be indicative of future success.

Former combat aviation brigade (CAB) commander Colonel Jimmy Blackmon observed that "pilots are the products of their experiences." Currently, there is a pressing challenge to create realistic training opportunities to prepare leadership for the rising threat of conflict with a peer or near-peer adversary. Army Aviation's primary focus over the past decade focused on meeting the requirement for training and completing missions during specific rotational deployments to stable theaters, with a focus on environmental conditions. In the Gulf War, close air support was not the primary goal for the air component. However, in the mountains of the Regional Command East, Afghanistan, it was essential to the mission. The primary objective for the limited contingency was close air support, but as the US Army gravitates back to the pressing challenge of Large Scale Combat Operations (LSCO), Army Aviation must be prepared to increase their deep attack and interdiction capabilities. LSCO, unlike counter-insurgency (COIN),

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will challenge the Army in all domains. In recent history, the Army has assumed air superiority and not contended with electronic warfare, but, within LSCO, these challenges will present themselves.[1]

The concept of AirLand Battle has evolved since its inception in US Army doctrine in the 1970s, and first significant test in the Gulf War. As defined in the 1986 *Field Manual (FM) 100-5, Operations*, AirLand Battle involves "securing or retaining the initiative to accomplish the mission by throwing the enemy off balance with a powerful blow from an unexpected direction and following up rapidly and continuously to achieve the higher commander's goals." The two main Army Aviation elements of AirLand Battle: close air support and deep attack, have not changed significantly since the Gulf War, but evolution in technology changed the manner in which aviation executes these roles. Improved technology has brought in different weapon systems for attack helicopters (AH), surveillance, reconnaissance, and interdiction technology for unmanned aerial systems (UAS), utility helicopter (UH) 60M and cargo helicopter (CH) 47F models with digital readouts, and hovering features for lift helicopters to assist with air assault operations.[2]

Despite advances in technology, aviation brigades still face numerous challenges. According to two battalion commanders of the 101st Airborne Division, deployed aviation commanders had similar numbers of attack helicopters (AH 64s) and observation helicopters (OH 58Ds), but did not have enough CH-47Fs, the US Army's only cargo helicopter, to get all of their missions and tasks done. As such, CABs had to remain flexible in their formations. Additional

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[1] Jimmy Blackmon, *Pale Horse: Hunting Terrorists and Commanding Heroes with the 101st Airborne Division* (New York: Saint Martin's Press, 2016), 58; Michael D. Lundy, *"*Meeting the Challenge of Large-Scale Combat Operations Today and Tomorrow*," Military Review* (September-October 2018): 112-113, accessed January 17, 2019, https://www.armyupress. army.mil/Journals/Military-Review/English-Edition-Archives/September-October-2018/.

[2] US Department of the Army, *Field Manual (FM) 100-5, Operations* (Washington, DC: Government Printing Office, 1986), 14; Blackmon, *Pale Horse*, 162; Diane T. Putney, *Airpower Advantage: Planning the Gulf War Air Campaign 1989-1991* (Washington, DC: Library of Congress, 2004), 37.

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challenges range from meteorological risks to a counterinsurgency-focused culture. However, Army Aviation will continue to play a vital role in future operations. As such, CABs must educate division and corps-sized headquarters on how best to utilize Army Aviation to shape the fight.[3]

Methodology

This monograph consists of three main sections. The initial section summarizes the relevant background of Army Aviation, the requirements involved with the move towards LSCO, and the current capability of the force to apply emerging doctrine. In the second section, a historical example of Army Aviation's transformation in the 1980s accounts for the significant change of Army operations doctrine to the AirLand Battle construct. This section includes analysis of Army Aviation roles in Operations Desert Storm and Desert Shield, evaluated using three key elements of operational art: operational reach, tempo, and risk. The third section provides analysis of the current gaps that exist between doctrinal requirements of Army Aviation and its current capability. This section also highlights the outlook for the next ten to fifteen years for Army Aviation, and the associated gaps that those advances could create or close. Lastly, this section provides proposed methods to meet any remaining gaps between requirements and capability within the branch.

Application of Operational Art in Army Aviation Doctrine

Operational Art has evolved alongside changes in technology and the incorporation of new battlefield domains into US Army doctrine. As described in *Army Doctrine Reference Publication (ADRP) 3-0*, *Operations*, operational art "requires creative vision, broad experience, and knowledge of capabilities, tactics, and techniques across multiple domains." Today's domains of cyber, space, electronic, and information present a significant challenge for officers maintaining the broad and creative vision as they are not as tangible as the traditional land, air,

[3] Blackmon, *Pale Horse*, 162.

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and maritime domains. The publication of *FM 3-0*, according to Lieutenant General Michael D. Lundy, provides the Army with "an expanded physical, virtual, cognitive, and temporal perspective for accounting for the multi-domain extended capabilities of friendly and threat forces." The Army strives to meet the challenges presented by the multi-domain concept and LSCO threats with new manuals appearing in 2017 alongside the current body of aviation doctrine. LSCO has become the measuring standard of future conflict on lethality and large-scale demands of Army training and capabilities. Army officers can apply operational art as they plan, prepare, execute, and assess current and future operations including LSCO. Three of the ten elements of operational art—tempo, operational reach, and risk—enable an assessment of aviation doctrine as applied by commanders and staffs.[4]

ADRP 3-0, Operations, defines tempo as "the relative speed and rhythm of military operations over time with respect to the enemy." In both cases, Army Aviation must control tempo when reacting to and assessing the urgent requests for support from ground forces and air components. The ability to keep the tempo at the optimal level requires both audacity and patience. High tempo only remains effective for so long before increasing the risk to the endurance of the mission. The increase in congested airspace due to the proliferation of UAS and lower operational ceiling will also increase tempo while pushing the limits of its optimal level. A commander must assess and apply operational art in the planning of missions while maintaining the tempo when necessary to avoid sacrificing the other elements of operational art such as operational reach and decisive points.[5]

---

[4] First quote from US Department of the Army, *Army Doctrine Reference Publication (ADRP) 3-0, Unified Land Operations* (Washington, DC: Government Printing Office, 1986), 2-4; second quote Michael D. Lundy, *"*Meeting the Challenge of Large-Scale Combat Operations Today and Tomorrow*,"* 113; US Department of the Army, *Army Doctrine Publication (ADP) 3-0, Operations* (Washington, DC: Government Printing Office, 2017), 13.

[5] US Army, *ADRP 3-0*, 2-37, 2-38, 2-39.

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Army Aviation enhances speed, flexibility, and lethality during US Army operations. Army Aviation helps maintain the tempo of the combat arms team through deep attacks, reconnaissance, close and security support, and air movements. Per *FM 3-04*, a successful attack contains "audacity, speed, concentration of combat power at the right time and place, violence of execution, simultaneity of joint fires with ground and air maneuver, and maximizing the element of surprise." The optimal tempo maximizes the element of surprise while patience creates the window for the concentration of combat power and the seamless rhythm of coordinated air-ground operations (AGO) for a successful mission. An operation in a deep area that is aligned with the Army's prior AirLand Battle construct and remains in accordance with the current *FM 3-04*, influences the tempo for the accompanying unified land operations.[6]

> Aviation operations in deep areas may include—
>
> Attacks to destroy, defeat, disrupt, divert or delay enemy forces or high-value capabilities that are out of friendly contact using manned-unmanned teaming (MUM-T) or independent UAS attack-reconnaissance operations.
>
> Reconnaissance operations by manned and/or unmanned aircraft (UA) to obtain combat information to answer priority intelligence requirements (PIR) on the terrain, enemy or civilian populations.
>
> Air assaults of conventional or special operations forces to seize an objective, destroy an enemy force, or capture or kill a high-value target.
>
> Infiltrations of conventional and special operations forces to recover isolated personnel, emplace sensors, conduct raids, establish special reconnaissance positions, or to conduct partisan linkup.
>
> Air movements of supplies and personnel to ground maneuver units operating decentralized in deep areas.[7]

These operational examples from *FM 3-04*, all involve setting a desired tempo by striking quickly and violently, thereby supporting the rhythm for the AGO to either follow or attack simultaneously. As US Army leaders shift their focus from COIN to LSCO, their need increases

[6] US Department of the Army, *Field Manual (FM) 3-04, Army Aviation* (Washington, DC: Government Printing Office, 2015), 3-14, 1-1.

[7] US Army, *FM 3-04,* 1-39.

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to incorporate coordinated attacks across multiple domains to present the enemy with multiple dilemmas simultaneously. *ADP 3-0* describes the goal of these coordinated attacks: "degrade enemy freedom of action, reduce enemy flexibility and endurance, and upset enemy plans and coordination." This remains a challenge for commanders shifting focus to LSCO, as many have rarely attempted or trained for this type of coordinated attack. If the coordinated attack is successful it will enhance the US Army's tempo.[8]

Tempo is not only essential in attack missions but also crucial in reconnaissance missions. A commander's ability to make sound and accurate decisions rest on the timely and accurate flow of reconnaissance. Army Aviation has a responsibility to perform at the optimal tempo to meet the needs of intelligence and respond when the situation develops. Aviation meets this need through employment of MUM-T. The MUM-T ensures longer reconnaissance windows of up to forty hours and decreased gaps in intelligence coverage caused by crew changes. The longer reconnaissance windows and increased depth of reconnaissance and maneuver of UAS systems increase endurance and increased reconnaissance abilities require commanders to initiate and sustain the most advantageous tempo with AGOs. MUM-T hinders tempo in the management of UAS communication as they descend below coordinating altitude from restricted operations zones as depicted in Figure 1. MUM-T requires extra time and communication, but the advantages of the higher commander's situational awareness due to intelligence surveillance and reconnaissance outweigh the extra airspace control authority, planning, and coordination.[9]

[8] US Army, *ADP 3-0*, 38.

[9] US Army, *FM 3-04*, 1-7, 2-95, 3-74.

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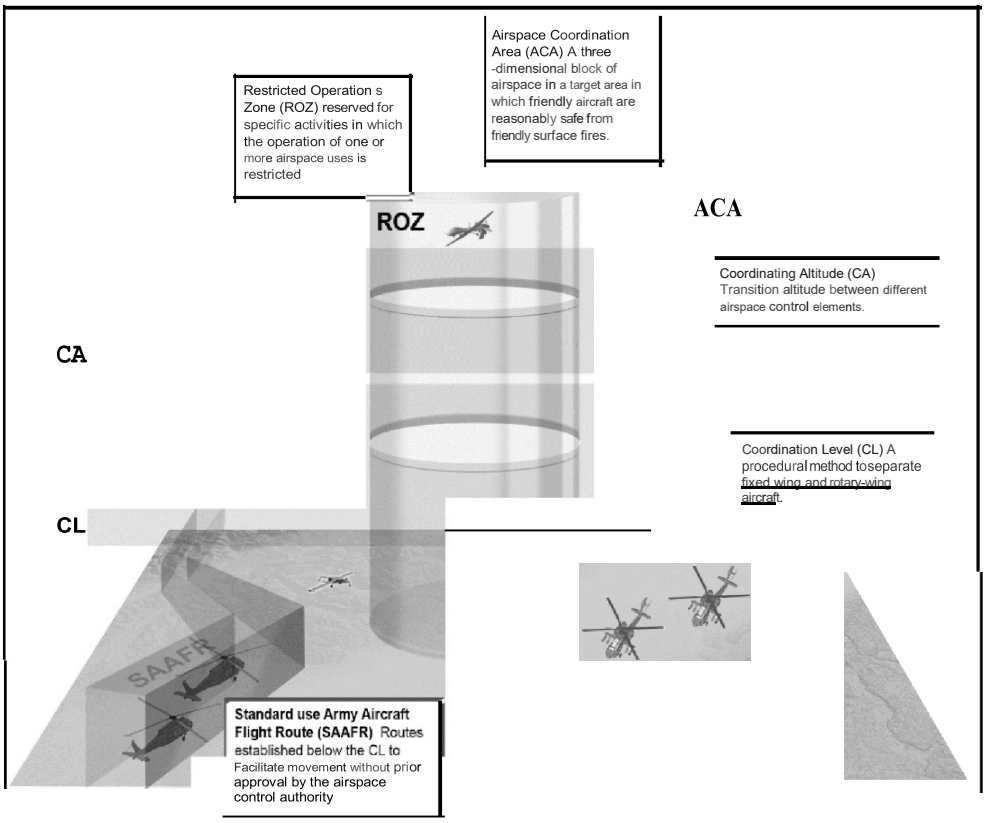


Figure 1. Common Army Airspace Coordinating Measures. *Field Manual (FM) 3-04, Army Aviation* 2015, 2-22.

Colonel Jimmy Blackmon has argued that recent COIN operations in Afghanistan and Iraq demonstrated that "the most underutilized collection assets were the rotary-wing aviation aircrews. Helicopters traverse and observe more of the brigade's battlespace daily than any other sensor on the battlefield." To keep the reconnaissance moving, all parties to include, UAS, pilots, and crews, whether lift or attack, need to be a part of the reconnaissance gathering as weather can prevent or limit employment of UAS and mission space does not always overlap. The US Army teaches soldiers to be critical thinkers. As one way to hone that skill, all aircrews should adopt a reconnaissance mindset.[10]

The tempo of the flow of reconnaissance is susceptible to disruption by many factors including natural and manmade, weather being the most prominent. Due to disruptions in

[10] Blackmon, *Pale Horse*, 58.

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reconnaissance "the commander must balance the time available versus the advantage of executing with tempo and surprise with the minimum mission essential information required to understand the friendly forces, terrain, weather and enemy forces to achieve success." Terrain can also limit the flow of reconnaissance because of visibility and poor communication. Additionally, the enemy will limit reconnaissance in LSCO through electronic warfare and their air defense systems. The last seventeen years of limited contingency operations have demonstrated that the experience gained while working in varied terrain, including mountains which limit line of sight, may reduce UAS range and data relay capability. Difficult weather patterns degrade communications between UAS and ground maneuver units, as do urban and desert terrain, as seen in Iraq and Afghanistan.[11]

The rhythm of the tempo created by the relationship between the air and ground forces is crucial to the success of the mission. The relationship takes time and practice to develop but, when the rhythm of AGOs is seamless, the mission success increases due to inherent flexibility and reaction time. Ideally, during COIN, CABs assigned specific task forces (TFs) to support a ground commander. This required pre-deployment training with the ground commander to establish habitual relationships with the CAB so that it could achieve its full potential. In this case, time permitted pre-deployment planning, but units might not have this luxury when a peer threat escalates quickly into LSCO. Integration of the CAB in air mission coordination meetings and air mission briefs increases awareness of effective ways to use Army Aviation. However, this remains difficult at the brigade level and proves even more of a challenge at the division and higher levels of command. The lack of rhythm of AGOs could also detract from the CAB's

[11] US Army, *FM 3-04*, 3-33; Charles K. Bartles and Lester W. Grau, *Mountain Warfare and Other Lofty Problems: Foreign Perspectives on High Altitude Combat* (West Midlands, England: Helion, 2016), 23; US Army, *FM 3-04*, 3-154; US Army, *ADP 3-0*, 15; Joshua Durham, "Testing the Army's Extended Range Gray Eagle UAS," *Army Aviation* (November 2018): 52-53.

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operational reach and increase risk until sound relationships develop and integration at the division level becomes routine.[12]

The second operational element routinely applied to Army Aviation is operational reach. *Joint Publication 3-0, Joint Operations,* defines operational reach as the "distance and duration across which a joint force can successfully employ military capabilities." The many changes in technology, new digital models of aircraft and MUM-T, have increased Army Aviation's length of optimal reach. Reach will play a pivotal role in Army Aviation's ability to shape the complex battlefield of LSCO. Army Aviation will need the ability to reach the centers of gravity to make the most impact on the conflict at hand. Difficulty could arise if a division, or above, does not understand how to effectively use Army Aviation's strengths, such as the potential reach of rotary wing operations or UAS, and therefore fails to integrate aviation effectively into their operations. The successful integration of MUM-T into a CAB can give commanders extended reach through continuous reconnaissance, current battle damage assessment, and contact with the enemy due to longer flight times of the Gray Eagle. The coordination of the UAS and AH-64 also extends reach for greater lethality by utilizing precision team targeting to give swift blows to high-payoff targets or against centers of gravity.[13]

Operational reach can be very critical to shaping operations as aviation's reach facilitates deep attacks. Aviation operational reach shapes the battlefield not only through deep attacks but also air assaults, and air movements. Placing critical supplies and soldiers where they will have the most impact on the battlefield extends the operational reach of the ground force to gain a position of relative advantage against threats that may outnumber US troops. Operational reach will be a critical element of any LSCO in order to keep the element of surprise, present multiple dilemmas simultaneously, disrupt troop reinforcements, and communications. The challenge is

[12] Blackmon, *Pale Horse*, 61; US Army, *FM 3-04*, 1-3.

[13] US Department of Defense, Joint Staff, *Joint Publication (JP) 3-0*, *Joint Operations* (Washington, DC: Government Printing Office, 2011), I-13; US Army, *FM 3-04*, 1-18.

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Army Aviation's ability to meet the demands within the new doctrine, especially in LSCO against a peer threat.[14]

Army Aviation has seven core competencies, as seen below in Figure 2, and most apply to the operational reach of combat arms teams. Air assaults, in coordination with special operations forces (SOF) or other combined arms teams, can extend operational reach by quickly assembling battalions of troops for covert operations to cut off reinforcements or destroy centers of gravity that terrain would otherwise make impossible to reach. Air movements performed by cargo and utility aircraft also support operational reach of combined arms teams, especially when overcoming effects of terrain or enemy forces in isolated locations only accessible by rotary wing aircraft. Air movements can be inefficient compared to transporting heavy supplies and equipment by plane and therefore US forces utilize air movements when terrain or emergency necessitates the use. CABs arrange air movements by priority because of the smaller number of CH-47s assigned to CABs as seen below in Figure 3.[15]

The seven core competencies of Army Aviation are:

- Provide accurate and timely information collection on the enemy, terrain, local populations and friendly forces.
- Provide reaction time and maneuver space.
- Destroy, defeat, disrupt, divert, or delay enemy forces.
- Air assault ground maneuver forces.
- Air move personnel, equipment, and supplies.
- Evacuate wounded or recover isolated personnel.
- Enable mission command over extended ranges and complex terrain.

Figure 2. Core Competencies of Army Aviation. *Field Manual (FM) 3-04, Army Aviation* 2015, 2-96.

[14] US Army, *FM 3-04*, 1-18, 4-46.

[15] US Army, *FM 3-04,* 1-23, 4-69.

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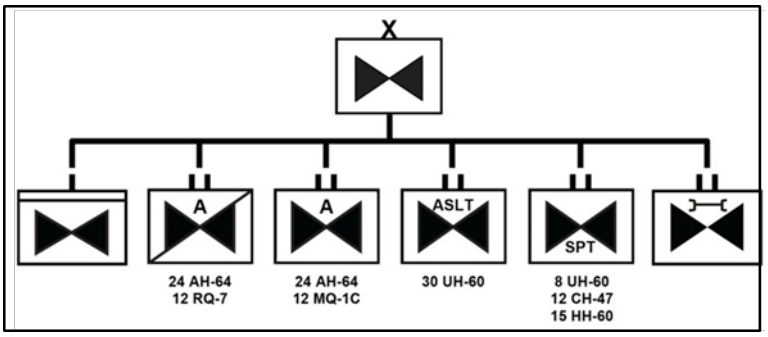


Figure 3. Combat Aviation Brigade. *Field Manual (FM) 3-04, Army Aviation* 2015, 2-2.

The third element of operational art that enables an assessment of Army Aviation doctrine is risk. LSCO presents a new demand on Army Aviation and will likely increase the risk of every mission. One of the demands of LSCO is the requirement of a CAB to retain flexibility within their formations. Formations may require tailored packages for different aircraft to facilitate different missions. The CAB contains finite resources and depending how LSCO unfolds it will be necessary to adjust formations to meet the demand of the ground force commander. This is like current COIN operations. However, it is likely the CAB must gain proficiency at adjusting frequently, where currently, they generally remain task organized for the duration of a deployment. Risk is inherent to all military operations. Commanders that are willing to incur a reasonable level of risk typically find it is "the key to exposing enemy weakness that the enemy considers beyond friendly reach."[16]

To mitigate risk, aviation commanders should—

Use the minimal security force required to gain contact while accomplishing the mission within the allotted time.

Maximize the use of UAS forward to provide reaction time and maneuver space.

Provide subordinates with control measures for not only their own areas of operations but also adjacent areas of operations to control and deconflict maneuver and fires.

Develop and coordinate air coordination measures to enable freedom of action of manned and unmanned systems.

[16] US Army, *ADRP 3-0*, 2-61; US Army, *FM 3-04*, 3-127-128; Blackmon, *Pale Horse,* 128.

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Plan and employ joint fires through the depth of the zone.

Employ communications relay packages, Army Airborne Command and Control System or Airborne Battle Command Console aircraft to maintain communications over extended distances.

Position FARPs, UAS launch locations, and holding areas (HAs) forward to enable rapid turns of combat power once enemy contact is gained.

And most importantly, use speed and audacity to develop the situation upon gaining contact.[17]

While it is important to find ways to mitigate risks like those listed above when applying operational art of the ends, ways, and means, it is also crucial to account for the level of risk and risk limits of a potential enemy. When attacking from multiple domains it can increase the risk taken by the CAB, as well as increase the threat to the enemy and their level of risk. Risk is unavoidable, but navigating aviation operations and AGOs, a commander must strike a balance between acceptable risk and expected gains. Ways to mitigate such risks are maintaining flexibility within plans, planning thoroughly for missions, and establishing a good relationship between air and ground forces.[18]

Commanders need to be flexible in their planning of AGOs. Flexibility comes from retaining options, a position influenced by training and experience. Aviators can pull from their experiences as well as the experiences of others to create a flexible plan to account for different variables. The challenge with LSCO is the unfamiliarity of current aviation crews with such operations and the finite resources of a CAB to manage the demands of LSCO. Units need to have adaptable plans to react to the evolving circumstances in LSCO. Training, especially in coordination with the ground forces and integration at division level and above, can give the force an edge and foster flexibility by providing additional repetitions in exercises. Another technique to gain flexibility is to strive for habitual relationships between air and ground units.

[17] US Army, *FM 3-04*, 3-10.

[18] US Army, *ADP 3-0*, 23, 38; US Army, *FM 3-04*, 3-20.

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Habitual relationships between air and ground units are ideal, but are often unattainable for varied reasons. It takes time and repetitions to cultivate such relationships. Given current demands, it is difficult to find the time to foster such relationships, and in a future LSCO it is doubtful there will be training time to build a relationship that does not exist. *FM 3-04*, operation doctrine refers to "hasty attacks in support of all friendly ground units regardless of their training level or habitual relationship, but with greater risk" as undesired, but this may become more common in future LSCO. Aviation doctrine teaches standardized procedures to reduce the risk of non-habitual relationships. Aviators must remain flexible and adaptive as Army Aviation moves forward into LSCO, to learn and mitigate risks to missions.[19]

One way to counterbalance the risks presented by a limited relationship with ground forces and experience is with reliable intelligence from reconnaissance. Reconnaissance mitigates risk by filling in the missing pieces of critical information, allowing commanders to make more informed decisions without jeopardizing the tempo of the mission set by waiting for the minimum critical mission information. Commanders require quick and reliable intelligence to be able to make bold decisions without large unnecessary risks, especially when having to coordinate and consider multiple domains in LSCO. The incorporation of MUM-T enables detection, consistent contact of enemy forces, and identification of high-payoff targets in a dynamic operating environment. MUM-T therefore provides flexibility as well as essential information which enables commanders to adjust their plans accordingly, while more accurately assessing risk. There is a potential risk in reliance on UAS, as other factors such as weather, or terrain, or the enemy's abilities may limit reconnaissance.[20]

Risk will always be a factor in operations, but it is the way aviators account and react to risk which ensures a successful mission. Aviators must strive to use and create a diverse

[19] US Army, *ADP 3-0*, 44; US Army, *FM 3-04*, 1-3.

[20] US Army, *FM 3-04*, 3-33, 3-40, 3-71, 3-154.

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knowledge base through training and experience to remain flexible in a complex mission environment such as LSCO. Combined arms teams must use the time they have together to train and create a quality learning environment, to standardize training objectives and mutual goals of the combined arms team.

Operational art "requires creative vision, broad experience, and knowledge of capabilities, tactics, and techniques across multiple domains." A future LSCO with a peer threat will stretch the US Army's current knowledge and capabilities. LSCO will require Army Aviation to provide the commander options to maneuver and position forces in a manner to best achieve their concept of operations. Army Aviation will meet the commander's need by leveraging their current doctrine to balance operational reach, tempo, and risk.[21]

Historical Case Study: Gulf War

The Gulf War, Desert Shield, and Desert Storm, illustrated the incorporation of operational art into AirLand Battle doctrine. According to author Robert Scales, AirLand Battle's "four tenets, initiative, agility, depth, and synchronization, are timeless, immutable precepts for present and future wars" as seen in unified land operations today. This historical case study will analyze how AirLand Battle and other Army doctrine applies to a near-peer threat in a short LSCO (in comparison to other LSCO like World War II). The three sections of operational art discussed in the doctrine portions: operational reach, tempo, and risk, are the basis for analysis of the historical case study.[22]

Background

In 1990, many evaluated the Iraqi Army as a near-peer threat to the US Army as Iraq had the fourth largest standing Army in the world. The livelihood of the Middle Eastern countries in

[21] US Army, *ADP 3-0*, 26.

[22] Robert H. Scales, *Certain Victory: The US Army in the Gulf War* (Fort Leavenworth, KS: US Army Command and Staff College Press, 1994), 107.

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1990 was oil production and Kuwait, even though small, was an oil-rich country. During the 1980s many countries, such as Saudi Arabia and Iraq, had negative returns from their oil industry. In contrast, Kuwait maintained a positive income from oil. During this time the organization of the petroleum exporting countries made agreements to reduce oil production to increase the cost of oil. Kuwait, along with Saudi Arabia, increased their production. The price per barrel reached a low of fourteen dollars in June of 1990. Saddam Hussein, Iraqi President, was concerned about increased oil output in Kuwait and Saudi Arabia. President Hussein also feared Kuwait's western leaning intentions. The size of Iraq's army increased due to the war with Iran from 1980 to 1988 but left their treasury depleted, and Hussein looked toward Kuwait as a "quick fix" for their financial troubles.[23]

Hussein took drastic measures in August of 1990 and invaded Kuwait to seize Kuwaiti oil platforms to bolster Iraq's own oil production. After the invasion, Hussein claimed that western foreigners had annexed Kuwait from Iraq after World War II and claimed Kuwait as the nineteenth province of Iraq. The United States and its allies responded with diplomatic solutions with the United Nations. While diplomatic channels were working, the United States with Saudi Arabia, set up a "line in the sand" near the border of Saudi Arabia and Kuwait. This was the start of Operation Desert Shield, which also afforded the train up prior to Desert Storm. Near the border, the United States and Saudi Arabia built up forces while training troops, and conducting exercises with aircraft and live fire munitions. Army Aviation conducted screening along the border to provide reconnaissance on Iraqi troop movements as an early warning system, and set

[23] Eliyahu Kanovsky, *The Economic Consequences of the Persian Gulf War: Accelerating OPEC's Demise* (Washington, DC: Washington Institute for Near East Policy, 1992), xvii; Lincoln R. Ward, "The Division Artillery: Linking Strategy to Tactics in Operations Desert Shield/Storm," in *Lethal and Non-Lethal Fires: Historical Case Studies of Converging Cross-Domain Fires in Large Scale Combat Operations,* ed. Thomas G. Bradbeer (Fort Leavenworth, KS: Army University Press, 2018), 94; Kanovsky, *The Economic Consequences of the Persian Gulf War*, xiii, xv; Dilip Hiro, *Desert Shield to Desert Storm: The Second Gulf War* (New York: Routledge, 1992), 85; US Army Aviation Warfighting Center, *United States Army Aviation in the Gulf War* (Fort Rucker, AL*:* US Army Aviation Warfighting Center, 1991), 10.

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up forward operating bases (FOBs) near the Saudi Arabian and Kuwaiti border. The buildup of troops in Saudi Arabia was enough to deter Saddam Hussein from invading the country; a fear held by King Fahd of Saudi Arabia.[24]

Desert Shield Analysis

Desert Storm's high-speed air and ground offense often overshadows Desert Shield's contribution to the Gulf War. Desert Shield was a necessary step that paved the way for the success of Desert Storm. The planning, training, and rehearsal time for Desert Storm was unprecedented. In past conflicts, the escalation to war with little intelligence "meant that first battles proved to be bloody schools in which green staffs and units were obliged to refine their skills on the battlefield." The training time afforded during Desert Shield gave not only US Army Aviation time to train the desert terrain, but also afforded time to develop joint relationships with sister services to "avoid another instance of learning in combat what the services could have practiced in pre-war training."[25]

Lieutenant Colonel Dell Dailey's 3-160th conducted a joint exercise that mitigated risk and cultivated relationships between the services by incorporating Navy, Marine, and Air Force pilots practicing combat search and rescue (CSAR). Colonel Jesse Johnson of Special Operations Command-Central (SOCCENT), oversaw all CSAR operations in Kuwait, Iraq, and twelve miles out into the gulf as SOF had the most experienced crews and best equipped aircraft for deep insertions. If available, Lieutenant Colonel Dailey fielded most of the calls as he had taken

[24] US Army Aviation Warfighting Center, *United States Army Aviation in the Gulf War,* 4; Herbert H. Blumberg and Christopher C. French, eds., *The Persian Gulf War: Views from the Social and Behavioral Sciences* (Lanham, MD: University Press of America, 1994), 29; James Williams, *A History of Army Aviation: From Its Beginnings to the War on Terror* (Lincoln, NE: iUniverse, 2005), 236-37; Scales, *Certain Victory*, 151; Thomas Houlahan, *Gulf War: The Complete History* (New London, NH: Schrenker Military Pub., 1999), 12-13.

[25] First quote from Scales, *Certain Victory,*153-154; second quote from Mark T. Calhoun, "Close Air Support and Bombardment Theory: Operation Cobra," in *Lethal and Non-Lethal Fires: Historical Case Studies of Converging Cross-Domain Fires in Large Scale Combat Operations,* ed. Thomas G. Bradbeer (Fort Leavenworth, KS: Army University Press. 2018), 179.

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measures to prepare his crews and build confidence in CSAR operations with sister services by creating CSAR scenarios in the deserts of Saudi Arabia during Desert Shield. Lieutenant Colonel Dailey dropped the Navy, Air Force, and Marine pilots in the desert at night, and then recovered them through extraction. This training was beneficial for those dropped off as it enhanced their survival, evasion, resistance, and escape (SERE) training for the pilots, then have his crews come in low and fast for a night extraction. By using the time of Desert Shield for training CSAR operations, Lieutenant Colonel Dailey was able to minimize risk, maximize tempo as crews were familiar with conducting night CSAR operations. Therefore, his pilots needed minimal planning as they were well trained. The incorporation of the other services' pilots fostered relationships across the services which facilitated the tempo of Desert Storm as the crews conducted close air support and deep attacks in concert.[26]

The risk was still present even for the more experienced SOF pilots and crews. SOCCENT had to determine, with every call, if it was an acceptable risk to expose aircraft and crews to danger to conduct CSAR operations. The SOF pilots had trained for CSAR operations and were better prepared for the risky situation of a hot landing zone. The 229th Attack Helicopter Battalion from Fort Rucker, Alabama, did not undergo the same training as the SOF pilots. A UH-60 from 2-229th attempted a CSAR operation, for a downed Air Force F-16 pilot, when SOF was not available and the enemy shot the UH-60 down. Only three of the seven CSAR missions throughout Desert Storm were successful. The SOF crews, who had received the extra training, flew all the successful CSARs. The specialized training of the SOF pilots and crews mitigated risk and allowed the crews to reach deep into enemy territory.[27]

Forces maintained operational tempo during Desert Storm because of the training performed during Desert Shield. The XVIII Airborne Commander, General Gary Luck, described

[26] Scales, *Certain Victory,* 195-198.

[27] Scales, *Certain Victory*, 195.

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it as "actually the best training we've probably ever had in this Army because of the resources and space put at our disposal." General Luck set up training areas and firing ranges to sharpen combat skills and to adjust to the desert climate and challenges. The AirLand Battle defines agility as "the ability of friendly forces to act faster than the enemy, [which] is the first prerequisite for seizing and holding the initiative." Desert Shield's training facilitated the agility demonstrated by forces upon the execution of Desert Storm.[28]

General Luck and XVIII Airborne Corps used AirLand Battle's tenet of agility by disseminating lessons learned from Desert Shield to combat risk while facilitating tempo. Pamphlets and handbooks circulated through department of the Army staff and US Army Training and Doctrine Command to share the knowledge of hard-learned lessons in the desert through official channels. This information and lessons learned greatly increased the incoming units learning curve for operating in the desert. As an example, initially, the AH-64 encountered issues with "losing control of the Hellfire caused by laser backscatter from the fine sand suspended in the air." AH-64 crews solved the issue before executing their deep attack mission in support of Operation Desert Storm and disseminated the lessons to adjacent and incoming units.[29]

Task Force Normandy

"One of the smallest yet most successful and important Joint-Army-Air Force operations in the initial strikes in Operation Desert Storm was Task Force Normandy." The TF consisted of eight Army AH-64 Apaches and four Air Force MH-53 Pave Low helicopters. The TF conducted a deep attack into Iraq to destroy two early warning sites to blind the Iraqi's air defense system prior to commencing the air campaign. US forces had to destroy the early warning sites simultaneously to avoid alerting the air defense system. TF Normandy meticulously planned and conducted many rehearsals to mitigate risk during their deep attack. This resulted in successfully

[28] First quote from Scales, *Certain Victory*, 151; second quote from Ward, *The Division Artillery*, 95; Scales, *Certain Victory*, 151

[29] Scales, *Certain Victory*, 151.

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blinding the Iraqis and serves as an example of operational reach and synchronization within AirLand Battle doctrine.[30]

"Deep operations require boldness and audacity and yet carry an element of risk due to overextension." TF Normandy assumed many risks besides conducting a deep attack into Iraq at night while flying nap of the earth. The teams trained for three months developing the habitual relationships necessary because "between inter-service aircrews there was a natural and mutual mistrust within the aviation community" and finding solutions to the different equipment needs, tactics, training, and procedures. As General Donn A. Starry accurately said, "deep attack is not a luxury; it is an absolute necessity to winning." Despite the higher risk, the United States approved TF Normandy to commence the attack against the two targets as seen below in Figure 4. The TF gained approval because of their training, proven synchronization, and necessity of the mission to blind the Iraqi air defense.[31]

[30] Williams, *A History of Army Aviation*, 246; Scales, *Certain Victory*, 158-159; Paul E. Berg and Kenneth E. Tilley, "Task Force Normandy: The Deep Operation that Started Operation Desert," in *Deep Maneuver: Historical Study of Deep Maneuver in Large-Scale Combat Operations,* ed. Jack D. Kem (Fort Leavenworth, KS: Army University Press, 2018), 140-142.

[31] First quote from Jack D. Kem, "Introduction," in *Deep Maneuver: Historical Study of Deep Maneuver in Large-Scale Combat Operations*, ed. Jack D. Kem (Fort Leavenworth, KS: Army University Press, 2018), xii; second quote from Berg and Tilley, "Task Force Normandy," 145; third quote from Kem, "Introduction," xi; Williamson Murray, *Air War in the Persian Gulf* (Baltimore, MA: Nautical and Aviation Publishing, 1995), 281; Berg and Tilley, "Task Force Normandy," 145-147.

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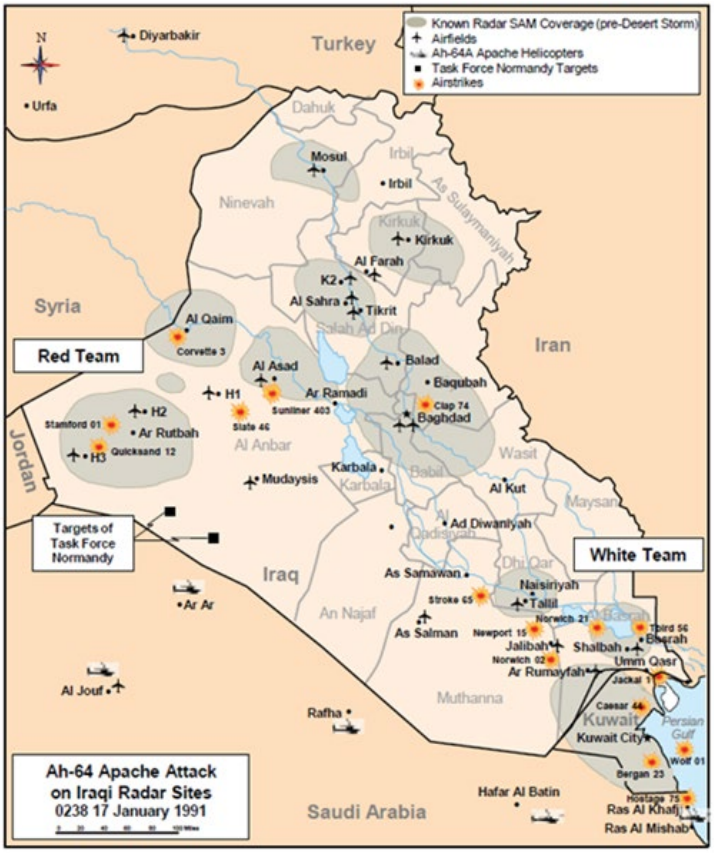


Figure 4. AH 64 Apache Attack on Iraqi Radar Sites. "Task Force Normandy," 141.

To reach twenty miles deep into Iraqi territory a great debate arose for the best aircraft and team for the mission. The qualifications came down to those discussed in AirLand Battle, "using speed, maneuver and firepower that is both precise and massive." The AH-64s had the speed and most accurate and massive firepower but were lacking in their ability to maneuver at night. The Air Force MH-53s did not have adequate firepower to conduct the attack, but did have the global positioning system capabilities that the AH-64 lacked. Therefore, the MH-53s lead them to a designated separation point. The deep attack was only possible using both airframes working together. Additionally, UH-60s in proximity with AH-64 mechanics were on hand to quickly react to downed or damaged aircraft. The timing and tempo of Desert Shield allowed the TF to focus on preparing their mission. The three months of training afforded them the time to solve problems such as chemical lights to mark the designated release points and limited reach of the AH-64 by switching out a rocket pod and replacing with an external fuel tank. The

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synchronization set the smooth tempo of TF Normandy as a "maximum economy of force, with every resource used where and when it will make the greatest contribution to success so that nothing is wasted or overlooked."[32]

Forward Operating Base Cobra and Air Assault to Highway 8

The establishment of FOB Cobra and the air assault to Highway 8 tested the tempo and synchronization of the 101st Airborne Division. General James Henry Binford Peay III had assembled six kilometers to the south of the Iraqi border "the largest air armada the United States had ever committed to a single air assault operation." AH-64 Apaches led a scouting party, and escorted the sixty-six UH-60 Blackhawks and thirty CH-47 Chinooks. The air assault transported the first 500 soldiers as well as sling loaded howitzers and high mobility multipurpose wheeled vehicle (HMMWV) 110 miles into Iraq to set up FOB Cobra for the next stage in the air assault, cutting off the Iraqi supply line on Highway 8 along the Euphrates River as seen in Figure 5 below. This risky air assault served as an excellent example of the use of an air assault to reach deep into enemy territory and disrupt lines of reinforcement and supply.[33]

[32] First quote from Houland, *Gulf War,*109; second quote from Scales, *Certain Victory*, 107; Berg and Tilley, "Task Force Normandy," 142-144; Scales, *Certain Victory,* 157.

[33] Scales, *Certain Victory*, 217, 218; Murray, *Air War in the Persian Gulf*, 277.

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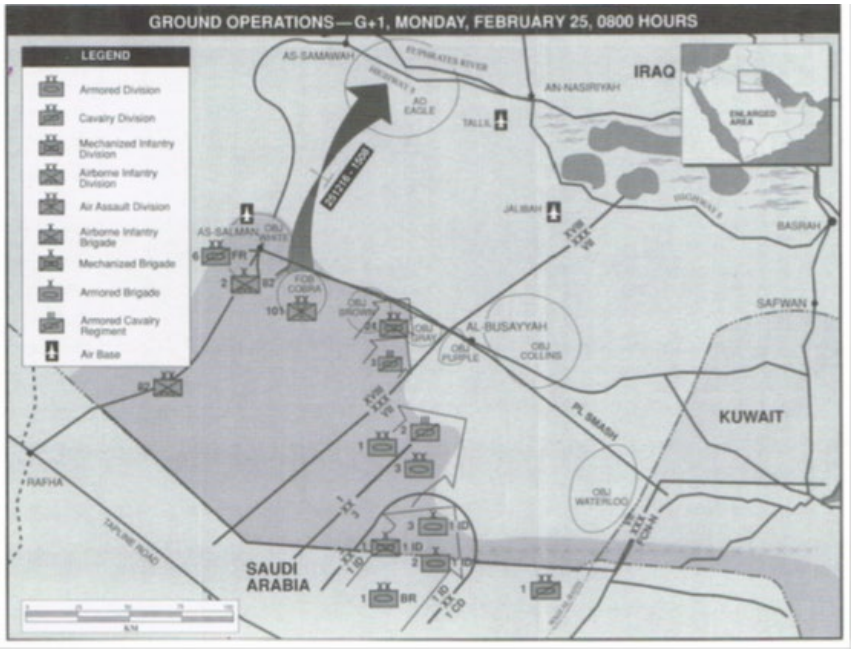


Figure 5. Ground Operations-G+1, Monday, February 25. *Certain Victory*, 304.

The air assault required intense planning as it required three turns to lift the whole brigade. The AH-64 Apaches and AH-1 Cobras scouted for possible enemy threats around FOB Cobra to maintain the FOB's security. The AH-1s discovered an Iraqi infantry battalion dug into the ridge along the east-west road. After discovery, the AH-1 crews landed and conferred with Infantry Company Commander Captain John Russell to establish friendly positions and plan of action. The size of the enemy footprint required support from Air Force A-10s. Fortunately, there was an embedded Air Force liaison officer with the Air Force unit. This enabled the force to maintain their tempo by quickly creating a Joint Air Attack Team of Air Force A-10s and Army Cobras and Apaches. The Joint Air Attack Team bombarded the Iraqi position, leading to 340 Iraqis surrendering, securing FOB Cobra, and providing mission security of the air assault to Highway 8.[34]

[34] Scales, *Certain Victory*, 219; Murray, *Air War in the Persian Gulf*, 277; 101st Airborne Division, "After Action Report Operation Desert Shield/Desert Storm" (Command Report, 13 June 1991), 45-47.

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Once the fifteen kilometers perimeter around FOB Cobra was secure, the next part of the mission began with the 101st and 229th Attack Helicopter Battalion AH-64s scouting landing zones and enemy near Highway 8. The 229th Attack Helicopter Battalion augmented 101st, providing flexibility to the CAB to conduct their deep attack mission. The reconnaissance and escort for UH-60 Blackhawks was crucial to the success of the deep insertions of long-range surveillance detachments. The weather changed to rain and therefore the AH-64 reconnaissance teams had to determine the available landing zones that were suitable for the air assaulting soldiers and vehicles as seen in Figure 6 below. The reconnaissance and long-range survival detachment maintained the tempo for the mission and mitigated risk of delay due to weather.[35]

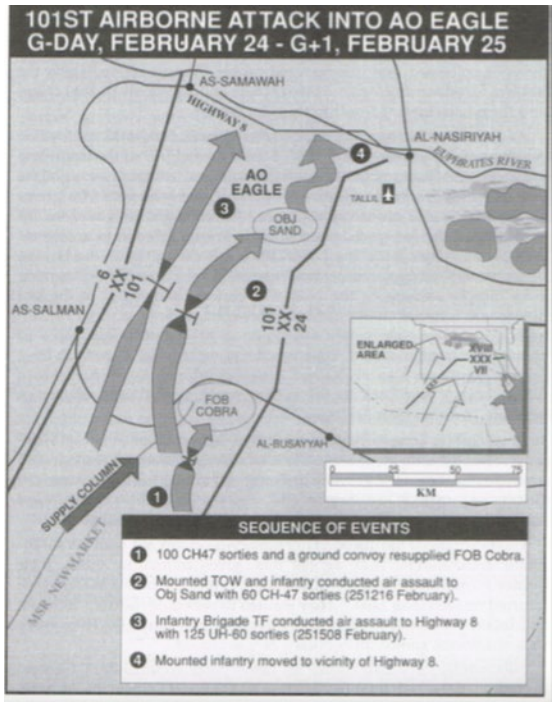


Figure 6. 101st Airborne Attack into AO Eagle. *Certain Victory*, 221.

The next step was the two-prong insertion of an infantry division and anti-armor, supply, and communication vehicles. The AH64 reconnaissance mission on landing zones enabled sixty UH-60s to insert the first 500 infantry soldiers into unobstructed landing zones adjacent to

[35] Scales, *Certain Victory*, 220; US Army Aviation Warfighting Center, *The United States Army in the Gulf War* (Fort Rucker, AL*:* US Army Aviation Warfighting Center, 1991), 30.

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Highway 8. In just thirty-one hours, in a bold and quick deep attack, the 101st had cut off "the key Iraqi Basrah-Baghdad lifeline." All four of the tenets of AirLand Battle doctrine; initiative, agility, depth, and synchronization, were a part of the air assault to Highway 8. The air assault was bold and risky, however, the 101st mitigated the risk through reconnaissance and building up to this assault with other, smaller assaults.[36]

Pre-Ground Day Raids

Before the start of the hundred-hour ground war, Army Aviation played a key role in shaping the battlefield with pre-ground day raids and feints that contributed to the success of the "great wheel." The pre-ground day raids served a dual purpose of interdicting the enemy's supply depots, surveillance posts, armored vehicles, antiaircraft positions, and securing the main supply routes. The second purpose was training for future deep attacks in a lower risk environment and building relationships with armor and infantry divisions that would prove crucial during the ground war.[37]

The biggest feint in the pre-ground day raids involved the VII Corps artillery and the AH-64 from the 11th Aviation Brigade serving as "a carefully rehearsed drill for later deep attacks." Generals Tommy Franks and Robert Abrams observed the feint from the artillery command post to pinpoint any improvements before future riskier deep attacks of the ground war. The pre-raids mitigated a lot of the risk by providing training, reviewing opportunities, and ensuring main supply routes were clear, which are crucial to support aviation missions. "Fuel is the lifeblood" of aviation, as an attack helicopter can burn an average of two and half gallons per minute. Without sufficient and well-placed refueling points, aviation's tempo is severely hindered.[38]

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[36] Scales, *Certain Victory*, 220; Murray, *Air War in the Persian Gulf*, 279.

[37] Scales, *Certain Victory*, 221.

[38] First quote from Scales, *Certain Victory*, 203; second quote from Scales, *Certain Victory*, 220.

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The pre-Ground Day raids not only opened main supply routes Texas and Newmarket, but lead to several Iraqi units to surrender. Aviation also teamed up with the Psychological Warfare Military Intelligence Battalion to use loudspeakers attached to some Blackhawks and drop leaflets to coax the Iraqis out of the bombarded bunkers, as seen in Figure 7 below. The 101st, with coordination of 187th Infantry, recovered 406 prisoners when they secured the site. Intel recovered from the site, along with information gained by debriefing the prisoners, benefited the planning of future deep attacks. The synchronization with psychological warfare and infantry battalions, allowed the combined arms team to utilize the strengths of many different branches to create an optimal tempo of mission and foster success.[39]



Figure 7. Psychological Warfare with a UH-60. *Certain Victory*, 199.

Concluding Analysis of Gulf War

The Gulf War comprised of Desert Shield and Storm lent itself very well to AirLand Battle doctrine. Iraq had a large army, but they were not well trained, and many of their resources were outdated. The transparent outline of Iraq's capabilities and weaponry acquired in a recent long war with Iran, allowed the United States to adequately prepare to counter and overmatch the threats posed by Iraq. Desert Shield also proved as a training ground for future missions, such as TF Normandy and the 101st air assault to Highway 8. The training time gained during Desert

[39] Scales, *Certain Victory*, 199-200.

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Shield, and the feints during the Great Wheel, demonstrated the Army's operational reach and high tempo.

The amount of planning time afforded to Desert Shield and Desert Storm, while Saddam Hussein was stalling diplomatic sanctions, will likely be unavailable in LSCO. The buildup time to conflict could be significantly faster and would require swift reaction of US forces to mobilize in theater. Iraq was not a peer threat and did not have the advantage of observing the United States implement the AH-64 and other new technologies before the Gulf War. Our current competitors and adversaries have observed the US in seventeen years of COIN and have observed how the United States fights, implements its technologies, and reacts to changes on the battlefield. New airframes, such as new UAS systems or future vertical lift platforms, must prove themselves effective in LSCO, just like the AH-64 did in Desert Storm. The proliferation of technology and multi-domain theaters will create more of a challenge for Army Aviation than in Desert Shield and Desert Storm. The timeless tenets of AirLand Battle doctrine are still current for a contemporary LSCO. In a current day LSCO Army Aviation needs to maintain a high tempo, long operational reach, and react quickly when a multi-domain window of opportunity opens.

Gaps and Recommendations for Future Army Aviation

Large Scale Combat Operations in a multi-domain environment is a drastic change from the last seventeen years of COIN. The culture of the Army evolved from fighting decentralized in brigades and now towards headquarters seen as the resource integrator, versus a resource provider. Changing the culture will take time, especially while the Army handles additional gaps in doctrine, training, and capabilities. World conflict will not wait for such an evolution in Army culture. The echelon above brigade (EAB) must be well organized and able to decongest a complex battlefield, to pinpoint the areas of convergence and dis-integrate them. Unlike the historical case study, potential adversaries can contest the airspace and match US air superiority. One of Army Aviation's main roles discussed in this paper is the capability to reach deep into

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contested areas, such as in the case study with TF Normandy and the 101st air assault to Highway 8.[40]

In the current operational environment, our adversaries have developed air defense systems to deny Army Aviation's freedom of maneuver in multi-domain operations (MDO). Unfortunately, it is not only an air defense system, but the Anti-Access/Area Denial (A2/AD) contesting many of the domains. The A2/AD system, depicted in Figure 8 below, illustrates the United States' peer threats A2/AD system. Russia and China have shared some of their A2/AD systems with other countries, which then serve as a testing ground of the A2/AD systems. The United States will be able to find weaknesses in the systems, and at the same time Russia and China will be watching to address those weaknesses in their A2/AD systems.[41]

[40] Erick Sweet, "Integration of Aviation Ops at Echelons Above Brigade," *Aviation Digest* (October-December 2015) 6.

[41] Peter Quinn, *Air Launched Effects Concept of Employment: Army Aviation Multi-Domain Force Multiplier* (Fort Rucker, AL: USAACE, 2018) 1-2.

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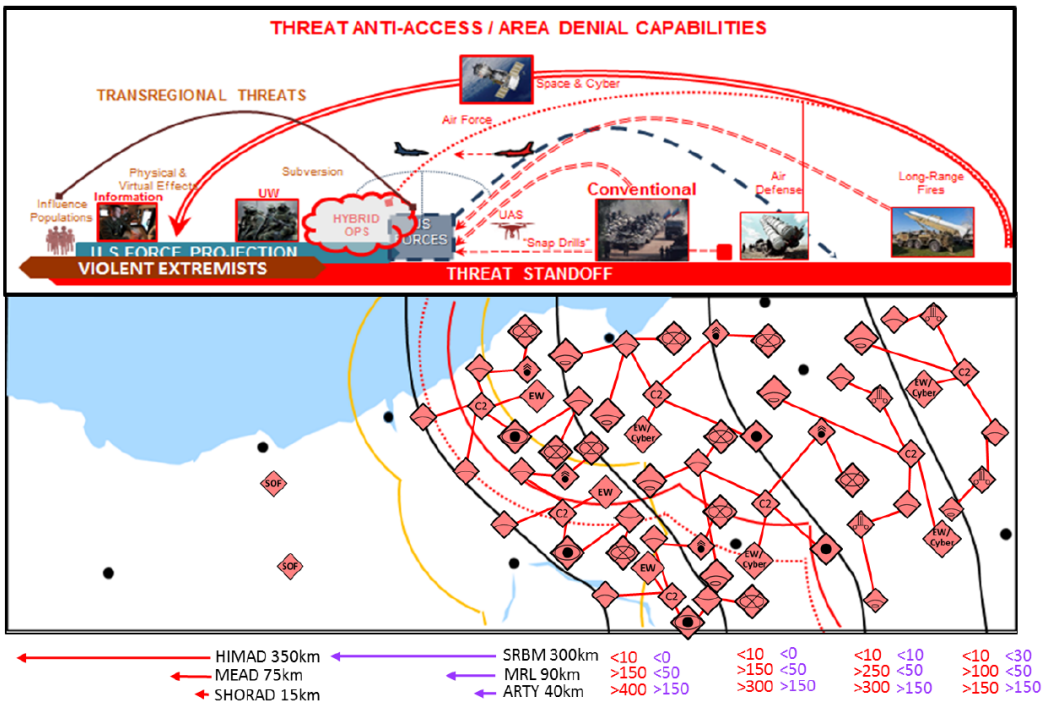


Figure 8. Threat Anti-Access/Area Denial Capabilities. *TRADOC Pamphlet 525-3-8*, 36.

Army Aviation will switch their focus to employ multiple cross-domain maneuvers designed by EAB to create windows of opportunity for maneuver forces. To achieve overmatch when facing a peer-adversary, Army Aviation must have the capability to reach, provide close air support, lethality, and situational understanding. For the consideration of this paper, the focus will be the gaps in capability to reach and play a crucial role in AGOs and ensuring freedom of maneuver. The second part of this discussion will analyze the training gaps for current and future Army Aviators, as well as EAB, to successfully utilize the asymmetric advantages that Army Aviation provides in LSCO.[42]

Reach: Range, Speed, Survivability, and Maneuverability

According to Army Aviation's equipment modernization strategy, reach is a part of the first four of seven key Army Aviation challenges and gaps, as identified in the Army's capability

[42] US Department of the Army, *TRADOC Pamphlet 525-3-8, The US Army Concept for Multi-Domain Combined Arms Operations at Echelons Above Brigade 2015-2045* (Fort Eustis, VA: Government Printing Office, 2018), 6.

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needs analysis. Army Aviation requires platforms to have adequate range, speed, survivability, maneuverability, and deploy quickly to strategic locations with little notice. Two of the major differences between COIN and LSCO are going to be the theater and availability of troops and divisions already on the ground, such as our contingent in Iraq and Afghanistan. Regarding LSCO, the theater could be immense and the range of UAS platforms could fall short of intelligence, surveillance, and reconnaissance requirements. The United States would have to project into an undeveloped theater and fight to gain a foothold, unlike the last seventeen years. The Apache AH-64D/E currently has lower combat range and cruise speed than the assault and air movement airframes.[43]

The deficient range capability of the AH-64 is priority number six out of sixty-seven high-priority programs for the Army fiscal year 2019 budget. The Army's improved turbine engine program attempts to resolve this shortfall, and intends to expand the program to the UH-60M. This program seeks improved fuel consumption and greater power to support increased maneuverability. Given the importance of range to aviation operations, the Army recently took great lengths to test the Army's range of the UAS MQ-1C extended range. The extended range Gray Eagle underwent an extensive fourty-two day training mission with F Company from 160th Special Operations Aviation Regiment Airborne (SOAR) at the National Training Center (NTC) in Fort Irwin, California. The MQ-1C extended range satisfied the demand for a combat radius of 1,000 kilometers and fourteen hours of loitering time. It also set the standard of forty hours of continuous flight with a common sensor payload and twenty-four hours with a payload of two Hellfire missiles. Army Aviation is making attempts to fill capability gaps, but it takes valuable

[43] US Army Aviation Center of Excellence, *Army Aviation Equipment Modernization Strategy: Equipping the Aviation Force to Win in a Complex World* (Fort Rucker, AL: US Army Aviation Center, January 2016), 3.

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time, and money as the MQ-1C Extended Range three-year project cost over thirteen million dollars but met with success.[44]

Future Vertical Lift (FVL) works toward improving future airframes with greater range, power, and sustainability. FVL, elevated into one of the six cross-functional teams in the new modernization strategy of the Army, as seen below in table 1. The new lines of effort are the future attack-reconnaissance aircraft, the future long-range assault aircraft, an advanced UAS, and a modular system approach. The challenge facing FVL is creating strategies and procuring technology to defeat (or make small windows of opportunity against) A2/AD systems as seen below in Figure 9. Another capability gap is the susceptibility of cyber-attack. FVL is working on implementing a "digital backbone that affords a cyberphysical interface" to not only protect, but enable quick, fleet wide updates to be proactive against an emerging threat. The capability to implement updates to current systems is usually a long process, but that will soon change with the installment of the CAB architecture integration lab. The Army does not have rights to most of the software on the aircraft, and any improvements or additions must go back to the manufacturing company for testing and approval. This is a timely and costly process. The UH-60V will be the first aircraft with the open systems architecture mission computer. The Army will own the rights to the software and rapidly speed up the process of new technology insertions in the refurbished UH-60L.[45]

[44] Government Accountability Office, GAO-19-132, *Army Modernization Priorities and Assigned Cross-Functional Teams* (Washington, DC: Government Printing Office, 2019), 14; Joshua Durham, "Testing the Army's Extended Range Gray Eagle UAS," 52-53.

[45] William Lewis and Carvil Chalk, "Science and Technology for Future Vertical Lift," *Army Aviation* (January 2019): 45; US Army Aviation Center of Excellence, *Army Aviation Equipment Modernization Strategy*, 8; Thomas H. Todd III, "PEO Aviation Meeting the Demands of the Future Battlefield," *Army Aviation* (December 2018): 10.

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Table 1. Army Modernization Priorities and Assigned Cross-Functional Teams

Army priority	Description of priority	Cross-functional team location
Long-Range Precision Fires	Capabilities, including munitions that restore Army dominance in range, lethality, and target acquisition.	Long-Range Precision Fires – Fort Sill, Okla.
Next Generation Combat Vehicle	Manned and unmanned combat vehicles with modern firepower, protection, mobility, and power generation.	Next Generation Combat Vehicle - Detroit Arsenal, Mich.
Future Vertical Lift	Manned and unmanned platforms capable of attack, lift, and reconnaissance missions on modern and future battlefields.	Future Vertical Lift – Redstone Arsenal, Ala.
Army Network	A mobile system of hardware, software, and infrastructure that can be used to fight cohesively in any environment where the electromagnetic spectrum is denied or degraded.	Network Command, Control, Communication, and Intelligence – Aberdeen Proving Ground, Md.
		Assured Positioning, Navigation, and Timing – Redstone Arsenal, Ala.
Air and Missile Defense	Capabilities that ensure future combat formations are protected from modern and advanced air and missile threats.	Air and Missile Defense – Fort Sill, Okla.
Soldier Lethality	Capabilities, equipment, and training for all fundamentals of combat—shooting, moving, communicating, protecting, and sustaining. This includes an expansion of simulated training.	Soldier Lethality – Fort Benning, Ga.
		Synthetic Training Environment – Orlando, Fla.

Source: Government Accountability Office, *GAO-19-132*, 8.

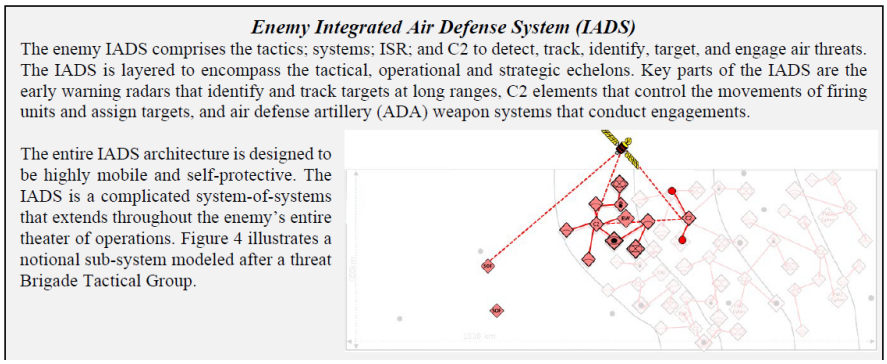


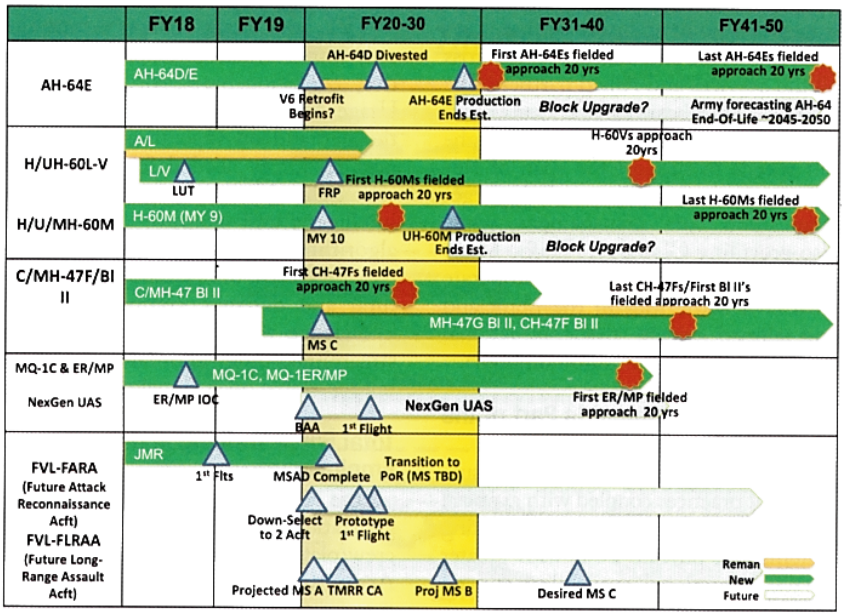
Figure 9. Enemy Integrated Air Defense System. *TRADOC Pamphlet 525-3-8*, 42.

FVL's challenge is the task of making the expeditionary aviation forces self-deployable, by increasing their range, as well as maintenance requirements. Several units that stand at the ready for deployment of large distances into US Indo-Pacific Command rely heavily on C17's for transport. The transportation issues arise at the low supply of C17's to mobilize CH-47s, UH-60s, AH-64s, and UAS. A C-17 can only take one CH-47 at a time, or two UH-60s, and that is after units have prepared the aircraft for transportation in the C-17. Upon landing, units must conduct hours of maintenance and test flights. It can take several weeks to mobilize just an aviation expeditionary force, which is not quick enough for mobilization in support of LSCO. Once the expeditionary forces mobilize, they need the flexibility of movement, which is typically dependent on sustainment. Aviation is reaching a pivotal point in the modernization of the fleet

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with investing in the legacy airframes to ensure readiness to fight LSCO today, versus the future fleet with upgraded capabilities. As seen below in table 2, the modernization chart has most of the legacy fleet in service until fiscal year 2050. The CH-47F, with the digital cockpit upgrades, cost the aircraft 4,000 pounds of payload. Army Aviation is attempting to regain the 4,000 pounds of capability through engine and rotor blade enhancements. The Army can only upgrade the legacy fleet to a certain point, as seen with the CH-47, and aviation must balance when to invest in new models over modifying the current fleet. The Army has the largest vertical fleet of the service, yet only spent twenty-seven and a half percent of the total military services rotary wing aviation spending on research and development. The Army needs to find a balance between sustaining the legacy fleet and investing in FVL.[46]

Table 2. Army Aviation Major Fleet Modernization Perspective



Source: Army Aviation "The Future of Vertical Lift–The Future of Army Aviation," 76.

[46] US Army Aviation Center of Excellence, *Army Aviation Equipment Modernization Strategy*, 8; Gabriel Coll, Andrew Hunter, and Robert Karlen, "Beating the Air into Submission: Investing in Vertical Lift Modernization" (Center for Strategic and International Studies Briefing, February 2019), 3.

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Sustainment

FVL's future goals include maintenance free intervals of their platforms for thirty days or sixty hours. Sergeant Major Mike Dove, Command Sergeant Major of Army Aviation and Missile Command (AMCOM) Life Cycle Management Command (LCMC), commented on the maintenance intervals as "a lofty goal" during the Cribbins Aviation product sustainment symposium, but later compared them to the commercial airline fleet maintenance schedule. Though it has not been much of a concern the last seventeen years in COIN, Army Aviation maintenance capability is a major concern for LSCO. Units delegated aircraft reset to contractors during COIN, along with other maintenance duties, but that may not be possible during LSCO. Army maintenance companies are now returning to completing phase inspections to gain battle readiness again, but it will take time and initiative in each division to wean maintenance companies off a strong contractor's presence. The reset program, now a part of CAB responsibility has undergone a new concept to rate aircraft reset needs based on a holistic approach of the aircraft, as seen in Figure 10, instead of just deployment cycle. The sustainment decision support tool makes the process more efficient, and takes into consideration more factors, such as operational tempo.[47]

[47] Mike Dove, "Final Report from the AAAA Cribbins Symposium," *Army Aviation* (January 2019): 16; Anthony W. Hudson and John Gipson, "1ID CAB Aviation Maintenance in a Post-ARFORGEN World," *Army Aviation* (January 2019): 42-43; Shawn T. Prickett and James P. Snyder, "Sustaining the Fleet–Leveraging Condition Based Reset," *Army Aviation* (January 2019): 36-37.

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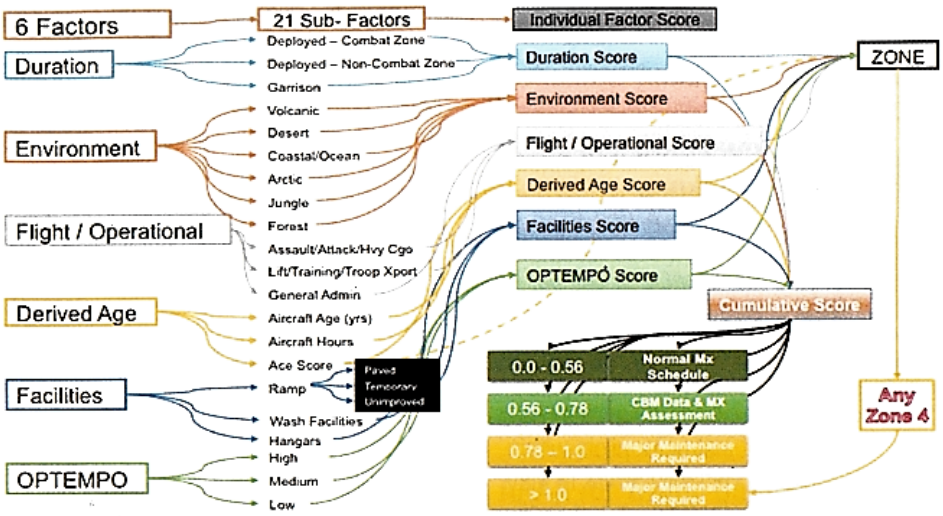


Figure 10. Condition Based Decision Support Tool Factors. "Sustaining the Fleet," 36.

A peer threat can target the Army's center of gravity, mainly the supply chain and maintenance capabilities, limiting the Army's operational reach. Maintenance will have to be agile, organically mobile, and expeditionary, as shown in Figure 11 below, to avoid becoming an easy target. The same will also be true for aviation aircraft. The CAB must be able to operate while breaking up maintenance organizations into smaller formations in multiple locations. If broken down into platoons, the formations of aircraft will become less of a target and less of a risk to the CAB. LSCO could require maintenance mobility time frames of every twenty-four to forty-eight hours as the CAB maneuvers.[48]

[48] Prickett and Snyder, "Sustaining the Fleet," 36-37.

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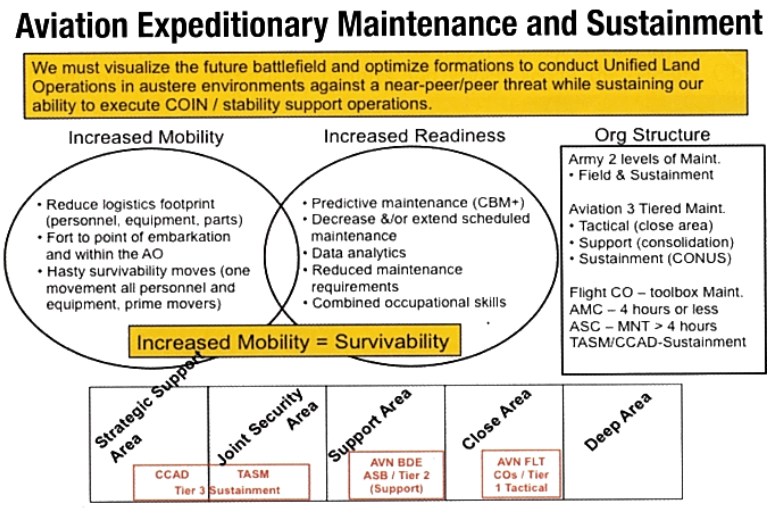


Figure 11. Aviation Expeditionary Maintenance and Sustainment. "Expeditionary Sustainment in Support of Large Scale Operations," 31.

AMCOM operated on the "Just-In-Time" inventory approach due to the logistics modernization program. The logistics modernization program focused on the most efficient method to keep the lowest possible stock on hand. The logistics modernization program was efficient and effective for Army Aviation's efforts in COIN, but represents another shock in Army culture in the change needed for fleet readiness of in-depth supply chains. The identified gaps in sustainment for LSCO, and goals set by AMCOM, includes ninety days of stock on hand with no backorder of more than thirty days for critical readiness parts. AMCOM identified the top readiness drivers as a priority for each aircraft to build enough supply depth. The question arises if AMCOM will be able to predict and anticipate the supply needs of LSCO, especially with the previous supply state of mind from the logistics modernization program, "Just in Time." AMCOM is setting the best goals, but LSCO is unknown. There are still capability gaps in the supply chain and formations of maintenance that need to adjust before the US engages in a conflict with near or peer threats. Maintenance is just one factor in the survivability of the aircraft.[49]

[49] David K Almquist and Brent Swart, "AMCOM-Working to Attain Strategic Supply Chain Depth," *Army Aviation* (October 2018): 56-57; Douglas M. Gabram, "Attacking Aviation Readiness Drivers," *Army Aviation* (October 2018): 11.

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Another integral part of survivability of Army Aviation in LSCO is equipment, current technology, and strategy to defend against a near or peer threat. The project management office for aircraft survivability equipment (PMO ASE) is fielding many systems, such as the advanced threat infrared countermeasures for CH-47 aircraft, to defend against man-portable air-defense systems. The PMO ASE found success and continues to test new updated versions to include the AN/AVR-2B laser detecting set, a passive laser warning system to increase aircrew situational awareness. The capability gap of facing an A2/AD system is still an ongoing issue, as PMO ASE is still pursuing multi-spectral detect and defeat technology to outmatch our near and peer threats. The PMO ASE made small successes on the path to defending against A2/AD systems, but are not currently enough for LSCO.[50]

Training Gaps

The NTC at Fort Irwin, California works to revitalize their training to fit an MDO scenario for live training against a near-peer threat. The slogan used by NTC is "Ready now to win against a near-peer threat. Readiness for ground combat remains our number one priority." NTC pushes to increase the tempo, lethality, complexity, and limited communication of an MDO with a peer threat. NTC brought to light the lack of knowledge of efficient use of Army Aviation, especially the UAS. One of the many lessons learned of NTC is to "learn faster, and synchronize combined arms faster than the enemy." Fighting at echelon is difficult due to the complex synchronization, especially when units are unfamiliar with how to employ Army Aviation in LSCO. NTC is striving to provide realistic training. However, electronic warfare and cyber-attacks are not yet present, and as such, units lack repetitions on operating with such threats. NTC is only capable of providing a near-peer threat in terms of capabilities which was a large transition from COIN. If the purpose of NTC, according to the commander of operations at NTC,

[50] Kevin S. Chaney, "Project Manager Aircraft Survivability Update," *Army Aviation* (October 2018): 29-31.

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Colonel Christopher R. Norrie, is to "ensure that units have their hardest day in the desert so that no soldier goes untrained into combat," then their ultimate goal should be to train against a peer threat instead of a near-peer threat.[51]

NTC's goal is not only to train the brigade, but also build up and train their leadership. One observation of Army Aviation made at NTC, was the diminished amount of platoon leaders serving as air mission commanders. CABs need to instill the younger officers with the experience they will need in mitigating risk, planning, and leading flight formations, and the burdens of mission success for the future company and battalion commands. Company commanders are the prime educators for their unit's air mission commander. If they lack in experience, it will reflect on the knowledge of the air mission commander. NTC is an excellent learning environment for young officers, but only if given the leadership roles that "will guarantee competent leaders and commanders at echelon that lead and fight in a complex environment," according to deputy commander of the Combat Readiness Center, COL Christopher Waters.[52]

The Joint Readiness Training Center (JRTC) has also been evolving its training techniques. JRTC focuses on the peer-threat faced by the United States in LSCO. JRTC expanded its training area in response to the break from COIN to mass combat capabilities and focus on combined arms integration. The fourteen-day crucible challenges brigades to integrate into the division level fight, not just at the brigade or battalion level. Similar to NTC, JRTC also needs to incorporate electronic warfare and cyber-attacks into training scenarios. The terrain of JRTC, although expanded, has little-improved roads to simulate urban conditions that will be a part of LSCO. The terrain does simulate lack of open areas as an urban environment would for massing

[51] First quote from Christopher R. Norrie, Thomas E. Lamb, and Michael J. Culler, "Ready Now-Our Number One Priority," *Military Review* (September-October 2018): 61; second quote from Norrie, Lamb, and Culler, "Ready Now-Our Number One Priority," 67; third quote from Norrie, Lamb, and Culler, "Ready Now-Our Number One Priority," 62.

[52] Christopher W. Waters, "The Importance of Platoon Leaders Serving as Air Mission Commander," *Army Aviation* (December 2018): 19.

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combat power but lacks the substantial noncombatant population challenge. JRTC is ever evolving and successfully breaking down the culture and norms established by the last seventeen years of COIN. JRTC is setting a foundation for fighting at EAB but still requires additional improvements to prepare units for LSCO by including electronic warfare, cyber warfare, and A2/AD.[53]

160th SOAR is trying to bridge the gap of tactics against defeating the A2/AD systems. SOAR identified the gap in training for advanced weaponry tactics compared to other sister aviation services, such as the Marine Corps' weapons and tactics instructor course, and the Air Force weapons school. SOAR is trying to solve the A2/AD threat and other challenges presented by an MDO by creating advancements in education and training. SOAR's motto is to "own the night," which without any changes and advancements will not be a given, as even SOF can no longer count on air superiority or unimpeded night operations. Figure 12 below demonstrates SOAR's vision for their tactics program. The vision is to fuse intelligence, electronic warfare, and Army Aviation Mission Survivability Officers (AMSO). The school will combine their expertise to enhance their crews' survivability. The key to fighting in an MDO is a combined effort to attack in multiple domains, but that is not possible without first establishing habitual relationships within the multiple domains.[54]

[53] David Doyle and Aaron Coombs, "How Has the JRTC Changed to Adapt to LSCOs?" *Military Review* (September-October 2018): 74-79.

[54] Sean Karrels and Brett McFarland, "Bridging the Aviation Education Gap," *Army Aviation* (June 2018): 28-31.

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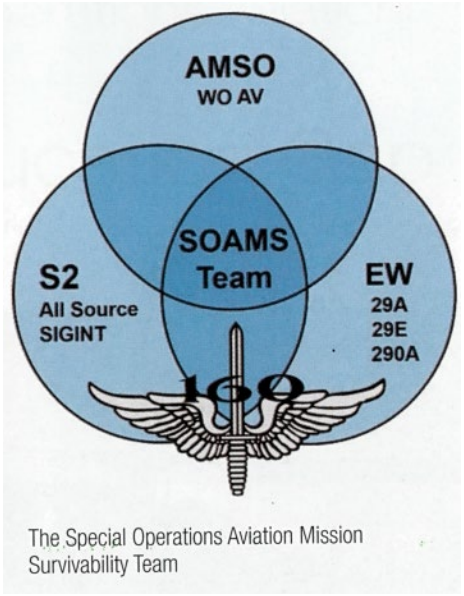


Figure 12. The Special Operations Mission Survivability Team. "Bridging the Aviation Education Gap," 28.

Mission command training program (MCTP) and the warfighter exercises observations are like the gaps observed by the 160th SOAR. The failure to integrate and synchronize resources degrade the efficiency of the AGO. The three main contributors to a failure of AGO at the warfighter exercises were "synchronization of operations in the deep area, integrated targeting at the division and higher level, and tasking and employment of the Gray Eagle UAS." The first and second issues are due to the decentralized mindset of a CAB from the many years of COIN. Headquarters must take an active role and integrate the CAB and artillery to ensure mission success. The third is concerning with misuse of UAS. UAS has so many capabilities, as seen in Figure 13 below, and division and corps must learn how to best utilize the UAS in multiple situations. The under or over utilization of Army Aviation at EAB is a concern for aviation. Vertical lift can be an asset by leveraging windows of opportunity for an AGO in an MDO, but only if used efficiently. The MCTP is working on training EABs to understand how to integrate the UAS, MUM-T, close support, air assaults, and deep attacks into their plans. The doctrine exists on how to employ MUM-T, but the training is still evolving to accomplish the guidelines set in *FM 3-04*. Flight school level and brigade level need new training simulators to incorporate

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UAS drivers and AH-64 teams to train together in a live virtual environment to develop the MUM-T relationships and familiarity.[55]

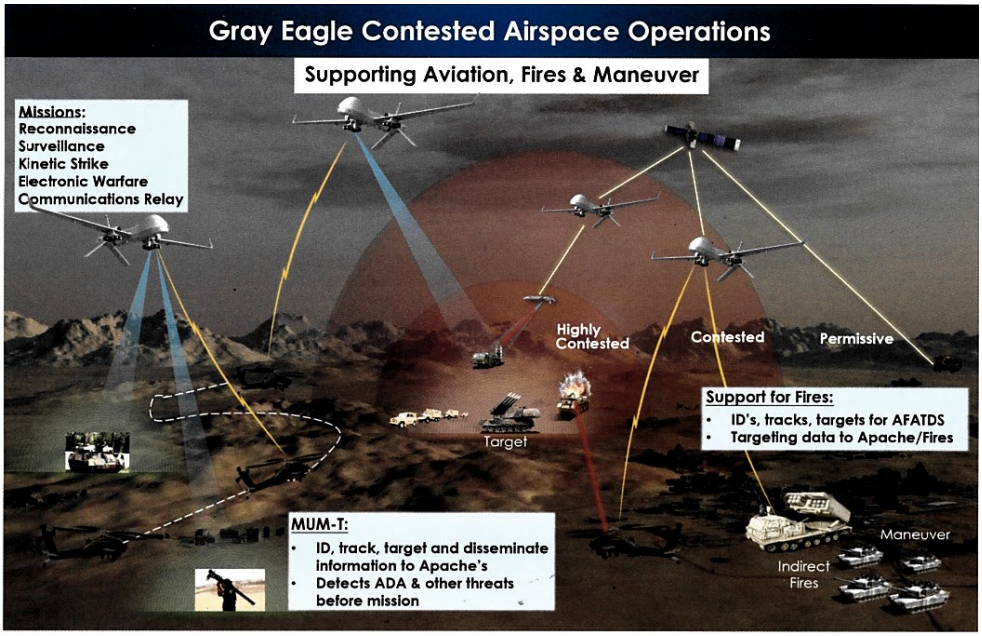


Figure 13. Gray Eagle Contested Airspace Operations. "Gray Eagle in Large Scale Combat Operations," 32.

Conclusion

Aviation is critical then, critical today, and critical tomorrow.

— Sergeant Major Woody Sullivan, "Greetings," *Army Aviation*

Army Aviation needs to integrate into a cross-functional team to be successful against the current near and peer threats in LSCO. The threat of robust A2/AD systems means Army Aviation needs to train toward the realization of limited air superiority and freedom of maneuver. Commanders and training centers need to update training to match the new Army Aviation doctrine standards set in *FM 3-04*. The Army took proactive steps by creating new doctrine to address the LSCO challenge, just as the Army did with AirLand Battle doctrine nearly half a century ago. AirLand Battle doctrine was written in the 1970s, well before being validated in

[55] Sweet, "Integration of Aviation OPS at EAB," 6; US Army Aviation Center of Excellence, *Army Aviation Equipment Modernization Strategy*, 11.

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Operation Desert Storm. In addition, AirLand Battle was put to the test with exercises at JRTC, NTC, and in Operation Desert Shield. The Army may not have ten years to perfect the new doctrine before LSCO against a near or peer threat, so training environments need to be as rigorous as a complex MDO will be. JRTC and NTC have made significant advancements in training for COIN to LSCO, but both need to integrate more domains to enable cross teaming and training against the specific air defense systems of our peer threats.

To be successful against peer threats, Army Aviation needs to continue modernizing the fleet to compete with new threats in MDO. The legacy fleet, based on thirty-one year-old airframes, will only reach so far in capabilities for Army Aviation. The Army needs to keep investing more heavily in FVL's new airframes, while still balancing the upgrades for the legacy fleet to ensure the ability to fight today. The Army needs to continue developing and implementing CAB architecture software and hardware to increase prototype capabilities and expedited technology insertion. Army Aviation needs to update the AH-64 crew trainers to include cross training with UAS, to develop a seamless relationship with MUM-T. UAS operators and AH-64 crews need to train how they will fight; as a team. Army Aviation continues to improve and learn from the new doctrine in place for fighting in LSCO. Training and dissemination of lessons learned at warfighter exercises, JRTC, NTC, and past near-peer LSCO, such as Desert Storm, are key to improving and challenging future aviators who will be charged with fighting in complex MDO.

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THE FIRST STEP: BUILDING A SPECIAL OPERATIONS AVIATION SPECIFIC UNMANNED AIRCRAFT SYSTEM CAPABILITY

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements for the degree

MASTER OF MILITARY ART AND SCIENCE
General Studies

by

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The Army began the testing and development of the unmanned aircraft system (UAS) capability in 1953. Since that point, the UAS has grown exponentially and proven itself as an essential capability on the battlefield in every major conflict since Desert Storm. In 2013, the United States Army Special Operations Command (USASOC) began to employ the first and only Special Operations Aviation (SOA) MQ-1C Gray Eagle UAS unit in the Army. The Army Special Operations Aviation (ARSOA) Gray Eagle unit is organized, trained, and equipped in an almost identical fashion as the conventional force (CF) Gray Eagle units. Conversely, the rotary wing units within ARSOA are organized, trained, and equipped in a very different manner than the CF rotary wing units.
The purpose of this study is to illustrate that capability gaps exist in the domains of organization, training, and equipping of the ARSOA Gray Eagle unit. A comparative analysis of ARSOA rotary wing units in relation to CF rotary wings is used to identify these capability gaps. The study then uses a modified doctrine, organization, training, materiel, leadership and education, personnel, facilities, policy (DOTMLPF-P) analysis and a capabilities-based assessment (CBA) to identify potential materiel and non-materiel solutions.

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

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ABSTRACT

THE FIRST STEP: BUILDING A SPECIAL OPERATIONS AVIATION SPECIFIC UNMANNED AIRCRAFT SYSTEM CAPABILITY, by Joshua J. Durham, 84 pages.

The Army began the testing and development of the unmanned aircraft system (UAS) capability in 1953. Since that point, the UAS has grown exponentially and proven itself as an essential capability on the battlefield in every major conflict since Desert Storm.

In 2013, the United States Army Special Operations Command (USASOC) began to employ the first and only Special Operations Aviation (SOA) MQ-1C Gray Eagle UAS unit in the Army. The Army Special Operations Aviation (ARSOA) Gray Eagle unit is organized, trained, and equipped in an almost identical fashion as the conventional force (CF) Gray Eagle units. Conversely, the rotary wing units within ARSOA are organized, trained, and equipped in a very different manner than the CF rotary wing units.

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ACRONYMS

ARSOA	Army Special Operations Aviation
CBA	Capabilities-Based Assessment
CF	Conventional Force
DOTMLPF-P	Doctrine, Organization, Materiel, Leadership and Education, Personnel, Facilities, Policy
SOA	Special Operations Aviation
SOF	Special Operations Forces
USASOAC	United States Army Special Operations Aviation Command
USASOC	United States Army Special Operations Command
USSOCOM	United States Special Operations Command
UAS	Unmanned Aircraft System

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CHAPTER 1

INTRODUCTION

Problem Statement

In 2013, Army Special Operations Aviation (ARSOA) began to employ the MQ-1C Gray Eagle Unmanned Aircraft System (UAS), hereafter referred to as Gray Eagle, in support of special operations around the globe. Unlike the rotary wing units within ARSOA, there is not a major difference in the way that the ARSOA Gray Eagle unit is manned, trained, and equipped from that of the Conventional Force (CF) Gray Eagle units. Conversely, the rotary wing units within ARSOA have major differences in the way they are manned, trained, and equipped, in comparison to CF rotary wing units, in order to provide a unique aviation capability in support of Special Operations Aviation (SOA). Therefore, if there currently are no major differences in the way that the ARSOA Gray Eagle unit is manned, trained, and equipped, in comparison to CF Gray Eagle units, then what unique capability does the ARSOA Gray Eagle unit provide SOA? Of note, the terms manning and equipping will be used synonymously throughout this thesis with the terms organization and materiel, respectively.

Background

The concept of unmanned flight was first introduced in 1915, and by 1919 an unmanned aircraft completed a successful engagement on a captured German submarine using gyroscope-guided technology. For the Army specifically, the UAS effort began in 1953, at Fort Huachuca, Arizona, the Army's first testing and fielding location. By 1979, the Army began its first UAS acquisition program with the Aquila, which completed its operational testing in only 7 of 105 scheduled flights. This led to the Department of

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Defense's first fully operational UAS program, the Pioneer, which successfully sought out SCUD missile systems and high value targets during more than 300 combat missions during Operations Desert Shield and Desert Storm. The Army continued to build its UAS capability and by the time the United States went to war in October 2001, the Army had 54 operational Hunter and Shadow unmanned aircraft in use and that number rapidly grew to over 4,000 unmanned aircraft by 2010 when the Army employed Groups 1-4 types of UAS.

Table 1. Current Systems

UAS Category	Max Gross Takeoff Weight	Normal Operating Altitude (Ft)	Airspeed	Current Army UAS in Operation
Group 1	< 20 pounds	< 1200 above ground level (AGL)	<100 Knots	RQ-11B Raven
Group 2	21-55 pounds	< 3500 AGL	<250 Knots	No current system
Group 3	< 1320 pounds	<18,000 mean sea level (MSL)		RQ-7B Shadow
Group 4	> 1320 pounds		Any Airspeed	MQ-5B, MQ-1C
Group 5		> 18,000 MSL		No current system

Source: Army UAS COE, *UAS Current Systems* (Ft. Rucker, AL. U.S. Army, 2012), 12.

The United States Army has employed the Gray Eagle for more than a decade, but it was not until 2013 that it joined the ranks of ARSOA. In 2013, Company E, 160th Special Operations Aviation Regiment (E/160) stood up as the first and only special operations aviation Gray Eagle company within the Army. Before that time Quick Reaction Capability Companies, made up of different CF UAS units, filled the SOA UAS requirements in both Iraq and Afghanistan. The formation of E/160 brought about an organic, Group 4 UAS capability to the United States Army Special Operations Command (USASOC) to support special operations forces (SOF). A holistic review of ARSOA Gray Eagle operations within SOA has not been written to capture the unique

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challenges this capability brings with it in terms of manning, training, and equipping. Currently ARSOA UAS is continuing to grow and is fielding a second Gray Eagle company (USA UAS COE 2010, 4-6). Now that the ARSOA Gray Eagle company appears to be a stable and growing capability, it is time to conduct a robust needs analysis to ensure that the unit is properly manned, trained, and equipped, from the SOF end-user perspective and not just utilizing the capabilities driven by CF requirements and analysis.

Primary Research Question

ARSOA does not employ the Gray Eagle like a CF UAS unit. However, the ARSOA Gray Eagle company is manned, trained, and equipped in almost an identical fashion as the CF UAS units. Conversely, the rotary wing ARSOA units are manned, trained, and equipped significantly different from that of rotary wing CF units. ARSOA has specific manning, training, and equipping approaches that enables its rotary wing units to have a unique capability that the CF does not have. This leads to the primary research question: are there organizational (manning), training, and materiel (equipping) capability gaps that are preventing the ARSOA Gray Eagle unit from providing a unique SOA capability? This study will illustrate whether or not the CF force development processes fully exploit the Gray Eagle's capabilities and meet SOF needs. Only by conducting a needs analysis from a SOF perspective can the force development process be reverse-engineered to ensure that ARSOA is fully exploiting the capabilities of their Gray Eagle units.

Primary Research Question

In order to answer the primary question, specific questions must be asked within the DOTMLPF-P domains of organization (manning), training, and materiel (equipping). The secondary questions to be answered in this thesis are:

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1. How does ARSOA man, train, and equip their UAS units in comparison to both CF UAS units and rotary wing ARSOA units?
2. Are there capability gaps in terms of manning, training, and equipping of the ARSOA Gray Eagle organization when compared to the rotary wing ARSOA units?
3. What are the potential materiel and non-materiel solutions to the ARSOA Gray Eagle units' domains of manning, training, and equipping, needed to provide a unique capability to SOF?

These secondary questions address specific issues under the DOTMLPF-P domains of organization, training, and materiel. Answering them will help to clearly define and focus the primary research question and this thesis.

Key Assumptions

The author makes two key assumptions in this paper. The first assumption is that the Gray Eagle and the near-term fielding of the MQ-1C Extended Range Gray Eagle UAS are the only Group 4 UAS platforms employed by ARSOA within the foreseeable future. United States Army Special Operations Aviation Command (USASOAC) has other Group 1, 2, and 3 UAS platforms, but for this study, the assumption will remain that the only Group 4 UAS employed by ARSOA is the Gray Eagle company within the 160th Special Operations Aviation Regiment (160th SOAR).

The second assumption is that the selected units used in this study represent their entire community. Specifically, this study used Company B, 3d Battalion, 82d Combat Aviation Brigade (B/3-82) to represent the CF rotary wing community; Company B, 101st Combat Aviation Brigade (B/101) to represent the CF Gray Eagle community;

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Company A, 2d Battalion, 160th Special Operations Aviation Regiment (A/2-160) to represent the ARSOA rotary wing community; and Company E, 160th Special Operations Aviation Regiment (E/160) to represent the ARSOA Gray Eagle community.

Definitions and Terms

The Unmanned Aircraft System (UAS) is a complex topic, and coupled with unique aspects of the special operations community, it makes appreciation of the issues identified in this thesis challenging without an understanding of the terms presented. The key terminology in this paper will discuss; the UAS, special operations aviation, general aviation, and key terms for understanding the applied professional case study methodology.

UAS Terms

Unmanned Aircraft System (UAS): The UAS is defined as the unmanned aerial vehicle (UAV), this study will be specifically looking at the MQ-1C Gray Eagle, the ground control station (GCS), and the communications architecture (USA UAS COE 2010, 8-10). This is a key concept to understand since the UAS will commonly be referred to as a UAV, and while the UAV is a component of the overall UAS, it is not the same thing as a UAS. Unlike manned platforms, the UAS requires all the components of the system to be operational, i.e. the UAV, the GCS and the communications architecture, for the UAS to be considered operational.

Unmanned Aircraft Crewmember (UAC): UAS crewmembers will be designated in writing by their unit commander, who will specify the UAS duties and crew stations that the UACs are authorized to occupy (HQDA 2006, 13).

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Unmanned Aircraft Operator (AO): The AO controls and/or monitors the actual flight of the UAS from within a GCS or similar device (HQDA 2006, 13).

Mission Payload Operator (PO): The PO is responsible for the operation of the payload sensor (HQDA 2006, 13).

Aircraft Commander (AC): The AC is responsible for control over all flight operations from pre-mission planning through debriefing. The UAS unit commander will designate aircraft commanders in writing. The AC will be responsible and have final authority for operating, servicing, and securing the UAS he or she commands, selected for each flight or series of flights, qualified and current in the UAS mission, type, design, and series (HQDA 2006, 13).

Instructor Operator (IO): The IO will train and evaluate UACs in accordance with the appropriate ATM, IOs must be designated in writing by the unit commander and be qualified and current in the UAS to be flown and must be qualified as an MC and successfully complete a Department of the Army approved IO course (HQDA 2006, 13).

Military Occupational Specialty (MOS): The grouping of duty positions requiring similar qualifications, and the performance of closely related duties (enlisted). It provides the branch, functional area, area of concentration, skill, language identification, and reporting classification used to classify the positions, and to identify individuals qualified to perform in those positions (officer) (DA PAM 611-21 2007, 12).

Additional Skill Identifier (ASI): A two-digit alpha-numeric or numeric-alpha code which identifies specialized skills that are closely related to and in addition to those required by the MOS (DA PAM 611-21 2007, 18).

Enlisted MOS 15W: Unmanned aircraft systems operator.

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Remote Split Operations (RSO): Allows operators to fly UASs from stateside locations while smaller in-theater teams control takeoffs and landings. RSO has two elements: a launch and recovery element (LRE) and a mission control element (MCE). The LRE is deployed forward to launch, recover, and conduct maintenance on the UAS. The MCE remains stateside to provide command and control and provides the operators to fly the UAV while on mission.

General Aviation Terms

Pilot (PI): A rated crewmember that is qualified and current in the aircraft mission, type, design, and series (HQDA 2014c, 26).

Pilot-in-Command (PIC): A rated crewmember that is qualified, current, designated Readiness Level (RL) 1 in the aircraft mission, type, design, series, and is the individual responsible and has final authority for operating, servicing, and securing the aircraft he or she pilots (HQDA 2014c, 25).

Unit Trainer (UT): The unit commander may appoint UTs to conduct specialized training to assist in unit training programs. Rated UTs are prohibited from conducting emergency procedures training in the aircraft. UTs are also prohibited from evaluating individual, crew, and maintenance tasks (HQDA 2014c, 26).

Instructor Pilot (IP): The IP will train and evaluate aviators and other personnel in designated aircraft per the aircrew training manual (ATM). To become qualified as an IP, an aviator must be qualified as a PC and must successfully complete an approved Department of the Army instructor pilot course (HQDA 2014c, 27).

Instrument Examiner (IE): The IE will conduct instrument training and instrument flight evaluations per the ATM. To become qualified as an IE, an aviator must be an IP in

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either aircraft category, and successfully complete a Department of the Army approved course of instruction for IEs (HQDA 2014c, 27).

Readiness Levels (RLs): Aviation commanders use a series of RLs to develop individual and crew proficiencies that support collective tasks. RLs identify the training phase in which aircrew members (ACM) are participating and measure ACM readiness (HQDA 2016a, 51).

Mission Approval Process: The mission approval process for aviation operations is accomplished in three steps that must be completed prior to mission execution. The three steps are: initial mission approval, mission briefing and planning, and final mission approval authority (HQDA 2014c, 9).

Initial Mission Approval: Commanders or their designated representatives (operations officer, S–3, and so forth) determine the mission feasibility and either accept or reject the mission for the command (HQDA 2014c, 9).

Mission Briefing Officer (MBO): The MBO is the Commander or his/her designated representative that interacts with the mission crew or air mission commander to identify, assess, and mitigate risk for the specific mission. Commanders will select MBOs based on their experience, maturity, judgment, and ability to effectively mitigate risk to the aircrew and designates them by name and in writing (HQDA 2014c, 9).

Final Mission Approval Authority (FMAA/MAA): Members of the chain of command who are responsible for accepting risk and approving all aviation operations (ground and air) within their unit. They approve missions for a specific risk level. FMAAs may only approve those missions whose assessed risk level is commensurate with their command level (HQDA 2014c, 9).

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Instrument Flight Rules (IFR): Instrument meteorological conditions is an aviation flight category that describes weather conditions that require pilots to fly primarily by reference to instruments, and therefore under instrument flight rules (IFR), rather than by outside visual references under visual flight rules.

Special Operations Aviation Terms

Army Special Operations Aviation (ARSOA): Designated active component forces and units organized, trained, and equipped specifically to conduct air mobility, close combat attack, and other special air operations (ADRP 3-05 2012, 47). Additionally, it is important to understand that Special Operations Aviation (SOA) supports other special operations forces units by planning and conducting special air operations in all operational environments. These specially organized, trained, and equipped aviation units provide the joint force special operations component commander with the capability to infiltrate, resupply, and exfiltrate SOF elements engaged in all special operations core activities (ADRP 3-05 2012, 47).

Battle-Rostering: Battle-rostering is defined as the designation of two or more individuals to routinely perform as a crew (HQDA 2013a, 12-13).

ARSOA Battle-Rostering: In addition to the practice of battle-rostering, individual crew members and SOA crews are further organized based on the level of mission qualification they have achieved. This modification to the aircrew model can be applied across the spectrum of SOA missions, in both training and combat, and provides the commander a clear tool to control risk while retaining mission flexibility and ensuring successful support of the ground force commander's intent (HQDA 2013a, 12-13).

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Basic Mission Qualified (BMQ): BMQ pilots may perform PC or pilot (PI) duties during internal training or perform PI duties on internal/external training (HQDA 2013a, 14-15).

Fully Mission Qualified (FMQ): FMQ pilots may perform PC or PI duties during the conduct of internal and external training; they may also formally train for Flight Lead (FL) during internal training (HQDA 2013a, 14-15).

Flight Lead Qualified (FLQ/FLD): FLQ pilots may perform FL, PC, or PI duties on any internal or external training as assigned. The FLQ is primarily responsible for the planning and execution of SOA missions (HQDA 2013a, 14-15).

Applied Professional Case Study Methodology Terms

The following professional terms are part of the applied professional case study methodology. They are used by the process operators in the force development community to describe the system utilized for developing capabilities routinely and are used in the methodology of this study.

Joint Capabilities Integration and Development System (JCIDS): The JCIDS is one of DOD's three primary decision support processes for shaping the military forces to support strategic guidance documents. JCIDS is a capabilities-based approach to identify current and future capability gaps in the joint force ability to carry out joint warfighting missions and functions. The objective of JCIDS is to develop a balanced and synchronized Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities, and Policy (DOTMLPF-P) solution (F102RA 2017, 2).

Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities, and Policy (DOTMLPF-P): This is the process used to develop change

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recommendations on how to optimize the joint force's ability to operate as an integrated force. The deliberate process is characterized by the traditional route to identifying capability gaps and proposed solutions, through the use of the capabilities-based assessment process (F102RA 2017, 2).

Capabilities-Based Assessment (CBA): An analytic basis to identify capability requirements and associated capability gaps, as part of a process that produces an integrated set of DOTMLPF-P solution approaches that collectively provide the required capabilities (F102RA 2017, 3).

Functional Area Analysis (FAA): The first analytical phase of the CBA and is strictly a capabilities-based task analysis. The FAA provides the framework to assess required capabilities in the follow-on Functional Needs Assessment (FNA). The FAA is based on professional military knowledge of established doctrine and standards that are modified to account for the projected concept for future operations and organizations (F102RA 2017, 21).

Functional Needs Assessment (FNA): This is the second analytic phase in the CBA. It assesses the ability of current and programmed Army capabilities to accomplish the tasks identified in the FAA and identifies any gaps and overlaps in capabilities and the risk posed by those gaps (F102RA 2017, 22).

Functional Solutions Analysis (FSA): The FSA is the third analytic phase in the CBA. It is an operationally based assessment of potential non-materiel DOTMLPF-P and/or materiel approaches to solving or mitigating one or more of the capability needs determined from the FNA. The FSA describes the ability of each identified approach to satisfy the need. Approaches proposed by an FSA must meet three criteria: first, they

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must be strategically responsive and deliver approaches when and where they are needed; second, they must be feasible with respect to policy, sustainment, personnel limitations, and technological risk; and third, they must be attainable, in that DOD could actually resource and implement the approaches within the timeframe required (F102RA 2017, 22).

The Kotter Change Model: An eight-step process used for leading change within an organization. The model provides a foundational approach, with each stage building upon the success of the previous stage. The first four stages assist in overcoming the existing status quo and set the conditions for leading change. Stages five through seven are the action stages that move the change effort from words to action by introducing new or different practices into the organization. Without successfully completing these three action stages the effort loses momentum, the sense of urgency dissipates, and the coalition becomes marginalized. Kotter's final stage, stage eight, is reached when the changes are inculcated into the culture of the organization; the change becomes the status quo and accepted within the organization (Miller and Turner 2017, 1-3).

Modification Table of Organization and Equipment (MTOE): A table which prescribes in a single document the modification of a basic table of organization and equipment necessary to adapt it to the needs of a specific unit or type of unit (DA PAM 611-21 2007, 14).

Limitations and Delimitations

The most significant limitation of this study will be the inability to publish classified data regarding the ARSOA Gray Eagle unit of study in this thesis. The study may not clearly depict the employment of this unit without being able to annotate its

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locations around the globe and effects on the battlefield. Specifically, the study will not assess the unit's current deployed locations or operations within those areas due to classification. This is significant, as one major premise of this paper is to accurately illustrate why the ARSOA UAS unit needs to be manned, trained and equipped differently than the CF to provide a unique capability within SOA. Additionally, the study will identify capability gaps and potential materiel and non-materiel solutions to ensure the Gray Eagle provides SOA with a unique UAS capability. Specific DOTMLPF-P domains that will be addressed are the organization, training, and materiel of the unit as it is currently being employed, which will be difficult to articulate without describing the unit's current and past employment due to classification. However, this study will look at all available unclassified sources pertaining to the primary and secondary research questions.

The next limitation is that there is no research, with regards to specific literature, that addresses the employment of the ARSOA Gray Eagle unit, in relation to UAS employment by the CF. This gives no predictive notion to address going into this study. This is significant, as there is no baseline to determine whether or not changes must be made to the unit's manning, training, and equipping to ensure continued success within the special operations community. To mitigate this limitation, the methodology being used will objectively look at the aspects surrounding this gap in literature, to present a non-biased solution to the key stakeholders. The study will also illustrate that a SOF-specific needs analysis must be conducted so that ARSOA Gray Eagle units are not vulnerable to changes in the CF's force development process and to define what future changes might mean for readiness and training.

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Another delimitation for this study is that it will only consider the employment of the ARSOA Gray Eagle as beginning with the creation of E/160 in 2013. The study will not include the employment of the Gray Eagle within special operations during the operations of the Quick Reaction Capability Companies, when they supported special operations forces in Iraq and Afghanistan prior to the creation of E/160.

The last delimitation is that in order to illustrate the difference between ARSOA and CF rotary wing capabilities, this study will only look at the difference between the similar ARSOA multi-mission rotary wing, MH-47, and the CF cargo rotary wing, CH-47 units. This comparison will be used to identify any gaps in the manning, training, and equipping of ARSOA Gray Eagle and the CF Gray Eagle units, in comparison to ARSOA and CF rotary wing units. This delimitation will not take away from the credibility of this study as the only other similar units between ARSOA and the CF would be between the ARSOA multi-mission rotary wing, MH-60, and the CF utility rotary wing, UH-60 units.

Significance of Study

The results of this study will identify any capability gaps in the manning, training, and equipping of the ARSOA Gray Eagle unit that may prevent it from providing a unique UAS SOA capability. This will be based on a comparative analysis of the CF Gray Eagle unit, by comparing the similarities and differences between the ARSOA and CF Gray Eagle units. The study will then look to the ARSOA rotary wing units for potential materiel and non-materiel solutions by analyzing the differences in the ARSOA rotary wing units from those of the CF rotary wing units. This is significant because it will not only identify the domains in which capability gaps exist, but will also look to an established SOA unit for potential solutions.

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R1: Initial Personal Recommendation

The applied professional case study is a research methodology that incorporates three different assessments throughout the process, R1, R2, and R3. The initial assessment, or R1, is the author's perspective, bias, and assumptions prior to beginning the review of literature. This initial assessment provides a starting point to the research and gives it credibility throughout the rest of the process.

The first part of the R1 discusses the primary research question and why it is important to the author and the key stakeholders within USASOC. The primary research question in this study is: are there organizational, training, and materiel capability gaps that are preventing the ARSOA Gray Eagle unit from providing a unique SOA capability? The author developed this research question after spending approximately 18 months in the only ARSOA Gray Eagle company, E/160, as the executive officer just prior to beginning this study. In addition to those 18 months in E/160, the author spent over 5 years in the 160th SOAR, primarily within the rotary wing units. This experience gave the author an understanding of the Gray Eagle, its role within the 160th SOAR, and the Soldiers who operate and maintain the Gray Eagle. With that understanding, the author believes there are capability gaps that must be addressed for this platform to perform at the same level as the rotary wing units within the 160th SOAR. The author has a vested interest in this study because he will be returning to the 160th SOAR after this study to work with E/160 and believes that it must begin to mirror the ARSOA rotary wing units in terms of manning, training, and equipping, to provide a unique SOA UAS capability to the special operations community.

This study is important because if E/160 is expected to provide the same unique capabilities as the rotary wing units within the 160th SOAR, then the key stakeholders

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need to look at the capability gaps that E/160 has in terms of manning, training, and equipping when compared to the rotary wing units in the 160th SOAR. The Gray Eagle is still within its first five years of employment within ARSOA, and the earlier that these capability gaps can be identified and addressed, the easier it will be to define the unique UAS capability that E/160 brings to the special operations community. Additionally, a second Gray Eagle company is currently being fielded with an August 2018 activation date. Any changes to the organization, training, and materiel of this new company will be less intrusive if identified and implemented early during the standing up of this new company.

The second part of the R1 addresses why this study is important and the possible consequences if this topic is not addressed. The demand for combat air patrols provided by ARSOA Gray Eagle is going to increase, as evidenced by the fielding of a second Gray Eagle company within the 160th SOAR. Additionally, the Department of Defense (DOD) is continuing to invest in the advancement of the Gray Eagle with the production of the Extended Range (ER) Gray Eagle, which is scheduled to undergo initial operational testing and evaluation (IOT&E) by ARSOA in fiscal year 2018 (FY18). The United States Special Operations Command (USSOCOM) is investing in the advancement of a unique SOA UAS capability and identifying the capability gaps in terms of organization, training, and materiel will ensure that these investments are made to the most critical capability gaps identified in this study. If this analysis is not done and investment is made in areas that do not truly increase the capability provided, the consequence will be that USSOCOM used constrained fiscal resources without equitable payoff.

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The final portion of the R1 identifies the potential for a solution to the problem statement, the methodology by which it could be answered, and the author's initial recommended solutions. The author believes that there are potential solutions to the problem statement and that looking to the ARSOA rotary wing units for these solutions should be the starting point. The 160th SOAR has had 36 years to develop and implement unique SOA capabilities. This is in line with the SOF truth that special operations capabilities cannot be mass produced. E/160 is reaching its 5th year of conducting operations as part of the 160th SOAR and the unit needs to start establishing unique SOA UAS capabilities to support special operations with abilities not offered by CF UAS units. Informing key stakeholders of these potential solutions, with a rich description of the environment, will persuade them to make key changes that will ensure this capability is poised to support the unique requirements of special operations.

This problem will require the methodology to use the correct data to determine possible solutions. To determine the potential capability gaps in E/160's manning, training, and equipping, this study will need to look at data that accurately depicts E/160's current organization structure, training process, and equipping. Additionally, this study will look at this same data from ARSOA rotary wing units, CF rotary wing units, and CF Gray Eagle units. After gathering the right data, an applied professional case study will be used,

> Case studies are a useful method for conducting qualitative research for problem areas that are human-centric, dynamic, volatile, and contain a mix of stakeholders, interests, variables and information concepts that demand a deep understanding of context in order to produce informed policy choices" (Creswell, 2009, 2013, 2014; Yin, 2014).

The study will then use a comparative analysis from the data gathered through the case study and use a modified DOTMLPF-P Capabilities Based Assessment (CBA) to

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determine the results. A CBA is appropriate since it is a structured three phased process that identifies and documents capability gaps; determines the attributes of a capability or combination of capabilities that would resolve the gaps; and identifies non-materiel as well as materiel approaches for possible solutions. By conducting the applied professional case study and then analyzing it using the CBA, we get the functional solution analysis (FSA). This will identify a resolution, and will look to potential DOTMLPF-P approaches, recommendations, and solutions to mitigate or eliminate the capability gaps and will produce suggestions to implement ideas for non-materiel DOTMLPF-P approaches; and ideas for materiel approaches.

Conclusion

Since its inception in 2013, the ARSOA Gray Eagle unit has enabled special operations across the globe with phenomenal results. This success brought an increased demand within ARSOA which led to the current fielding of another MQ-1C Gray Eagle company within ARSOA. This chapter discussed the background, the problem, and the process by which this study will be conducted. The next chapter will analyze the literature used for this study.

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CHAPTER 2

LITERATURE REVIEW

Introduction

The purpose of this research is to gain a rich understanding of the unique capabilities required by the ARSOA Gray Eagle unit to meet special operations specific requirements, and to persuade the Chief Decision Maker (CDM) and key stakeholders to affect change. The literature is primarily from the Department of Defense (DOD) and other federal agencies because the purpose of this study is to persuade key stakeholders within the DOD. By primarily using the professional body of knowledge, it tailors the information and makes it credible to the target audience. This remains in line with the research methodology as a professional applied case study.

The specific areas that will be addressed in this chapter are the manning, training, and equipping of the unit and whether it is specifically designed to support special operations in the same manner as the rotary wing ARSOA units.

Key Literature

The following graph depicts the literature reviewed in this study and how each piece of literature specifically applies to the different aspects of this paper.

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Table 2. Literature Analysis

	Organization	Training	Materiel	Primary	Secondary 1	Secondary 2	Secondary 3
USAR 2035	X	X	X	X			X
USIR 2038	X	X	X	X			X
MQ-1C SAR	X		X	X	X		
3255.01		X		X	X		
TC 3-04.63		X		X	X		
TC 3-04.11		X		X	X		
ARSOA TC 3-04.11		X		X	X	X	X
TC 3-04.34		X		X	X		
ARSOA ATM		X		X	X	X	X
MH-47G -10			X	X	X	X	X
CH-47F -10			X	X	X		
AR 95-23	X	X		X			
AR 95-1	X	X		X			
USAFM	X		X	X	X	X	
MQ-1C -10		X	X	X	X	X	
USASOC 2035 ARSOF 2022	X	X	X	X			X

Source: Created by author.

The *United States Army Roadmap for UAS 2010-2035* is the Army's vision to develop, organize, employ, and build a comprehensive strategy for defining future UAS requirements. This publication breaks down this strategy into the time periods of near (2010-2015), mid (2016-2025), and far (2026-2035). Through these different time frames, the document focuses on issues such as identifying current gaps in capabilities, integrating UAS into other Army operations such as networking and cargo capabilities, and increasing the overall capability of the UAS while reducing its size, power, and weight requirements. This roadmap is reviewed every two years, but a new edition has

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not been published since this initial document. While the document is over seven years out of date, it still provides a good assessment as to whether or not the Army is on the right track to meet its intended goals.

This reference applies to this study as it addresses both the primary and secondary research questions of this thesis. Specifically, it describes the UAS in terms of manning, training, and equipping, and it breaks down the assessment into the DOTMLPF-P domains, which falls directly in line with the methodology used in this study. Additionally, this document discusses the challenges with UAS operations within the NAS and addresses many other issues with the employment of the UAS, which may fall outside the scope of this study, but are still necessary to consider.

The *Unmanned Systems Integrated Roadmap FY2013-2038* is a document intended to "articulate a vision and strategy for the continued development, production, test, training, operation, and sustainment of unmanned systems technology across DoD." It looks at both current and future capabilities in a 25-year window to address where UAS is now, and to develop a strategy to determine where it should go. While this document does not specifically address special operations, it does identify with many of the same gaps in capabilities that could be used within special operations as well as with CFs. Additionally, it addresses the manning, training, and equipping aspects of this thesis.

Much like the *United States Army Roadmap for UAS 2010-2035*, this document discusses UAS operations in terms of near, mid, and far time frames. Unlike the *United States Army Roadmap for UAS 2010-2035*, this publication is not solely focused on the Army UAS program but on the Department of Defense as a whole, which gives this document a more strategic aim. Specifically, the *Unmanned Systems Integrated Roadmap*

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FY 2013-2038 discusses strategic planning and policy, combatant commander mission and capability needs, technologies for unmanned systems, operating environment, sustainment and logistics, training, and international cooperation.

Of the topics discussed in this thesis, *The Unmanned Systems Integrated Roadmap FY 2013-2038* addresses the equipping aspect in the most detail. For example, it addresses several types of munitions that could improve the capabilities of the MQ-1C Gray Eagle aerial vehicle. One of which is the Direct Attack Guided Rocket (DAGR). The DAGR is a 2.75-inch laser guided rocket that is fully compatible with the current Hellfire system. This new munition would potentially allow the MQ-1C Gray Eagle to carry up to four times as much payload as its current configuration. Additionally, this document extensively describes the communications architecture and potential use of existing networks, specifically the Defense Information Systems Network (DISN) and the teleport standard tactical entry point (STEP) sites. The ability to plug into these global networks and gain access to satellite coverage around the globe would provide an increased capability for ARSOA UAS in terms of its operational reach. *The Unmanned Systems Integrated Roadmap FY 2013-2038* provides a great deal of information from very specific aircraft-defining characteristics to broad strategic level policy. It provides insight to many of the topics discussed in this thesis and other aspects within the UAS community.

The *MQ-1C Gray Eagle Selected Acquisition Report (SAR),* as of the FY2017 President's budget, discusses several topics relevant to this study. First, it discusses the proposed employment design of Gray Eagle units in terms of organization. Specifically, it addresses how the unit is intended to operate and why it is organized the way that it is. In

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support of United States Army Divisions, the UAS company is part of the combat aviation brigade (CAB); in support of Intelligence Command (INSCOM), it is part of the 116th Military Intelligence Brigade, and in support of USASOC it is part of the 160th SOAR. Within each of these organizations, the UAS company is broken down into three identical platoons, giving the commander extreme flexibility to employ this asset. This document explains that the intent of the UAS company's structure from inception was for each platoon to be able to operate independently at three geographically dispersed locations.

The Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3255.01- Joint Unmanned Aircraft System Minimum Training Standards document provides the basis for joint unmanned aircraft system minimum training standards and identifies the training requirements for UAS crewmembers to operate in support of a joint force commander. It breaks the requirements down into three categories: Basic UAS Qualification (possessing the general aviation and UAS knowledge to safely operate a UAS), possessing the skills required to both operate the UAS and maintain situational awareness to execute tasks, and Joint Mission Qualification (understanding the UAS mission/objective and its role in accomplishing the larger military operation). This document directly applies to this thesis as it is essentially a contract between the Department of Defense and the FAA, establishing the minimum training requirements that a UAS operator must possess to operate in the NAS.

The *TC 3-04.63 MQ–1C Unmanned Aircraft System Commander's Aircrew Training Program and Aircrew Training Manual* applies to Gray Eagle crewmembers and their commanders. The purpose of this document is to standardize aircrew training

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programs and flight evaluation procedures by providing specific guidelines for executing UAS aircrew training. This training circular outlines both the individual and collective training requirements for crewmembers in order to advise the commander on an effective aircrew training program that supports combined arms training. Of note, the *MQ–1C Unmanned Aircraft System Commander's Aircrew Training Program and Aircrew Training Manual* is combined into one document to cover both the Gray Eagle specific aircrew training program and the commander's aircrew training program for individual, crew, and collective training. While the Commander's Aviation Training and Standardization Program incorporates the UAS, it admittedly states that the UAS integration is still developing and needs refinement, which makes the *MQ–1C Unmanned Aircraft System Commander's Aircrew Training Program and Aircrew Training Manual* publication the most relevant document to Gray Eagle operations. This is significant because this study will examine the corresponding CF and ARSOA rotary wing publications as part of the analysis for this thesis. For those elements, there are two distinct publications, an airframe specific aircrew training manual and a general aviation commander's aircrew training program for individual, crew, and collective training. Additionally, it is important to note that the CF and ARSOA Gray Eagle units both use this same document.

The aircrew training program outlined in this publication applies to crewmembers that perform duties controlling the flight of a UAV or the operation of its mission equipment. This includes starting the engine, takeoff and/or landing the UAV and consists of qualification, refresher, mission, and continuation training. It outlines the requirements for qualification in the Gray Eagle, criteria for readiness level progression,

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flight activity category designation, flight hour/currency requirements and annual task and iteration requirements. This publication also outlines the testing and evaluating requirements for crewmembers during a proficiency flight evaluation, annual proficiency and readiness evaluation, and other crewmember proficiency based testing.

In summary, this document contains the necessary guidance for a Gray Eagle company commander to execute the aircrew training program that covers everything from individual to collective unit training. Additionally, this document is the aircrew training manual for the Gray Eagle and is the basis for the crewmember's training from the individual to collective training levels.

The *TC 3-04.11 Commander's Aviation Training and Standardization Program* is the commander's guidance for implementing a standardized aviation training program. It applies to all individuals flying Army aircraft and for the purposes of this study, it directly applies to CH-47F and Gray Eagle crewmembers. It does not apply to ARSOA MH-47G crewmembers, as ARSOA has its own publication for the execution of the commander's aircrew training program.

This publication focuses on the implementation of an effective, standardized aircrew training program that supports the mission of the combat aviation brigade. It outlines the individual responsibilities in executing the training program from the brigade commander down to the individual crewmember. Like the aircrew training manuals, it addresses individual qualification, currency, and flight hour requirements, but these are not the focus. In contrast to an aircrew training manual, the focus of this document is to serve as a guideline to all Army aircraft as a holistic approach to Army aviation training and standardization. For example, it specifically addresses aircrew training plan

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management, doctrinal training concepts, unit collective training requirements, and the implementation of the Army standardization program.

The *ARSOA TC 3-04.11 Commander's Aircrew Training Program for Individual, Crew, and Collective Training* is the keystone publication that establishes the requirements for commanders at all levels to develop, manage, and administer a comprehensive aircrew training program. In the context of this study, this publication applies directly to the ARSOA MH-47G crewmembers, but does not address ARSOA Gray Eagle crewmembers.

This reference covers much of the same material as the *TC 3-04.11 Commander's Aviation Training and Standardization Program*, but applies only to ARSOA crewmembers. This publication addresses the responsibilities of the 160th SOAR Commander down to the individual crewmember, aircrew training program administration, risk management, training and evaluation requirements, and standardization for aviation records. The most important element of this publication, with regards to this study, is that it addresses how ARSOA battle rosters their crews in terms of PI, PC, BMQ, FMQ, and FLD designations. This is an important distinction as the *TC 3-04.11 Commander's Aviation Training and Standardization Program* also addresses crew battle rostering but only in terms of PI/AO and PC/AC designations. This distinction will be addressed in chapter four, but it is important to note that while the ARSOA MH-47G crewmembers have additional crewmember designations of BMQ, FMQ, and FLD, the ARSOA Gray Eagle crewmembers only have the designations of AO and AC. *The ARSOA TC 3-04.11 Commander's Aircrew Training Program for Individual Crew, and Collective Training* specifies the type of crew mix (PI, PC, BMQ, FMQ, FLD)

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required for different mission sets (internal training, external training, administrative support, and tactical).

The *TC 3-04.34 Aircrew Training Manual, Cargo Rotary wing, CH-47D/F* applies to all CH-47 crewmembers and their commanders in the active Army, the Army National Guard Bureau/United States Army National Guard, the United States Army Reserve, and provides specific guidelines for executing CH-47D/F aircrew training. This publication is the basis for crewmember qualification training, refresher training, mission training, and continuation training and evaluation requirements.

This reference is used in conjunction with the *TC 3-04.11 Commander's Aviation Training and Standardization Program* publication to help commanders and crewmembers execute the aviation training program. The main difference is that the *TC 3-04.34 Aircrew Training Manual, Cargo Rotary wing, CH-47D/F*, provides the performance standards and evaluation guidelines for every individual/mission/collective task, so that crewmembers know the level of performance expected. It is the primary tool used by commanders and standardization officers to implement the aircrew training program. This manual is intended to support the unit's mission essential task list by enhancing training in individual and aircrew proficiency.

The *ARSOA Aircrew Training Program Aircrew Training Manual Multi-Mission Rotary wing MH-47*, much like the *TC 3-04.34 Aircrew Training Manual, Cargo Rotary wing, CH-47D/F*, is the basis for crewmember qualification training, refresher training, mission training, and continuation training and evaluation requirements. It applies to all MH-47 crewmembers, their commanders, and standardization officers. It is used in conjunction with the *ARSOA TC 3-04.11 Commander's Aircrew Training Program for*

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Individual Crew, and Collective Training and other applicable publications to aid both the individual and commander in developing an effective and standardized aircrew training program for the unit. It establishes the task, conditions, and standards for all individual and collective tasks for employment of the MH-47 aircraft. Specific to this study, the *ARSOA TC 3-04.11 Commander's Aircrew Training Program for Individual Crew, and Collective Training* outlines specific special operations aviation tasks that are not listed in the CF *TC 3-04.34 Aircrew Training Manual, Cargo Rotary wing, CH-47D/F*. These tasks provide additional capabilities to the special operations community that the CF cargo rotary wing, CH-47D/F, units cannot provide.

After reviewing the applicable aircrew training documents for the ARSOA and CF units used in this study, the following discussion on aircrew training progression and crewmember designations is necessary to understand the results of this study described in chapter four. This discussion will begin with describing the aircrew training program, which is almost identical for manned and unmanned airframes, and will conclude with aircrew member designations that distinguish the ARSOA process from the CF process, and is a key point to understand for this study.

Readiness levels (RLs) are used by aviation commanders to determine the proficiency of crewmembers in their base, mission, and additional tasks. RLs are designated progression points that range from RL1 to RL3, with RL3 being the designation for a crewmember focusing on base tasks, to a mission ready crewmember with an RL1 designation (HQDA 2016a, 51). Base tasks, or 1000 series tasks, are made up of individual tasks or maneuvers that a crewmember is expected to be able to perform, both in and out of the airframe. An example of a base task for a CH-47F rated

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crewmember would be to perform hovering flight, task #1038 (HQDA 2013b, 101). Once the crewmember demonstrates proficiency in all base tasks listed in that airframes applicable aircrew training manual, they are designated RL2. During RL2 training, the crewmember must demonstrate proficiency in all mission and additional tasks (or 2000 series and 3000 series tasks, respectively) that support the unit's mission essential task list, as assigned by that crewmember's aircrew training program commander. An example of a mission task for a Gray Eagle operator would be to operate synthetic aperture radar, task #2305 (HQDA 2014b, 200). Once a crewmember completes all RL2 training requirements, they are designated RL1.

Once a crewmember is designated RL1, they continue their flight training through continuation training which has different requirements based on that crewmembers Flight Activity Category (FAC). FAC levels are designated by the brigade level commander and are based on flight task requirements and the proficiency required by the individual crewmember's MTOE or TDA position. FAC levels are broken down into FAC 1 through FAC 3. A FAC 1 position requires a high degree of proficiency in the tactical employment of the assigned airframe. A FAC 2 position requires the same proficiency in individual and crew tasks as a FAC 1 position but does not necessarily require the same collective proficiency in unit tasks. FAC 3 positions are not authorized to perform crewmember duties in their assigned airframes but must complete applicable simulator hour requirements, if a compatible simulator is available. Each FAC level has a corresponding semi-annual flight hour requirement, that is considered the continuation training as previously discussed (HQDA 2016a, 66-67). For example, an RL1, FAC 1, MH-47G rated crewmember has a semi-annual flight hour requirement of 60 hours, 30 of

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which must be completed using night vision goggles. An RL1, FAC 2, MH-47G rated crewmember has a semi-annual flight hour requirement of 33 hours, 18 of which must be completed using night vision goggles (HQDA 2013a, 47; ATM 2014, 19). In addition to semi-annual flight hour requirements, crewmembers have an annual requirement to complete an annual proficiency and readiness test (APART). The APART is conducted each year during a crewmember's APART window which is based on their birth month. The APART is slightly different for each airframe, but it essentially consists of a hands-on evaluation, a written evaluation, and a flight physical (DD Form 2992, Medical Recommendation for Flying Duty) (HQDA 2016a, 71).

Crewmembers have an obligation to complete applicable RL progression and continuation training but are also required to progress in their crewmember designation. In the Gray Eagle community, UAS crewmembers (UACs) have the following designations; unmanned aircraft operator (AO), mission payload operator, (PO), aircraft commander (AC), unit trainer (UT), instructor operator (IO), standardization instructor operator (SO), and mission commander (MC). Upon successful completion of a Department of the Army approved Gray Eagle qualification course and designation in writing from the aircrew training program commander, UACs begin their aviation careers with the designation as an AO, and a PO.

An AO is responsible to control the flight of an UAS or the operation of its mission equipment and remain tactically and technically proficient as an UAC. The individual operator should have the ultimate goal of achieving AC status (HQDA 2016a, 51). An AC has the same requirements as an AO, but additionally they are responsible for the overall safety of the UAV, be proficient in the UAV and all aspects of the unit

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mission essential task list, the conduct of all operational and training aspects of a specific mission, all actions of the crew, assigning duties to the crew, and for accomplishing the assigned missions.

From there, the UAC looks to progress to a UT, who has all the responsibilities of an AC but is additionally responsible to instruct in appropriate tasks and subjects, recognize errors in performance or understanding, make recommendations for improvement, train to standards, and document training (HQDA 2014b, 24-32). After designation as a UT, and with input and concurrence of the command level leadership, a UT will attend an approved Department of the Army Gray Eagle Instructor Operator (IO) course to undergo training. Of note, a UAC does not have to be designated as a UT to be sent to the IO course, this just represents a normal progression for a UAC from initial assignment to designation as an IO.

After successful completion of the IO course and designation in writing from the aircrew training program commander, that UAC is designated as an IO. The IO has all the requirements of a UT and is the unit's primary trainer and evaluator of all UACs. The SO is the final aircrew designation for a UAC. Normally, an IO will train for multiple years before being recommended by the command to be designated as an SO. After designation in writing by an aircrew training program commander, an IO is authorized to perform SO duties. An SO has all the responsibilities of an IO and primarily trains and evaluates the unit's IO. Additionally, an SO is the primary advisor to the commander on all aspects of the unit's aircrew training program (HQDA 2006, 14).

The CH-47F and MH-47G rated aviators used in this study have the following aircrew designations; Pilot (PI), Pilot in Command (PC), Unit Trainer (UT), Instructor

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Pilot (IP), Instrument Examiner or Instrument Flight Examiner (IE or IFE), and Standardization Instructor Pilot (SP). Of note, rated aviators have other aircrew designations, but those are not applicable for the purposes of this study (HQDA 2014c, 27).

Upon successful completion of a Department of an Army approved qualification course, and designation in writing by the ATP commander, new rated aviators begin their aviation career with the designation as a PI. A PI has the responsibility to remain tactically and technically proficient in all aircrew member tasks as dictated by the applicable aircraft training manual. PIs should take advantage of every training opportunity with the goal of attaining designation as a PC.

After demonstrating proficiency in all required aircraft tasks, successfully completing a PC evaluation in accordance with applicable publications, displaying proper judgement and maturity, and being designated in writing by the ATP commander, a rated aviator is then designated as a PC. A PC has all the responsibilities as a PI, but is additionally responsible to ensure the overall safe and effective operation of the aircraft, to serve as the unit's first-level trainer, be proficient in the aircraft and all aspects of the unit's collective tasks. The PC is responsible for the safety of all occupants, and the conduct of all operational and training aspects of a specific mission, responsible for all actions of the crew, responsible for assigning duties to the crew, and responsible for accomplishing assigned missions (HQDA 2014c, 26).

At this point in the aircrew progression process, it is important to note several significant differences between rotary wing pilots and UAS operators. First, the Army's rotary wing pilots are primarily warrant officers and the Army's UAS operators are

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primarily enlisted soldiers and non-commissioned officers. To be clear, there are also commissioned officers that are rated aviators and there are warrant officers that are UAS operators, but for the purposes of this study, they are not included in the discussion. The next significant difference is that warrant officers track different career paths during their professional careers. Unlike UAS operators, a warrant officer's progression to IP is dependent upon the career path they decide to track. For example, a warrant officer may decide that they would like to track safety to become an aviation safety officer and because of that, they would never achieve an aircrew designation as an IP. There are a few warrant officers that track multiple career paths, but it is not the norm. In contrast, UAS operators do not have multiple career track options like warrant officers and because of this each UAS operator should strive to progress to IO.

For comparison in this study, a warrant officer who decides to career track IP would look to progress to the designation of a UT after achieving PC status. A UT has the same responsibilities as a PC; but in addition, a UT has demonstrated the ability to train other pilots and focuses primarily on RL 2 and RL 1 progression training. At some point in the warrant officer's career and service as a UT, they will attend a Department of the Army instructor pilot qualification course resulting in designation as a unit IP by the ATP commander. IPs have the same responsibilities as a PC, but in addition, they serve as the primary instructors and evaluators for the unit. Normally after a few years as an IP, the command will determine whether or not to give an IP an SP evaluation based on their performance as an IP. After successfully completing an SP evaluation in accordance with applicable publications and a designation in writing by the ATP commander, an IP is designated as an SP. An SP has all the responsibilities of an IP but SPs are also primarily

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responsible for the training and evaluation of IPs, and serve as the primary advisor to the commander on all matters pertaining to the unit's ATP.

The final aircrew designation for this study is the designation as an IE or IFE. There is not a correlating designation within the UAS community but it is still relevant for the purpose of this study. The reason is that the Gray Eagle is not rated for IFR flight, and because of that, there is no need to designate UACs as IEs. To be designated as an IE, an aircrew member must already be designated as an IP and successfully complete a Department of the Army approved IE qualification course and be designated in writing by the ATP commander. An IE has the primary responsibility to administer instrument flight evaluations within the unit. The designation as an IE is not airframe specific like the other aircrew designations; for example, an IE whose primary aircraft is a CH-47 can give an instrument evaluation to an aviator whose primary aircraft is a UH-60 (HQDA 2014c, 27).

An understanding of the aircrew member training, progression, and aircrew designation processes of both the manned and unmanned platforms discussed in this study is essential to gain an understanding of the unique ARSOA mission qualification and battle-rostering process discussed in the next section.

ARSOA rotary wing units use a unique battle-rostering process that is based on mission qualification. This process is unique to ARSOA and is not used by CFs rotary wing units, B/101, or by E/160, that is key to note for the purposes of this study. The intent of this unique battle-rostering process is to ensure successful accomplishment with the minimum amount of risk to the force and to the SOA mission. ARSOA has the following mission qualification designations; basic mission qualified (BMQ), fully

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mission qualified (FMQ), and flight lead qualified (FLD). Once a rated crewmember successfully completes the special operations basic mission qualification course conducted by the 160th Special Operations Aviation Training Battalion, that crewmember is designated as an RL 1, PI, BMQ, and assigned to an operational company within the 160th SOAR. The rated crewmember then conducts mission training with the goal of achieving FMQ designation. After extensive training and successful completion of an FMQ evaluation and designation in writing by the ATP commander, that crewmember is designated as an FMQ. The final mission qualification is that of FLD. Significant to this study, the FLD qualification usually takes many years to achieve, and is a designation that not every rated crewmember in the 160th SOAR will achieve. It illustrates mastery of all SOA required mission sets and the highest degree of tactical and technical proficiency. After many years of extensive training, successful completion of a FLD evaluation, and designation in writing by the 160th SOAR Commander, that crewmember is designated as a FLD. These mission qualifications are used to determine the right battle-rostering based on mission requirements.

The *Technical Manual Operator's Manual for the MH-47G, TM 1-1520-272-10-1* provides complete operating instructions and procedures for the multi-mission rotary wing, MH-47G. Specifically, it covers aircraft and systems description and operation, avionics, mission equipment, operating limits and restrictions, weight/balance and loading, performance data, normal procedures, and emergency procedures for the MH-47G.

The *Operator's Manual for the CH-47F, TM 1-1520-271-10-1* provides complete operating instructions and procedures for the cargo rotary wing, CH-47F. Specifically, it

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covers aircraft and systems description and operation, avionics, mission equipment, operating limits and restrictions, weight/balance and loading, performance data, normal procedures, and emergency procedures for the CH-47F.

The *Operator's Manual for the MQ-1C Unmanned Aircraft System, TM DTM 1-1550-697-10-1*, provides complete operating instructions and procedures for the unmanned aircraft system, MQ-1C. Specifically, it covers aircraft and systems description and operation, avionics, mission equipment, operating limits and restrictions, weight/balance and loading, performance data, normal procedures, and emergency procedures for the MQ-1C.

The *Unmanned Aircraft System Flight Regulations, AR 95-23*, much like the *TC 3-04.11 Commander's Aviation Training and Standardization Program*, provides guidance on UAS crewmember training, risk management, currency requirements, training and standardization. In addition, this regulation also covers flight rules, UAS general provisions, and management of UAS resources. It is not specific to the Gray Eagle, but applies to all categories of UAS employed by the United States Army active duty/reserve/national guard units and supporting civilian contractors.

Flight Regulations, AR 95-1, covers the same topics and is applicable to the same organizations as the *Unmanned Aircraft System Flight Regulations, AR 95-23*, but while it is applicable to UAS, it is not specific to UAS and does not address UAS specific policy. The only UAS specific guidance in this publication is guidance that addresses the recovery operations associated with unmanned aircraft. For the purposes of this study, *Flight Regulations, AR 95-1*, applies directly to the CH-47 and MH-47 units used for this thesis.

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The United States Army Force Management Support Agency (USAFMSA) provides online access to the *Force Management System* website that provides extensive information on how Army units are manned and equipped. For this study, the website was used to access the Modification Table of Organization and Equipment (MTOE) for the Army units used in this study: Company B, 3d Battalion, 82d Combat Aviation Brigade (CF CH-47F unit); Company A, 2d Battalion, 160th Special Operations Aviation Regiment (ARSOA MH-47G unit); Company B, 101st Aviation Regiment (CF MQ-1C unit); and Company E, 160th Special Operations Aviation Regiment (ARSOA MQ-1C unit).

An MTOE is an authorization document that prescribes the modification of a basic Table of Organization and Equipment (TOE). It is a document that prescribes the wartime mission, capabilities, organizational structure, and mission essential personnel and equipment requirements for military units, and adjusts it as necessary to adapt it to the needs of a specific unit or type of unit. For example, the MTOE for an MQ-1C Gray Eagle company shows how many personnel, by grade, and how many airframes, by type, would be required for a company to conduct its wartime mission. For the purposes of this thesis, the different MTOE documents for each of the units being analyzed in this study clearly depicts the differences and similarities between the CF and ARSOA units.

The documents *USASOC Strategy 2035* and *ARSOF 2022* provide guidance for the development of future ARSOF operational and institutional capabilities. For the purposes of this study, these two documents were used to form the basis by which the Chief Decision Maker (CDM) for this study would evaluate the proposed results of this thesis, through the R3: Stakeholder Recommended Solution.

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Conclusion

The review of the cited literature primarily from the military's professional body of knowledge offers insight into the primary and secondary research questions, and also establishes the foundation for the remainder of this thesis. Additionally, this review of literature was conducted in line with the research methodology, using sources from the professional body of knowledge, applicable to the CDM. The next chapter, Chapter 3, will outline the research methodology for this study.

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CHAPTER 3

RESEARCH METHODOLOGY

Purpose of the Research and the Research Questions

The purpose of this study is to persuade the Chief Decision Maker (CDM), the commander of USASOC, that the proposed solutions to E/160's manning, training, and equipping capability gaps, would enable E/160 to provide a unique UAS capability to special operations. The main concerns of the CDM are to obtain next generation unmanned aircraft systems that provide longer operational range and over horizon observation; can be launched and recovered by tactical units; and employ advanced unmanned aircraft systems and intelligence collection capabilities at the tactical level. This includes the concern to provide joint force commanders with professionals who are agile, adaptive, flexible, bold, innovative, and possess a high degree of advanced training; provide the nation with premier special operations forces; and deliver appropriate and effective capabilities to joint force commanders and interagency leaders across the entire spectrum of conflict under any operating conditions. The CDM must broaden the range of special operations aviation-related individual training and education including unmanned aerial systems; and improve army unmanned aerial-system programs of record (Raven, Shadow and Gray Eagle) to meet joint expeditionary tactics, techniques, procedures, forward-based networking and sensor requirements (HQDA 2014a, 24; ARSOF 2035 2017, 3-6).

In order to implement the findings from this research, the CDM would have to utilize the Army Joint Capabilities Integration Development System (JCIDS), the Defense Acquisition System (DAS), and the Planning, Programming, Budgeting, and

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Execution (PPBE) process to develop new solutions to the organization, training, and equipping of USASOC Gray Eagle units (F102Ra 2017, 2). The USASOAC Commander, the 160th SOAR Regimental Commander and the 160th SOAR Battalion Commanders are the other stakeholders who will be influenced by the changes to the units' organization, training, and equipping and who will also be the ones to implement these changes. Additionally, the research findings would have to be in line with current national strategic guidance to include the National Security Strategy (NSS), the National Defense Strategy (NDS), and the National Military Strategy (NMS). The CDM's primary evaluation criteria to assess the results of this research will be based on these available resources: the NSS, the NDS, and the NMS.

In order to answer the primary research question, three secondary questions were developed: (1) How does ARSOA man, train, and equip their UAS units in comparison to both CFs UAS units, and rotary wing ARSOA units? (2) Are there capability gaps in terms of manning, training, and equipping of the ARSOA Gray Eagle organization when compared to the rotary wing ARSOA units? (3) What are the potential materiel and non-materiel solutions to the ARSOA Gray Eagle units' domains of manning, training, and equipping, needed to provide a unique capability to SOF?

To answer these questions, the author conducted a comparative analysis of the literature within the professional body of knowledge dealing with the organization, training, and equipping of ARSOA UAS and rotary wing units, and CF UAS and rotary wing units. The professional body of knowledge primarily included training manuals, technical manuals, Army and Joint Publications, MTOE documents, and Army regulations. This literature illustrated how the units used in this study were organized,

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trained and equipped. The units were then compared and contrasted to determine capability gaps within the ARSOA Gray Eagle unit. These capability gaps were based on capabilities provided by ARSOA rotary wing units that their CF counterparts were unable to provide. The same analysis was then done with the ARSOA and CF UAS units to determine whether or not ARSOA UAS provided additional capabilities like those provided by the ARSOA rotary wings units.

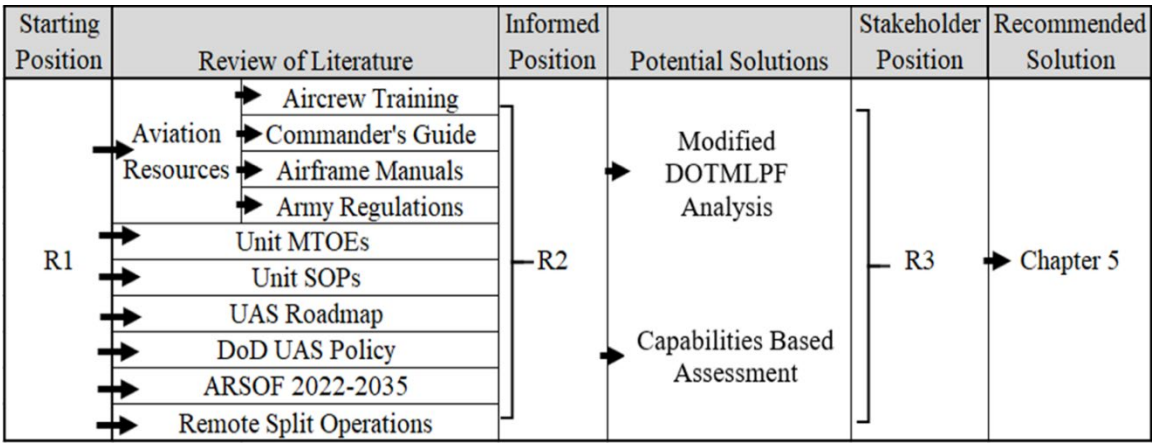
Research Methodology

The author used an applied professional case study methodology for the study. The applied professional case study is a method of research which is systematic, disciplined, multi-perspective, critical, and designed to both solve a problem and incorporate a research perspective. This case study will inform decision making through the rich description of the environment and recommend a policy by persuasion, reason, and evidence (Long 2016).

This research is an applied professional case study with a modified DOTMLPF-P analysis utilizing a capabilities-based assessment (CBA) to determine potential materiel and non-materiel solutions. The modified DOTMLPF-P analysis utilized the organization, training, and materiel (OTM) domains. The CBA used the professional body of knowledge in the literature review to identify capability gaps and propose material and non-material solutions. The figure and paragraphs below describe the five-chapter format used for this applied professional case study.

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Table 3. Research Methodology Flow Chart



Source: Created by author.

In Chapter 1, the initial going-in position is captured through the first assessment in the three-part reflective process of the professional applied case study. The R1 assessment, or the initial, personal disposition on the subject is captured in this chapter. This assessment establishes the author's perspective going in and gives credibility to the research by defining what the author knew and felt about the topic prior to conducting the research, as well as establishing any pre-conceived biases going into the literature review.

In Chapter 2, the focus is to review literature from the professional body of knowledge that is both relevant to addressing the research question, and credible to the key stakeholders that the author is trying to persuade. The majority of literature for this research will come from sources within the DOD. These sources of information give the research instant credibility as they come from recognized, credible sources within the same community as the stakeholders the author is trying to persuade.

Chapter 3 describes how the study takes the "raw material" from the literature review and compares the manning, training, and equipping of the ARSOA Gray Eagle

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unit against ARSOA rotary wing units and CF UAS and rotary wing units. Once the relevant information is broken down and categorized, the study is able to conduct a CBA, focused on a modified DOTMLPF-P analysis, only utilizing the domains of organization, training, and materiel. This process will produce the results necessary to publish the findings in the next chapter.

In Chapter 4, after conducting an objective review of the literature and analyzing the relevant data, the author is able to complete the second assessment, R2. In contrast to the initial assessment, R1 in Chapter 1, the R2 assessment is an updated personal recommendation based on the author's review of the literature (Long 2016).

In Chapter 5, the study makes the final assessment, R3, that are the results from Chapter 4 examined through the lens of the pre-identified CDM and stakeholders that the study is trying to persuade. After the R3, the study takes these findings and uses the Kotter Change Model to address their implementation. Within this process, the research will also identify any new requirements that emerged as a result of the findings. Lastly, the study will address any lessons learned throughout the process. This personal reflection will also address any significant findings throughout the research that fell outside the scope of the research, but are areas that may be worth addressing in a future study.

Conclusion

This chapter provided the background and description of the applied professional case study used to answer the primary and secondary research questions. The benefit of using an applied professional case study as the methodology for this study is that it is a qualitative, complex, and human-centric topic, and it requires a deep understanding of the

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environment to produce informed decision-making. Specifically, this methodology results in compelling and supported recommendations through the process of organizing and analyzing different types of knowledge/information in a defined setting to enable informed action to improve the current conditions. In the case of this thesis, the research will result in recommendations to enhance the manning, training and equipping of the Gray Eagle company within special operations (Hancock and Algozzine 2011; Gagnon 2010). The next chapter contains the findings of the data collected within this study.

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CHAPTER 4

RESEARCH FINDINGS

Introduction

The purpose of this chapter is to explain the findings of the research and to apply those findings to the applied professional case study methodology. The chapter will be broken down into three parts: the DOTMLPF-P type analysis focused on the domains of organization, materiel, training, and using the capabilities based assessment with the results expressed in the terms of a functional area analysis (FAA), functional needs analysis (FNA), and a functional solutions analysis (FSA); the R2 assessment; and a key stakeholder analysis resulting in the final assessment, R3.

Organization (Manning), Training, Materiel (Equipping) Analysis

The following table depicts the domains of organization, training, and materiel of the components that makeup the CBA, which are functional area analysis, functional needs analysis, and a functional solutions analysis.

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Table 4. Organization (Manning), Training, Materiel (Equipping) Analysis

	ORGANIZATION	TRAINING	MATERIEL
FAA (Needs)	• Task- Provide C2 for ARSOA UAS employment IAW unit MTOE • Condition- Three simultaneous missions in separate locations • Standard- IAW ARSOA detachment C2 requirements	• Task- Provide specially selected, highly trained, ARSOA 15W operators to support special operations forces • Condition- In support of SOA missions requiring a unique skill or capability to complete. • Standard- IAW ARSOA TC 3-04.11 battle rostering requirements	• Task- Provide a UAS platform with a unique capability to support SOA • Condition- ISO SOA missions conducted outside of current MQ-1C Grey Eagle UAS capabilities • Standard- To support mission sets IAW ARSOA MTOE narrative
FNA (Gaps and Risks)	• Gap- CW4 MTOE allocation as C2 node for 3x separate locations (CONUS/OCONUS) does not meet ARSOA C2 requirements • Risk- UAS detachments in austere locations operating without commissioned, company grade C2	• Gap- ARSOA 15W operators do not have an ARSOA specific training plan or battle rostering process. • Risk- ARSOA 15W operators do not provide a unique skill or capability to support SOA.	• Gap- ARSOA MQ-1C Grey Eagle UAS platform does not provide a unique or additional capability to SOA • Risk- ARSOA MQ-1C Grey Eagle UAS unit unable to support unique SOA missions
FSA (Solution Approaches)	• Non-materiel- Increase O3 MTOE billets to 5x O3 to support C2 requirements for up to 3x simultaneous missions in separate locations • Materiel- Conduct UAS operations through use of RSO with a central MCE	• Non-materiel- Implement a BMQ, FMQ, FLD training equivalent to the ARSOA 15W operator training process.	• Materiel- Modification of MQ-1C Grey Eagle UAS to support expeditionary operations.

Source: Created by author.

Organization (Manning) Analysis

The first FAA on E/160's organization used the unit's MTOE narrative as the basis to determine the task and condition for this analysis. The MTOE narrative states that this unit has the task of supporting up to three simultaneous missions. This narrative also defines the conditions of the task by stating that the unit must be able to support these three simultaneous missions in three separate locations. In order to meet this requirement, E/160 is configured to deploy one CW4 and one E7 as the command and control node for each of the three separate locations. To determine the ARSOA command and control requirements for detached elements conducting operations, this study used a comparative analysis of the MTOE and MTOE narratives from the ARSOA rotary wing

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company, A/2-160, against the MTOE of E/160. The MTOE narrative for 2-160, which is the battalion that A/2-160 falls under, states that the battalion is not designed to deploy as a whole battalion, but rather as slice elements as part of a Joint Task Force, or as part of a Joint Special Operations Air Component. It also states that the battalion is responsible to provide up to five mission command nodes to simultaneously support split geographic locations. To support this requirement, the MTOE of 2-160 has six commissioned officers, one major and 5 captains, assigned to each rotary wing flight company. E/160's MTOE only has two commissioned officers, one major and one captain. This analysis was used to establish the criteria for commissioned officers in the grade of captain or above and was the standard for geographically dispersed detachment command and control requirements. Additionally, the majority of the battalions in the 160th SOAR mirror the MTOE of 2-160, which reinforced the standard used during the FAA. Importantly, the personal experience of the author attests that CW4s do not serve in a command and control capacity within the 160th SOAR at geographically dispersed locations.

The FNA took the analysis from the FAA to determine any potential capability gaps in the organization of the unit. The first premise that determined the gap in the organization of E/160 was the MTOE comparative analysis. The ARSOA rotary wing companies are manned with an appropriate amount of commissioned officers in the rank of O3 and above to support the detachment command and control requirement as stated in their MTOE narrative. E/160 is manned with CW4s to fulfill their command and control requirement for three geographically dispersed missions. This analysis concludes that the 160th SOAR requires commissioned officers in the rank of O3 and above to act as the

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command and control elements of geographically dispersed detachments, and identifies a gap in E/160's organization, as E/160 is not able to organically support three geographically dispersed missions with an O3 or above as the command and control element.

This capability gap results in operational risk because it does not give E/160 the organic capability to conduct three geographically dispersed mission sets with a command and control element that meets the requirements of the 160th SOAR. Additionally, this presents risk in the mission approval process for aviation operations at geographically dispersed locations. The final portion of the aviation mission approval process requires the signatures of a mission briefing officer (MBO) and a final mission approval authority (FMAA). The FMAA is the individual that assumes the overall risk of the mission, and assuming risk is primarily the responsibility of commanders in the grade of O3 and above. A CW4 can have FMAA, but it is not the normal process for aviation operations and for that reason it is not included in this analysis of the risk.

The FSA identified a materiel and non-materiel solution to this capability gap. The non-materiel solution would re-allocate MTOE personnel billets of existing human resources in order to fill this capability gap and ensure no increase to the current E/160 MTOE of 165 personnel. The proposed solution would change the five CW4 personnel billets on E/160's MTOE to the grade of O3. This would change paragraph number 102, line number 01, UAS OPERATIONS OFFICER and paragraph number 105, line number 01, UAS PLATOON LEADER, from CW4 allocated billets to O3 billets, which would add five additional O3s to E/160's MTOE. This change would align E/160's MTOE to mirror the rotary wing companies' MTOEs that have six O3 MTOE billets each. This

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solution would enable E/160 to organically provide a command and control element with an O3 or above to support three geographically dispersed locations at a 1:2 deployment ratio.

The proposed materiel solution to this capability gap would be for E/160 to conduct remote split operations (RSO). RSO would solve this capability gap by providing a central mission control element (MCE) at E/160's home station to provide command and control of three geographically dispersed locations. E/160 would have two commissioned officers in the grade of O3 and above to provide command and control of three launch and recovery elements (LRE) at three geographically dispersed locations. This is a materiel solution because it would require an investment to the current communications architecture in order for E/160 to conduct RSO.

The second FAA on E/160's organization used Army doctrine, *ADRP 3-05 Special Operations,* and Joint doctrine, *JP 3-05 Special Operations,* to establish the task for this analysis. Of note, the author did not include this second analysis in the table at the beginning of this chapter because while the following analysis is relevant and identified a follow-on research question in chapter five, it did not make it past the author's updated individual recommendation and would not be brought before the CDM in the R3. These guiding doctrinal references state that in order to be a special operations unit, the unit must be specially organized, trained, and equipped. The FAA task in terms of organization is that E/160 must have more senior and experienced 15W Gray Eagle operators. Army and Joint doctrine also provide the condition for this analysis, that E/160 must be able to provide special operations forces with a unique capability in terms of employment, tactics, techniques, procedures, and equipment. An increase in the grade of

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15Ws assigned to E/160 would provide this unique capability, differentiating E/160 from conventional MQ-1C Gray Eagle units. To determine the standard for the FAA, this study used an MTOE comparative analysis of ARSOA rotary wings units to CF rotary wing units and compared them to ARSOA Gray Eagle in relation to CF Gray Eagle formations. This established the standard set for this study. The graphs below illustrate that airframe operators, in this case MH-47/CH-47 pilots and MQ-1C Gray Eagle 15W operators, are more senior in ARSOA rotary wings units compared to CF rotary wing units, but that is not the case for ARSOA Gray Eagle operators.

The number of personnel must be taken into account when viewing this graph since the ARSOA units have a higher overall number of personnel assigned than the CF units.

Table 5. Operator and Pilot Analysis

MQ-1C OPERATORS BY GRADE	E/160TH SOAR	B/101ST ABN
E-7	4	3
E-6	8	6
E-5	16	9
E-4	24	16

H-47 PILOTS BY GRADE	A/2-160TH SOAR	B/3-82ND
W4	8	0
W3	13	3
W2	0	17

Source: Created by author.

The A/2-160's MTOE total is 139 personnel, compared to B/3-82's MTOE of 52 personnel, and E/160's MTOE total of 165 personnel, compared to B/101's MTOE of

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127 personnel. Even with the overall MTOE number taken into account, it is clear that A/2-160 has more senior pilots than B/3-82. A/2-160 has no CW2s assigned while the majority of pilots assigned to B/3-82 are made up of CW2s. Conversely, B/3-82 has zero CW4s assigned while A/2-160 has eight. When looking at the MTOEs of E/160 and B/101, the same differences are not evident. When the difference in overall MTOE personnel assigned is taken into account, the operators by grade are essentially the same for E/160 and B/101. Since the overall majority of ARSOA has MTOEs that mirror A/2-160, this analysis determined that the standard for ARSOA is to have more senior pilots and operators than the CF counterparts.

The FNA took the analysis from the FAA to determine any potential capability gaps in the organization of the unit. The first premise that determined this gap in E/160's organization was the MTOE comparative analysis. The ARSOA rotary wing companies are manned with pilots of a higher grade than the CF rotary wing units. This comparison illustrated a gap in E/160's capability because when compared to the MTOE of B/101, the operator by grade, is essentially the same. This is a capability gap, because E/160 is not specially manned to support special operations, as compared to ARSOA units.

This capability gap results in operational risk by not providing a unique capability in terms of organization to special operations because E/160 does not have more senior Gray Eagle operators than CF Gray Eagle units. Part of ARSOA's ability to provide a unique aviation capability to special operations is by manning the rotary wing units with more senior pilots to conduct ARSOA missions. ARSOA mitigates risk and is able to conduct operations that CFs are unable to accomplish, in part, because ARSOA has deliberately organized its rotary wing units with senior grade pilots. E/160 does not have

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this same organization, which increases the risk of conducting unique missions in support of special operations.

The FSA used the analysis of the ARSOA rotary wing unit, A/2-160, presented in this study, as the basis for the recommended materiel solution. The materiel solution would be to increase MTOE billets of the enlisted Gray Eagle 15W operators in the grades of E5, E6, and E7. This solution would not add additional personnel to E/160's overall personnel count of 165, but would take those billets from the E4 15W billets. This change is in line with the organization of A/2-160, as that unit's pilot billets have no CW2s, and only have MTOE billets in the grade of CW3 and above. The increase of E5, E6, and E7 15W MTOE billets would increase the overall experience level of 15W operators to match the capabilities provided by ARSOA rotary wing units. Additionally, increasing E7 15W MTOE billets within E/160 will enable experienced operators to remain within the unit, increasing the unit's capability. Currently, E/160 only has four E7 15W MTOE billets, as UAS PLATOON SERGEANTS, that focuses those E7 15W operators on the leadership and administrative requirements of the platoon. In comparison, A/2-160 has CW4 MTOE billets at the platoon level as SR IP/IFE, which is a position that focuses on the tactical employment of the MH-47G. This analysis illustrates that ARSOA rotary wing units have MTOE billets that enable their most experienced pilots to remain at the platoon level that adds a unique capability in terms of organization and manning, that the CF does not. This materiel solution to E/160's manning would enable them to provide the same capability as the ARSOA rotary wing units.

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Training Analysis

The FAA on E/160's training also used Army doctrine, *ADRP 3-05 Special Operations,* and Joint doctrine, *JP 3-05 Special Operations,* to establish the condition for analysis focused on distinctive capabilities required of special operations forces. This study used the unique ARSOA mission battle-rostering requirements in accordance with *ARSOA 3-04.11* as the basis for the standard in the FAA. This standard determined that battle-rostering within special operations aviation is unique and ensures the ground force commander has support by providing a clear tool to control risk while retaining mission flexibility. ARSOA accomplishes this through its unique battle-rostering, which organizes crews by mission qualification.

The FNA took the analysis from the FAA to determine potential capability gaps in unit training. The analysis determined that E/160 does not have an ARSOA specific mission training process for 15W Gray Eagle operators. The ARSOA rotary wings units have a unique training and battle-rostering process that uses the aircrew mission designations of BMQ, FMQ, and FLD to provide a unique, special operations specific, capability. E/160 uses the same battle-rostering process as conventional Gray Eagle units and does not have unique, special operations aviation specific aircrew designation of BMQ, FMQ, and FLD. This study used this analysis to define this as a training capability gap within E/160.

The risk associated with this capability gap is that there is an expectation from supported special operations forces that ARSOA provides a unique Gray Eagle capability, and part of that expectation involves uniquely trained 15W operators. This expectation is determined by both the doctrinal definition of a special operations unit and by the precedent set by ARSOA rotary wing over the past 36 years. ARSOA rotary wing

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units use their unique battle-rostering process to reduce risk for the ground force commander during aviation operations. Without a unique, mission tailored battle-rostering process, E/160 cannot provide the same risk reduction capability to the ground force commander that the ARSOA rotary wing units provide.

The FSA used the unique ARSOA rotary wing mission training process as the basis for this solution. The proposed non-materiel solution to this capability gap would be for E/160 to implement an ARSOA specific 15W operator training and mission battle-rostering process that mirrors the ARSOA rotary wing units. This would include adding additional aircrew designations, like BMQ, FMQ, and FLD, to the unit's aircrew training programs that would enable E/160 to battle-roster their crews to tailor specific mission requirements. This would enable E/160 to provide a unique special operations Gray Eagle capability to the ground force commander that would enable them to control risk while retaining mission flexibility.

Materiel (Equipping) Analysis

The FAA related to materiel (equipping) also used Army doctrine, *ADRP 3-05 Special Operations,* and Joint doctrine, *JP 3-05 Special Operations,* to establish the task for analysis focused on distinctive capabilities required of special operations forces. To define the standard for the FAA, this study used a comparative analysis of the airframe operator's manuals from the different units included in this study. This comparison illustrated that the ARSOA rotary wing unit, A/2-160, has a modified version of the CF Army CH-47F Chinook, heavy lift rotary wing. A/2-160 employs the MH-47G Chinook, a heavy assault rotary wing which provides special operations forces with a unique piece of equipment that provides additional capability to special operations. For example, the

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MH-47G has an in-flight refuel capability that provides special operations forces with a long-range infiltration capability not provided by the CF's CH-47F. When this same comparison is made between the ARSOA and CFs Gray Eagle units, there is no specialized equipment that enables E/160 to provide an additional capability to special operations forces. The Gray Eagle employed by E/160 is identical to the one employed by the CF Gray Eagle unit, B/101. Given the results of this comparison, this study then used the MTOE narrative of the ARSOA rotary wing units to define the standard that states the unit has unique equipment, tailored to support specific mission profiles.

The FNA used the analysis from the FAA to determine any potential capability gaps in the equipping of the unit. The analysis determined that E/160 does not have equipment that provides a unique capability to the ground force commander like the ARSOA rotary wing units. To further define the possible equipment capability gaps, this study used three unique capabilities provided by ARSOA rotary wing units in comparison to CF's rotary wing units. These capabilities are extended range, advanced aircraft survivability equipment, and advanced onboard radar allowing rotary wing operations in degraded environmental conditions. These equipment capabilities provide a unique capability to support the ground force commander over those that exist within the conventional forces (CF). This illustrates an equipment capability gap for E/160, because their equipment does not provide a unique capability in comparison to the CF Gray Eagle units.

The risk associated with the identified equipment capability gap is that E/160, in terms of UAS support, does not offer the ground force commander a unique capability to execute missions that are outside of the CF's Gray Eagle capability. Special operations

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require a unique equipment capability because they are often conducted in denied or hostile environments, under unfavorable weather and environmental conditions, and require real time intelligence. As an intelligence, surveillance, and reconnaissance platform in support of special operations, E/160 has to have a unique capability that can operate in conditions that exceed the ability of those found in the CF units.

The FSA used the unique capabilities provided by the ARSOA rotary wing units as the basis for this solution. The proposed materiel solution would be for ARSOA to invest in research and development to modify the Gray Eagle to provide a unique UAV platform capability specifically designed to support the special operations community. The specific modifications should be the focus of a follow-on study; however, based on the author's operational experience, the author would recommend two potential materiel solutions to the current Gray Eagle company equipment resources to enhance its ability to support special operations. First, the engineers should reduce the size of the ground control station, satellite and ground data terminals, and secondly, they should reduce the total amount of ground support equipment required to operate the Gray Eagle to improve the company's expeditionary capability.

R2: The Updated Individual Recommendation

The R2: Updated Individual Recommendation is composed of the same questions that were answered in the R1: Initial Personal Recommendation. The difference is that these same questions will be answered after conducting the literature review. This illustrates the changes in opinion and recommendation after completing a review of the relevant literature. The R2 provides credibility to the applied professional case study methodology by demonstrating to the reader the changes in perception by the author after

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completing the literature review. The R2: Updated Individual Recommendation will only address significant changes from the R1: Initial Personal Recommendation.

The first part of the R2 discusses the primary research question and why it is important to the author and the key stakeholders within the United States Army Special Operations Command (USASOC). When this research effort was initiated the primary research question in this study was framed as: how should United States Special Operations Command adapt manning, training, and equipping of the ARSOA Gray Eagle unit to provide the unique capabilities required by the special operations community? Joint and Army doctrine both define special operations as activities requiring unique capabilities not provided by the CF. Doctrine also affirms that special operations forces must be specially organized, trained, and equipped to provide this unique capability (ADRP 3-05, 2012; JCS 2011). After analyzing the similarities and differences of a CF Gray Eagle company to an ARSOA Gray Eagle company and comparing them to the similarities and differences between a CF rotary wing company and an ARSOA rotary wing company, it is evident that there are gaps in capabilities provided by the ARSOA Gray Eagle company. Specifically, the manned ARSOA rotary wing company analyzed in this study provides unique special operations capabilities because it is specifically manned, trained, and equipped differently than the CF rotary wing company analyzed in this study. However, the same cannot be said about the ARSOA MQ-1C Gray Eagle company in comparison to the CF MQ-1C Gray Eagle company. This new knowledge and understanding led the author to update the primary research question to: are there organizational (manning), training, and materiel (equipping) capability gaps that are

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preventing the ARSOA Gray Eagle unit from providing a unique special operations aviation capability?

During the course of this study, the author was informed that upon completion of the Command and General Staff College, he would be taking command of the newly fielded ARSOA Gray Eagle company, Company F, 160th Special Operations Aviation Regiment, scheduled to officially activate in August of 2018. In turn, this made the author a stakeholder in this research at the tactical level and more invested than at the beginning. The review of literature also defined the stakeholders' position and established the basis that the CDM will evaluate this study through the R3: Stakeholder Recommended Solution, presented in the final assessment.

The second part of the R2 addresses why this study is important and the possible consequences if this topic is not addressed. The new ARSOA Gray Eagle company, F/160, is scheduled to activate in August 2018 and results in the fielding of two ARSOA Gray Eagle companies within a five-year period. This highlights the importance that the DOD is placing on the development of UAS within ARSOA. The review of literature confirmed the author's initial position and opinion that the UAS capability provided to special operations aviation must provide a unique capability not provided by the CF Gray Eagle units. Additionally, the earlier that these gaps can be identified and validated by the CDM, the earlier the solutions can be implemented.

The final portion of the R2 identifies the potential solutions to the problem statement identified through the review of literature. The review of literature identified gaps within the manning, training, and equipping of the ARSOA Gray Eagle company. The primary sources of data for this study were DOD publications. The MTOE

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documents for the four units used in this study provided a clear comparison of the CF and ARSOA Gray Eagle companies in relation to the ARSOA and CF rotary wing companies. This analysis provided evidence to support a capability gap in the manning of the ARSOA MQ-1C Gray Eagle company. The MTOE narrative and aircrew training publications provided the necessary information to compare and contrast the training requirements and processes within the different ARSOA and CF companies used in this study. This provided insight on gaps within the training domain of the ARSOA Gray Eagle company. Lastly, by comparing airframe specific technical manuals, it was evident that there was no unique equipping capability provided by the ARSOA Gray Eagle company in comparison to the CF's UAS company. In contrast, by comparing the airframe specific technical manuals of the ARSOA and CFs rotary wing companies, ARSOA aircraft provided a unique equipping capability when compared to the CF's. By identifying these gaps and the risks associated with them, the potential materiel and non-materiel solutions for each were identified and explained earlier in this chapter.

R3: Stakeholder Recommended Solution

To determine the R3: Stakeholder Recommended Solution, the author evaluated the R2 through the lens of the Chief Decision Maker (CDM) and the stakeholders. The CDM for this applied professional case study is the Commander of the United States Army Special Operations Command (USASOC), the stakeholders include the 160th SOAR Regimental Commander, and to a smaller extent, the 160th SOAR Battalion Commanders. The USASOC Commander was chosen as the CDM as opposed to the Commander of United States Special Operations Command (USSOCOM) because the purpose of this applied professional case study is to persuade the CDM in order to affect

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change. The USSOCOM Commander already employs Group 4 UAS within the other services, but this study is specific to employment of the Gray Eagle within ARSOA, which is focused on the Army and its mission of unified land operations, "to apply land power as part of unified action to defeat an enemy on land and establish conditions that achieve the JFC's commander's end state" (FM 3-0 2017, 34; USSOCOM Fact Book 2017, 49). This means that the USASOC Commander must be persuaded that the ARSOA Gray Eagle needs to provide a unique UAS capability to enhance ARSOA before these potential solutions are presented to the USSOCOM Commander.

ARSOF 2022 and *USASOC Strategy-2035* comprised the literature used as the basis for the CDM's concerns. Additionally, the concerns presented were compared to the 2018 USSOCOM Posture Statement made by the Commander, General Raymond A. Thomas, on February 15, 2018 before the House Armed Services Committee, to ensure that these concerns are nested within the next higher echelon of command. The main concerns of the CDM were to:

- Obtain next generation unmanned aircraft systems that provide longer operational range, over horizon observation, and can be launched and recovered by tactical units;
- Employ advanced unmanned aircraft systems and intelligence collection capabilities at the tactical level; provide joint force commanders with professionals who are agile, adaptive, flexible, bold, innovative, and possess a high degree of advanced training;
- Provide the nation's premier special operations forces, delivering appropriate and effective capabilities to joint force commanders and interagency leaders across the entire spectrum of conflict and under any operating conditions;
- Broaden the range of special operations aviation-related individual training and education including unmanned aircraft systems; and
- Improve army unmanned aircraft system programs of record (Raven, Shadow and Gray Eagle) to meet joint expeditionary tactics, techniques, procedures, forward-

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based networking, and sensor requirements (HQDA 2014a, 24; ARSOF 2035 2017, 3-6).

The first part of the R3 will discuss the primary research question and why it is important to the CDM, the Commander of United States Army Special Operations Command (USSOCOM). The primary research question for this study is: are there organizational (manning), training, and materiel (equipping) capability gaps that are preventing the ARSOA Gray Eagle unit from providing a unique special operations aviation capability? The primary research question in this study is directly in line with the CDM's position because it specifically addresses the objectives for improved UAS capabilities within special operations as defined in *ARSOF 2022* and *USASOC Strategy-2035*. However, the CDM would disagree with the premise that E/160 does not provide a unique special operations aviation capability. The CDM would argue that the unique capability provided by E/160 is that it is manned and equipped to support three geographically dispersed mission sets simultaneously, as stated in the MTOE narrative, "this unit was specifically designed to meet SOA requirements for multiple simultaneous deployments to widely separated areas." From a manning perspective this is clearly evidenced by E/160's MTOE total of 165 personnel, compared to B/101's MTOE of 127 personnel. However, from an equipping perspective, both E/160 and B/101 are supplied with the same amount of equipment that makes up the UAS company; 12 x unmanned aerial vehicles (UAVs), 6 x ground control stations (GCSs), 6 x ground data terminals, and 3 x satellite ground data terminals. E/160 is equipped with slightly more ground support equipment, specific to the UAS, and has three additional generators. This means that from a purely equipment perspective, B/101 could support three geographically dispersed mission sets simultaneously, just like E/160.

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The second part of the R3 addresses why this study is important and the possible consequences if this topic is not addressed. In contrast to the author, the CDM would have to take into account competing resources when reviewing the results of this study. The CDM is responsible for a much bigger organization than what the author addresses in the R2, meaning that this study would have to persuade him to believe that the capability gaps addressed in this study outweigh other requirements in the USASOC enterprise. This would make the consequences to the CDM very different than the consequences stated by the author, while acknowledging that the CDM may face other consequences in the USASOC enterprise by electing to use valuable resources to pursue any of these proposed materiel solutions.

The final portion of the R3 takes the recommended solutions from this study and filters them through the lens of the CDM. The first organizational (manning) capability gap identified in this study was the lack of commissioned, company grade and above officers to perform the command and control requirement for three geographically dispersed mission sets. The two recommended solutions to this capability gap were to conduct RSO or to increase the O3 MTOE billets to six. The CDM views RSO as a viable option for ARSOA to employ its Gray Eagle assets. The author's personal operational experience attests that DOD conducted a study into RSO for ARSOA, but due to classification cannot disclose the findings or implications for future ARSOA employment.

The second recommended solution, to increase O3 MTOE billets, would not be accepted by the CDM for two reasons. First, this solution does not address any of the CDM's chief concerns. Second, it would not be feasible with respect to personnel

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limitations within ARSOA. Additionally, E/160 is attached to 2d Battalion, 160th SOAR, that the CDM would argue has the ability to support E/160 with its O3 command and control requirements to support three simultaneous, geographically dispersed missions. The second organizational (manning) gap addressed by the author was the need to increase the 15W MTOE billets of E5, E6, E7, and to reduce the number of E4s. The CDM would not approve this solution because it does not fall within his main concerns. The CDM is concerned with broadening the range of special operations aviation-related individual training and education including unmanned aerial systems, and would invest in that as opposed to the additional cost of increasing the rank structure of the 15Ws.

The training capability gap addressed in this study is that E/160 does not have an ARSOA specific mission training process for 15W Gray Eagle operators. The proposed non-materiel solution to this capability gap would be for E/160 to implement an ARSOA specific 15W operator training and mission battle-rostering process that mirrors the ARSOA rotary wing units. The CDM would approve this proposed solution because it meets all the criteria of an FSA, is non-materiel, and is in-line with his concern of broadening the range of special operations aviation-related individual training and education including unmanned aerial systems.

The materiel capability gap addressed in this study is that E/160 is not equipped to provide a unique ARSOA UAS capability. The proposed materiel solution would be for ARSOA to invest in research and development to modify the Gray Eagle to provide a unique aviation capability. The author recommended a modification to the Gray Eagle that increases its expeditionary capability by reducing the physical size of the ground control station, and satellite and ground data terminals as well as reducing the total

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amount of ground support equipment required to operate the Gray Eagle. The CDM would agree with the author's recommendation to conduct research and development into the modification of the Gray Eagle to increase its expeditionary capability. This recommendation is in-line with the CDM's concern of improving Army unmanned aircraft-system programs of record (Raven, Shadow and Gray Eagle) to meet joint expeditionary tactics, techniques, procedures, forward-based networking, and sensor requirements.

Conclusion

This chapter explained the findings of the research and applied those findings to the applied professional case study methodology. The modified DOTMLPF-P analysis provided recommended solutions to the CDM through the use of a CBA. These proposed solutions were then vetted by the CDM, through the final assessment, the R3. The next chapter, Chapter 5, will address the final recommendations of this study.

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CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Recommended Solutions

This section will discuss the implementation plan for the two recommended solutions proposed by this study. The implementation plan is broken down into short term (one to two years) and long term (three to five years) time frames and will use the principles of the Kotter Change Model for implementation. The two proposed solutions are a direct result of the author's professional operational experience in ARSOA, extensive literature review based in the professional body of knowledge that exists for this topic, and the analysis of that knowledge through the use of the applied professional case study methodology.

The United States Army is an organization that is not always willing to acknowledge and embrace the need for change. There are many ways to accomplish change within an organization and one that is both appropriate for this study and used in Army doctrine is the Kotter Change Model, hereafter referred to as the Kotter Model. This model uses the following eight-step process to affect change within an organization.

The first step in the Kotter Model is to establish a sense of urgency. This is done by creating a climate within the organization that is dissatisfied with the status quo by setting aggressive goals and objectives that force the organization to make significant change and overcome complacency.

The second step is to create the guiding coalition. After establishing a sense of urgency, a group of senior, influential, and respected individuals within the organization

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that support and are fully committed to implementing the change must be formed to propel the change forward.

The third step is to develop a vision and a strategy. Once the guiding coalition is formed, that group is used to develop a feasible vision and strategy that is imaginable, desirable, feasible, focused, flexible, communicable, provides an imaginable picture of the future, a shared sense of purpose, focuses efforts, aligns priorities, and sparks excitement for members of the organization.

The fourth step is to communicate the change vision. This is one of the most important stages within the process. Simply creating a vision and strategy to affect change accomplishes nothing unless the entire organization knows what the vision is and why it is so important for the organization to undertake.

The fifth step is to empower broad-based action. This involves empowering subordinate leaders that are committed to the change, potentially removing leaders that oppose it, creating an environment of decentralized control, and developing a shared understanding with mutual trust.

The sixth step is to generate short term wins. These accomplishments enable the organization to see tangible results toward accomplishing the desired change, which in some cases could take years to complete. Identifying and rewarding these short term gains helps to maintain the momentum of the change effort.

The seventh step is to consolidate gains and produce more change. Consolidating the effects garnished from the short terms wins will open the change initiative to other areas within the organization that were not evident at the start of the change process.

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Identifying these other changes and capitalizing on them during the process is essential to preventing regression while maintaining the momentum for further change.

The eighth and final step is to anchor the new approach into the culture. Kotter defines culture as, “norms of behavior and shared values among a group of people”. This final step is vital as it is the point where the organization as a whole, believes that the new process is the way the organization now does business and ensures the practice remains even if the current leadership at the time of the change, switches out (Miller and Turner 2017, 1-8)

The proposed solution identified for short term implementation (one to two years) is to implement an ARSOA-specific 15W operator training and mission battle-rostering process that mirrors the ARSOA rotary wing units. This change to the training domain of ARSOA Gray Eagle units would be a fairly simple change to make. This is because the process for this type of training plan is already in place for the ARSOA rotary wing units. This is a mission specific training program and could theoretically be implemented with minimal increase to the individual operator required flight hours. Affecting this change would not necessarily have to be approved by the Chief Decision Maker (CDM), but could be implemented by the other stakeholders, most likely by the 160th SOAR Commander. Additionally, because this is a non-materiel solution, it is very realistic for short term implementation. This proposed solution was recommended because it is nested within the main concerns of the CDM, as stated in *ARSOF 2022* and *USASOC Strategy-2035*, that include: (1) provide joint force commanders with professionals who are agile, adaptive, flexible, bold, innovative, and possess a high degree of advanced training, and

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(2) broaden the range of special operations aviation-related individual training and education including unmanned aircraft systems.

Using the principles of the Kotter Model, the author recommends the following short term implementation plan for the proposed change to the training domain of the ARSOA Gray Eagle units. It is once again important to note that the author will be taking command of the newly fielded ARSOA Gray Eagle company, F/160, with an activation date set for August 2018, and will attempt to affect this proposed change to the training domain of F/160. The author's professional operational experience attests that the biggest obstacles to implementing this change will be with steps one and two of the Kotter Model. The first ARSOA Gray Eagle company, E/160, is viewed as a critical capability within the SOF community, and because of that, the author believes that establishing a sense of urgency, as well as forming a guiding coalition will be difficult. The argument to overcome this is that the ARSOA rotary wings success over the past 36 years is directly attributed to this process of training. Additionally, because this process is already in use by the ARSOA rotary wing units, step three of the Kotter Model will be extremely easy to produce, since it already exists. That is also why the author believes that this recommendation is so viable, because the organization has already bought into the process and can easily identify with it. The challenge will be in convincing the other stakeholders, as well as the senior members of the unit, that this process can be as beneficial for the ARSOA Gray Eagle community as it is for the ARSOA rotary wing community.

After garnishing support for this recommended change, the next biggest task will be to generate short term wins in order to ensure this change gains momentum and

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becomes part of the established training process within the organization. The immediate result of applying this training process within the organization, will be the increased confidence that the individual operators will have when conducting their mission and specifically with their ability to conduct professional air mission briefs. The ARSOA mission training process involves extensive training in the process of conducting professional military air mission briefings. Making that a part of the ARSOA 15W training process will dramatically increase their confidence in their briefing abilities and propel this change forward from the bottom up. With a bottom up approach, this will ensure the majority of the company buys into the new training process which will help to confirm this solution with the organization's leadership and stakeholders.

Once the recommended training process is established at the company level, this implementation plan will look to consolidate gains and further the change process by establishing this recommended change at the battalion and regimental levels. To accomplish this, the training process will first need to be standardized within the battalion and then, to anchor the change, written into the regimental standard operating procedure. Once the process is refined and standardized enough to be written into the official regimental standing operating procedure, it will ensure that this process is the approved way that the organization does business, and will remain in place once the implementing leadership switches out.

The proposed solution identified for long term implementation (three to five years) would be for ARSOA to invest in research and development to modify the Gray Eagle to provide a unique aviation capability to the SOF community. It is important to note that this recommendation was selected for long term implementation because

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ARSOA is currently scheduled to conduct the full operational testing and evaluation of the MQ-1C Gray Eagle Extended Range UAS in July of 2018. This new version of the Gray Eagle will provide additional capabilities and, because of this, it is unlikely that the CDM will have an appetite for any additional investment into research and development of the Gray Eagle until the added benefits of this new version are fully understood. It is also important to note that while ARSOA is conducting the full operational testing and development of the MQ-1C Gray Eagle Extended Range UAS, this new version will be fielded to both ARSOA and CF Gray Eagle units and the new capability will not be unique to the SOF community.

The specific modification to the Gray Eagle should be the focus of a follow-on study. Based on the author's operational experience, the author would recommend a modification that would increase its expeditionary capability, specifically by reducing the size of the ground control station, satellite and ground data terminals, and reducing the total amount of ground support equipment required to operate the Gray Eagle. This proposed solution was recommended because it is nested within the main concerns of the CDM, as stated in *ARSOF 2022* and *USASOC Strategy-2035*, that include: (1) obtain next generation unmanned aircraft systems that provide longer operational range, over horizon observation, and can be launched and recovered by tactical units, and to (2) improve army unmanned aircraft system programs of record (Raven, Shadow and Gray Eagle) to meet joint expeditionary tactics, techniques, procedures, forward-based networking, and sensor requirements.

Using the principles of the Kotter Model, the author recommends the following long term implementation plan for the proposed change to the materiel domain of the

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ARSOA Gray Eagle units. Unlike the proposed short term solution, the identified long term solution is simply a recommendation to invest in research that will lead to a change in the future. For this reason, the implementation plan will not use all eight steps of the Kotter Model, but will focus on Steps One and Two. The author believes that creating a sense of urgency and building a guiding coalition among the CDM and stakeholders for this recommended solution will be difficult, given the fact that a new version of the MQ-1C Gray UAS is currently being fielded. The key to overcoming this obstacle is to emphasize to the CDM and stakeholders the fact that the new version of the Gray Eagle was based upon the needs of the CF, and that a SOA specific research and development process has not been conducted to meet SOF specific UAS needs. This will remain in line with ARSOA common practice, as the rotary wings employed by ARSOA were modified based on SOF specific operational needs, and that the same should hold true for the platform employed by the ARSOA UAS units.

Recommendations for Further Study

The first recommendation for further study would be to increase the expeditionary capability of the Gray Eagle by reducing the size of the ground control station, satellite and ground data terminals, and the amount of ground support equipment required to operate the Gray Eagle. The study would need to focus on the current breakdown and buildup times of the Gray Eagle in its current configuration as well as the amount of pallet space aboard United States Air Force (USAF) aircraft that is required to move one Gray Eagle flight platoon from one location to another. The study would then need to establish the timeline and cargo requirements needed to support United States Special Operations Command (USSOCOM) type of mission sets. Once this baseline is

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established, the study would be able to determine the specific requirements needed to publish the Operational Needs Statements (ONS) request to industry leaders and produce a modified version of the Gray Eagle to address the capability gap in supporting this USSOCOM mission set.

The second recommendation for further study would be to further research the capability provided by using Remote Split Operations (RSO) to employ ARSOA UAS. As stated earlier in this thesis, the professional operational experience of the author attests that there has been a study conducted on RSO, but due to classification cannot publish the results. However, the author would argue that another study needs to be conducted looking specifically at the benefits gained by the communication architecture needed to conduct RSO. In addition to the expeditionary and manning benefits of RSO, the author believes that RSO would also benefit the training level of 15W operators.

Affording 15W operators different training environments is difficult due to the fact that UAS operations within the national airspace are very hard to conduct. Currently, the process involved with transiting the national airspace with a UAV is next to impossible because of the restrictions imposed by the Federal Aviation Administration (FAA). This forces ARSOA Gray Eagle units to exclusively train at their home base or incur the high costs of transporting all the equipment necessary to operate at another US location. The author believes that these costs could be greatly reduced by the infrastructure associated with conducting RSO, which would make training at different locations within the United States more of a reality. The study would need to look at a cost analysis of being able to move a relatively small UAS package, due to the communication architecture of RSO, from one location to another, in order to train with

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different SOF units across the United States. The author believes that by conducting this analysis, the CDM and stakeholders would see another benefit of RSO that has not been previously addressed.

The final recommendation for further study would be to further research small precision guided munitions. The Gray Eagle needs to have the ability to tailor its payload based on the mission set. Weight will always be a factor regarding UAS operations and further research needs to be conducted to find an alternate payload for the Gray Eagle other than its current restriction to the Hellfire missile. This is not to say that the Hellfire is not an effective munition for the Gray Eagle, but in its current configuration, it can only carry up to four Hellfire missiles. This recommendation for further study would be to give the Gray Eagle an alternate, lighter, precision guided munition that would provide the ground force commander with more options when supporting different mission sets.

In addition to the aforementioned recommendations, the author and his thesis committee members developed four additional recommendations for further study after conducting the formal thesis defense. The four recommendations for further study are: (1) What are the training requirements that will be driven by an upgraded Gray Eagle materiel solution? (2) Perform a manpower grade analysis to document personnel requirements in the grades of O3 and CW4, for six MTOE positions. (3) Determine if ARSOA manning policy needs to be amended to account for UAS needs. (4) Conduct a SOF specific mission analysis for UAS platforms to define materiel key performance parameters.

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Personal Learning Reflections

By conducting this research, the author gained a clear understanding of the current capabilities of the ARSOA Gray Eagle units, and more importantly, an understanding of the current capability gaps in the domains of organization, training, and materiel. As a future stakeholder in this community, this research enabled the author to develop a vision and strategy for commanding the newly fielded ARSOA Gray Eagle company, F/160. Additionally, by focusing this study within the professional body of knowledge associated with this topic, the author was able to both confirm and reject various biases that were held prior to conducting this study. This is significant, as the applied professional case study methodology ensured that the author's understanding of this topic moving forward is objective and based solely on the credible literature that was reviewed during the study.

In addition to his own professional growth, the author believes that this study is the first step for the ARSOA UAS community to begin to define its role within SOA. The Gray Eagle platform was designed to meet the needs of the CF and this paper has illustrated the fact that while this current capability is successful in ARSOA, it is now at the point where ARSOA needs to modify the current capability for SOA. Just like the ARSOA rotary wing units took CF rotary wing organizations and modified them to meet SOA specific needs, the ARSOA Gray Eagle units need to begin making the same organizational, training, and materiel modifications to support specific SOA needs.

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THE FIRST STEP: BUILDING A SPECIAL OPERATIONS AVIATION SPECIFIC UNMANNED AIRCRAFT SYSTEM CAPABILITY

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements for the degree

MASTER OF MILITARY ART AND SCIENCE
General Studies

by

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2018

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14. ABSTRACT

The Army began the testing and development of the unmanned aircraft system (UAS) capability in 1953. Since that point, the UAS has grown exponentially and proven itself as an essential capability on the battlefield in every major conflict since Desert Storm. In 2013, the United States Army Special Operations Command (USASOC) began to employ the first and only Special Operations Aviation (SOA) MQ-1C Gray Eagle UAS unit in the Army. The Army Special Operations Aviation (ARSOA) Gray Eagle unit is organized, trained, and equipped in an almost identical fashion as the conventional force (CF) Gray Eagle units. Conversely, the rotary wing units within ARSOA are organized, trained, and equipped in a very different manner than the CF rotary wing units.
The purpose of this study is to illustrate that capability gaps exist in the domains of organization, training, and equipping of the ARSOA Gray Eagle unit. A comparative analysis of ARSOA rotary wing units in relation to CF rotary wings is used to identify these capability gaps. The study then uses a modified doctrine, organization, training, materiel, leadership and education, personnel, facilities, policy (DOTMLPF-P) analysis and a capabilities-based assessment (CBA) to identify potential materiel and non-materiel solutions.

15. SUBJECT TERMS
Unmanned Aircraft System, Army Special Operations Aviation, Capabilities Based Assessment, DOTMLPF-P Analysis

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

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ABSTRACT

THE FIRST STEP: BUILDING A SPECIAL OPERATIONS AVIATION SPECIFIC UNMANNED AIRCRAFT SYSTEM CAPABILITY, by Joshua J. Durham, 84 pages.

The Army began the testing and development of the unmanned aircraft system (UAS) capability in 1953. Since that point, the UAS has grown exponentially and proven itself as an essential capability on the battlefield in every major conflict since Desert Storm.

In 2013, the United States Army Special Operations Command (USASOC) began to employ the first and only Special Operations Aviation (SOA) MQ-1C Gray Eagle UAS unit in the Army. The Army Special Operations Aviation (ARSOA) Gray Eagle unit is organized, trained, and equipped in an almost identical fashion as the conventional force (CF) Gray Eagle units. Conversely, the rotary wing units within ARSOA are organized, trained, and equipped in a very different manner than the CF rotary wing units.

The purpose of this study is to illustrate that capability gaps exist in the domains of organization, training, and equipping of the ARSOA Gray Eagle unit. A comparative analysis of ARSOA rotary wing units in relation to CF rotary wings is used to identify these capability gaps. The study then uses a modified doctrine, organization, training, materiel, leadership and education, personnel, facilities, policy (DOTMLPF-P) analysis and a capabilities-based assessment (CBA) to identify potential materiel and non-materiel solutions.

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ACRONYMS

ARSOA	Army Special Operations Aviation
CBA	Capabilities-Based Assessment
CF	Conventional Force
DOTMLPF-P	Doctrine, Organization, Materiel, Leadership and Education, Personnel, Facilities, Policy
SOA	Special Operations Aviation
SOF	Special Operations Forces
USASOAC	United States Army Special Operations Aviation Command
USASOC	United States Army Special Operations Command
USSOCOM	United States Special Operations Command
UAS	Unmanned Aircraft System

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CHAPTER 1

INTRODUCTION

Problem Statement

In 2013, Army Special Operations Aviation (ARSOA) began to employ the MQ-1C Gray Eagle Unmanned Aircraft System (UAS), hereafter referred to as Gray Eagle, in support of special operations around the globe. Unlike the rotary wing units within ARSOA, there is not a major difference in the way that the ARSOA Gray Eagle unit is manned, trained, and equipped from that of the Conventional Force (CF) Gray Eagle units. Conversely, the rotary wing units within ARSOA have major differences in the way they are manned, trained, and equipped, in comparison to CF rotary wing units, in order to provide a unique aviation capability in support of Special Operations Aviation (SOA). Therefore, if there currently are no major differences in the way that the ARSOA Gray Eagle unit is manned, trained, and equipped, in comparison to CF Gray Eagle units, then what unique capability does the ARSOA Gray Eagle unit provide SOA? Of note, the terms manning and equipping will be used synonymously throughout this thesis with the terms organization and materiel, respectively.

Background

The concept of unmanned flight was first introduced in 1915, and by 1919 an unmanned aircraft completed a successful engagement on a captured German submarine using gyroscope-guided technology. For the Army specifically, the UAS effort began in 1953, at Fort Huachuca, Arizona, the Army's first testing and fielding location. By 1979, the Army began its first UAS acquisition program with the Aquila, which completed its operational testing in only 7 of 105 scheduled flights. This led to the Department of

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Defense's first fully operational UAS program, the Pioneer, which successfully sought out SCUD missile systems and high value targets during more than 300 combat missions during Operations Desert Shield and Desert Storm. The Army continued to build its UAS capability and by the time the United States went to war in October 2001, the Army had 54 operational Hunter and Shadow unmanned aircraft in use and that number rapidly grew to over 4,000 unmanned aircraft by 2010 when the Army employed Groups 1-4 types of UAS.

Table 1. Current Systems

UAS Category	Max Gross Takeoff Weight	Normal Operating Altitude (Ft)	Airspeed	Current Army UAS in Operation
Group 1	< 20 pounds	< 1200 above ground level (AGL)	<100 Knots	RQ-11B Raven
Group 2	21-55 pounds	< 3500 AGL	<250 Knots	No current system
Group 3	< 1320 pounds	<18,000 mean sea level (MSL)		RQ-7B Shadow
Group 4	> 1320 pounds		Any Airspeed	MQ-5B, MQ-1C
Group 5		> 18,000 MSL		No current system

Source: Army UAS COE, *UAS Current Systems* (Ft. Rucker, AL. U.S. Army, 2012), 12.

The United States Army has employed the Gray Eagle for more than a decade, but it was not until 2013 that it joined the ranks of ARSOA. In 2013, Company E, 160th Special Operations Aviation Regiment (E/160) stood up as the first and only special operations aviation Gray Eagle company within the Army. Before that time Quick Reaction Capability Companies, made up of different CF UAS units, filled the SOA UAS requirements in both Iraq and Afghanistan. The formation of E/160 brought about an organic, Group 4 UAS capability to the United States Army Special Operations Command (USASOC) to support special operations forces (SOF). A holistic review of ARSOA Gray Eagle operations within SOA has not been written to capture the unique

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challenges this capability brings with it in terms of manning, training, and equipping. Currently ARSOA UAS is continuing to grow and is fielding a second Gray Eagle company (USA UAS COE 2010, 4-6). Now that the ARSOA Gray Eagle company appears to be a stable and growing capability, it is time to conduct a robust needs analysis to ensure that the unit is properly manned, trained, and equipped, from the SOF end-user perspective and not just utilizing the capabilities driven by CF requirements and analysis.

Primary Research Question

ARSOA does not employ the Gray Eagle like a CF UAS unit. However, the ARSOA Gray Eagle company is manned, trained, and equipped in almost an identical fashion as the CF UAS units. Conversely, the rotary wing ARSOA units are manned, trained, and equipped significantly different from that of rotary wing CF units. ARSOA has specific manning, training, and equipping approaches that enables its rotary wing units to have a unique capability that the CF does not have. This leads to the primary research question: are there organizational (manning), training, and materiel (equipping) capability gaps that are preventing the ARSOA Gray Eagle unit from providing a unique SOA capability? This study will illustrate whether or not the CF force development processes fully exploit the Gray Eagle's capabilities and meet SOF needs. Only by conducting a needs analysis from a SOF perspective can the force development process be reverse-engineered to ensure that ARSOA is fully exploiting the capabilities of their Gray Eagle units.

Primary Research Question

In order to answer the primary question, specific questions must be asked within the DOTMLPF-P domains of organization (manning), training, and materiel (equipping). The secondary questions to be answered in this thesis are:

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1. How does ARSOA man, train, and equip their UAS units in comparison to both CF UAS units and rotary wing ARSOA units?
2. Are there capability gaps in terms of manning, training, and equipping of the ARSOA Gray Eagle organization when compared to the rotary wing ARSOA units?
3. What are the potential materiel and non-materiel solutions to the ARSOA Gray Eagle units' domains of manning, training, and equipping, needed to provide a unique capability to SOF?

These secondary questions address specific issues under the DOTMLPF-P domains of organization, training, and materiel. Answering them will help to clearly define and focus the primary research question and this thesis.

Key Assumptions

The author makes two key assumptions in this paper. The first assumption is that the Gray Eagle and the near-term fielding of the MQ-1C Extended Range Gray Eagle UAS are the only Group 4 UAS platforms employed by ARSOA within the foreseeable future. United States Army Special Operations Aviation Command (USASOAC) has other Group 1, 2, and 3 UAS platforms, but for this study, the assumption will remain that the only Group 4 UAS employed by ARSOA is the Gray Eagle company within the 160th Special Operations Aviation Regiment (160th SOAR).

The second assumption is that the selected units used in this study represent their entire community. Specifically, this study used Company B, 3d Battalion, 82d Combat Aviation Brigade (B/3-82) to represent the CF rotary wing community; Company B, 101st Combat Aviation Brigade (B/101) to represent the CF Gray Eagle community;

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Company A, 2d Battalion, 160th Special Operations Aviation Regiment (A/2-160) to represent the ARSOA rotary wing community; and Company E, 160th Special Operations Aviation Regiment (E/160) to represent the ARSOA Gray Eagle community.

Definitions and Terms

The Unmanned Aircraft System (UAS) is a complex topic, and coupled with unique aspects of the special operations community, it makes appreciation of the issues identified in this thesis challenging without an understanding of the terms presented. The key terminology in this paper will discuss; the UAS, special operations aviation, general aviation, and key terms for understanding the applied professional case study methodology.

UAS Terms

Unmanned Aircraft System (UAS): The UAS is defined as the unmanned aerial vehicle (UAV), this study will be specifically looking at the MQ-1C Gray Eagle, the ground control station (GCS), and the communications architecture (USA UAS COE 2010, 8-10). This is a key concept to understand since the UAS will commonly be referred to as a UAV, and while the UAV is a component of the overall UAS, it is not the same thing as a UAS. Unlike manned platforms, the UAS requires all the components of the system to be operational, i.e. the UAV, the GCS and the communications architecture, for the UAS to be considered operational.

Unmanned Aircraft Crewmember (UAC): UAS crewmembers will be designated in writing by their unit commander, who will specify the UAS duties and crew stations that the UACs are authorized to occupy (HQDA 2006, 13).

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Unmanned Aircraft Operator (AO): The AO controls and/or monitors the actual flight of the UAS from within a GCS or similar device (HQDA 2006, 13).

Mission Payload Operator (PO): The PO is responsible for the operation of the payload sensor (HQDA 2006, 13).

Aircraft Commander (AC): The AC is responsible for control over all flight operations from pre-mission planning through debriefing. The UAS unit commander will designate aircraft commanders in writing. The AC will be responsible and have final authority for operating, servicing, and securing the UAS he or she commands, selected for each flight or series of flights, qualified and current in the UAS mission, type, design, and series (HQDA 2006, 13).

Instructor Operator (IO): The IO will train and evaluate UACs in accordance with the appropriate ATM, IOs must be designated in writing by the unit commander and be qualified and current in the UAS to be flown and must be qualified as an MC and successfully complete a Department of the Army approved IO course (HQDA 2006, 13).

Military Occupational Specialty (MOS): The grouping of duty positions requiring similar qualifications, and the performance of closely related duties (enlisted). It provides the branch, functional area, area of concentration, skill, language identification, and reporting classification used to classify the positions, and to identify individuals qualified to perform in those positions (officer) (DA PAM 611-21 2007, 12).

Additional Skill Identifier (ASI): A two-digit alpha-numeric or numeric-alpha code which identifies specialized skills that are closely related to and in addition to those required by the MOS (DA PAM 611-21 2007, 18).

Enlisted MOS 15W: Unmanned aircraft systems operator.

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Remote Split Operations (RSO): Allows operators to fly UASs from stateside locations while smaller in-theater teams control takeoffs and landings. RSO has two elements: a launch and recovery element (LRE) and a mission control element (MCE). The LRE is deployed forward to launch, recover, and conduct maintenance on the UAS. The MCE remains stateside to provide command and control and provides the operators to fly the UAV while on mission.

General Aviation Terms

Pilot (PI): A rated crewmember that is qualified and current in the aircraft mission, type, design, and series (HQDA 2014c, 26).

Pilot-in-Command (PIC): A rated crewmember that is qualified, current, designated Readiness Level (RL) 1 in the aircraft mission, type, design, series, and is the individual responsible and has final authority for operating, servicing, and securing the aircraft he or she pilots (HQDA 2014c, 25).

Unit Trainer (UT): The unit commander may appoint UTs to conduct specialized training to assist in unit training programs. Rated UTs are prohibited from conducting emergency procedures training in the aircraft. UTs are also prohibited from evaluating individual, crew, and maintenance tasks (HQDA 2014c, 26).

Instructor Pilot (IP): The IP will train and evaluate aviators and other personnel in designated aircraft per the aircrew training manual (ATM). To become qualified as an IP, an aviator must be qualified as a PC and must successfully complete an approved Department of the Army instructor pilot course (HQDA 2014c, 27).

Instrument Examiner (IE): The IE will conduct instrument training and instrument flight evaluations per the ATM. To become qualified as an IE, an aviator must be an IP in

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either aircraft category, and successfully complete a Department of the Army approved course of instruction for IEs (HQDA 2014c, 27).

Readiness Levels (RLs): Aviation commanders use a series of RLs to develop individual and crew proficiencies that support collective tasks. RLs identify the training phase in which aircrew members (ACM) are participating and measure ACM readiness (HQDA 2016a, 51).

Mission Approval Process: The mission approval process for aviation operations is accomplished in three steps that must be completed prior to mission execution. The three steps are: initial mission approval, mission briefing and planning, and final mission approval authority (HQDA 2014c, 9).

Initial Mission Approval: Commanders or their designated representatives (operations officer, S–3, and so forth) determine the mission feasibility and either accept or reject the mission for the command (HQDA 2014c, 9).

Mission Briefing Officer (MBO): The MBO is the Commander or his/her designated representative that interacts with the mission crew or air mission commander to identify, assess, and mitigate risk for the specific mission. Commanders will select MBOs based on their experience, maturity, judgment, and ability to effectively mitigate risk to the aircrew and designates them by name and in writing (HQDA 2014c, 9).

Final Mission Approval Authority (FMAA/MAA): Members of the chain of command who are responsible for accepting risk and approving all aviation operations (ground and air) within their unit. They approve missions for a specific risk level. FMAAs may only approve those missions whose assessed risk level is commensurate with their command level (HQDA 2014c, 9).

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Instrument Flight Rules (IFR): Instrument meteorological conditions is an aviation flight category that describes weather conditions that require pilots to fly primarily by reference to instruments, and therefore under instrument flight rules (IFR), rather than by outside visual references under visual flight rules.

Special Operations Aviation Terms

Army Special Operations Aviation (ARSOA): Designated active component forces and units organized, trained, and equipped specifically to conduct air mobility, close combat attack, and other special air operations (ADRP 3-05 2012, 47). Additionally, it is important to understand that Special Operations Aviation (SOA) supports other special operations forces units by planning and conducting special air operations in all operational environments. These specially organized, trained, and equipped aviation units provide the joint force special operations component commander with the capability to infiltrate, resupply, and exfiltrate SOF elements engaged in all special operations core activities (ADRP 3-05 2012, 47).

Battle-Rostering: Battle-rostering is defined as the designation of two or more individuals to routinely perform as a crew (HQDA 2013a, 12-13).

ARSOA Battle-Rostering: In addition to the practice of battle-rostering, individual crew members and SOA crews are further organized based on the level of mission qualification they have achieved. This modification to the aircrew model can be applied across the spectrum of SOA missions, in both training and combat, and provides the commander a clear tool to control risk while retaining mission flexibility and ensuring successful support of the ground force commander's intent (HQDA 2013a, 12-13).

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Basic Mission Qualified (BMQ): BMQ pilots may perform PC or pilot (PI) duties during internal training or perform PI duties on internal/external training (HQDA 2013a, 14-15).

Fully Mission Qualified (FMQ): FMQ pilots may perform PC or PI duties during the conduct of internal and external training; they may also formally train for Flight Lead (FL) during internal training (HQDA 2013a, 14-15).

Flight Lead Qualified (FLQ/FLD): FLQ pilots may perform FL, PC, or PI duties on any internal or external training as assigned. The FLQ is primarily responsible for the planning and execution of SOA missions (HQDA 2013a, 14-15).

Applied Professional Case Study Methodology Terms

The following professional terms are part of the applied professional case study methodology. They are used by the process operators in the force development community to describe the system utilized for developing capabilities routinely and are used in the methodology of this study.

Joint Capabilities Integration and Development System (JCIDS): The JCIDS is one of DOD's three primary decision support processes for shaping the military forces to support strategic guidance documents. JCIDS is a capabilities-based approach to identify current and future capability gaps in the joint force ability to carry out joint warfighting missions and functions. The objective of JCIDS is to develop a balanced and synchronized Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities, and Policy (DOTMLPF-P) solution (F102RA 2017, 2).

Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities, and Policy (DOTMLPF-P): This is the process used to develop change

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recommendations on how to optimize the joint force's ability to operate as an integrated force. The deliberate process is characterized by the traditional route to identifying capability gaps and proposed solutions, through the use of the capabilities-based assessment process (F102RA 2017, 2).

Capabilities-Based Assessment (CBA): An analytic basis to identify capability requirements and associated capability gaps, as part of a process that produces an integrated set of DOTMLPF-P solution approaches that collectively provide the required capabilities (F102RA 2017, 3).

Functional Area Analysis (FAA): The first analytical phase of the CBA and is strictly a capabilities-based task analysis. The FAA provides the framework to assess required capabilities in the follow-on Functional Needs Assessment (FNA). The FAA is based on professional military knowledge of established doctrine and standards that are modified to account for the projected concept for future operations and organizations (F102RA 2017, 21).

Functional Needs Assessment (FNA): This is the second analytic phase in the CBA. It assesses the ability of current and programmed Army capabilities to accomplish the tasks identified in the FAA and identifies any gaps and overlaps in capabilities and the risk posed by those gaps (F102RA 2017, 22).

Functional Solutions Analysis (FSA): The FSA is the third analytic phase in the CBA. It is an operationally based assessment of potential non-materiel DOTMLPF-P and/or materiel approaches to solving or mitigating one or more of the capability needs determined from the FNA. The FSA describes the ability of each identified approach to satisfy the need. Approaches proposed by an FSA must meet three criteria: first, they

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must be strategically responsive and deliver approaches when and where they are needed; second, they must be feasible with respect to policy, sustainment, personnel limitations, and technological risk; and third, they must be attainable, in that DOD could actually resource and implement the approaches within the timeframe required (F102RA 2017, 22).

The Kotter Change Model: An eight-step process used for leading change within an organization. The model provides a foundational approach, with each stage building upon the success of the previous stage. The first four stages assist in overcoming the existing status quo and set the conditions for leading change. Stages five through seven are the action stages that move the change effort from words to action by introducing new or different practices into the organization. Without successfully completing these three action stages the effort loses momentum, the sense of urgency dissipates, and the coalition becomes marginalized. Kotter's final stage, stage eight, is reached when the changes are inculcated into the culture of the organization; the change becomes the status quo and accepted within the organization (Miller and Turner 2017, 1-3).

Modification Table of Organization and Equipment (MTOE): A table which prescribes in a single document the modification of a basic table of organization and equipment necessary to adapt it to the needs of a specific unit or type of unit (DA PAM 611-21 2007, 14).

Limitations and Delimitations

The most significant limitation of this study will be the inability to publish classified data regarding the ARSOA Gray Eagle unit of study in this thesis. The study may not clearly depict the employment of this unit without being able to annotate its

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locations around the globe and effects on the battlefield. Specifically, the study will not assess the unit's current deployed locations or operations within those areas due to classification. This is significant, as one major premise of this paper is to accurately illustrate why the ARSOA UAS unit needs to be manned, trained and equipped differently than the CF to provide a unique capability within SOA. Additionally, the study will identify capability gaps and potential materiel and non-materiel solutions to ensure the Gray Eagle provides SOA with a unique UAS capability. Specific DOTMLPF-P domains that will be addressed are the organization, training, and materiel of the unit as it is currently being employed, which will be difficult to articulate without describing the unit's current and past employment due to classification. However, this study will look at all available unclassified sources pertaining to the primary and secondary research questions.

The next limitation is that there is no research, with regards to specific literature, that addresses the employment of the ARSOA Gray Eagle unit, in relation to UAS employment by the CF. This gives no predictive notion to address going into this study. This is significant, as there is no baseline to determine whether or not changes must be made to the unit's manning, training, and equipping to ensure continued success within the special operations community. To mitigate this limitation, the methodology being used will objectively look at the aspects surrounding this gap in literature, to present a non-biased solution to the key stakeholders. The study will also illustrate that a SOF-specific needs analysis must be conducted so that ARSOA Gray Eagle units are not vulnerable to changes in the CF's force development process and to define what future changes might mean for readiness and training.

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Another delimitation for this study is that it will only consider the employment of the ARSOA Gray Eagle as beginning with the creation of E/160 in 2013. The study will not include the employment of the Gray Eagle within special operations during the operations of the Quick Reaction Capability Companies, when they supported special operations forces in Iraq and Afghanistan prior to the creation of E/160.

The last delimitation is that in order to illustrate the difference between ARSOA and CF rotary wing capabilities, this study will only look at the difference between the similar ARSOA multi-mission rotary wing, MH-47, and the CF cargo rotary wing, CH-47 units. This comparison will be used to identify any gaps in the manning, training, and equipping of ARSOA Gray Eagle and the CF Gray Eagle units, in comparison to ARSOA and CF rotary wing units. This delimitation will not take away from the credibility of this study as the only other similar units between ARSOA and the CF would be between the ARSOA multi-mission rotary wing, MH-60, and the CF utility rotary wing, UH-60 units.

Significance of Study

The results of this study will identify any capability gaps in the manning, training, and equipping of the ARSOA Gray Eagle unit that may prevent it from providing a unique UAS SOA capability. This will be based on a comparative analysis of the CF Gray Eagle unit, by comparing the similarities and differences between the ARSOA and CF Gray Eagle units. The study will then look to the ARSOA rotary wing units for potential materiel and non-materiel solutions by analyzing the differences in the ARSOA rotary wing units from those of the CF rotary wing units. This is significant because it will not only identify the domains in which capability gaps exist, but will also look to an established SOA unit for potential solutions.

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R1: Initial Personal Recommendation

The applied professional case study is a research methodology that incorporates three different assessments throughout the process, R1, R2, and R3. The initial assessment, or R1, is the author's perspective, bias, and assumptions prior to beginning the review of literature. This initial assessment provides a starting point to the research and gives it credibility throughout the rest of the process.

The first part of the R1 discusses the primary research question and why it is important to the author and the key stakeholders within USASOC. The primary research question in this study is: are there organizational, training, and materiel capability gaps that are preventing the ARSOA Gray Eagle unit from providing a unique SOA capability? The author developed this research question after spending approximately 18 months in the only ARSOA Gray Eagle company, E/160, as the executive officer just prior to beginning this study. In addition to those 18 months in E/160, the author spent over 5 years in the 160th SOAR, primarily within the rotary wing units. This experience gave the author an understanding of the Gray Eagle, its role within the 160th SOAR, and the Soldiers who operate and maintain the Gray Eagle. With that understanding, the author believes there are capability gaps that must be addressed for this platform to perform at the same level as the rotary wing units within the 160th SOAR. The author has a vested interest in this study because he will be returning to the 160th SOAR after this study to work with E/160 and believes that it must begin to mirror the ARSOA rotary wing units in terms of manning, training, and equipping, to provide a unique SOA UAS capability to the special operations community.

This study is important because if E/160 is expected to provide the same unique capabilities as the rotary wing units within the 160th SOAR, then the key stakeholders

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need to look at the capability gaps that E/160 has in terms of manning, training, and equipping when compared to the rotary wing units in the 160th SOAR. The Gray Eagle is still within its first five years of employment within ARSOA, and the earlier that these capability gaps can be identified and addressed, the easier it will be to define the unique UAS capability that E/160 brings to the special operations community. Additionally, a second Gray Eagle company is currently being fielded with an August 2018 activation date. Any changes to the organization, training, and materiel of this new company will be less intrusive if identified and implemented early during the standing up of this new company.

The second part of the R1 addresses why this study is important and the possible consequences if this topic is not addressed. The demand for combat air patrols provided by ARSOA Gray Eagle is going to increase, as evidenced by the fielding of a second Gray Eagle company within the 160th SOAR. Additionally, the Department of Defense (DOD) is continuing to invest in the advancement of the Gray Eagle with the production of the Extended Range (ER) Gray Eagle, which is scheduled to undergo initial operational testing and evaluation (IOT&E) by ARSOA in fiscal year 2018 (FY18). The United States Special Operations Command (USSOCOM) is investing in the advancement of a unique SOA UAS capability and identifying the capability gaps in terms of organization, training, and materiel will ensure that these investments are made to the most critical capability gaps identified in this study. If this analysis is not done and investment is made in areas that do not truly increase the capability provided, the consequence will be that USSOCOM used constrained fiscal resources without equitable payoff.

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The final portion of the R1 identifies the potential for a solution to the problem statement, the methodology by which it could be answered, and the author's initial recommended solutions. The author believes that there are potential solutions to the problem statement and that looking to the ARSOA rotary wing units for these solutions should be the starting point. The 160th SOAR has had 36 years to develop and implement unique SOA capabilities. This is in line with the SOF truth that special operations capabilities cannot be mass produced. E/160 is reaching its 5th year of conducting operations as part of the 160th SOAR and the unit needs to start establishing unique SOA UAS capabilities to support special operations with abilities not offered by CF UAS units. Informing key stakeholders of these potential solutions, with a rich description of the environment, will persuade them to make key changes that will ensure this capability is poised to support the unique requirements of special operations.

This problem will require the methodology to use the correct data to determine possible solutions. To determine the potential capability gaps in E/160's manning, training, and equipping, this study will need to look at data that accurately depicts E/160's current organization structure, training process, and equipping. Additionally, this study will look at this same data from ARSOA rotary wing units, CF rotary wing units, and CF Gray Eagle units. After gathering the right data, an applied professional case study will be used,

> Case studies are a useful method for conducting qualitative research for problem areas that are human-centric, dynamic, volatile, and contain a mix of stakeholders, interests, variables and information concepts that demand a deep understanding of context in order to produce informed policy choices" (Creswell, 2009, 2013, 2014; Yin, 2014).

The study will then use a comparative analysis from the data gathered through the case study and use a modified DOTMLPF-P Capabilities Based Assessment (CBA) to

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determine the results. A CBA is appropriate since it is a structured three phased process that identifies and documents capability gaps; determines the attributes of a capability or combination of capabilities that would resolve the gaps; and identifies non-materiel as well as materiel approaches for possible solutions. By conducting the applied professional case study and then analyzing it using the CBA, we get the functional solution analysis (FSA). This will identify a resolution, and will look to potential DOTMLPF-P approaches, recommendations, and solutions to mitigate or eliminate the capability gaps and will produce suggestions to implement ideas for non-materiel DOTMLPF-P approaches; and ideas for materiel approaches.

Conclusion

Since its inception in 2013, the ARSOA Gray Eagle unit has enabled special operations across the globe with phenomenal results. This success brought an increased demand within ARSOA which led to the current fielding of another MQ-1C Gray Eagle company within ARSOA. This chapter discussed the background, the problem, and the process by which this study will be conducted. The next chapter will analyze the literature used for this study.

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CHAPTER 2

LITERATURE REVIEW

Introduction

The purpose of this research is to gain a rich understanding of the unique capabilities required by the ARSOA Gray Eagle unit to meet special operations specific requirements, and to persuade the Chief Decision Maker (CDM) and key stakeholders to affect change. The literature is primarily from the Department of Defense (DOD) and other federal agencies because the purpose of this study is to persuade key stakeholders within the DOD. By primarily using the professional body of knowledge, it tailors the information and makes it credible to the target audience. This remains in line with the research methodology as a professional applied case study.

The specific areas that will be addressed in this chapter are the manning, training, and equipping of the unit and whether it is specifically designed to support special operations in the same manner as the rotary wing ARSOA units.

Key Literature

The following graph depicts the literature reviewed in this study and how each piece of literature specifically applies to the different aspects of this paper.

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Table 2. Literature Analysis

	Organization	Training	Materiel	Primary	Secondary 1	Secondary 2	Secondary 3
USAR 2035	X	X	X	X			X
USIR 2038	X	X	X	X			X
MQ-1C SAR	X		X	X	X		
3255.01		X		X	X		
TC 3-04.63		X		X	X		
TC 3-04.11		X		X	X		
ARSOA TC 3-04.11		X		X	X	X	X
TC 3-04.34		X		X	X		
ARSOA ATM		X		X	X	X	X
MH-47G -10			X	X	X	X	X
CH-47F -10			X	X	X		
AR 95-23	X	X		X			
AR 95-1	X	X		X			
USAFM	X		X	X	X	X	
MQ-1C -10		X	X	X	X	X	
USASOC 2035 ARSOF 2022	X	X	X	X			X

Source: Created by author.

The *United States Army Roadmap for UAS 2010-2035* is the Army's vision to develop, organize, employ, and build a comprehensive strategy for defining future UAS requirements. This publication breaks down this strategy into the time periods of near (2010-2015), mid (2016-2025), and far (2026-2035). Through these different time frames, the document focuses on issues such as identifying current gaps in capabilities, integrating UAS into other Army operations such as networking and cargo capabilities, and increasing the overall capability of the UAS while reducing its size, power, and weight requirements. This roadmap is reviewed every two years, but a new edition has

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not been published since this initial document. While the document is over seven years out of date, it still provides a good assessment as to whether or not the Army is on the right track to meet its intended goals.

This reference applies to this study as it addresses both the primary and secondary research questions of this thesis. Specifically, it describes the UAS in terms of manning, training, and equipping, and it breaks down the assessment into the DOTMLPF-P domains, which falls directly in line with the methodology used in this study. Additionally, this document discusses the challenges with UAS operations within the NAS and addresses many other issues with the employment of the UAS, which may fall outside the scope of this study, but are still necessary to consider.

The *Unmanned Systems Integrated Roadmap FY2013-2038* is a document intended to "articulate a vision and strategy for the continued development, production, test, training, operation, and sustainment of unmanned systems technology across DoD." It looks at both current and future capabilities in a 25-year window to address where UAS is now, and to develop a strategy to determine where it should go. While this document does not specifically address special operations, it does identify with many of the same gaps in capabilities that could be used within special operations as well as with CFs. Additionally, it addresses the manning, training, and equipping aspects of this thesis.

Much like the *United States Army Roadmap for UAS 2010-2035*, this document discusses UAS operations in terms of near, mid, and far time frames. Unlike the *United States Army Roadmap for UAS 2010-2035*, this publication is not solely focused on the Army UAS program but on the Department of Defense as a whole, which gives this document a more strategic aim. Specifically, the *Unmanned Systems Integrated Roadmap*

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FY 2013-2038 discusses strategic planning and policy, combatant commander mission and capability needs, technologies for unmanned systems, operating environment, sustainment and logistics, training, and international cooperation.

Of the topics discussed in this thesis, *The Unmanned Systems Integrated Roadmap FY 2013-2038* addresses the equipping aspect in the most detail. For example, it addresses several types of munitions that could improve the capabilities of the MQ-1C Gray Eagle aerial vehicle. One of which is the Direct Attack Guided Rocket (DAGR). The DAGR is a 2.75-inch laser guided rocket that is fully compatible with the current Hellfire system. This new munition would potentially allow the MQ-1C Gray Eagle to carry up to four times as much payload as its current configuration. Additionally, this document extensively describes the communications architecture and potential use of existing networks, specifically the Defense Information Systems Network (DISN) and the teleport standard tactical entry point (STEP) sites. The ability to plug into these global networks and gain access to satellite coverage around the globe would provide an increased capability for ARSOA UAS in terms of its operational reach. *The Unmanned Systems Integrated Roadmap FY 2013-2038* provides a great deal of information from very specific aircraft-defining characteristics to broad strategic level policy. It provides insight to many of the topics discussed in this thesis and other aspects within the UAS community.

The *MQ-1C Gray Eagle Selected Acquisition Report (SAR),* as of the FY2017 President's budget, discusses several topics relevant to this study. First, it discusses the proposed employment design of Gray Eagle units in terms of organization. Specifically, it addresses how the unit is intended to operate and why it is organized the way that it is. In

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support of United States Army Divisions, the UAS company is part of the combat aviation brigade (CAB); in support of Intelligence Command (INSCOM), it is part of the 116th Military Intelligence Brigade, and in support of USASOC it is part of the 160th SOAR. Within each of these organizations, the UAS company is broken down into three identical platoons, giving the commander extreme flexibility to employ this asset. This document explains that the intent of the UAS company's structure from inception was for each platoon to be able to operate independently at three geographically dispersed locations.

The Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3255.01- Joint Unmanned Aircraft System Minimum Training Standards document provides the basis for joint unmanned aircraft system minimum training standards and identifies the training requirements for UAS crewmembers to operate in support of a joint force commander. It breaks the requirements down into three categories: Basic UAS Qualification (possessing the general aviation and UAS knowledge to safely operate a UAS), possessing the skills required to both operate the UAS and maintain situational awareness to execute tasks, and Joint Mission Qualification (understanding the UAS mission/objective and its role in accomplishing the larger military operation). This document directly applies to this thesis as it is essentially a contract between the Department of Defense and the FAA, establishing the minimum training requirements that a UAS operator must possess to operate in the NAS.

The *TC 3-04.63 MQ–1C Unmanned Aircraft System Commander's Aircrew Training Program and Aircrew Training Manual* applies to Gray Eagle crewmembers and their commanders. The purpose of this document is to standardize aircrew training

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programs and flight evaluation procedures by providing specific guidelines for executing UAS aircrew training. This training circular outlines both the individual and collective training requirements for crewmembers in order to advise the commander on an effective aircrew training program that supports combined arms training. Of note, the *MQ–1C Unmanned Aircraft System Commander's Aircrew Training Program and Aircrew Training Manual* is combined into one document to cover both the Gray Eagle specific aircrew training program and the commander's aircrew training program for individual, crew, and collective training. While the Commander's Aviation Training and Standardization Program incorporates the UAS, it admittedly states that the UAS integration is still developing and needs refinement, which makes the *MQ–1C Unmanned Aircraft System Commander's Aircrew Training Program and Aircrew Training Manual* publication the most relevant document to Gray Eagle operations. This is significant because this study will examine the corresponding CF and ARSOA rotary wing publications as part of the analysis for this thesis. For those elements, there are two distinct publications, an airframe specific aircrew training manual and a general aviation commander's aircrew training program for individual, crew, and collective training. Additionally, it is important to note that the CF and ARSOA Gray Eagle units both use this same document.

The aircrew training program outlined in this publication applies to crewmembers that perform duties controlling the flight of a UAV or the operation of its mission equipment. This includes starting the engine, takeoff and/or landing the UAV and consists of qualification, refresher, mission, and continuation training. It outlines the requirements for qualification in the Gray Eagle, criteria for readiness level progression,

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flight activity category designation, flight hour/currency requirements and annual task and iteration requirements. This publication also outlines the testing and evaluating requirements for crewmembers during a proficiency flight evaluation, annual proficiency and readiness evaluation, and other crewmember proficiency based testing.

In summary, this document contains the necessary guidance for a Gray Eagle company commander to execute the aircrew training program that covers everything from individual to collective unit training. Additionally, this document is the aircrew training manual for the Gray Eagle and is the basis for the crewmember's training from the individual to collective training levels.

The *TC 3-04.11 Commander's Aviation Training and Standardization Program* is the commander's guidance for implementing a standardized aviation training program. It applies to all individuals flying Army aircraft and for the purposes of this study, it directly applies to CH-47F and Gray Eagle crewmembers. It does not apply to ARSOA MH-47G crewmembers, as ARSOA has its own publication for the execution of the commander's aircrew training program.

This publication focuses on the implementation of an effective, standardized aircrew training program that supports the mission of the combat aviation brigade. It outlines the individual responsibilities in executing the training program from the brigade commander down to the individual crewmember. Like the aircrew training manuals, it addresses individual qualification, currency, and flight hour requirements, but these are not the focus. In contrast to an aircrew training manual, the focus of this document is to serve as a guideline to all Army aircraft as a holistic approach to Army aviation training and standardization. For example, it specifically addresses aircrew training plan

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management, doctrinal training concepts, unit collective training requirements, and the implementation of the Army standardization program.

The *ARSOA TC 3-04.11 Commander's Aircrew Training Program for Individual, Crew, and Collective Training* is the keystone publication that establishes the requirements for commanders at all levels to develop, manage, and administer a comprehensive aircrew training program. In the context of this study, this publication applies directly to the ARSOA MH-47G crewmembers, but does not address ARSOA Gray Eagle crewmembers.

This reference covers much of the same material as the *TC 3-04.11 Commander's Aviation Training and Standardization Program*, but applies only to ARSOA crewmembers. This publication addresses the responsibilities of the 160th SOAR Commander down to the individual crewmember, aircrew training program administration, risk management, training and evaluation requirements, and standardization for aviation records. The most important element of this publication, with regards to this study, is that it addresses how ARSOA battle rosters their crews in terms of PI, PC, BMQ, FMQ, and FLD designations. This is an important distinction as the *TC 3-04.11 Commander's Aviation Training and Standardization Program* also addresses crew battle rostering but only in terms of PI/AO and PC/AC designations. This distinction will be addressed in chapter four, but it is important to note that while the ARSOA MH-47G crewmembers have additional crewmember designations of BMQ, FMQ, and FLD, the ARSOA Gray Eagle crewmembers only have the designations of AO and AC. *The ARSOA TC 3-04.11 Commander's Aircrew Training Program for Individual Crew, and Collective Training* specifies the type of crew mix (PI, PC, BMQ, FMQ, FLD)

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required for different mission sets (internal training, external training, administrative support, and tactical).

The *TC 3-04.34 Aircrew Training Manual, Cargo Rotary wing, CH-47D/F* applies to all CH-47 crewmembers and their commanders in the active Army, the Army National Guard Bureau/United States Army National Guard, the United States Army Reserve, and provides specific guidelines for executing CH-47D/F aircrew training. This publication is the basis for crewmember qualification training, refresher training, mission training, and continuation training and evaluation requirements.

This reference is used in conjunction with the *TC 3-04.11 Commander's Aviation Training and Standardization Program* publication to help commanders and crewmembers execute the aviation training program. The main difference is that the *TC 3-04.34 Aircrew Training Manual, Cargo Rotary wing, CH-47D/F*, provides the performance standards and evaluation guidelines for every individual/mission/collective task, so that crewmembers know the level of performance expected. It is the primary tool used by commanders and standardization officers to implement the aircrew training program. This manual is intended to support the unit's mission essential task list by enhancing training in individual and aircrew proficiency.

The *ARSOA Aircrew Training Program Aircrew Training Manual Multi-Mission Rotary wing MH-47*, much like the *TC 3-04.34 Aircrew Training Manual, Cargo Rotary wing, CH-47D/F*, is the basis for crewmember qualification training, refresher training, mission training, and continuation training and evaluation requirements. It applies to all MH-47 crewmembers, their commanders, and standardization officers. It is used in conjunction with the *ARSOA TC 3-04.11 Commander's Aircrew Training Program for*

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Individual Crew, and Collective Training and other applicable publications to aid both the individual and commander in developing an effective and standardized aircrew training program for the unit. It establishes the task, conditions, and standards for all individual and collective tasks for employment of the MH-47 aircraft. Specific to this study, the *ARSOA TC 3-04.11 Commander's Aircrew Training Program for Individual Crew, and Collective Training* outlines specific special operations aviation tasks that are not listed in the CF *TC 3-04.34 Aircrew Training Manual, Cargo Rotary wing, CH-47D/F*. These tasks provide additional capabilities to the special operations community that the CF cargo rotary wing, CH-47D/F, units cannot provide.

After reviewing the applicable aircrew training documents for the ARSOA and CF units used in this study, the following discussion on aircrew training progression and crewmember designations is necessary to understand the results of this study described in chapter four. This discussion will begin with describing the aircrew training program, which is almost identical for manned and unmanned airframes, and will conclude with aircrew member designations that distinguish the ARSOA process from the CF process, and is a key point to understand for this study.

Readiness levels (RLs) are used by aviation commanders to determine the proficiency of crewmembers in their base, mission, and additional tasks. RLs are designated progression points that range from RL1 to RL3, with RL3 being the designation for a crewmember focusing on base tasks, to a mission ready crewmember with an RL1 designation (HQDA 2016a, 51). Base tasks, or 1000 series tasks, are made up of individual tasks or maneuvers that a crewmember is expected to be able to perform, both in and out of the airframe. An example of a base task for a CH-47F rated

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crewmember would be to perform hovering flight, task #1038 (HQDA 2013b, 101). Once the crewmember demonstrates proficiency in all base tasks listed in that airframes applicable aircrew training manual, they are designated RL2. During RL2 training, the crewmember must demonstrate proficiency in all mission and additional tasks (or 2000 series and 3000 series tasks, respectively) that support the unit's mission essential task list, as assigned by that crewmember's aircrew training program commander. An example of a mission task for a Gray Eagle operator would be to operate synthetic aperture radar, task #2305 (HQDA 2014b, 200). Once a crewmember completes all RL2 training requirements, they are designated RL1.

Once a crewmember is designated RL1, they continue their flight training through continuation training which has different requirements based on that crewmembers Flight Activity Category (FAC). FAC levels are designated by the brigade level commander and are based on flight task requirements and the proficiency required by the individual crewmember's MTOE or TDA position. FAC levels are broken down into FAC 1 through FAC 3. A FAC 1 position requires a high degree of proficiency in the tactical employment of the assigned airframe. A FAC 2 position requires the same proficiency in individual and crew tasks as a FAC 1 position but does not necessarily require the same collective proficiency in unit tasks. FAC 3 positions are not authorized to perform crewmember duties in their assigned airframes but must complete applicable simulator hour requirements, if a compatible simulator is available. Each FAC level has a corresponding semi-annual flight hour requirement, that is considered the continuation training as previously discussed (HQDA 2016a, 66-67). For example, an RL1, FAC 1, MH-47G rated crewmember has a semi-annual flight hour requirement of 60 hours, 30 of

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which must be completed using night vision goggles. An RL1, FAC 2, MH-47G rated crewmember has a semi-annual flight hour requirement of 33 hours, 18 of which must be completed using night vision goggles (HQDA 2013a, 47; ATM 2014, 19). In addition to semi-annual flight hour requirements, crewmembers have an annual requirement to complete an annual proficiency and readiness test (APART). The APART is conducted each year during a crewmember's APART window which is based on their birth month. The APART is slightly different for each airframe, but it essentially consists of a hands-on evaluation, a written evaluation, and a flight physical (DD Form 2992, Medical Recommendation for Flying Duty) (HQDA 2016a, 71).

Crewmembers have an obligation to complete applicable RL progression and continuation training but are also required to progress in their crewmember designation. In the Gray Eagle community, UAS crewmembers (UACs) have the following designations; unmanned aircraft operator (AO), mission payload operator, (PO), aircraft commander (AC), unit trainer (UT), instructor operator (IO), standardization instructor operator (SO), and mission commander (MC). Upon successful completion of a Department of the Army approved Gray Eagle qualification course and designation in writing from the aircrew training program commander, UACs begin their aviation careers with the designation as an AO, and a PO.

An AO is responsible to control the flight of an UAS or the operation of its mission equipment and remain tactically and technically proficient as an UAC. The individual operator should have the ultimate goal of achieving AC status (HQDA 2016a, 51). An AC has the same requirements as an AO, but additionally they are responsible for the overall safety of the UAV, be proficient in the UAV and all aspects of the unit

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mission essential task list, the conduct of all operational and training aspects of a specific mission, all actions of the crew, assigning duties to the crew, and for accomplishing the assigned missions.

From there, the UAC looks to progress to a UT, who has all the responsibilities of an AC but is additionally responsible to instruct in appropriate tasks and subjects, recognize errors in performance or understanding, make recommendations for improvement, train to standards, and document training (HQDA 2014b, 24-32). After designation as a UT, and with input and concurrence of the command level leadership, a UT will attend an approved Department of the Army Gray Eagle Instructor Operator (IO) course to undergo training. Of note, a UAC does not have to be designated as a UT to be sent to the IO course, this just represents a normal progression for a UAC from initial assignment to designation as an IO.

After successful completion of the IO course and designation in writing from the aircrew training program commander, that UAC is designated as an IO. The IO has all the requirements of a UT and is the unit's primary trainer and evaluator of all UACs. The SO is the final aircrew designation for a UAC. Normally, an IO will train for multiple years before being recommended by the command to be designated as an SO. After designation in writing by an aircrew training program commander, an IO is authorized to perform SO duties. An SO has all the responsibilities of an IO and primarily trains and evaluates the unit's IO. Additionally, an SO is the primary advisor to the commander on all aspects of the unit's aircrew training program (HQDA 2006, 14).

The CH-47F and MH-47G rated aviators used in this study have the following aircrew designations; Pilot (PI), Pilot in Command (PC), Unit Trainer (UT), Instructor

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Pilot (IP), Instrument Examiner or Instrument Flight Examiner (IE or IFE), and Standardization Instructor Pilot (SP). Of note, rated aviators have other aircrew designations, but those are not applicable for the purposes of this study (HQDA 2014c, 27).

Upon successful completion of a Department of an Army approved qualification course, and designation in writing by the ATP commander, new rated aviators begin their aviation career with the designation as a PI. A PI has the responsibility to remain tactically and technically proficient in all aircrew member tasks as dictated by the applicable aircraft training manual. PIs should take advantage of every training opportunity with the goal of attaining designation as a PC.

After demonstrating proficiency in all required aircraft tasks, successfully completing a PC evaluation in accordance with applicable publications, displaying proper judgement and maturity, and being designated in writing by the ATP commander, a rated aviator is then designated as a PC. A PC has all the responsibilities as a PI, but is additionally responsible to ensure the overall safe and effective operation of the aircraft, to serve as the unit's first-level trainer, be proficient in the aircraft and all aspects of the unit's collective tasks. The PC is responsible for the safety of all occupants, and the conduct of all operational and training aspects of a specific mission, responsible for all actions of the crew, responsible for assigning duties to the crew, and responsible for accomplishing assigned missions (HQDA 2014c, 26).

At this point in the aircrew progression process, it is important to note several significant differences between rotary wing pilots and UAS operators. First, the Army's rotary wing pilots are primarily warrant officers and the Army's UAS operators are

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primarily enlisted soldiers and non-commissioned officers. To be clear, there are also commissioned officers that are rated aviators and there are warrant officers that are UAS operators, but for the purposes of this study, they are not included in the discussion. The next significant difference is that warrant officers track different career paths during their professional careers. Unlike UAS operators, a warrant officer's progression to IP is dependent upon the career path they decide to track. For example, a warrant officer may decide that they would like to track safety to become an aviation safety officer and because of that, they would never achieve an aircrew designation as an IP. There are a few warrant officers that track multiple career paths, but it is not the norm. In contrast, UAS operators do not have multiple career track options like warrant officers and because of this each UAS operator should strive to progress to IO.

For comparison in this study, a warrant officer who decides to career track IP would look to progress to the designation of a UT after achieving PC status. A UT has the same responsibilities as a PC; but in addition, a UT has demonstrated the ability to train other pilots and focuses primarily on RL 2 and RL 1 progression training. At some point in the warrant officer's career and service as a UT, they will attend a Department of the Army instructor pilot qualification course resulting in designation as a unit IP by the ATP commander. IPs have the same responsibilities as a PC, but in addition, they serve as the primary instructors and evaluators for the unit. Normally after a few years as an IP, the command will determine whether or not to give an IP an SP evaluation based on their performance as an IP. After successfully completing an SP evaluation in accordance with applicable publications and a designation in writing by the ATP commander, an IP is designated as an SP. An SP has all the responsibilities of an IP but SPs are also primarily

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responsible for the training and evaluation of IPs, and serve as the primary advisor to the commander on all matters pertaining to the unit's ATP.

The final aircrew designation for this study is the designation as an IE or IFE. There is not a correlating designation within the UAS community but it is still relevant for the purpose of this study. The reason is that the Gray Eagle is not rated for IFR flight, and because of that, there is no need to designate UACs as IEs. To be designated as an IE, an aircrew member must already be designated as an IP and successfully complete a Department of the Army approved IE qualification course and be designated in writing by the ATP commander. An IE has the primary responsibility to administer instrument flight evaluations within the unit. The designation as an IE is not airframe specific like the other aircrew designations; for example, an IE whose primary aircraft is a CH-47 can give an instrument evaluation to an aviator whose primary aircraft is a UH-60 (HQDA 2014c, 27).

An understanding of the aircrew member training, progression, and aircrew designation processes of both the manned and unmanned platforms discussed in this study is essential to gain an understanding of the unique ARSOA mission qualification and battle-rostering process discussed in the next section.

ARSOA rotary wing units use a unique battle-rostering process that is based on mission qualification. This process is unique to ARSOA and is not used by CFs rotary wing units, B/101, or by E/160, that is key to note for the purposes of this study. The intent of this unique battle-rostering process is to ensure successful accomplishment with the minimum amount of risk to the force and to the SOA mission. ARSOA has the following mission qualification designations; basic mission qualified (BMQ), fully

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mission qualified (FMQ), and flight lead qualified (FLD). Once a rated crewmember successfully completes the special operations basic mission qualification course conducted by the 160th Special Operations Aviation Training Battalion, that crewmember is designated as an RL 1, PI, BMQ, and assigned to an operational company within the 160th SOAR. The rated crewmember then conducts mission training with the goal of achieving FMQ designation. After extensive training and successful completion of an FMQ evaluation and designation in writing by the ATP commander, that crewmember is designated as an FMQ. The final mission qualification is that of FLD. Significant to this study, the FLD qualification usually takes many years to achieve, and is a designation that not every rated crewmember in the 160th SOAR will achieve. It illustrates mastery of all SOA required mission sets and the highest degree of tactical and technical proficiency. After many years of extensive training, successful completion of a FLD evaluation, and designation in writing by the 160th SOAR Commander, that crewmember is designated as a FLD. These mission qualifications are used to determine the right battle-rostering based on mission requirements.

The *Technical Manual Operator's Manual for the MH-47G, TM 1-1520-272-10-1* provides complete operating instructions and procedures for the multi-mission rotary wing, MH-47G. Specifically, it covers aircraft and systems description and operation, avionics, mission equipment, operating limits and restrictions, weight/balance and loading, performance data, normal procedures, and emergency procedures for the MH-47G.

The *Operator's Manual for the CH-47F, TM 1-1520-271-10-1* provides complete operating instructions and procedures for the cargo rotary wing, CH-47F. Specifically, it

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covers aircraft and systems description and operation, avionics, mission equipment, operating limits and restrictions, weight/balance and loading, performance data, normal procedures, and emergency procedures for the CH-47F.

The *Operator's Manual for the MQ-1C Unmanned Aircraft System, TM DTM 1-1550-697-10-1*, provides complete operating instructions and procedures for the unmanned aircraft system, MQ-1C. Specifically, it covers aircraft and systems description and operation, avionics, mission equipment, operating limits and restrictions, weight/balance and loading, performance data, normal procedures, and emergency procedures for the MQ-1C.

The *Unmanned Aircraft System Flight Regulations, AR 95-23*, much like the *TC 3-04.11 Commander's Aviation Training and Standardization Program*, provides guidance on UAS crewmember training, risk management, currency requirements, training and standardization. In addition, this regulation also covers flight rules, UAS general provisions, and management of UAS resources. It is not specific to the Gray Eagle, but applies to all categories of UAS employed by the United States Army active duty/reserve/national guard units and supporting civilian contractors.

Flight Regulations, AR 95-1, covers the same topics and is applicable to the same organizations as the *Unmanned Aircraft System Flight Regulations, AR 95-23*, but while it is applicable to UAS, it is not specific to UAS and does not address UAS specific policy. The only UAS specific guidance in this publication is guidance that addresses the recovery operations associated with unmanned aircraft. For the purposes of this study, *Flight Regulations, AR 95-1*, applies directly to the CH-47 and MH-47 units used for this thesis.

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The United States Army Force Management Support Agency (USAFMSA) provides online access to the *Force Management System* website that provides extensive information on how Army units are manned and equipped. For this study, the website was used to access the Modification Table of Organization and Equipment (MTOE) for the Army units used in this study: Company B, 3d Battalion, 82d Combat Aviation Brigade (CF CH-47F unit); Company A, 2d Battalion, 160th Special Operations Aviation Regiment (ARSOA MH-47G unit); Company B, 101st Aviation Regiment (CF MQ-1C unit); and Company E, 160th Special Operations Aviation Regiment (ARSOA MQ-1C unit).

An MTOE is an authorization document that prescribes the modification of a basic Table of Organization and Equipment (TOE). It is a document that prescribes the wartime mission, capabilities, organizational structure, and mission essential personnel and equipment requirements for military units, and adjusts it as necessary to adapt it to the needs of a specific unit or type of unit. For example, the MTOE for an MQ-1C Gray Eagle company shows how many personnel, by grade, and how many airframes, by type, would be required for a company to conduct its wartime mission. For the purposes of this thesis, the different MTOE documents for each of the units being analyzed in this study clearly depicts the differences and similarities between the CF and ARSOA units.

The documents *USASOC Strategy 2035* and *ARSOF 2022* provide guidance for the development of future ARSOF operational and institutional capabilities. For the purposes of this study, these two documents were used to form the basis by which the Chief Decision Maker (CDM) for this study would evaluate the proposed results of this thesis, through the R3: Stakeholder Recommended Solution.

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Conclusion

The review of the cited literature primarily from the military's professional body of knowledge offers insight into the primary and secondary research questions, and also establishes the foundation for the remainder of this thesis. Additionally, this review of literature was conducted in line with the research methodology, using sources from the professional body of knowledge, applicable to the CDM. The next chapter, Chapter 3, will outline the research methodology for this study.

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CHAPTER 3

RESEARCH METHODOLOGY

Purpose of the Research and the Research Questions

The purpose of this study is to persuade the Chief Decision Maker (CDM), the commander of USASOC, that the proposed solutions to E/160's manning, training, and equipping capability gaps, would enable E/160 to provide a unique UAS capability to special operations. The main concerns of the CDM are to obtain next generation unmanned aircraft systems that provide longer operational range and over horizon observation; can be launched and recovered by tactical units; and employ advanced unmanned aircraft systems and intelligence collection capabilities at the tactical level. This includes the concern to provide joint force commanders with professionals who are agile, adaptive, flexible, bold, innovative, and possess a high degree of advanced training; provide the nation with premier special operations forces; and deliver appropriate and effective capabilities to joint force commanders and interagency leaders across the entire spectrum of conflict under any operating conditions. The CDM must broaden the range of special operations aviation-related individual training and education including unmanned aerial systems; and improve army unmanned aerial-system programs of record (Raven, Shadow and Gray Eagle) to meet joint expeditionary tactics, techniques, procedures, forward-based networking and sensor requirements (HQDA 2014a, 24; ARSOF 2035 2017, 3-6).

In order to implement the findings from this research, the CDM would have to utilize the Army Joint Capabilities Integration Development System (JCIDS), the Defense Acquisition System (DAS), and the Planning, Programming, Budgeting, and

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Execution (PPBE) process to develop new solutions to the organization, training, and equipping of USASOC Gray Eagle units (F102Ra 2017, 2). The USASOAC Commander, the 160th SOAR Regimental Commander and the 160th SOAR Battalion Commanders are the other stakeholders who will be influenced by the changes to the units' organization, training, and equipping and who will also be the ones to implement these changes. Additionally, the research findings would have to be in line with current national strategic guidance to include the National Security Strategy (NSS), the National Defense Strategy (NDS), and the National Military Strategy (NMS). The CDM's primary evaluation criteria to assess the results of this research will be based on these available resources: the NSS, the NDS, and the NMS.

In order to answer the primary research question, three secondary questions were developed: (1) How does ARSOA man, train, and equip their UAS units in comparison to both CFs UAS units, and rotary wing ARSOA units? (2) Are there capability gaps in terms of manning, training, and equipping of the ARSOA Gray Eagle organization when compared to the rotary wing ARSOA units? (3) What are the potential materiel and non-materiel solutions to the ARSOA Gray Eagle units' domains of manning, training, and equipping, needed to provide a unique capability to SOF?

To answer these questions, the author conducted a comparative analysis of the literature within the professional body of knowledge dealing with the organization, training, and equipping of ARSOA UAS and rotary wing units, and CF UAS and rotary wing units. The professional body of knowledge primarily included training manuals, technical manuals, Army and Joint Publications, MTOE documents, and Army regulations. This literature illustrated how the units used in this study were organized,

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trained and equipped. The units were then compared and contrasted to determine capability gaps within the ARSOA Gray Eagle unit. These capability gaps were based on capabilities provided by ARSOA rotary wing units that their CF counterparts were unable to provide. The same analysis was then done with the ARSOA and CF UAS units to determine whether or not ARSOA UAS provided additional capabilities like those provided by the ARSOA rotary wings units.

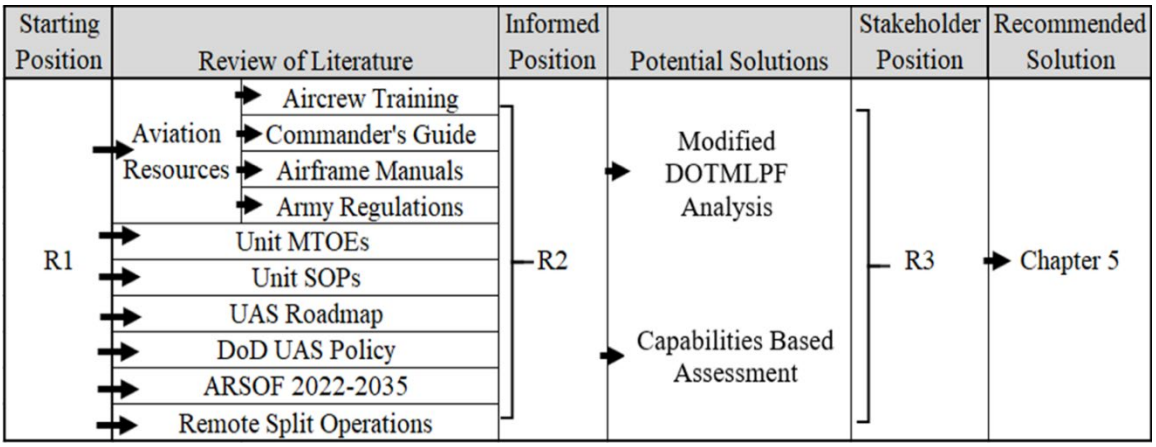
Research Methodology

The author used an applied professional case study methodology for the study. The applied professional case study is a method of research which is systematic, disciplined, multi-perspective, critical, and designed to both solve a problem and incorporate a research perspective. This case study will inform decision making through the rich description of the environment and recommend a policy by persuasion, reason, and evidence (Long 2016).

This research is an applied professional case study with a modified DOTMLPF-P analysis utilizing a capabilities-based assessment (CBA) to determine potential materiel and non-materiel solutions. The modified DOTMLPF-P analysis utilized the organization, training, and materiel (OTM) domains. The CBA used the professional body of knowledge in the literature review to identify capability gaps and propose material and non-material solutions. The figure and paragraphs below describe the five-chapter format used for this applied professional case study.

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Table 3. Research Methodology Flow Chart



Source: Created by author.

In Chapter 1, the initial going-in position is captured through the first assessment in the three-part reflective process of the professional applied case study. The R1 assessment, or the initial, personal disposition on the subject is captured in this chapter. This assessment establishes the author's perspective going in and gives credibility to the research by defining what the author knew and felt about the topic prior to conducting the research, as well as establishing any pre-conceived biases going into the literature review.

In Chapter 2, the focus is to review literature from the professional body of knowledge that is both relevant to addressing the research question, and credible to the key stakeholders that the author is trying to persuade. The majority of literature for this research will come from sources within the DOD. These sources of information give the research instant credibility as they come from recognized, credible sources within the same community as the stakeholders the author is trying to persuade.

Chapter 3 describes how the study takes the "raw material" from the literature review and compares the manning, training, and equipping of the ARSOA Gray Eagle

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unit against ARSOA rotary wing units and CF UAS and rotary wing units. Once the relevant information is broken down and categorized, the study is able to conduct a CBA, focused on a modified DOTMLPF-P analysis, only utilizing the domains of organization, training, and materiel. This process will produce the results necessary to publish the findings in the next chapter.

In Chapter 4, after conducting an objective review of the literature and analyzing the relevant data, the author is able to complete the second assessment, R2. In contrast to the initial assessment, R1 in Chapter 1, the R2 assessment is an updated personal recommendation based on the author's review of the literature (Long 2016).

In Chapter 5, the study makes the final assessment, R3, that are the results from Chapter 4 examined through the lens of the pre-identified CDM and stakeholders that the study is trying to persuade. After the R3, the study takes these findings and uses the Kotter Change Model to address their implementation. Within this process, the research will also identify any new requirements that emerged as a result of the findings. Lastly, the study will address any lessons learned throughout the process. This personal reflection will also address any significant findings throughout the research that fell outside the scope of the research, but are areas that may be worth addressing in a future study.

Conclusion

This chapter provided the background and description of the applied professional case study used to answer the primary and secondary research questions. The benefit of using an applied professional case study as the methodology for this study is that it is a qualitative, complex, and human-centric topic, and it requires a deep understanding of the

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environment to produce informed decision-making. Specifically, this methodology results in compelling and supported recommendations through the process of organizing and analyzing different types of knowledge/information in a defined setting to enable informed action to improve the current conditions. In the case of this thesis, the research will result in recommendations to enhance the manning, training and equipping of the Gray Eagle company within special operations (Hancock and Algozzine 2011; Gagnon 2010). The next chapter contains the findings of the data collected within this study.

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CHAPTER 4

RESEARCH FINDINGS

Introduction

The purpose of this chapter is to explain the findings of the research and to apply those findings to the applied professional case study methodology. The chapter will be broken down into three parts: the DOTMLPF-P type analysis focused on the domains of organization, materiel, training, and using the capabilities based assessment with the results expressed in the terms of a functional area analysis (FAA), functional needs analysis (FNA), and a functional solutions analysis (FSA); the R2 assessment; and a key stakeholder analysis resulting in the final assessment, R3.

Organization (Manning), Training, Materiel (Equipping) Analysis

The following table depicts the domains of organization, training, and materiel of the components that makeup the CBA, which are functional area analysis, functional needs analysis, and a functional solutions analysis.

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Table 4. Organization (Manning), Training, Materiel (Equipping) Analysis

	ORGANIZATION	TRAINING	MATERIEL
FAA (Needs)	• Task- Provide C2 for ARSOA UAS employment IAW unit MTOE • Condition- Three simultaneous missions in separate locations • Standard- IAW ARSOA detachment C2 requirements	• Task- Provide specially selected, highly trained, ARSOA 15W operators to support special operations forces • Condition- In support of SOA missions requiring a unique skill or capability to complete. • Standard- IAW ARSOA TC 3-04.11 battle rostering requirements	• Task- Provide a UAS platform with a unique capability to support SOA • Condition- ISO SOA missions conducted outside of current MQ-1C Grey Eagle UAS capabilities • Standard- To support mission sets IAW ARSOA MTOE narrative
FNA (Gaps and Risks)	• Gap- CW4 MTOE allocation as C2 node for 3x separate locations (CONUS/OCONUS) does not meet ARSOA C2 requirements • Risk- UAS detachments in austere locations operating without commissioned, company grade C2	• Gap- ARSOA 15W operators do not have an ARSOA specific training plan or battle rostering process. • Risk- ARSOA 15W operators do not provide a unique skill or capability to support SOA.	• Gap- ARSOA MQ-1C Grey Eagle UAS platform does not provide a unique or additional capability to SOA • Risk- ARSOA MQ-1C Grey Eagle UAS unit unable to support unique SOA missions
FSA (Solution Approaches)	• Non-materiel- Increase O3 MTOE billets to 5x O3 to support C2 requirements for up to 3x simultaneous missions in separate locations • Materiel- Conduct UAS operations through use of RSO with a central MCE	• Non-materiel- Implement a BMQ, FMQ, FLD training equivalent to the ARSOA 15W operator training process.	• Materiel- Modification of MQ-1C Grey Eagle UAS to support expeditionary operations.

Source: Created by author.

Organization (Manning) Analysis

The first FAA on E/160's organization used the unit's MTOE narrative as the basis to determine the task and condition for this analysis. The MTOE narrative states that this unit has the task of supporting up to three simultaneous missions. This narrative also defines the conditions of the task by stating that the unit must be able to support these three simultaneous missions in three separate locations. In order to meet this requirement, E/160 is configured to deploy one CW4 and one E7 as the command and control node for each of the three separate locations. To determine the ARSOA command and control requirements for detached elements conducting operations, this study used a comparative analysis of the MTOE and MTOE narratives from the ARSOA rotary wing

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company, A/2-160, against the MTOE of E/160. The MTOE narrative for 2-160, which is the battalion that A/2-160 falls under, states that the battalion is not designed to deploy as a whole battalion, but rather as slice elements as part of a Joint Task Force, or as part of a Joint Special Operations Air Component. It also states that the battalion is responsible to provide up to five mission command nodes to simultaneously support split geographic locations. To support this requirement, the MTOE of 2-160 has six commissioned officers, one major and 5 captains, assigned to each rotary wing flight company. E/160's MTOE only has two commissioned officers, one major and one captain. This analysis was used to establish the criteria for commissioned officers in the grade of captain or above and was the standard for geographically dispersed detachment command and control requirements. Additionally, the majority of the battalions in the 160th SOAR mirror the MTOE of 2-160, which reinforced the standard used during the FAA. Importantly, the personal experience of the author attests that CW4s do not serve in a command and control capacity within the 160th SOAR at geographically dispersed locations.

The FNA took the analysis from the FAA to determine any potential capability gaps in the organization of the unit. The first premise that determined the gap in the organization of E/160 was the MTOE comparative analysis. The ARSOA rotary wing companies are manned with an appropriate amount of commissioned officers in the rank of O3 and above to support the detachment command and control requirement as stated in their MTOE narrative. E/160 is manned with CW4s to fulfill their command and control requirement for three geographically dispersed missions. This analysis concludes that the 160th SOAR requires commissioned officers in the rank of O3 and above to act as the

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command and control elements of geographically dispersed detachments, and identifies a gap in E/160's organization, as E/160 is not able to organically support three geographically dispersed missions with an O3 or above as the command and control element.

This capability gap results in operational risk because it does not give E/160 the organic capability to conduct three geographically dispersed mission sets with a command and control element that meets the requirements of the 160th SOAR. Additionally, this presents risk in the mission approval process for aviation operations at geographically dispersed locations. The final portion of the aviation mission approval process requires the signatures of a mission briefing officer (MBO) and a final mission approval authority (FMAA). The FMAA is the individual that assumes the overall risk of the mission, and assuming risk is primarily the responsibility of commanders in the grade of O3 and above. A CW4 can have FMAA, but it is not the normal process for aviation operations and for that reason it is not included in this analysis of the risk.

The FSA identified a materiel and non-materiel solution to this capability gap. The non-materiel solution would re-allocate MTOE personnel billets of existing human resources in order to fill this capability gap and ensure no increase to the current E/160 MTOE of 165 personnel. The proposed solution would change the five CW4 personnel billets on E/160's MTOE to the grade of O3. This would change paragraph number 102, line number 01, UAS OPERATIONS OFFICER and paragraph number 105, line number 01, UAS PLATOON LEADER, from CW4 allocated billets to O3 billets, which would add five additional O3s to E/160's MTOE. This change would align E/160's MTOE to mirror the rotary wing companies' MTOEs that have six O3 MTOE billets each. This

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solution would enable E/160 to organically provide a command and control element with an O3 or above to support three geographically dispersed locations at a 1:2 deployment ratio.

The proposed materiel solution to this capability gap would be for E/160 to conduct remote split operations (RSO). RSO would solve this capability gap by providing a central mission control element (MCE) at E/160's home station to provide command and control of three geographically dispersed locations. E/160 would have two commissioned officers in the grade of O3 and above to provide command and control of three launch and recovery elements (LRE) at three geographically dispersed locations. This is a materiel solution because it would require an investment to the current communications architecture in order for E/160 to conduct RSO.

The second FAA on E/160's organization used Army doctrine, *ADRP 3-05 Special Operations,* and Joint doctrine, *JP 3-05 Special Operations,* to establish the task for this analysis. Of note, the author did not include this second analysis in the table at the beginning of this chapter because while the following analysis is relevant and identified a follow-on research question in chapter five, it did not make it past the author's updated individual recommendation and would not be brought before the CDM in the R3. These guiding doctrinal references state that in order to be a special operations unit, the unit must be specially organized, trained, and equipped. The FAA task in terms of organization is that E/160 must have more senior and experienced 15W Gray Eagle operators. Army and Joint doctrine also provide the condition for this analysis, that E/160 must be able to provide special operations forces with a unique capability in terms of employment, tactics, techniques, procedures, and equipment. An increase in the grade of

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15Ws assigned to E/160 would provide this unique capability, differentiating E/160 from conventional MQ-1C Gray Eagle units. To determine the standard for the FAA, this study used an MTOE comparative analysis of ARSOA rotary wings units to CF rotary wing units and compared them to ARSOA Gray Eagle in relation to CF Gray Eagle formations. This established the standard set for this study. The graphs below illustrate that airframe operators, in this case MH-47/CH-47 pilots and MQ-1C Gray Eagle 15W operators, are more senior in ARSOA rotary wings units compared to CF rotary wing units, but that is not the case for ARSOA Gray Eagle operators.

The number of personnel must be taken into account when viewing this graph since the ARSOA units have a higher overall number of personnel assigned than the CF units.

Table 5. Operator and Pilot Analysis

MQ-1C OPERATORS BY GRADE	E/160TH SOAR	B/101ST ABN
E-7	4	3
E-6	8	6
E-5	16	9
E-4	24	16

H-47 PILOTS BY GRADE	A/2-160TH SOAR	B/3-82ND
W4	8	0
W3	13	3
W2	0	17

Source: Created by author.

The A/2-160's MTOE total is 139 personnel, compared to B/3-82's MTOE of 52 personnel, and E/160's MTOE total of 165 personnel, compared to B/101's MTOE of

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127 personnel. Even with the overall MTOE number taken into account, it is clear that A/2-160 has more senior pilots than B/3-82. A/2-160 has no CW2s assigned while the majority of pilots assigned to B/3-82 are made up of CW2s. Conversely, B/3-82 has zero CW4s assigned while A/2-160 has eight. When looking at the MTOEs of E/160 and B/101, the same differences are not evident. When the difference in overall MTOE personnel assigned is taken into account, the operators by grade are essentially the same for E/160 and B/101. Since the overall majority of ARSOA has MTOEs that mirror A/2-160, this analysis determined that the standard for ARSOA is to have more senior pilots and operators than the CF counterparts.

The FNA took the analysis from the FAA to determine any potential capability gaps in the organization of the unit. The first premise that determined this gap in E/160's organization was the MTOE comparative analysis. The ARSOA rotary wing companies are manned with pilots of a higher grade than the CF rotary wing units. This comparison illustrated a gap in E/160's capability because when compared to the MTOE of B/101, the operator by grade, is essentially the same. This is a capability gap, because E/160 is not specially manned to support special operations, as compared to ARSOA units.

This capability gap results in operational risk by not providing a unique capability in terms of organization to special operations because E/160 does not have more senior Gray Eagle operators than CF Gray Eagle units. Part of ARSOA's ability to provide a unique aviation capability to special operations is by manning the rotary wing units with more senior pilots to conduct ARSOA missions. ARSOA mitigates risk and is able to conduct operations that CFs are unable to accomplish, in part, because ARSOA has deliberately organized its rotary wing units with senior grade pilots. E/160 does not have

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this same organization, which increases the risk of conducting unique missions in support of special operations.

The FSA used the analysis of the ARSOA rotary wing unit, A/2-160, presented in this study, as the basis for the recommended materiel solution. The materiel solution would be to increase MTOE billets of the enlisted Gray Eagle 15W operators in the grades of E5, E6, and E7. This solution would not add additional personnel to E/160's overall personnel count of 165, but would take those billets from the E4 15W billets. This change is in line with the organization of A/2-160, as that unit's pilot billets have no CW2s, and only have MTOE billets in the grade of CW3 and above. The increase of E5, E6, and E7 15W MTOE billets would increase the overall experience level of 15W operators to match the capabilities provided by ARSOA rotary wing units. Additionally, increasing E7 15W MTOE billets within E/160 will enable experienced operators to remain within the unit, increasing the unit's capability. Currently, E/160 only has four E7 15W MTOE billets, as UAS PLATOON SERGEANTS, that focuses those E7 15W operators on the leadership and administrative requirements of the platoon. In comparison, A/2-160 has CW4 MTOE billets at the platoon level as SR IP/IFE, which is a position that focuses on the tactical employment of the MH-47G. This analysis illustrates that ARSOA rotary wing units have MTOE billets that enable their most experienced pilots to remain at the platoon level that adds a unique capability in terms of organization and manning, that the CF does not. This materiel solution to E/160's manning would enable them to provide the same capability as the ARSOA rotary wing units.

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Training Analysis

The FAA on E/160's training also used Army doctrine, *ADRP 3-05 Special Operations,* and Joint doctrine, *JP 3-05 Special Operations,* to establish the condition for analysis focused on distinctive capabilities required of special operations forces. This study used the unique ARSOA mission battle-rostering requirements in accordance with *ARSOA 3-04.11* as the basis for the standard in the FAA. This standard determined that battle-rostering within special operations aviation is unique and ensures the ground force commander has support by providing a clear tool to control risk while retaining mission flexibility. ARSOA accomplishes this through its unique battle-rostering, which organizes crews by mission qualification.

The FNA took the analysis from the FAA to determine potential capability gaps in unit training. The analysis determined that E/160 does not have an ARSOA specific mission training process for 15W Gray Eagle operators. The ARSOA rotary wings units have a unique training and battle-rostering process that uses the aircrew mission designations of BMQ, FMQ, and FLD to provide a unique, special operations specific, capability. E/160 uses the same battle-rostering process as conventional Gray Eagle units and does not have unique, special operations aviation specific aircrew designation of BMQ, FMQ, and FLD. This study used this analysis to define this as a training capability gap within E/160.

The risk associated with this capability gap is that there is an expectation from supported special operations forces that ARSOA provides a unique Gray Eagle capability, and part of that expectation involves uniquely trained 15W operators. This expectation is determined by both the doctrinal definition of a special operations unit and by the precedent set by ARSOA rotary wing over the past 36 years. ARSOA rotary wing

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units use their unique battle-rostering process to reduce risk for the ground force commander during aviation operations. Without a unique, mission tailored battle-rostering process, E/160 cannot provide the same risk reduction capability to the ground force commander that the ARSOA rotary wing units provide.

The FSA used the unique ARSOA rotary wing mission training process as the basis for this solution. The proposed non-materiel solution to this capability gap would be for E/160 to implement an ARSOA specific 15W operator training and mission battle-rostering process that mirrors the ARSOA rotary wing units. This would include adding additional aircrew designations, like BMQ, FMQ, and FLD, to the unit's aircrew training programs that would enable E/160 to battle-roster their crews to tailor specific mission requirements. This would enable E/160 to provide a unique special operations Gray Eagle capability to the ground force commander that would enable them to control risk while retaining mission flexibility.

Materiel (Equipping) Analysis

The FAA related to materiel (equipping) also used Army doctrine, *ADRP 3-05 Special Operations,* and Joint doctrine, *JP 3-05 Special Operations,* to establish the task for analysis focused on distinctive capabilities required of special operations forces. To define the standard for the FAA, this study used a comparative analysis of the airframe operator's manuals from the different units included in this study. This comparison illustrated that the ARSOA rotary wing unit, A/2-160, has a modified version of the CF Army CH-47F Chinook, heavy lift rotary wing. A/2-160 employs the MH-47G Chinook, a heavy assault rotary wing which provides special operations forces with a unique piece of equipment that provides additional capability to special operations. For example, the

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MH-47G has an in-flight refuel capability that provides special operations forces with a long-range infiltration capability not provided by the CF's CH-47F. When this same comparison is made between the ARSOA and CFs Gray Eagle units, there is no specialized equipment that enables E/160 to provide an additional capability to special operations forces. The Gray Eagle employed by E/160 is identical to the one employed by the CF Gray Eagle unit, B/101. Given the results of this comparison, this study then used the MTOE narrative of the ARSOA rotary wing units to define the standard that states the unit has unique equipment, tailored to support specific mission profiles.

The FNA used the analysis from the FAA to determine any potential capability gaps in the equipping of the unit. The analysis determined that E/160 does not have equipment that provides a unique capability to the ground force commander like the ARSOA rotary wing units. To further define the possible equipment capability gaps, this study used three unique capabilities provided by ARSOA rotary wing units in comparison to CF's rotary wing units. These capabilities are extended range, advanced aircraft survivability equipment, and advanced onboard radar allowing rotary wing operations in degraded environmental conditions. These equipment capabilities provide a unique capability to support the ground force commander over those that exist within the conventional forces (CF). This illustrates an equipment capability gap for E/160, because their equipment does not provide a unique capability in comparison to the CF Gray Eagle units.

The risk associated with the identified equipment capability gap is that E/160, in terms of UAS support, does not offer the ground force commander a unique capability to execute missions that are outside of the CF's Gray Eagle capability. Special operations

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require a unique equipment capability because they are often conducted in denied or hostile environments, under unfavorable weather and environmental conditions, and require real time intelligence. As an intelligence, surveillance, and reconnaissance platform in support of special operations, E/160 has to have a unique capability that can operate in conditions that exceed the ability of those found in the CF units.

The FSA used the unique capabilities provided by the ARSOA rotary wing units as the basis for this solution. The proposed materiel solution would be for ARSOA to invest in research and development to modify the Gray Eagle to provide a unique UAV platform capability specifically designed to support the special operations community. The specific modifications should be the focus of a follow-on study; however, based on the author's operational experience, the author would recommend two potential materiel solutions to the current Gray Eagle company equipment resources to enhance its ability to support special operations. First, the engineers should reduce the size of the ground control station, satellite and ground data terminals, and secondly, they should reduce the total amount of ground support equipment required to operate the Gray Eagle to improve the company's expeditionary capability.

R2: The Updated Individual Recommendation

The R2: Updated Individual Recommendation is composed of the same questions that were answered in the R1: Initial Personal Recommendation. The difference is that these same questions will be answered after conducting the literature review. This illustrates the changes in opinion and recommendation after completing a review of the relevant literature. The R2 provides credibility to the applied professional case study methodology by demonstrating to the reader the changes in perception by the author after

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completing the literature review. The R2: Updated Individual Recommendation will only address significant changes from the R1: Initial Personal Recommendation.

The first part of the R2 discusses the primary research question and why it is important to the author and the key stakeholders within the United States Army Special Operations Command (USASOC). When this research effort was initiated the primary research question in this study was framed as: how should United States Special Operations Command adapt manning, training, and equipping of the ARSOA Gray Eagle unit to provide the unique capabilities required by the special operations community? Joint and Army doctrine both define special operations as activities requiring unique capabilities not provided by the CF. Doctrine also affirms that special operations forces must be specially organized, trained, and equipped to provide this unique capability (ADRP 3-05, 2012; JCS 2011). After analyzing the similarities and differences of a CF Gray Eagle company to an ARSOA Gray Eagle company and comparing them to the similarities and differences between a CF rotary wing company and an ARSOA rotary wing company, it is evident that there are gaps in capabilities provided by the ARSOA Gray Eagle company. Specifically, the manned ARSOA rotary wing company analyzed in this study provides unique special operations capabilities because it is specifically manned, trained, and equipped differently than the CF rotary wing company analyzed in this study. However, the same cannot be said about the ARSOA MQ-1C Gray Eagle company in comparison to the CF MQ-1C Gray Eagle company. This new knowledge and understanding led the author to update the primary research question to: are there organizational (manning), training, and materiel (equipping) capability gaps that are

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preventing the ARSOA Gray Eagle unit from providing a unique special operations aviation capability?

During the course of this study, the author was informed that upon completion of the Command and General Staff College, he would be taking command of the newly fielded ARSOA Gray Eagle company, Company F, 160th Special Operations Aviation Regiment, scheduled to officially activate in August of 2018. In turn, this made the author a stakeholder in this research at the tactical level and more invested than at the beginning. The review of literature also defined the stakeholders' position and established the basis that the CDM will evaluate this study through the R3: Stakeholder Recommended Solution, presented in the final assessment.

The second part of the R2 addresses why this study is important and the possible consequences if this topic is not addressed. The new ARSOA Gray Eagle company, F/160, is scheduled to activate in August 2018 and results in the fielding of two ARSOA Gray Eagle companies within a five-year period. This highlights the importance that the DOD is placing on the development of UAS within ARSOA. The review of literature confirmed the author's initial position and opinion that the UAS capability provided to special operations aviation must provide a unique capability not provided by the CF Gray Eagle units. Additionally, the earlier that these gaps can be identified and validated by the CDM, the earlier the solutions can be implemented.

The final portion of the R2 identifies the potential solutions to the problem statement identified through the review of literature. The review of literature identified gaps within the manning, training, and equipping of the ARSOA Gray Eagle company. The primary sources of data for this study were DOD publications. The MTOE

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documents for the four units used in this study provided a clear comparison of the CF and ARSOA Gray Eagle companies in relation to the ARSOA and CF rotary wing companies. This analysis provided evidence to support a capability gap in the manning of the ARSOA MQ-1C Gray Eagle company. The MTOE narrative and aircrew training publications provided the necessary information to compare and contrast the training requirements and processes within the different ARSOA and CF companies used in this study. This provided insight on gaps within the training domain of the ARSOA Gray Eagle company. Lastly, by comparing airframe specific technical manuals, it was evident that there was no unique equipping capability provided by the ARSOA Gray Eagle company in comparison to the CF's UAS company. In contrast, by comparing the airframe specific technical manuals of the ARSOA and CFs rotary wing companies, ARSOA aircraft provided a unique equipping capability when compared to the CF's. By identifying these gaps and the risks associated with them, the potential materiel and non-materiel solutions for each were identified and explained earlier in this chapter.

R3: Stakeholder Recommended Solution

To determine the R3: Stakeholder Recommended Solution, the author evaluated the R2 through the lens of the Chief Decision Maker (CDM) and the stakeholders. The CDM for this applied professional case study is the Commander of the United States Army Special Operations Command (USASOC), the stakeholders include the 160th SOAR Regimental Commander, and to a smaller extent, the 160th SOAR Battalion Commanders. The USASOC Commander was chosen as the CDM as opposed to the Commander of United States Special Operations Command (USSOCOM) because the purpose of this applied professional case study is to persuade the CDM in order to affect

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change. The USSOCOM Commander already employs Group 4 UAS within the other services, but this study is specific to employment of the Gray Eagle within ARSOA, which is focused on the Army and its mission of unified land operations, "to apply land power as part of unified action to defeat an enemy on land and establish conditions that achieve the JFC's commander's end state" (FM 3-0 2017, 34; USSOCOM Fact Book 2017, 49). This means that the USASOC Commander must be persuaded that the ARSOA Gray Eagle needs to provide a unique UAS capability to enhance ARSOA before these potential solutions are presented to the USSOCOM Commander.

ARSOF 2022 and *USASOC Strategy-2035* comprised the literature used as the basis for the CDM's concerns. Additionally, the concerns presented were compared to the 2018 USSOCOM Posture Statement made by the Commander, General Raymond A. Thomas, on February 15, 2018 before the House Armed Services Committee, to ensure that these concerns are nested within the next higher echelon of command. The main concerns of the CDM were to:

- Obtain next generation unmanned aircraft systems that provide longer operational range, over horizon observation, and can be launched and recovered by tactical units;
- Employ advanced unmanned aircraft systems and intelligence collection capabilities at the tactical level; provide joint force commanders with professionals who are agile, adaptive, flexible, bold, innovative, and possess a high degree of advanced training;
- Provide the nation's premier special operations forces, delivering appropriate and effective capabilities to joint force commanders and interagency leaders across the entire spectrum of conflict and under any operating conditions;
- Broaden the range of special operations aviation-related individual training and education including unmanned aircraft systems; and
- Improve army unmanned aircraft system programs of record (Raven, Shadow and Gray Eagle) to meet joint expeditionary tactics, techniques, procedures, forward-

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based networking, and sensor requirements (HQDA 2014a, 24; ARSOF 2035 2017, 3-6).

The first part of the R3 will discuss the primary research question and why it is important to the CDM, the Commander of United States Army Special Operations Command (USSOCOM). The primary research question for this study is: are there organizational (manning), training, and materiel (equipping) capability gaps that are preventing the ARSOA Gray Eagle unit from providing a unique special operations aviation capability? The primary research question in this study is directly in line with the CDM's position because it specifically addresses the objectives for improved UAS capabilities within special operations as defined in *ARSOF 2022* and *USASOC Strategy-2035*. However, the CDM would disagree with the premise that E/160 does not provide a unique special operations aviation capability. The CDM would argue that the unique capability provided by E/160 is that it is manned and equipped to support three geographically dispersed mission sets simultaneously, as stated in the MTOE narrative, "this unit was specifically designed to meet SOA requirements for multiple simultaneous deployments to widely separated areas." From a manning perspective this is clearly evidenced by E/160's MTOE total of 165 personnel, compared to B/101's MTOE of 127 personnel. However, from an equipping perspective, both E/160 and B/101 are supplied with the same amount of equipment that makes up the UAS company; 12 x unmanned aerial vehicles (UAVs), 6 x ground control stations (GCSs), 6 x ground data terminals, and 3 x satellite ground data terminals. E/160 is equipped with slightly more ground support equipment, specific to the UAS, and has three additional generators. This means that from a purely equipment perspective, B/101 could support three geographically dispersed mission sets simultaneously, just like E/160.

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The second part of the R3 addresses why this study is important and the possible consequences if this topic is not addressed. In contrast to the author, the CDM would have to take into account competing resources when reviewing the results of this study. The CDM is responsible for a much bigger organization than what the author addresses in the R2, meaning that this study would have to persuade him to believe that the capability gaps addressed in this study outweigh other requirements in the USASOC enterprise. This would make the consequences to the CDM very different than the consequences stated by the author, while acknowledging that the CDM may face other consequences in the USASOC enterprise by electing to use valuable resources to pursue any of these proposed materiel solutions.

The final portion of the R3 takes the recommended solutions from this study and filters them through the lens of the CDM. The first organizational (manning) capability gap identified in this study was the lack of commissioned, company grade and above officers to perform the command and control requirement for three geographically dispersed mission sets. The two recommended solutions to this capability gap were to conduct RSO or to increase the O3 MTOE billets to six. The CDM views RSO as a viable option for ARSOA to employ its Gray Eagle assets. The author's personal operational experience attests that DOD conducted a study into RSO for ARSOA, but due to classification cannot disclose the findings or implications for future ARSOA employment.

The second recommended solution, to increase O3 MTOE billets, would not be accepted by the CDM for two reasons. First, this solution does not address any of the CDM's chief concerns. Second, it would not be feasible with respect to personnel

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limitations within ARSOA. Additionally, E/160 is attached to 2d Battalion, 160th SOAR, that the CDM would argue has the ability to support E/160 with its O3 command and control requirements to support three simultaneous, geographically dispersed missions. The second organizational (manning) gap addressed by the author was the need to increase the 15W MTOE billets of E5, E6, E7, and to reduce the number of E4s. The CDM would not approve this solution because it does not fall within his main concerns. The CDM is concerned with broadening the range of special operations aviation-related individual training and education including unmanned aerial systems, and would invest in that as opposed to the additional cost of increasing the rank structure of the 15Ws.

The training capability gap addressed in this study is that E/160 does not have an ARSOA specific mission training process for 15W Gray Eagle operators. The proposed non-materiel solution to this capability gap would be for E/160 to implement an ARSOA specific 15W operator training and mission battle-rostering process that mirrors the ARSOA rotary wing units. The CDM would approve this proposed solution because it meets all the criteria of an FSA, is non-materiel, and is in-line with his concern of broadening the range of special operations aviation-related individual training and education including unmanned aerial systems.

The materiel capability gap addressed in this study is that E/160 is not equipped to provide a unique ARSOA UAS capability. The proposed materiel solution would be for ARSOA to invest in research and development to modify the Gray Eagle to provide a unique aviation capability. The author recommended a modification to the Gray Eagle that increases its expeditionary capability by reducing the physical size of the ground control station, and satellite and ground data terminals as well as reducing the total

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amount of ground support equipment required to operate the Gray Eagle. The CDM would agree with the author's recommendation to conduct research and development into the modification of the Gray Eagle to increase its expeditionary capability. This recommendation is in-line with the CDM's concern of improving Army unmanned aircraft-system programs of record (Raven, Shadow and Gray Eagle) to meet joint expeditionary tactics, techniques, procedures, forward-based networking, and sensor requirements.

Conclusion

This chapter explained the findings of the research and applied those findings to the applied professional case study methodology. The modified DOTMLPF-P analysis provided recommended solutions to the CDM through the use of a CBA. These proposed solutions were then vetted by the CDM, through the final assessment, the R3. The next chapter, Chapter 5, will address the final recommendations of this study.

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CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Recommended Solutions

This section will discuss the implementation plan for the two recommended solutions proposed by this study. The implementation plan is broken down into short term (one to two years) and long term (three to five years) time frames and will use the principles of the Kotter Change Model for implementation. The two proposed solutions are a direct result of the author's professional operational experience in ARSOA, extensive literature review based in the professional body of knowledge that exists for this topic, and the analysis of that knowledge through the use of the applied professional case study methodology.

The United States Army is an organization that is not always willing to acknowledge and embrace the need for change. There are many ways to accomplish change within an organization and one that is both appropriate for this study and used in Army doctrine is the Kotter Change Model, hereafter referred to as the Kotter Model. This model uses the following eight-step process to affect change within an organization.

The first step in the Kotter Model is to establish a sense of urgency. This is done by creating a climate within the organization that is dissatisfied with the status quo by setting aggressive goals and objectives that force the organization to make significant change and overcome complacency.

The second step is to create the guiding coalition. After establishing a sense of urgency, a group of senior, influential, and respected individuals within the organization

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that support and are fully committed to implementing the change must be formed to propel the change forward.

The third step is to develop a vision and a strategy. Once the guiding coalition is formed, that group is used to develop a feasible vision and strategy that is imaginable, desirable, feasible, focused, flexible, communicable, provides an imaginable picture of the future, a shared sense of purpose, focuses efforts, aligns priorities, and sparks excitement for members of the organization.

The fourth step is to communicate the change vision. This is one of the most important stages within the process. Simply creating a vision and strategy to affect change accomplishes nothing unless the entire organization knows what the vision is and why it is so important for the organization to undertake.

The fifth step is to empower broad-based action. This involves empowering subordinate leaders that are committed to the change, potentially removing leaders that oppose it, creating an environment of decentralized control, and developing a shared understanding with mutual trust.

The sixth step is to generate short term wins. These accomplishments enable the organization to see tangible results toward accomplishing the desired change, which in some cases could take years to complete. Identifying and rewarding these short term gains helps to maintain the momentum of the change effort.

The seventh step is to consolidate gains and produce more change. Consolidating the effects garnished from the short terms wins will open the change initiative to other areas within the organization that were not evident at the start of the change process.

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Identifying these other changes and capitalizing on them during the process is essential to preventing regression while maintaining the momentum for further change.

The eighth and final step is to anchor the new approach into the culture. Kotter defines culture as, “norms of behavior and shared values among a group of people”. This final step is vital as it is the point where the organization as a whole, believes that the new process is the way the organization now does business and ensures the practice remains even if the current leadership at the time of the change, switches out (Miller and Turner 2017, 1-8)

The proposed solution identified for short term implementation (one to two years) is to implement an ARSOA-specific 15W operator training and mission battle-rostering process that mirrors the ARSOA rotary wing units. This change to the training domain of ARSOA Gray Eagle units would be a fairly simple change to make. This is because the process for this type of training plan is already in place for the ARSOA rotary wing units. This is a mission specific training program and could theoretically be implemented with minimal increase to the individual operator required flight hours. Affecting this change would not necessarily have to be approved by the Chief Decision Maker (CDM), but could be implemented by the other stakeholders, most likely by the 160th SOAR Commander. Additionally, because this is a non-materiel solution, it is very realistic for short term implementation. This proposed solution was recommended because it is nested within the main concerns of the CDM, as stated in *ARSOF 2022* and *USASOC Strategy-2035*, that include: (1) provide joint force commanders with professionals who are agile, adaptive, flexible, bold, innovative, and possess a high degree of advanced training, and

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(2) broaden the range of special operations aviation-related individual training and education including unmanned aircraft systems.

Using the principles of the Kotter Model, the author recommends the following short term implementation plan for the proposed change to the training domain of the ARSOA Gray Eagle units. It is once again important to note that the author will be taking command of the newly fielded ARSOA Gray Eagle company, F/160, with an activation date set for August 2018, and will attempt to affect this proposed change to the training domain of F/160. The author's professional operational experience attests that the biggest obstacles to implementing this change will be with steps one and two of the Kotter Model. The first ARSOA Gray Eagle company, E/160, is viewed as a critical capability within the SOF community, and because of that, the author believes that establishing a sense of urgency, as well as forming a guiding coalition will be difficult. The argument to overcome this is that the ARSOA rotary wings success over the past 36 years is directly attributed to this process of training. Additionally, because this process is already in use by the ARSOA rotary wing units, step three of the Kotter Model will be extremely easy to produce, since it already exists. That is also why the author believes that this recommendation is so viable, because the organization has already bought into the process and can easily identify with it. The challenge will be in convincing the other stakeholders, as well as the senior members of the unit, that this process can be as beneficial for the ARSOA Gray Eagle community as it is for the ARSOA rotary wing community.

After garnishing support for this recommended change, the next biggest task will be to generate short term wins in order to ensure this change gains momentum and

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becomes part of the established training process within the organization. The immediate result of applying this training process within the organization, will be the increased confidence that the individual operators will have when conducting their mission and specifically with their ability to conduct professional air mission briefs. The ARSOA mission training process involves extensive training in the process of conducting professional military air mission briefings. Making that a part of the ARSOA 15W training process will dramatically increase their confidence in their briefing abilities and propel this change forward from the bottom up. With a bottom up approach, this will ensure the majority of the company buys into the new training process which will help to confirm this solution with the organization's leadership and stakeholders.

Once the recommended training process is established at the company level, this implementation plan will look to consolidate gains and further the change process by establishing this recommended change at the battalion and regimental levels. To accomplish this, the training process will first need to be standardized within the battalion and then, to anchor the change, written into the regimental standard operating procedure. Once the process is refined and standardized enough to be written into the official regimental standing operating procedure, it will ensure that this process is the approved way that the organization does business, and will remain in place once the implementing leadership switches out.

The proposed solution identified for long term implementation (three to five years) would be for ARSOA to invest in research and development to modify the Gray Eagle to provide a unique aviation capability to the SOF community. It is important to note that this recommendation was selected for long term implementation because

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ARSOA is currently scheduled to conduct the full operational testing and evaluation of the MQ-1C Gray Eagle Extended Range UAS in July of 2018. This new version of the Gray Eagle will provide additional capabilities and, because of this, it is unlikely that the CDM will have an appetite for any additional investment into research and development of the Gray Eagle until the added benefits of this new version are fully understood. It is also important to note that while ARSOA is conducting the full operational testing and development of the MQ-1C Gray Eagle Extended Range UAS, this new version will be fielded to both ARSOA and CF Gray Eagle units and the new capability will not be unique to the SOF community.

The specific modification to the Gray Eagle should be the focus of a follow-on study. Based on the author's operational experience, the author would recommend a modification that would increase its expeditionary capability, specifically by reducing the size of the ground control station, satellite and ground data terminals, and reducing the total amount of ground support equipment required to operate the Gray Eagle. This proposed solution was recommended because it is nested within the main concerns of the CDM, as stated in *ARSOF 2022* and *USASOC Strategy-2035*, that include: (1) obtain next generation unmanned aircraft systems that provide longer operational range, over horizon observation, and can be launched and recovered by tactical units, and to (2) improve army unmanned aircraft system programs of record (Raven, Shadow and Gray Eagle) to meet joint expeditionary tactics, techniques, procedures, forward-based networking, and sensor requirements.

Using the principles of the Kotter Model, the author recommends the following long term implementation plan for the proposed change to the materiel domain of the

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ARSOA Gray Eagle units. Unlike the proposed short term solution, the identified long term solution is simply a recommendation to invest in research that will lead to a change in the future. For this reason, the implementation plan will not use all eight steps of the Kotter Model, but will focus on Steps One and Two. The author believes that creating a sense of urgency and building a guiding coalition among the CDM and stakeholders for this recommended solution will be difficult, given the fact that a new version of the MQ-1C Gray UAS is currently being fielded. The key to overcoming this obstacle is to emphasize to the CDM and stakeholders the fact that the new version of the Gray Eagle was based upon the needs of the CF, and that a SOA specific research and development process has not been conducted to meet SOF specific UAS needs. This will remain in line with ARSOA common practice, as the rotary wings employed by ARSOA were modified based on SOF specific operational needs, and that the same should hold true for the platform employed by the ARSOA UAS units.

Recommendations for Further Study

The first recommendation for further study would be to increase the expeditionary capability of the Gray Eagle by reducing the size of the ground control station, satellite and ground data terminals, and the amount of ground support equipment required to operate the Gray Eagle. The study would need to focus on the current breakdown and buildup times of the Gray Eagle in its current configuration as well as the amount of pallet space aboard United States Air Force (USAF) aircraft that is required to move one Gray Eagle flight platoon from one location to another. The study would then need to establish the timeline and cargo requirements needed to support United States Special Operations Command (USSOCOM) type of mission sets. Once this baseline is

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established, the study would be able to determine the specific requirements needed to publish the Operational Needs Statements (ONS) request to industry leaders and produce a modified version of the Gray Eagle to address the capability gap in supporting this USSOCOM mission set.

The second recommendation for further study would be to further research the capability provided by using Remote Split Operations (RSO) to employ ARSOA UAS. As stated earlier in this thesis, the professional operational experience of the author attests that there has been a study conducted on RSO, but due to classification cannot publish the results. However, the author would argue that another study needs to be conducted looking specifically at the benefits gained by the communication architecture needed to conduct RSO. In addition to the expeditionary and manning benefits of RSO, the author believes that RSO would also benefit the training level of 15W operators.

Affording 15W operators different training environments is difficult due to the fact that UAS operations within the national airspace are very hard to conduct. Currently, the process involved with transiting the national airspace with a UAV is next to impossible because of the restrictions imposed by the Federal Aviation Administration (FAA). This forces ARSOA Gray Eagle units to exclusively train at their home base or incur the high costs of transporting all the equipment necessary to operate at another US location. The author believes that these costs could be greatly reduced by the infrastructure associated with conducting RSO, which would make training at different locations within the United States more of a reality. The study would need to look at a cost analysis of being able to move a relatively small UAS package, due to the communication architecture of RSO, from one location to another, in order to train with

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different SOF units across the United States. The author believes that by conducting this analysis, the CDM and stakeholders would see another benefit of RSO that has not been previously addressed.

The final recommendation for further study would be to further research small precision guided munitions. The Gray Eagle needs to have the ability to tailor its payload based on the mission set. Weight will always be a factor regarding UAS operations and further research needs to be conducted to find an alternate payload for the Gray Eagle other than its current restriction to the Hellfire missile. This is not to say that the Hellfire is not an effective munition for the Gray Eagle, but in its current configuration, it can only carry up to four Hellfire missiles. This recommendation for further study would be to give the Gray Eagle an alternate, lighter, precision guided munition that would provide the ground force commander with more options when supporting different mission sets.

In addition to the aforementioned recommendations, the author and his thesis committee members developed four additional recommendations for further study after conducting the formal thesis defense. The four recommendations for further study are: (1) What are the training requirements that will be driven by an upgraded Gray Eagle materiel solution? (2) Perform a manpower grade analysis to document personnel requirements in the grades of O3 and CW4, for six MTOE positions. (3) Determine if ARSOA manning policy needs to be amended to account for UAS needs. (4) Conduct a SOF specific mission analysis for UAS platforms to define materiel key performance parameters.

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Personal Learning Reflections

By conducting this research, the author gained a clear understanding of the current capabilities of the ARSOA Gray Eagle units, and more importantly, an understanding of the current capability gaps in the domains of organization, training, and materiel. As a future stakeholder in this community, this research enabled the author to develop a vision and strategy for commanding the newly fielded ARSOA Gray Eagle company, F/160. Additionally, by focusing this study within the professional body of knowledge associated with this topic, the author was able to both confirm and reject various biases that were held prior to conducting this study. This is significant, as the applied professional case study methodology ensured that the author's understanding of this topic moving forward is objective and based solely on the credible literature that was reviewed during the study.

In addition to his own professional growth, the author believes that this study is the first step for the ARSOA UAS community to begin to define its role within SOA. The Gray Eagle platform was designed to meet the needs of the CF and this paper has illustrated the fact that while this current capability is successful in ARSOA, it is now at the point where ARSOA needs to modify the current capability for SOA. Just like the ARSOA rotary wing units took CF rotary wing organizations and modified them to meet SOA specific needs, the ARSOA Gray Eagle units need to begin making the same organizational, training, and materiel modifications to support specific SOA needs.

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Acoustic Measurement of Unmanned Aircraft Systems (UAS)

Efrem R. Reeves

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14. ABSTRACT
This report details the measurement of sound levels around a Shadow and a Gray Eagle unmanned aircraft system (UAS). Sound levels inside of Universal Ground Control Stations (UGCS) were also measured. The results indicate the Shadow UAS operator should be well protected using the David Clark H10 headset. The Gray Eagle operators did not wear hearing protection and it is recommended that they use some sort of hearing protection. The sound levels in the measured UGCSs were relatively low and the RACAL RA5000/1/1026 Raptor headsets that are currently being used will provide more than adequate hearing protection.

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Hearing protection, UAS, Shadow, Gray Eagle, sound level, UGCS

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Summary

An unmanned aircraft system (UAS) is an unmanned aircraft (UA) with associated support equipment, control station, data links, telemetry, communications, and navigation equipment necessary to operate it (FDOT, 2019). USAARL tested sound levels produced by two different UA systems—the RQ-7Bv2 Shadow and MQ-1C Gray Eagle. The RQ-7 Shadow Tactical Unmanned Aircraft System (TUAS) provides reconnaissance, surveillance, target acquisition, and force protection for the Brigade Combat Team (BCT) in near-real-time during day, night, and limited adverse weather conditions. The MQ-1C Gray Eagle is a medium-altitude, long-endurance (MALE) UAS and is an upgrade to the MQ-1 Predator UAV drone line.

The purpose of this test was to determine the sound level around the Shadow and Gray Eagle UASs and inside the universal ground control station (UGCSs). The study also looked at the effectiveness of headsets currently used with those systems.

Results indicated that sound levels around the Shadow and Gray Eagle require the use of hearing protection per Section 7-13 of DA PAM 40-501 which states that appropriate hearing protection must be worn when working with or around aircraft that produces exposure to steady state noise levels of 85 dB(A) of *any* duration. The Shadow (at the operator position) reaches a maximum sound level of 98dB(A). The Grey Eagle produces sound levels of 87 dB(A) next to the UAS on the right side, and a measurement of 92 dB(A) underneath during short intervals of time. Sound levels inside the UGCS do not reach the threshold to require additional hearing protection per Section 7-13 of DA PAM 40-501.

Results related to the evaluation of the current headsets being used by UAS operators indicate that Shadow UAS operators should be well protected using the current David Clark H10 headset. However, it is recommended that Gray Eagle operators use some sort of hearing protection. The sound levels in both UGCSs were relatively low and the RACAL RA5000/1/1026 Raptor headsets that are currently being used provide more than adequate hearing protection.

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Introduction

An unmanned aircraft system (UAS) is an unmanned aircraft (UA) with associated support equipment, control station, data links, telemetry, communications, and navigation equipment necessary to operate it (FDOT, 2019). The focus of this test is to accurately quantify sound levels produced by two different UA systems. The two systems tested are the RQ-7Bv2 Shadow and the MQ-1C Gray Eagle. The RQ-7 Shadow Tactical Unmanned Aircraft System (TUAS) provides reconnaissance, surveillance, target acquisition and force protection for the Brigade Combat Team (BCT) in near-real-time during day, night and limited adverse weather conditions. The MQ-1C Gray Eagle is a medium-altitude, long-endurance (MALE) UAS and is an upgrade to the MQ-1 Predator UAV drone line.

The universal ground control station (UGCS) is the common control station for the U.S. Army's Shadow and Gray Eagle unmanned aircraft systems. Built on a flexible crew station architecture, the UGCS can be configured and housed based on army mission requirements, supporting a wide variety of assets and operations (Textron Systems website, 2019). In order to get a complete picture of the noise exposure of UAS operators sound measurements were conducted inside UGCS as well as around the aircraft.



Figure 1. The RQ-7 Shadow Tactical Unmanned Aircraft System (TUAS).

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Figure 2. The General Atomics MQ-1C Gray Eagle unmanned aircraft system (UAS).



Figure 3. Universal ground control stations (UGCS).

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Methods

Measurements were conducted around the RQ-7Bv2 Shadow and the MQ-1C Gray Eagle UAS vehicles at Fort Huachuca, AZ in July 2019. Measurements were also conducted inside of the UGCS for both vehicles. The same equipment was used for all measurements.

Unmanned Aerial Systems

Microphone placement was similar for both the Shadow and Gray Eagle UAS sound level measurements. Due to a limited opportunity to collect data, since training exercises could not be altered or interrupted, it was decided to place the microphones at varying distances perpendicular to the aircraft centerline. The height of each microphone diaphragm was 5 feet except for the microphone closest to the Gray Eagle UAS which was 4 feet high. The relative microphone positions for the Gray Eagle can be seen in Figure 4 and the first three microphones can be seen in Figure 5. The first four microphone locations at the Shadow launch site can be seen in Figure 6. The microphone distances from the aircraft centerline are shown in Table 1.

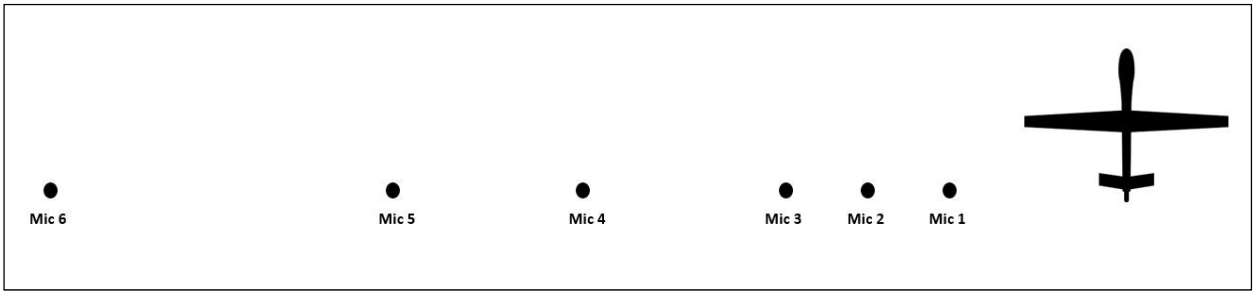


Figure 4. Microphone positions for the Gray Eagle.

Table 1. Microphone distances from the aircraft centerline in feet

Mic	Distance in Feet	
	Grey Eagle	Shadow
Mic 1	30	30
Mic 2	40	45
Mic 3	60	90
Mic 4	90	115
Mic 5	125	150
Mic 6	183	171

Prior to aircraft start up, the data acquisition modules were set up for standalone recording. This mode of operation allowed for the data to be saved as a .WAV file to a microSD card that was plugged into each module. The recording parameters were set to a sampling rate of 131,072 Hz with a frequency span of 51.2 kHz and 24-bit resolution. The data acquisition modules were powered on after all microphones were in place, but the recording was not started until the aircraft were in place and ready to be powered up.

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Figure 5. Gray Eagle UAS with first three microphone positions.



Figure 6. Shadow UAS on launcher showing first four microphone positions.

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Universal Ground Control Systems

Inside the UGCS the same six microphones and data acquisition modules that were used to measure the UAS sound levels captured the ambient sound level while the UGCS was powered on but not occupied. Figure 7 shows the dimensions and microphone layout for the Shadow UGCS. Microphone 4 and Microphone 6 were placed on the chairs to approximate crew member head positions. Figure 8 shows the front-most microphone positions in the Shadow UGCS.

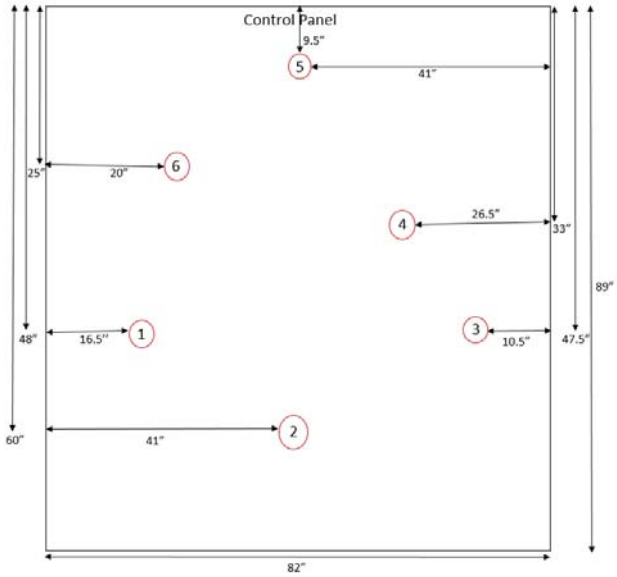


Figure 7. Shadow UGCS dimensions and microphone placement.



Figure 8. Microphone positions four, five, and six in Shadow UGCS.

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A similar microphone layout was used in the Gray Eagle UGCS. Figure 9 shows the dimensions and microphone layout for the Gray Eagle UGCS. Microphone 1 and Microphone 2 were placed on the chairs to approximate crew member head positions. Figure 10 shows the first five microphone positions in the Gray Eagle UGCS.

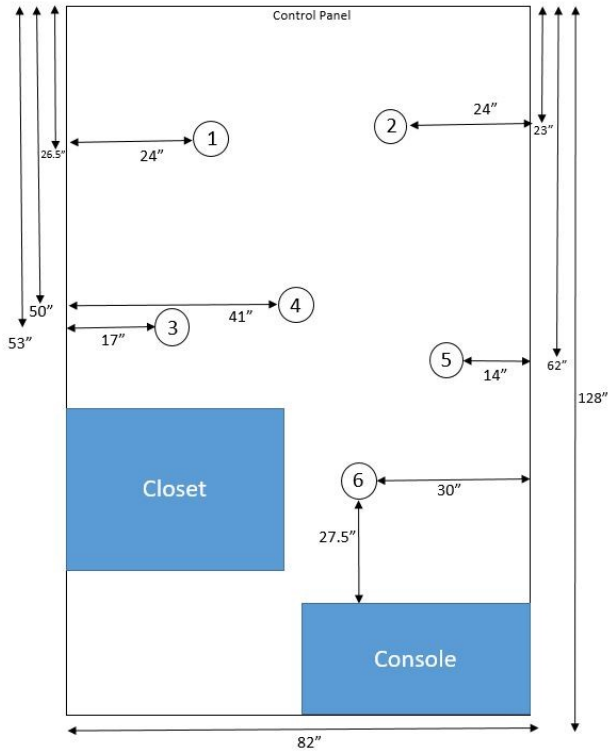


Figure 9. Gray Eagle UGCS dimensions and microphone placement.



Figure 10. Microphone positions one, two, three, four, and five in Gray Eagle UGCS.

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Materials

Brüel & Kjær (B&K) Type 4938-A-011 (4938) microphones with Type 2670 preamplifiers (Figure 4) were used to measure sound levels. The 4938s are ¼-inch pressure-field microphones designed for high-level and high-frequency measurements. The microphones have a frequency range of 4 Hz to 70 kHz, and a dynamic measurement range of 42 dB to 172 dB with a maximum peak sound level of 180 dB(P).



Figure 11. Brüel & Kjær Type 4938-A-011 microphones with Type 2670 preamplifiers.

The microphones provided the input signal to a B&K LAN-XI Type 3050 module running Notar Time Data Recorder software in stand-alone mode. The module is a six channel system with a bandwidth of 51.2 kHz (sample rate of 131 kHz). A B&K 2270 hand-held analyzer was also used to supplement the measurement hardware. The 2270 is a multifunctional Class 1 sound measurement system the use of which added flexibility to the measurement activity. Additionally, a B&K Type 3052-A-3/0 LAN-XI data acquisition module, which has three input channels and a frequency range of direct current (DC) to 102.4 kHz, was to be used to collect additional data. Figure 5 shows the B&K Type 3052-A-3/0 LAN-XI and 2270 hand-held analyzer.

Power for the Type 3050 and Type 3052 modules was provided by Battery Module Types 2831-A. The battery module is a rechargeable Lithium (Li)-Ion battery with an output voltage of 14.8 V and a capacity of 6400 mAh. The battery is capable of powering a LAN-XI data acquisition module for over 7 hours (Brüel & Kjær, 2017).

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Figure 12. B&K Type 3052-A-3/0 LAN-XI and 2270 hand-held analyzer.

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Figure 13. LAN-XI data acquisition systems (circled) at Shadow launch site.

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Results

The results below are A-weighted average sound levels (LAeq) measured during the listed condition in decibels [dB(A)].

Shadow



Figure 14. Close up of Shadow on launcher.

Measurements were conducted during the launches of two Shadow UASs. The launches were separated by about 30 minutes. The results are shown in Table 2.

Table 2. Shadow UAS sound levels

dB(A)	Shadow UAS Sound Levels							
	Launch 1				Launch 2			
	Start-up	Low Idle	High (Snaps)	Launch	Start-up	Low Idle	High (Snaps)	Launch
Mic 1	96.8	91.7	110	105	97	91.4	108	107
Mic 2	92.7	87.2	105	101	92.6	87.4	104	103
Mic 3	87.9	81.9	99.3	94.8	86.9	81.8	97.7	97
Mic 4	84.8	79.4	96.5	91.2	84.5	80.1	94.9	94.4
Mic 5	82.2	76.5	93.5	87.6	81.3	77.2	92.1	92.3
Mic 6	81.3	75	92.2	95.9	80.3	76.1	90.7	90.5

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Sound levels measured in the Shadow UGCS are shown in Table 3. Each measurement sample was one minute long.

Table 3. A weighted ambient sound levels in Shadow UGCS

dB(A)	Shadow UGCS Sound Levels		
	Sample 1	Sample 2	Sample 3
Mic 1	79.5	79	78.6
Mic 2	77	75.8	76.7
Mic 3	81.3	80.8	79.7
Mic 4	76.2	76.6	76.1
Mic 5	73.1	73	72.4
Mic 6	74.2	72.5	72.8

Gray Eagle



Figure 15. Gray Eagle UAS.

Measurements were conducted prior to launch while the Gray Eagle UAS idled on the tarmac. The results are shown in Table 4. During the 'Low Idle' measurement Microphone 2 and Microphone 5 malfunctioned therefore no result (NR) was measured.

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Table 4. Gray Eagle UAS sound levels

dB(A)	Gray Eagle UAS Sound Levels	
	Low Idle	High Idle
Mic 1	78.7	103
Mic 2	NR	100
Mic 3	75.1	98.3
Mic 4	72.7	95.1
Mic 5	NR	89.4
Mic 6	61.6	85

Sound levels measured in the Gray Eagle UGCS are shown in Table 5. Each measurement sample was one minute long. The results of Microphone 2 and Microphone 5 are highlighted to indicate potential microphone malfunctions.

Table 5. A-weighted ambient sound levels in Gray Eagle UGCS

dB(A)	Gray Eagle UGCS Sound Levels		
	Sample 1	Sample 2	Sample 3
Mic 1	76.2	74.8	77
Mic 2	93.1	88.7	83.8
Mic 3	77.1	77	77.8
Mic 4	78.6	76.9	77.4
Mic 5	81.5	75.8	76.1
Mic 6	74.4	73.6	74.8

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Discussion

In order to assess the noise exposure of the Shadow UAS operator a microphone was placed near his position, which was about 100 ft away from the launcher, as shown in Figure 16. The operator was wearing a David Clark H10 Headset which has a listed Noise Reduction Rating (NRR) of 23 dB. Unfortunately, due to a hardware malfunction no data was collected at the operator position. However, looking at the results in Table 2 for mic 3 and mic 4, which were 90 feet and 115 feet away from the launcher respectively, it can be determined that the sound levels at the operator position would reach a maximum of approximately 98 dB(A). The NRR provided by the headset should offer adequate protection for the operator, especially due to the short exposure time of the maximum sound levels which occur during snaps (engine alternating between high and low idle) and at launch.



Figure 16. Shadow operator with microphone nearby.

The Gray Eagle Operator did not wear hearing protection. For the majority of time that the Gray Eagle UAS was on the tarmac it was at low idle and the operator was standing back at least 60 feet from the aircraft. However, there was an occasion shortly after start-up that the operator had to be next to and even under the aircraft. Measurements taken at these positions with the hand-held analyzer resulted in a measurement of 87 dB(A) next to the UAS on the right side, and a measurement of 92 dB(A) underneath. The operator was not exposed to these levels for more than a few minutes but it is still recommended that some type of hearing protection be worn. Further, Section 7-13 of DA PAM 40-501 states that appropriate hearing protection must be worn

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when working with or around aircraft that produces exposure to steady state noise levels of 85 dB(A) of any duration.

The headsets worn in the UGCSs were the RACAL RA5000/1/1026 Raptor which have an NRR of 18 dB. The UGCS sound levels are shown in Table 3 and Table 5 and according to DA PAM 40-501 hearing protection would not be required since levels do not exceed 85 dB(A).

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Conclusions

The purpose of this test was to determine the sound level around the Shadow and Gray Eagle UASs and inside the UGCSs. The results indicate the Shadow UAS operator should be well protected using the David Clark H10 headset. However, it is recommended that the Gray Eagle operators use some sort of hearing protection. The sound levels in both UGCSs were relatively low and the RACAL RA5000/1/1026 Raptor headsets that are currently being used will provide more than adequate hearing protection.

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Appendix A. Acronyms and Abbreviations

BCT	Brigade Combat Team
dB(A)	decibels
kHz	kilohertz
LAeq	A-weighted equivalent
Li	Lithium
mAh	milliampere hour
MALE	Medium Altitude, Long Endurance
NR	no result
NRR	Noise Reduction Rating
TUAS	Tactics Unmanned Aircraft System
UA	unmanned aircraft
UAS	Unmanned Aircraft System
UAV	unmanned aerial vehicle
UGCS	universal ground control station
USAARL	U.S. Army Aeromedical Research Laboratory
V	volt
WPG	Warfighter Protection Group

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TRADE-SPACE ANALYSIS OF A SMALL UNMANNED VEHICLE SYSTEM FOR RADIOLOGICAL SEARCH MISSIONS

THESIS

Sam B. Harriger, Captain, USAF

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TRADE-SPACE ANALYSIS OF A SMALL UNMANNED VEHICLE SYSTEM FOR RADIOLOGICAL SEARCH MISSIONS

THESIS

Presented to the Faculty

Department of Systems Engineering and Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

Sam B. Harriger, BS

Captain, USAF

March 2020

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TRADE-SPACE ANALYSIS OF A SMALL UNMANNED VEHICLE SYSTEM FOR RADIOLOGICAL SEARCH MISSIONS

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Chair

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Dr. Christopher M. Chini
Member

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Abstract

Nuclear and radiological terrorism is a persistent threat to United States national security. The research and development of new technological capabilities is vital to bolstering emergency response and prevention capabilities in support of national security initiatives. This research characterized the applicable trade-space for a system of unmanned vehicles deployed for search, detection, and identification of radiological source material. Exploration included the development of a CONOPS, a functional decomposition and physical allocation, design considerations, and an analysis of feasibility and utility. The concept system comprises of a ground control station, ground vehicle, hybrid-electric multirotor, and fixed-wing vehicle with an open architecture permitting the exchange of payload components. Payload options include a Geiger-Müller detector or scintillator for large area search and a scintillator or high purity germanium semiconductor for radioisotope identification. Endurance estimates revealed that a hybrid-electric multirotor is capable of carrying a 6.8-kilogram payload for 58 minutes. Similar estimates indicated that a battery-powered fixed-wing vehicle can provide a minimum of 41 minutes of endurance with a payload mass fraction of 15% (1.36-kilogram payload), whereas a gasoline-powered vehicle with the same payload mass fraction (1.95-kilogram payload) can operate for 12 hours. Electric multirotors are limited to a maximum endurance of 20 minutes, which is insufficient for radiological search missions. The system concept proves effective to the radiological search mission and can be expanded to other mission areas through its open architecture.

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Sam B. Harriger

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TRADE-SPACE ANALYSIS OF A SMALL UNMANNED VEHICLE SYSTEM FOR RADIOLOGICAL SEARCH MISSIONS

I. Introduction

Overview

The purpose of this research is to characterize the applicable trade-space for a small unmanned vehicle system (SUVS) to conduct search, detection, and identification of radiological and nuclear materials. The system will comprise a combination of airborne and ground platforms with integrated radiation detectors to complete a radiological search mission with input from a human operator. Both the platforms and radiation detectors suitable for the platforms will be discussed to understand the limitations and feasibility of employment.

Background

Compared to chemical and biological weapons, which also fall under the weapons of mass destruction (WMD) umbrella, nuclear and radiological materials utilize more sophisticated and technical processes in order to produce quality material for use. Due to this complexity, terrorist organizations are unlikely to produce their own materials and must acquire them through illicit means. These materials are characteristically secured and monitored during production, transportation, storage, and use so that they are not compromised. However, there are also large quantities of material available on the black market due to deficient security and accountability from previous decades. Due to the numerous uses and locations of radiological and nuclear materials, the opportunity for

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these materials to fall outside of responsible control and be utilized in nuclear terrorism is a very real threat to national and international security. In order to locate and secure these materials, federal, state, local, and international partners deploy personnel, technology, and other investigative methods to detect and interdict illicit radiological and nuclear materials before being weaponized. As stated by President Trump in the 2018 National Strategy for Countering Weapons of Mass Destruction Terrorism, "as the threat of WMD terrorism continues to evolve, however, our defenses against it must evolve as well" [1].

As part of the counter-WMD mission space, it is necessary for law enforcement and military organizations to be able to detect, locate, and confirm radioactive source material within moderate to large-sized geographic areas. Intelligence gathering may provide advanced knowledge of personnel, vehicles, infrastructure, location, and intent associated with radiological materials. However, the radiological search mission is still a difficult and potentially dangerous logistical problem that is traditionally accomplished by personnel with handheld detectors. Depending on the quantity and activity of the radiological isotope as well as the delivery method of an assembled WMD, hazards exist from both the radioactive material and the weapon's delivery system. Detectors capable of confirming radiological materials must be operated and sometimes placed within short distances of source material for long periods of time to produce accurate and usable data. Radiation exposure from highly radioactive material can cause health effects or even death if too much time is spent near the material. Furthermore, explosively driven WMDs present the potential for severe injury or death if detonated near responding

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personnel. The capability to find, locate, and confirm the existence of these hazardous materials utilizing an unmanned system would be a valued asset that could mitigate these hazards to personnel.

Research and development of unmanned vehicles for radiological response began in the 1970s with the reactor meltdown at Three Mile Island, which was further expanded with the second global nuclear accident at Chernobyl in 1986 [2]. There are many sources of research that have looked at optimizing detector technologies, configurations, and software to effectively detect, locate, and map radiation strengths [3]–[8]. There are commercially available systems that utilize detector technologies to provide usable data to an operator about radiation concentrations as well as real-time video imagery [9]. These systems have only been commercially available for a matter of years, and with constantly improving hardware and software, this is an area that will continue to progress and provide a more accurate and practical product to the end user. However, there is little research looking at utilizing a system of UVs to accomplish radiological search operations. The development of this system poses unique challenges due to the differing unmanned platforms: vehicles capable of rapid search may not be capable of dwelling near a target, while vehicles capable of long dwell times generally have short mission duration and are incapable of quickly covering large geographic areas. Creating a flexible system with multiple platforms and multiple integrable detectors allows the use of one system in several configurations to accomplish a variety of detection, location, and confirmation scenarios.

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Problem Statement

Several hazards endanger personnel when conducting radiological search operations. There are potential health effects from the radiation being emitted from the source material, as well as threats from enemy combatants and potential deterrent devices in contested areas. Radiation exposure should be kept as low as reasonably achievable, commonly known by the acronym ALARA [10]. The concept of the ALARA principle is to expose the minimum amount of people to the minimum amount of radiation for the minimum amount of time. The same principle can also be applied to the other inherent dangers of radiological WMD search that are posed by enemy combatants, which would be to limit time on target to minimize the risk to responding personnel. Therefore, the development of an unmanned vehicle system for radiological search could contribute to the radiological search mission by reducing hazardous exposures to personnel and minimizing the number of personnel required for search operations.

Research Objectives

As mentioned in the background, the threat of WMD terrorism is ever present and capabilities need to be continually developed and improved to counter their employment [1]. Establishing a system of UVs for the detection, location, and identification of radiological and nuclear materials can assist in this mission set and act as a force multiplier for law enforcement and military organizations. Several research objectives have been established to fully characterize the system of UVs that could be developed for radiological search operations:

1. Characterize the SUVS trade-space for radiological search missions

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2. Develop the system framework along with the system limitations, capabilities, and design considerations
3. Assess the operational feasibility and utility from a functional and scenario perspective

For the purposes of this research, a trade-space analysis frames the solution space in which a viable and feasible result may reside [11]. When considering a radiological search SUVS and the research objectives identified above, several questions arise that will assist with addressing the objectives and the concept system design. What radiological sources are of the most interest? Which detectors are suitable for finding these sources and can be incorporated on an unmanned platform? What are the operating characteristics and limitations of these detectors? What would a shared system architecture consist of in terms of similar and differing components for radiological search and detector integration?

Methodology Overview

This research is a targeted mission area analysis scoped at the feasibility and suitability of a SUVS in support of radiological search and geolocation missions. The methods include a survey of the existing state of technology for both radiological detection and unmanned vehicle capabilities, the development of a concept of operations (CONOPS), a system decomposition, and an analysis of the feasibility and utility of the proposed system.

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Research Limitations

The focus for this research is limited to sealed radiological and nuclear source material search, detection, location, and confirmation. A sealed source is any radioactive material that is encased in a manner that prevents leakage or escape of the material [10]. The encasement's primary purpose is to prevent the spread of contamination during regular use or transportation of the material. Radiological sources can be found in medicine, agriculture, industry, transportation, research, construction, geology, and mining. These sources are regularly lost or stolen, which can lead to weaponization in the form of a WMD. This research is not addressing WMD-related hazards or tactics, techniques, and procedures for operating in the vicinity of suspect WMDs. Additionally, this research is not focusing on nuclear and radiological incident consequence management operations that address the spread of contamination to people and the environment [12].

Previous Work

A previous Air Force Institute of Technology (AFIT) graduate student researched various radiation detector technologies to be flown on a small autonomous unmanned air vehicle and developed algorithms to rapidly detect, locate, and identify radiation sources. Another AFIT graduate student investigated the use of employing chemical sensors on unmanned aerial systems (UAS) in a tactical environment. The research focused on developing and employing tactics, techniques, and procedures for conducting chemical, biological, radiological, and nuclear (CBRN) reconnaissance and surveillance utilizing small UAS [13]. This research was used as a starting point for this thesis.

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Preview of Thesis

This thesis is written in a traditional format. Chapter II discusses terminology, existing technologies, and previous research regarding radiation detectors and unmanned platforms. Chapter III addresses the methodology used to characterize the unmanned system and radiation detection trade-spaces. The findings and results from trade-space analysis are detailed in Chapter IV. The thesis is concluded with Chapter V, which reviews the research findings and presents potential avenues for additional research.

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II. Literature Review

Chapter Overview

This chapter will cover the fundamental science of radiation detectors to better understand the different parameters that may affect design decisions for equipping an unmanned vehicle. Furthermore, current unmanned technologies will be discussed to provide background information on the current state of technology that is available through commercial sources or pre-existing government systems.

Types of Radiation

There are multiple forms of radiation that are typically categorized by charged particle emissions and uncharged radiation. Charged particle radiation includes alpha particles, beta particles, and fission fragments. Uncharged radiation includes neutrons, gamma rays, and x-rays. X-rays, alpha particles, and beta particles are typically measured for contamination monitoring or for surveying and assessing a consequence management scenario (e.g. post nuclear detonation). Gamma rays and neutrons travel orders of magnitude further than alpha or beta particles, making them better suited for initial detection and location of radiological material [14]. Within the confines of the radiological search mission space and this research, gamma rays are the primary radiation of concern.

Gamma rays are photons with energies typically in the kilo- and mega-electron volt (keV, MeV) range. These photons are typically emitted when an excited nuclei transitions to a lower energy level, with the gamma energy determined by the differential

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of the excited and ground states of the nucleus. Many radioisotope decay events, such as alpha particle emission or nuclear fission, produce subsequent gamma photons in order to maintain nuclear stability [14].

Radiological Sources of Concern

There are over one thousand isotopes that have been found or created on earth, with the large majority being radioactive. Of the hundreds of radioactive isotopes, the International Atomic Energy Agency (IAEA) developed a list of isotopes that have hazardous direct human health effects when exposed to a sufficient quantity of said isotopes over a period of time. Using this list, the US Nuclear Regulatory Commission (NRC), working with the Department of Energy (DOE) and other agencies, established a list of 16 radionuclides of concern that, if gathered in significant quantities based on radioactivity (measured in Terabecquerels or Curies), carry the greatest risk of being incorporated into a radiological dispersal device (RDD) by terrorists (Table 1). The 16 threat isotopes can be found in most developed countries and are commonly used in research, medical, and industrial applications [15].

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Table 1. Category 1 and category 2 radioactive material thresholds [16]

Radioactive Material	Category 1 (Terabecquerel)	Category 1 (Curie)	Category 2 (Terabecquerel)	Category 2 (Curie)
Americium-241	60	1,620	0.6	16.2
Americium-241/Be	60	1,620	0.6	16.2
Californium-252	20	540	0.2	5.4
Cobalt-60	30	810	0.3	8.1
Curium-244	50	1,350	0.5	13.5
Cesium-137	100	2,700	1	27
Gadolinium-153	1,000	27,000	10	270
Iridium-192	80	2,160	0.8	21.6
Plutonium-238	60	1,620	0.6	16.2
Plutonium-239/Be	60	1,620	0.6	16.2
Promethium-147	40,000	1,080,000	400	10,800
Radium-226	40	1,080	0.4	10.8
Selenium-75	200	5,400	2	54
Strontium-90	1,000	27,000	10	270
Thulium-170	20,000	540,000	200	5,400
Ytterbium-169	300	8,100	3	81

Categories of Radiological and Nuclear WMDs

In the realm of WMDs, there are a few types that encompass the radiological and nuclear category, which are radiological dispersal devices (RDD), radiological exposure devices (RED), and improvised nuclear devices (IND). INDs are different from RDDs and REDs in that they use fissile materials, such as Uranium-235 or Plutonium-239, in order to create a nuclear yield through a nuclear fission chain reaction. They can either be an illicit nuclear weapon that is bought, stolen, or obtained from a nuclear state, or is fabricated by a terrorist group using illegally obtained fissile nuclear material. The

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nuclear explosion from an IND releases intense amounts of energy through shockwaves, heat, prompt radiation emission, and radioactive fission fragments (also known as radioactive fallout). INDs are not the focus of this research, as they present unique challenges for detecting, but it is important to understand the differences between INDs, REDs, and RDDs. REDs utilize highly radioactive materials to irradiate some arbitrary area without physically disbursing the radioisotopes [17]. An example of a RED is a gamma ray source, such as Cobalt-60, that is taped to the underside of a public bus seat. This would expose all passengers within a certain area with potentially harmful doses of gamma radiation while remaining inconspicuous. RDDs also utilize highly radioactive materials, but actively disburse them using delivery systems such as explosives, pressurized containers, fans, sprayers, crop dusters, or building ventilation systems. Compared to REDs, RDDs can potentially contaminate very large areas with extremely small pieces of radioactive material [17]. The resultant cleanup and decontamination are a serious and challenging problem for emergency first responders, which stresses the importance of detecting and locating illicit source material before a WMD can be constructed and employed.

Gamma Interactions

In order to locate and identify gamma photons from the radioisotopes discussed previously, we need to understand how they will interact with materials in the environment as well as our detectors. There are two primary mechanisms by which this occurs; photoelectric absorption (PE) and Compton scattering (CS). In PE absorption, a gamma photon is absorbed by an atomic electron that is then ejected from one of the

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atom's electron shells. This electron then deposits its energy in the material; if this interaction occurs in a radiation detector, it can produce a signal (voltage, current, etc.) that is proportional to the energy of the incident photon. Similarly, CS occurs when a gamma ray collides with an atomic electron; in this event, the gamma ray transfers a portion of its energy to the electron and scatters in a different direction from its incident trajectory. As with a PE electron, the recoiled electron will traverse the material where the interaction occurred and deposit its energy, possibly producing an output signal in our radiation detector [14].

Gamma Spectroscopy

Once the gamma photons interact with our detector and produce measurable signals, a histogram can be produced that correlates said signals to incident gamma energies. The measured gamma energies are grouped into energy bins, typically quantified in kiloelectron volts (keV). The height of an energy bin represents the number of counted interactions that correspond to the energy bin. Across the measured energy spectrum, the histogram of energy bins and corresponding counts represents a wave-shaped line called a pulse height spectrum. The clarity of a pulse height spectrum varies and is characterized by the detector resolution, which is a measure of the detector's ability to differentiate the signals produced by gamma interactions. The full width at half maximum (FWHM) is the width of the gamma ray peak at half of the highest point on the peak distribution. Detector resolution is the FWHM divided by the energy of this peak gamma ray and is conventionally expressed as a percentage. The lower the detector resolution percentage, the more defined a spectral line is, resulting in a higher likelihood

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to identify radioisotopes. Detector resolution is affected by the detector technology, the algorithms associated with the detector software, and varies with the energy of the incident gamma ray [14]. An example pulse height spectrum delineated into energy bins and counted events is shown in Figure 1. It is important to understand how a detector's resolution impacts the accuracy of identifying the radioisotopes that are present.

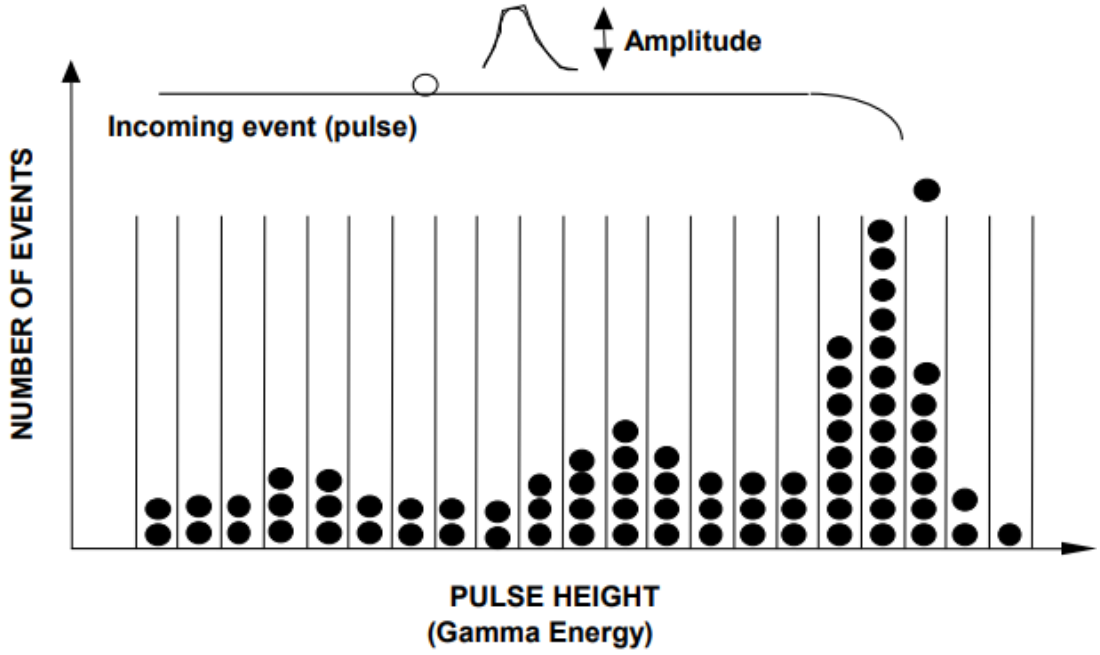


Figure 1. Voltage pulses collected into energy bins [18]

High-resolution (low percentage) detectors are more likely to differentiate between measured energy bins, allowing a more accurate assessment of which isotopes may be present. Low-resolution (high percentage) detectors may struggle to differentiate gamma photons that have similar energies, as they may be lumped together into a single energy bin. The precision of different detector technologies can be seen in Table 2. Energy

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resolutions of different radionuclide identification devices (RID) gamma ray detector types and Figure 2.

Table 2. Energy resolutions of different radionuclide identification devices (RID) gamma ray detector types [19]

Detector Type	Resolution at 662 keV
Thallium-doped Sodium Iodide (NaI(Tl))	6 - 8%
Lanthanum Bromide ($LaBr_3$)	2 - 4%
Cadmium Zinc Telluride (CZT)	1 - 2%
High Purity Germanium (HPGe)	< 0.2%

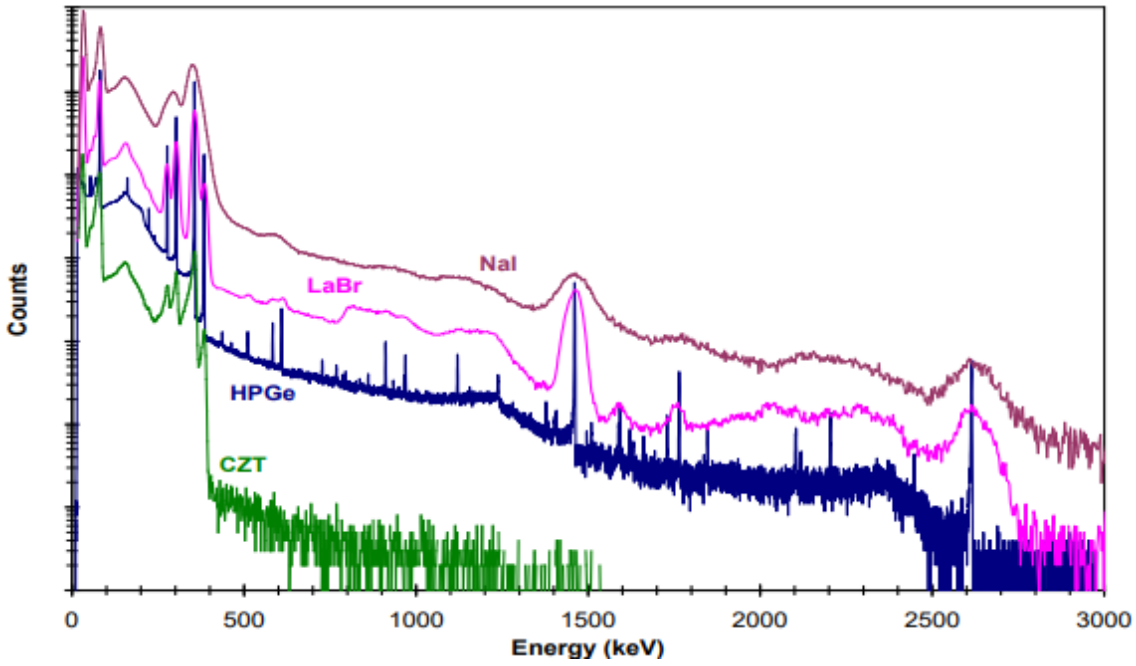


Figure 2. Barium-133 gamma ray spectra acquired with various RIDs [19]

Low-resolution detector materials, such as NaI, can lead to energy measurements blurring together into one energy peak, which does not accurately represent the energy spectrum and can lead to the misidentification of a radioisotope or a false negative. This blurring

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of NaI spectra can be seen in Figure 2 in the 300 keV to 400 keV range when compared to the other detector technologies. Furthermore, to attain the resolution of 7% listed in Table 2, the NaI detector measurement has a FWHM of about 47 keV from a 662 keV incident gamma ray. On the other hand, high-resolution detectors (e.g. high purity germanium) can differentiate between gamma energies that are within a few keV of each other [19]. In order to achieve a resolution of 0.2% listed in Table 2, the HPGe detector measurement has a FWHM of about 1.5 keV at 662 keV.

Detection Efficiency

A competing characteristic to detector resolution is efficiency; there are two components that make up detection efficiency, geometric and intrinsic. The geometric efficiency is determined primarily by a detector's distance from the radiation source and, to a lesser degree, the size of the detector. If we make the reasonable assumption that our gamma source is emitting photons isotropically, and that the size of the detector is small compared to the distance between it and the source, the fraction of emitted photons that will reach the detector (ε_G) is inversely proportional to the square of the separation distance (r^2) (Equation 1) [14].

$$\boldsymbol{\varepsilon_G \propto \frac{1}{r^2}} \tag{1}$$

If there is little to no material for the gammas to interact with between the source and the detector, this relationship can inform operational parameters such as standoff distance and loiter time.

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In contrast, intrinsic efficiency is a function of the detector itself, and is determined by the interaction material, its volume, and the energy of the incident photon. Dense materials, such as scintillators and semiconductors discussed later, have a higher concentration of electrons per volume for photons to interact with compared to gaseous material. All other parameters being equal, e.g. charge collection or conversion efficiency, a detector with a low-density material will need a larger volume than one with a higher density, affecting operational parameters such as vehicle size and carry capacity [14], [18].

Gamma Attenuation

Gamma attenuation is when a certain quantity of gamma rays passes through an intervening material. This is due to the previously mentioned PE and CS interactions that occur. Attenuation can have a large effect on the amount and strength of gamma energies incident on a detector volume. When intervening material is present, the quantity of incident gamma rays is decreased and Equation 1 no longer applies; such intervening material, such as building walls or radiation shielding, would require a detector to be closer for detection and identification.

Gas-Filled Detectors

Gas-filled detectors operate when incident radiation interacts with fill gas to create ionizations. Using an applied voltage across a cathode and anode, ions are collected to create an electrical signal in the form of a current or pulse [20]. Gas-filled detector volumes are typically sealed and pressurized in order to preserve the

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performance of the fill gas [21]. The output signal of a gas-filled detector is dependent on the voltage applied, which is pictured in Figure 3. The higher the applied voltage, the higher the output signal. Gas-filled detectors for radiation surveying are typically operated in three regions: ionization, proportional, and Geiger-Müller (G-M). Due to the low voltage of the ionization region, there is no amplification of the number of ions created by incident radiation, resulting in a detector measurement that is directly proportional to the number of original ion pairs created. The proportional region has a higher-applied voltage and operates similarly to the ionization region, except that the original ion pairs are amplified, creating more ionizations in the detector volume. The measurement of the resulting pulse is proportional to the number of original ion pairs formed. The G-M region has the highest usable operating voltage. This significant voltage difference leads to an avalanche effect following gamma interactions, increasing the produced ions by up to one million-fold throughout the entire detector volume [22].

Gas is not dense and has a low probability for interaction with incident radiation. Therefore, a larger gas-filled volume increases the probability for interaction. Additionally, operating gas-filled detectors in the G-M region increases the potential for ion pairs to be attracted to the charged electrodes, making it ideal for large area searches. Operation in this region gives the most sensitive detection capability but requires the addition of a separate power supply in order to meet voltage requirements.

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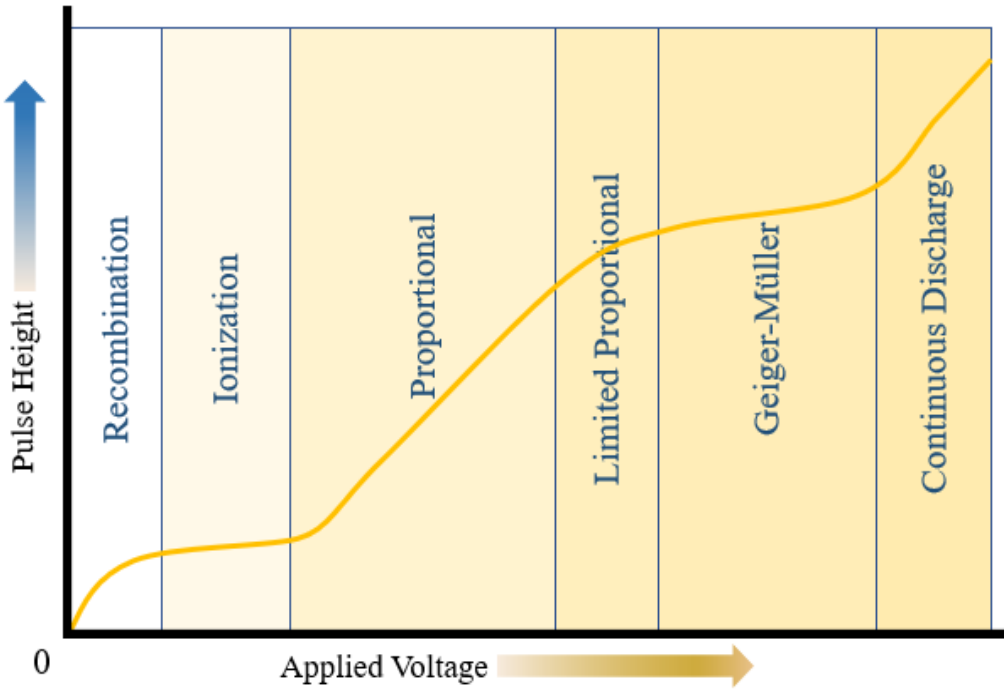


Figure 3. Gas-filled detector six region curve for gamma interactions [22]

The extra batteries, along with the necessity to increase detector volume, increases weight and space requirements and adds heat to the system. A negative aspect of gas-filled detectors is the inability to differentiate between different radiation energies. However, this is a capability that scintillators and semiconductors possess.

Scintillation Detectors

Scintillation is when radiation interacts with certain detector media and produces visual light. Scintillators can be organic or inorganic and can be a liquid, solid, or gas, but solid materials are the most common for detectors. They are typically encased in reflective materials to provide extra rigidity, waterproofing, and to prevent luminesced

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light from escaping [20]. A photomultiplier tube or photodiode converts the light into an electrical pulse that can be interpreted by detector software [14].

Each scintillation material has different inherent properties that need to be considered for detector selection, such as hygroscopicity, decay time, and sensitivity to shock. Some materials degrade if exposed to water, even water vapor in ambient air, so airtight chambers are required for certain scintillators. Additionally, scintillators are typically dense crystals that require photomultiplier tubes to convert light into meaningful data. This adds weight and space requirements that need to be considered for UV application. However, scintillators require significantly lower applied potential compared to gas-filled detectors, so a separate power supply is not necessary for operation. Vibrations can also be of concern for some scintillating materials. Depending on the scintillator, vibrations can induce counts in the materials and can damage brittle crystals, which could produce false positives and unreliable data if using for search operations [3], [23].

Plastic scintillators are low-cost, robust, and can be made very large. However, the detectors lack resolution and are ineffective for identification of a radioisotope. NaI scintillators are very common and have been employed for decades. NaI crystals can be made large (in excess of 10 centimeters x 10 centimeters x 46 centimeters) but are considerably more expensive than plastic scintillators. The advantage of sodium iodide is that it can be applied to both initial search and identification of source material. Handheld versions may be undersized for UV purposes, but a larger crystal could give

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better detection efficiency while maintaining spectroscopic abilities for isotope identification [4].

Semiconductor Detectors

Semiconductor detectors do not luminesce when interacting with gamma rays. The process is similar to gas-filled detectors, which measure resulting ionizations from radiation interactions over a voltage difference [14]. However, semiconductor detectors differ from scintillators and gas-filled detectors in that they directly measure excited electrons, which produces much better energy resolution [22]. HPGe detectors are commonly used for the detection and identification of radioisotopes due to their excellent resolution. The disadvantages of these systems are that they must be cryogenically cooled with liquid nitrogen or an electromechanical Stirling-cycle cooler, resulting in a very heavy instrument. Additionally, HPGe detectors are significantly more expensive than scintillators. An example system is the Ortec Micro-Detective. This is a 15-pound (6.8-kilogram) handheld detector that utilizes an electromechanically cooled HPGe crystal. It is capable of producing a resolution of less than one percent and can operate for 5 hours on a rechargeable Lithium-ion battery. However, the detector performance can be affected by vibration and heat [4].

Multirotor Unmanned Aerial Vehicles

Current commercially available multirotor systems use either electric power plants using lithium polymer batteries or hybrid-electric systems that utilize gas engines as generators to produce power for electrically driven motors. Electrically driven

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systems have limited operational flight times due to the low energy density of battery technology. Electric multirotor systems with sensors other than small cameras are typically limited to 30-minute duration flights, which is not ideal for conducting radiological search operations. On the other hand, hybrid-electric systems have had success in more robust and longer duration applications due to the higher energy density that gasoline provides as an energy source [24]. Gasoline-powered generators allow hybrid-electric multirotor vehicles to fly much longer and farther than their all-electric counterparts. Commercially available hybrid-electric systems currently on the market list specifications that are vast improvements upon battery powered systems. Claims of 5-hour flight duration, payloads as heavy as 12 pounds (5.5 kilograms), and a range of 110 miles (177 kilometers) are a few examples from Skyfront's Perimeter-8 model [25]. The longer duration, range, and heavier payload capabilities make multirotor systems much more attractive and applicable to arenas such as emergency response and military operations [24]. However, gasoline engines present unique design and operating issues that do not affect battery-powered systems, such as mechanical noise, combustion noise, engine start-up, generator maintenance, exhaust, cooling, and vibrations. These additional side effects of a hybrid-electric power plant could affect the overall performance of the system and the feasibility of deploying and operating in constrained environments.

Fixed-wing Unmanned Aerial Vehicles

The purpose of a fixed-wing vehicle within this system would be to cover a large area during initial the search for radiological material. In order to increase the likelihood

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for successful detection, the vehicle should operate at lower altitudes to have the highest probability of radiation interaction with the on-board radiological detection system. Additionally, time over target is also an issue due to detector hardware and software delays. A fast platform may not detect radiological material during overflight compared to a slower moving platform. Therefore, a balance between speed and endurance must be managed in order to adequately meet desired performance outcomes. Fixed-wing platforms have been around longer than multirotor systems and can vary greatly in size and in the type of power plant. Hand-thrown battery-powered platforms have been operated in many restrictive and rural environments but are limited by the payload weight and area that can be covered. Incorporating liquid fuel engines to drive single propellers has proven successful for platforms over 20 pounds (9.1 kilograms). An example of small UAS capabilities is the UAV Factory Penguin series. It is available as a battery-powered system or with an electronic fuel-injected engine, with claims such as endurance from 110 minutes to 20 hours, range of up to 60 miles (97 kilometers), and a payload upwards of 22 pounds (10 kilograms). Early models of the system have been flown since 2009 and are utilized in more than 43 countries [26].

Unmanned Ground Vehicles

Unmanned ground vehicles were some of the earliest operated unmanned mobile systems. They were utilized as early as 1981 during the Chernobyl nuclear reactor meltdown in the attempt to limit exposure to responding personnel [2]. Many variants and sizes are currently operated by federal and local governments across the United States and internationally. Ground vehicles have the advantage of being able to loiter in

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an area for long periods of time and also carry the heaviest payloads compared to aerial vehicles. However, ground vehicles are limited in range and can be disabled by rough terrain and obstructions.

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III. Methodology

Chapter Overview

The purpose of this chapter is to discuss the methods used for analyzing multiple focus areas of the radiological search mission. The resulting research will culminate in characterizing the trade-space for the unmanned vehicle system. Methods to be used include a concept of operations, a system decomposition, and a feasibility analysis of utilizing the system for radiological search operations and other mission areas. The flow of this research will resemble the highlighted portion of the systems engineering "V", which is depicted on the left side of Figure 4.

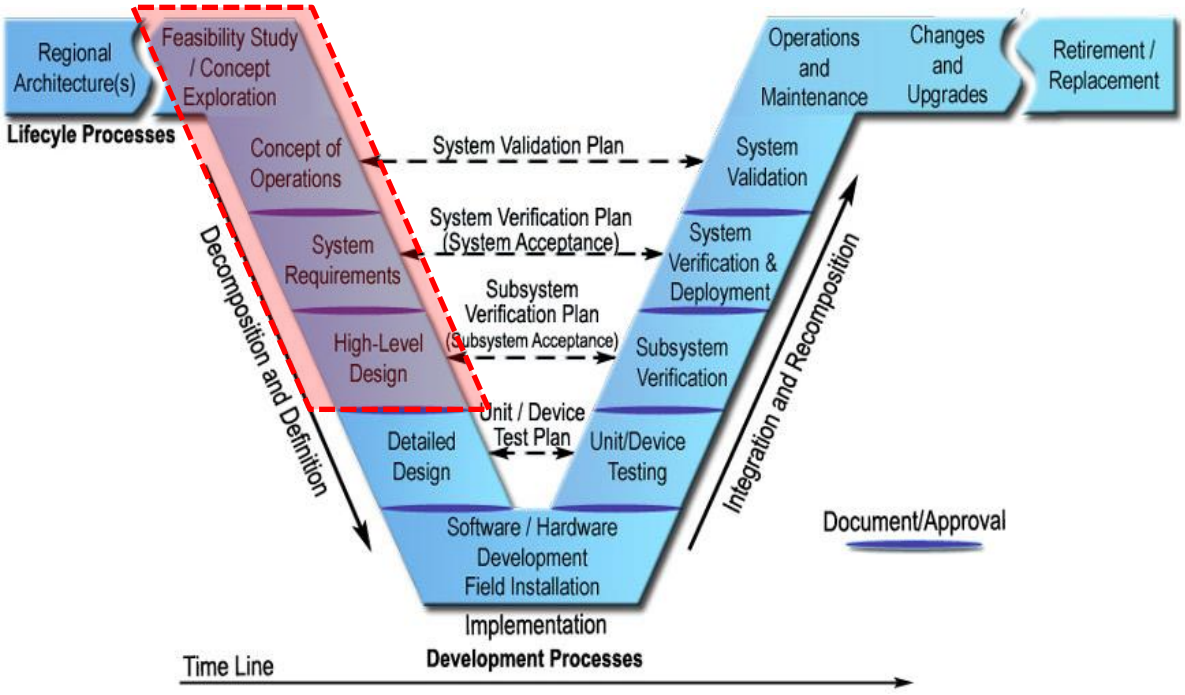


Figure 4. Systems engineering "V" for system development [27]

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A CONOPS for the system will be established with corresponding measures of effectiveness (MOEs) at the mission level. The CONOPS is not linked to user requirements, but rather a hypothetical approach to unmanned vehicles for completing radiological search missions currently accomplished with human operators. Use cases will be derived from the CONOPS, as well as resulting tasks, attributes and measures of performance (MOPs). A system decomposition of the functional system architecture with functional tasks and a physical hierarchy will be derived in order to allocate system functions to componentry. The approaches to these methods will be further discussed below.

Concept of Operations

An assessment of radiological search operations will be conducted in order to determine the realistic operational umbrella that an unmanned system could be deployed in support of. Understanding the limitations of the mission space that the system is applicable to will also apply to the derivation of the system's architectural makeup as well as potential architecture modifications needed to make the system useful in other mission areas. Within the overarching mission of performing radiological search, it is important to understand what limitations there are by introducing unmanned platforms and what information needs to be collected and delivered by an unmanned system. A CONOPS will be established which will detail mission needs, limitations, capabilities, and scenarios appropriate to the system. Additionally, it will include the tasks, attributes, and measures of the conceptualized system [28].

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The CONOPS will also include a mission timeframe, operational needs, system limitations, enabling capabilities for system operation, and valid scenarios for system employment. The system CONOPS will frame the mission set that it can be deployed in support of. An example CONOPS from the 2019 AFIT UAS three-course design and testing series will be used as a baseline for this research. In addition, some imposed design requirements of the system will be presumed and discussed in terms of their functionality to the mission and why they are important for operational use.

Mission needs will provide information about expected capabilities the system should have to perform the radiological search mission. These can be made for both friendly and adversarial conditions and will be logical, realistic, and necessary for continuing the conceptualization process. Unrealistic assumptions will be avoided, with the focus being placed on gaps in knowledge that are important for successful planning and characterization of the system. Operational limitations can be physical in nature or be due to self-imposed policy that restricts operational functionality. Policy can be leadership driven, multinational, or economic based. Operational constraints can be imposed in the form of rules of engagement, which can vary between commands, organizations, and political boundaries. Policy concerns will not be discussed in this research, with the focus being placed on physical operational limitations of the various subsystems of the unmanned system. Environmental and scenario-specific constraints will be addressed as part of the physical limitations.

Lastly, scenario examples will be provided in order to understand the range of missions that the conceptualized system can cover. These scenarios define friendly and

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adversarial conditions, enabling capabilities for system functionality, and the expected value toward mission completion. The scenarios used in this research are not all-encompassing of the system's abilities but provide context to the potential utility of the system.

System Decomposition

Using the CONOPS, a decomposition of the system will be derived. The decomposition will consist of a use case model for the system, a functional decomposition, and an allocation of system functions to physical componentry. The CONOPS will drive the contents of the functional decomposition. The CONOPS will have traceability to the functional decomposition and the physical architecture of each system module. At the basic level, physical componentry of the various systems will be linked to performing all tasks associated with completing the radiological search mission.

The functional decomposition and allocation will be completed using Cameo System Modeler 19.0, which is a model-based systems engineering software tool that uses Systems Modeling Language (SysML) to develop systems engineering solutions [29]. As a starting point for the functional decomposition and allocation, a reference architecture will be used and expanded upon. The reference architecture (RA) was developed by several AFIT professors associated with the small unmanned aerial system courses [30]. The RA is organized by four top-level packages, which comprise a component library, a basic multirotor system, a basic ground control station (GCS), and an example system concept integrating the GCS and fixed-wing UV. Components within each package are further broken down into value properties and ports that characterize

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the component, such as memory capacity, operating system type, radio frequency, and cost. The properties are customizable for the user's desired specificity, but not comprehensive of everything that may need to be measured. Additional properties can be added to the concept system's componentry blocks as needed. Lastly, the RA provides an example of a decomposed CONOPS for a remote targeting system with a use case model and the associated activity diagrams. The user of the RA is responsible for developing a use case model and functional tasks that meet the requirements for the pertinent CONOPS with traceability to physical componentry, which is the end state of the system decomposition for this research.

Using the established use cases, tasks, attributes, measures, as well as MOEs, MOPs, and performance factors will be derived that exemplify mission execution of the use cases [31]. Mission-level tasks that feed into mission execution will be identified along with important attributes that are valuable and feasible to measure. These tasks, attributes, and measures are evaluating the mission space from an agnostic perspective, pertaining to both human and system execution. An MOE is a measure of how well an operational task or set of tasks is executed within its expected operational environment. MOEs will be established that pertain to the radiological search mission and the expected operating environmental conditions yet are mission-based and not system-specific [32]. MOPs are a refinement of MOEs and provide measurable performance factors that help evaluate an MOE's status. The attributes will coincide with MOPs and the attributes' measures will be analogous to listed performance parameters. The list will not be exhaustive of all potential MOEs, MOPs, and performance parameters, but will highlight

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key factors that characterize the system's effectiveness at completing the radiological search mission.

Analysis of Feasibility and Utility

The last segment of this research is to evaluate the feasibility of incorporating the system into radiological search operations. The spectrum of mission operations will be considered, to include execution of the entire operation with an unmanned system, incorporating the system into a portion of operations, or not utilizing the system for radiological search missions. However, the focus of the feasibility discussion will be the scenarios identified in the CONOPS. As part of the feasibility analysis, estimates of vehicle endurance will be determined corresponding to vehicle size, battery and fuel capacity, and payload size. Furthermore, the system's utility to other mission areas will be assessed, along with the necessary system architecture modifications to expand its capabilities for current and emerging missions.

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IV. Analysis and Results

Chapter Overview

From the methodology presented in Chapter III, the analysis of the radiological search system will be approached from an academic yet practical perspective. Characterizing the system, its capabilities, and the physical framework to meet those capabilities are beneficial for gaining an accurate sight picture of the conceptualized system. However, the academic approach will culminate with the feasibility analysis of the system by realistically considering the potential benefits and possible drawbacks that this system could present to gaining units and agencies for the radiological search mission and other mission areas. New technological capabilities are not always viable to replace or supplement current tactics, techniques, and procedures, which will be discussed at the end of this chapter.

Concept of Operations

This CONOPS defines a prototype system and the associated efforts to assess system architecture and demonstrate the feasibility and utility of a concept solution before a prototype demonstration phase. The CONOPS, and the proposed system framework solutions associated with it, address the system's vehicles, sensors, user interface software, communication system, support functions, and operator actions for application to the radiological search mission.

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Scope

This CONOPS is intended to be an enabling concept and is written at the tactical level. More specifically, the radiological search CONOPS describes the projected utilization by Department of Defense (DoD) CBRN personnel, explosive ordnance disposal (EOD) technicians, and special operations forces (SOF), as well as analogous federal, state, and local entities necessitating the capability to detect, locate and confirm the existence of hazardous radiological material. The radiological sources will be in one of two categories: an orphan source where the material is lost or stolen or when the material has already been weaponized into an RDD or RED.

Mission Timeframe

Mission timeframe refers to the expected time it will take to research, develop, acquire, test, and deploy the objective system to operational units. The intent for the system's research and development phase is to utilize commercial off the shelf (COTS) and government off the shelf (GOTS) technologies to reduce initial startup time typically seen for newly developed systems. Applying previously researched and tested equipment to system construction will expedite this portion of the process. It will also shorten the time required to develop training programs and support equipment required to field the system. The mission timeframe is expected to be between two and five years. Two years is a best-case estimate to allow for research, acquisition, testing of the separate components, and assembling them into an operative system of systems. This also includes the procurement of support equipment and the development and execution of training for system operation and maintenance. The system should be completed and fielded within

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five years due to the rapid pace of innovation in the unmanned vehicle industry. A system under development for a longer period of time will be outpaced and become obsolete prior to becoming operationally fielded.

Mission Needs

The system will deploy to meet intelligence-based missions as required or to aid in the search and recovery of lost, stolen, or other forms of radiological source material. The system under consideration should be small in size but capable of searching an area of 3 square kilometers or larger, to include, but not be limited to, large urban buildings and sea-based vessels. The system is to be used by tactically deployable units from federal, state, and local organizations, so logistical requirements should be moderately small in size. The system should function with no more than four human operators and should be deployable utilizing no more than a transport vehicle and trailer for transportation. The objective system should be easily maintainable and should integrate as many COTS and GOTS components as possible. Garrison maintenance equipment capabilities and battery charging units are within the scope of the objective system. This does not include commonly found tools such as wrenches and screw drivers. While the unmanned vehicles are intended to be reusable, the cost of the systems should be sufficiently low to allow disposal in lieu of costly decontamination, hazardous recovery, and vehicle loss or theft. Due to the potential operation in contested areas, loss or theft of system vehicles should not provide substantial exploitable information or materiel to adversarial forces.

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The baseline system shall contain a combination of air vehicles, a ground vehicle, and a ground control station for user interface. Using the system of vehicles equipped with various and interchangeable payloads, the system will be able to locate and confirm the existence of radiological source material, as well as generate a three-dimensional radiation dose rate contour map of the search area. Due to the continuous improvement of technology in unmanned vehicles and radiation detection equipment, the system shall employ a modular, open system architecture which facilitates the integration of new sensors and subsystems throughout its lifecycle. This includes but is not limited to defense programs of record (PORs), COTS and GOTS technologies, and sensors associated with other CBRN constituents. However, the system should make extensive use of COTS and GOTS componentry and existing vehicles in order to minimize development time and system cost. The objective system's air vehicles shall adhere to DoD UAS Group 1, Group 2, or small Group 3 weight, altitude, and speed requirements for low altitude maneuverability and tactical deployability (Table 3).

Lastly, the system will allow for semi-autonomous operation with real-time, human-in-the-loop control. Each operational task will require a certain level of human input, which necessitates a varying degree of control given to the GCS or on-board processor. The level of autonomy will be driven by the risk of each task and the impact it has on mission completion. The overall level of autonomy is relatively low, with most tasks requiring operator input or pre-planned tasks for the system to execute. Consequentially, the shared responsibility between a human operator and the system GCS

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Table 3. Unmanned aircraft systems categorization chart [33]

UA Category	Maximum Gross Takeoff Weight (lb)[kg]	Normal Operating Altitude (ft)[m]	Speed (KIAS)	Representative UAS
Group 1	(0-20) [0-9]	(< 1,200 AGL) [< 366 AGL]	(100)	WASP III, TACMAV RQ-14A/B, Buster, Nighthawk, RQ-11B, FPASS, RQ16A, Pointer, Aqua/Terra Puma
Group 2	(21-55) [10-25]	(< 3500 AGL) [< 1,067 AGL]	(< 250)	ScanEagle, Silver Fox, Aerosonde
Group 3	(< 1,320) [< 599]	(< 18,000 MSL) [< 5,486 MSL]	(< 250)	RQ-7B Shadow, RQ-15 Neptune, XPV-1 Tern, XPV-2 Mako
Group 4	(> 1,320) [> 599]		Any Airspeed	MQ-5B Hunter, MQ-8B Fire Scout, MQ-1C Gray Eagle, MQ-1A/B/C Predator
Group 5	(> 1,320) [> 599]	(> 18,000 MSL) [> 5,486 MSL]	Any Airspeed	MQ-9 Reaper, RQ-4 Global Hawk, RQ-4N Triton

Legend

AGL	above ground level	m	meter
ft	feet	MSL	mean sea level
KIAS	knots indicated airspeed	UA	unmanned aircraft
kg	kilogram	UAS	unmanned aircraft system
lb	pound		

will range from #1 to #4 across the Taxonomy of the Distribution of Responsibility between Human and Computer (Figure 5).

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1. Human does all planning, scheduling, optimizing, etc. and turns task over to computer merely for deterministic execution.
2. Computer provides options but the human chooses between them, plans the operations, and then turns task over to computer for execution.
3. Computer helps to determine options, and suggests one for use, which human may or may not accept before turning task over to computer for execution.
4. Computer selects option and plans action, which human may or may not approve, computer can reuse options suggested by human.
5. Computer selects action and carries it out if human approves.
6. Computer selects options, plans, and actions and displays them in time for human to intervene and then carries them out in default if there is no human input.
7. Computer does entire task and informs human of what it has done.
8. Computer does entire task and informs human only if requested.
9. Computer does entire task and informs human if it believes the latter needs to know.
10. Computer performs entire task autonomously, ignoring the human supervisor who must completely trust the computer in all aspects of decision making.

Figure 5. Taxonomy of the distribution of responsibility between human and computer [34]

Enabling Capabilities

Some capabilities fall outside of the radiological search SUVS scope but are necessary to enable the system's effective use. While the system may make use of on-board navigation sensors for terrain avoidance, it is anticipated that the system will utilize the global navigation satellite system (GNSS) for maneuvering to waypoints, tracking its position, and mapping radiation strength of the search area. Low cost alternative navigation (non-GNSS) technologies are emerging but may not be available for deployment in the two to five-year window envisioned for this system. The system should be transportable by a light to medium-duty truck with a trailer or a small

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waterborne vessel for deploying the system to the operational area of concern. The transport vehicle should be capable of powering the GCS and associated GCS-operated equipment, as well as charging vehicle batteries when forward deployed. However, external power may be required when forward deployed for multiple missions or long durations.

Scenarios

The listed scenarios are broad and cover the entirety of mission phases that need to be accomplished by the system. The scenarios not only pertain to the conceptualized system, but also entail inherent interactions and inputs from the human operators of the system. The envisioned phases of system operation include ground control setup and teardown, vehicle deployment, mission execution, and system recovery.

Ground Control Setup & Teardown Phase

This phase encompasses all actions necessary to deploy the SUVS including unpacking, inventory, assembly, function checks, mission planning, disassembly, and reconstitution. Since the system is intended for use with forward deployable units, transportation of the system must be compatible with deployed vehicles or small waterborne vessels. The system must be capable of operating without externally supplied power. A system built-in-test will signal to the operator if the system is fully operational; if the system is not 100% operational, the built-in-test will identify all system faults. Mission planning for the system should be practicable prior to deployment, prior to beginning operations when on site, and modifiable during on-going operations once vehicles have been launched.

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Vehicle Deployment Phase

This phase encompasses all actions necessary to achieve initial vehicle movement starting from a properly configured vehicle or vehicles and a ground control station. No more than two operators should be required to deploy a vehicle. Following built-in-tests, mission plans should be wirelessly uploaded to involved vehicles prior to launch. The vehicle deployment phase ends once movement toward the target area is achieved and the system begins waypoint navigation.

Mission Phase

This phase includes a variety of tasks as defined by the selected payloads and established mission plan. It is envisioned that the system will be capable of waypoint navigation to both pre-planned and ad-hoc waypoints, can loiter or hover depending on the vehicle type, can navigate terrain, and can operate attached sensors at designated waypoints per the mission requirements. Mission tasks that should be accomplished in order to meet the desired capabilities of the system include:

1. Loiter or hover about a waypoint or navigate to a sequence of waypoints while providing real-time radiological strength measurements to the ground control station. Video imagery from search should be recorded and displayed to the ground control station in real-time. Video options will be available for both daytime and low-light conditions, with enough quality for the ground control station operator to detect human figures based on the displayed imagery. The operator will designate a target search area with the ground control station software and the system will

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search the designated target area based on vehicle telemetry, with a desired accuracy of 15 meters distance root mean squared (DRMS). The initial search should yield calculated location(s) of radiological source material based upon maximum radiation readings and telemetry data. The system should be capable of displaying a radiological strength contour map of the target area to the ground control station operator.

2. Navigate to a waypoint and hover, land, or dwell at the location while providing real-time video imagery to the ground control station. Video imagery should be recorded and displayed to the ground control station in real-time. The operator will designate the target location(s) calculated from the initial area search. Once at a designated target location, the system will confirm the detected radiological sources by collecting a gamma spectrum of the source material. Spectrum data will be provided to the ground control station and the system will predict the radioisotopes based off the measured gamma energies.

3. Traverse the exterior wall faces of an urban structure, covering both the horizontal and vertical extent of a building. The system should employ terrain avoidance while maintaining a safe distance from a structure in order to avoid damage to or loss of a vehicle. The desired location accuracy of 15 meters DRMS is driven by the need to avoid collateral damage in urban environments. While traversing the exterior wall faces of a building, the system will record radiation strength measurements at

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locations adjacent to the walls. These radiation measurements will be used to develop a three-dimensional contour map to pinpoint probable locations for the source material.

4. Perform a commanded ditch or crash maneuver in the event of system faults or circumstances making recovery impossible or undesirable, such as unavoidable contact with hostile personnel or compromise of the system. Each system vehicle will encompass a self-destruct module to make the system unusable if seized by unfriendly forces.
5. Perform a return to launch (RTL) at any time during operation. An RTL will return the vehicle to a pre-programmed location where it will perform the recovery phase.

Recovery Phase

This phase involves recovering the vehicles upon completion of the mission or as deemed necessary. The UVs should be capable of navigating to a recovery location designated by the ground control station operator. Unassisted takeoff and landing of air vehicles are desirable if done safely and to ensure rapid recovery and reuse of the vehicle. Batteries must be replaceable in the field and additional fuel should be available for sequential search or continuing large area search or surveillance operations.

System Decomposition

Use Cases

A use case model for the system has been developed using Cameo Systems Modeler to visualize the main operational functions that the system needs to perform, as

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well as the interactions the system has with actors, external systems, and the environment (Figure 6). The use cases are based on mission needs, enabling capabilities, and scenarios previously mentioned. The entire system is responsible for performing setup, planning the mission, deploying and ingress, performing search and confirmation activities, egressing and recovery, and self-destruction if necessary. Several use cases require interactions with the GNSS, the physical environment, and human operators,

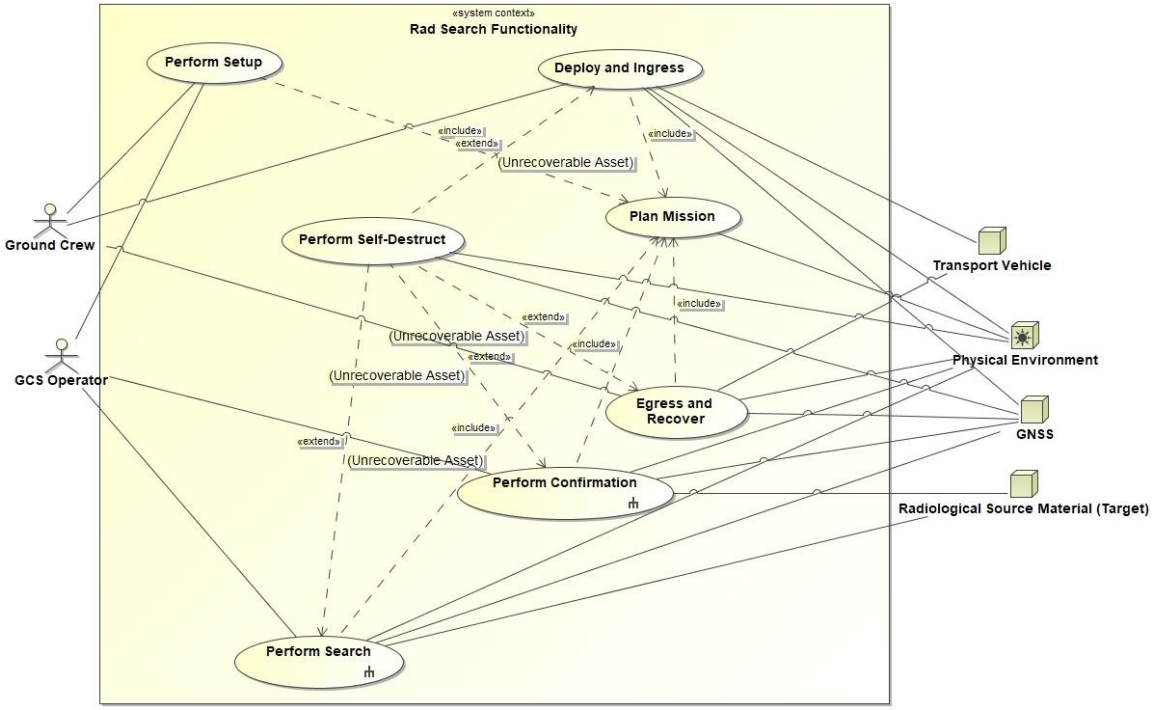


Figure 6. Use case model for the radiological search system

whereas the target radiological source material only relates to performing search and confirmation. The use cases holistically provide the necessary functions to execute the entire spectrum of the radiological search mission, as determined by the CONOPS. The details of the individual use cases can be found in Appendix B.

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Tasks, Attributes, and Measures

Within the confines of the radiological search mission, there are basic tasks that must be accomplished as part of mission execution. The tasks, along with the associated attributes and measures, can be seen in Table 4. This list highlights important variables

Table 4. Mission-level key tasks, attributes, and measures

Task	Attribute	Measure
Search	Coverage	Duration [min]
		Total area searched [m^2]
		Area coverage rate [m^2/s]
Detect	Accurate	Probability of detection [%]
		False alarm rate [alarms/mission]
Navigate	Accurate	DRMS absolute location error [m]
		DRMS relative location error [m]
Communicate	Secure	Encrypted/not encrypted
	Range	Range [m]
Confirm	Spectral resolution	Resolution [% FWHM]
	Source position accuracy	DRMS location error [m]
Mission-wide	Workload	Minimum crew size required [# personnel]
	Availability	Mission turn time [min]
		Mission ready rate [% mission capable]

that apply to the mission. The tasks are essential for executing the individual use cases, and therefore meeting the intent established in the CONOPS. The attributes and measures capture what can be considered significant measurable data for task evaluation if system development were to occur. It should be noted that the list does not encompass all tasks that need to be performed nor all measures that should be considered for evaluation. Additionally, there are some attributes and measures that apply across all mission tasks, which are combined in a "mission-wide" task category. The major tasks

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for mission completion are search, detection, navigation, communication, and confirmation. The established mission-level tasks feed MOEs for the radiological search mission and the expected operating environmental conditions [32]. From there, system-specific MOPs were developed including measurable performance factors for evaluating the MOEs. The MOPs are related to the task attributes and the attributes' measures correspond to performance parameters. The list of developed MOEs, MOPs, and performance parameters are in Table 5. As mentioned previously, the MOEs, MOPs, and performance parameters are not exhaustive and provide an academic assessment of critical data that should be measured to assess system performance against mission execution.

Table 5. MOEs with system-specific MOPs and performance parameters

MOE	MOP	Performance Parameters
Success rate of locating and identifying radiological source material in a 3 square kilometer search area	Location accuracy of radiological source(s)	Detector dead time [ms]
		Detector dose rate range [mSv]
		DRMS relative location error [m]
		DRMS absolute location error [m]
	Confirmation accuracy of radiological isotope(s)	Spectrum resolution [%]
		Minimum energy detected [keV]
		Maximum energy detected [keV]
	Endurance	Weight [kg]
		Power capacity [W]
	Area coverage rate	Camera FOV [°]
		Operating altitude [m]
		Vehicle cruise speed [m/s]
	Degree of autonomy	Autonomy scale [Figure 5]
	Video imagery resolution	Ground sample distance [m]
Ability to communicate data to a remote-control point across a 3-kilometer distance	Data processing speed	GCS processing speed [GHz]
		Data transmission rate [Mbps]
	Data encryption	Y/N
	Transmission range	Tx power [dB]
		Rx power [dB]

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Functional Decomposition and Physical Allocation

Continuing with the system hierarchy, the functional decomposition and allocation of physical componentry can be produced. For the purposes of this research, the CONOPS identified system requirements are based on assumptions and personal knowledge of the radiological search mission space. This is unlike traditional processes where requirements are identified by operational users of a conceptualized system [28]. The requirements as presented herein are traceable to the use cases, tasks, attributes, measures, and now to the functional decomposition and physical architecture of the system. Individual tasks are essential for the completion of the different scenarios mentioned in the CONOPS as well as for the execution of each use case. A conglomeration of all derived tasks for a vehicle and the GCS can be seen in Table 6.

Table 6. Derived system tasks between vehicle and GCS

Vehicle Activities		GCS Activities	
Auto land	Load MP	Analyze spectrum data	Display video
Auto takeoff	Loiter	Calculate target coord	Receive MP status
Capture video	Navigate waypoints	Combine rad data/telemetry	Receive rad data
Collect rad data	Send rad data	Connect to vehicle	Receive spectrum data
Collect rad spectrum	Send spectrum data	Construct MP	Receive telemetry
Conduct BIT	Send telemetry	Create rad map	Send cmd
Follow search pattern	Send video	Display rad data	Store rad data
Initiate search	Trigger self-destruct	Display rad map	Store spectrum data
		Display rad spectrum	Store target coord
		Display radionuclide	Store telemetry
		Display target coord	Store video
		Display telemetry	Write MP

The functional decomposition has been split at the system level into vehicle activities and GCS activities, represented in the MBSE format in Figure 7. For this research, the vehicle activities generally apply to and cover all activities for the ground, fixed-wing,

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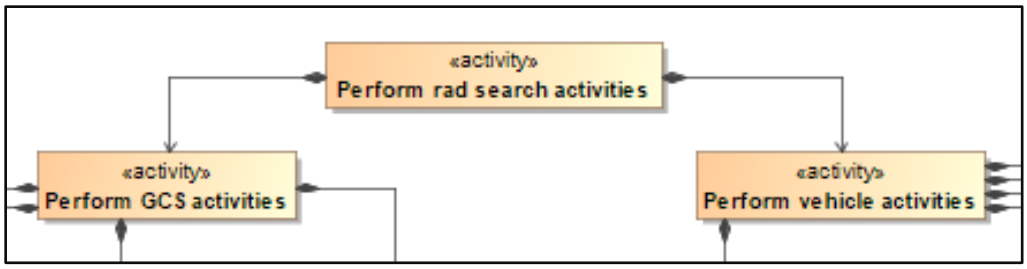


Figure 7. System functional decomposition

and multirotor UVs. The activities for the various vehicles are broken down into performing controlled movement, autopilot function, vehicle data communications, radiation measurement, and providing video (Figure 8).

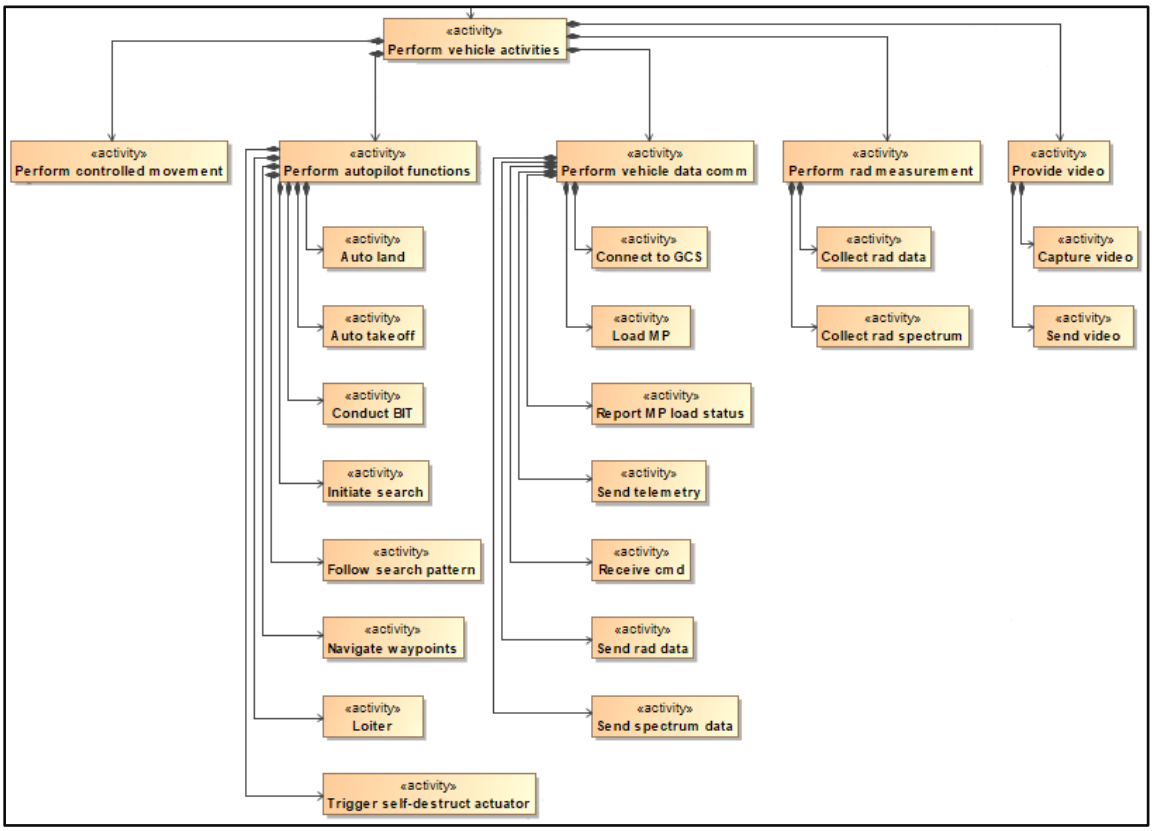


Figure 8. Generic vehicle functional decomposition

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For the ground control station, the functional decomposition is categorized by processing, providing data communication with system vehicles, providing interface and output for the GCS operator, and receiving video from vehicles. The GCS sends commands to system vehicles, receives and displays video, and receives, processes, and displays critical flight and radiation measurement data (Figure 9).

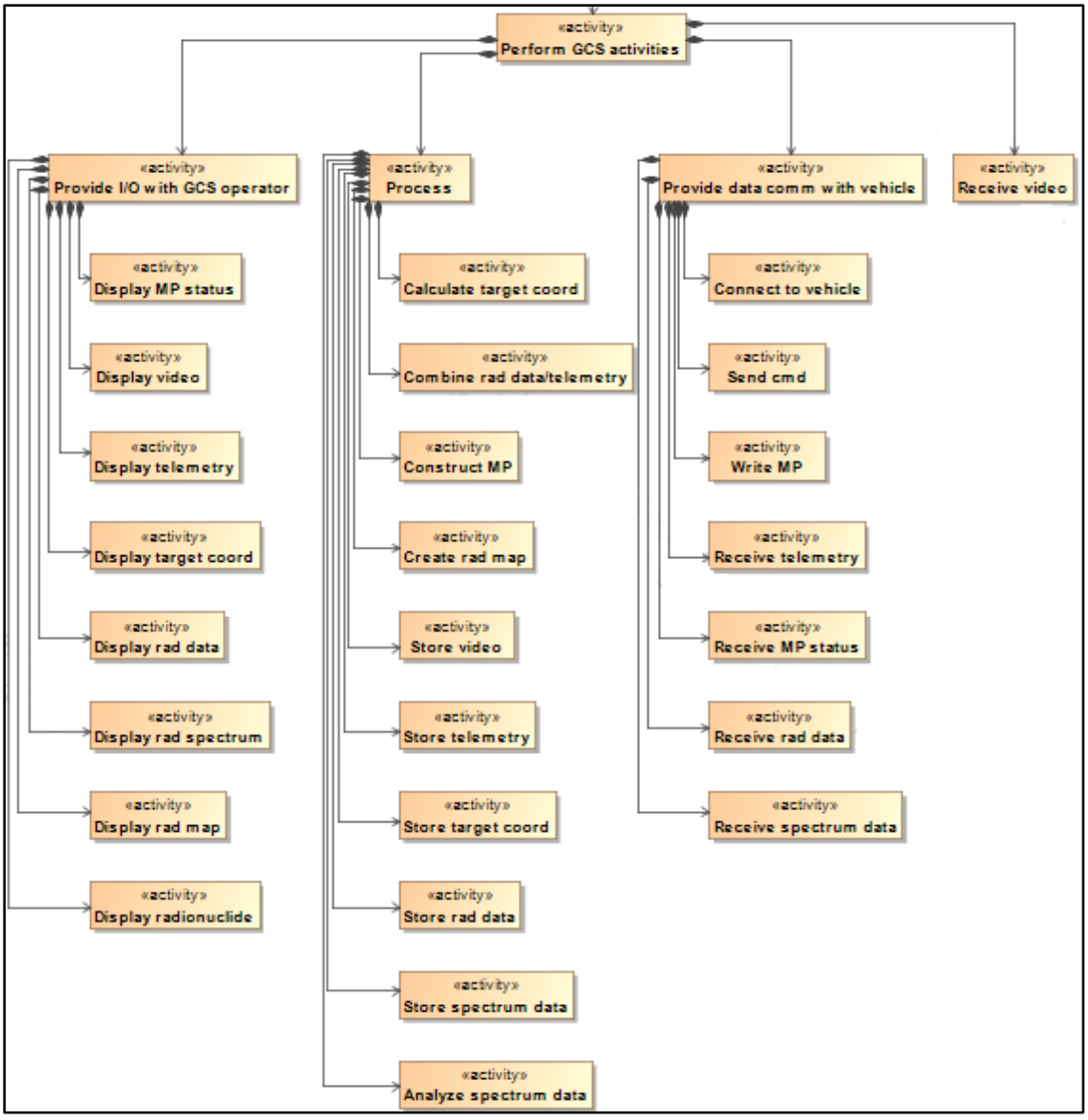


Figure 9. GCS functional decomposition

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The physical architecture consists of singular components, organized into system modules, that fulfill the execution of tasks listed in the vehicle and GCS functional decompositions (Figure 10-13). The vehicle modules are navigation, payload, power, self-destruct, and the vehicle itself. The subsystem breakdowns are not exhaustive lists

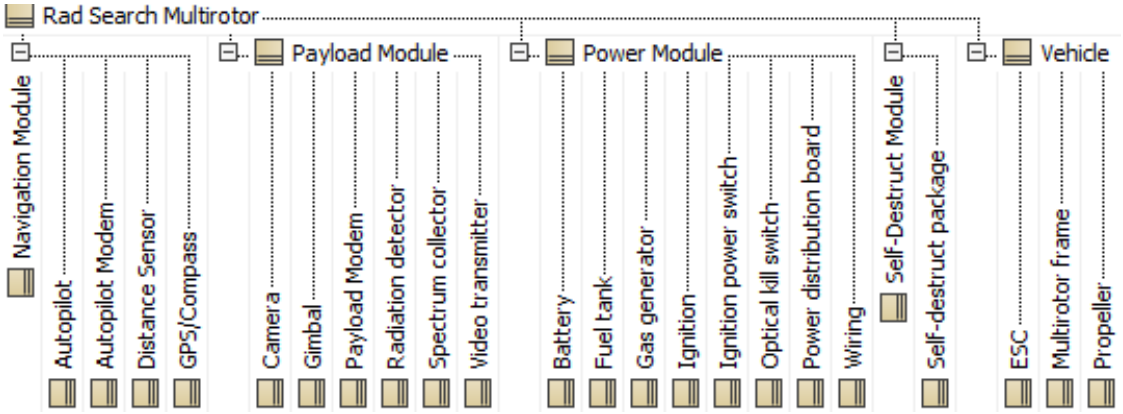


Figure 10. Multirotor physical architecture

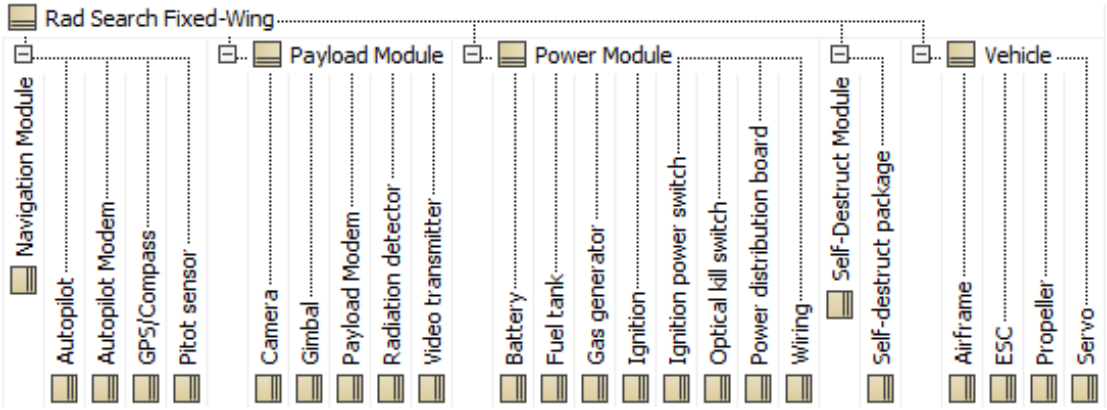


Figure 11. Fixed-wing physical architecture

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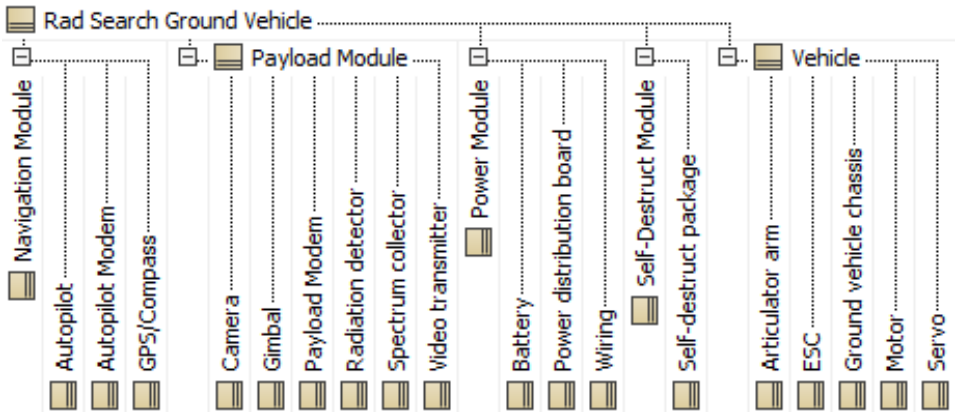


Figure 12. Ground vehicle physical architecture

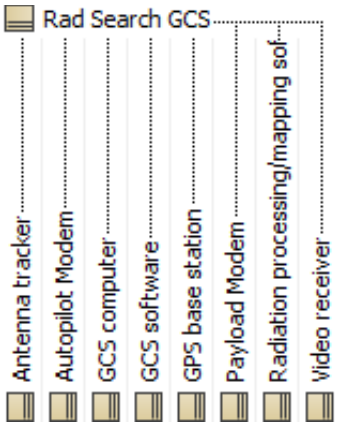


Figure 13. Ground control station physical architecture

of all physical hardware but include major components that should be considered for future design and sizing. It should be noted that the power modules for the multirotor and fixed-wing vehicles contain both batteries and gasoline-based engines, which will be discussed later in Chapter IV. Additionally, there is no power system listed for the ground control station, as this will be powered by the transport vehicle used to deploy the system and human operators.

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From the different physical architectures, the subsystem components can be allocated against all system tasks from the functional decomposition. Allocating each individual task against each component within the system continues the traceability from the CONOPS, to the use cases, to the tasks, and lastly to the physical hierarchy of the system. An allocation of each activity to a subsystem component satisfies this traceability (Table 7). Each activity that is necessary for mission completion is being satisfied by at least one component or one subsystem module. The individual vehicle and GCS physical allocation matrices can be found at Appendix A. By categorizing the subsystems, the physical components, and the executable tasks, a simplified analysis for potential hardware redundancy is possible.

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Table 7. System physical allocation matrix

Legend Allocated - ↗	Rad Search Fixed-Wing	Rad Search Ground Vehicle	Rad Search Multirotor	Rad Search GCS	Legend Allocated - ↗	Rad Search Fixed-Wing	Rad Search Ground Vehicle	Rad Search Multirotor	Rad Search GCS
Analyze spectrum data				↗	Perform GCS activities				↗
Auto land	↗	↗	↗		Perform rad measurement	↗	↗	↗	
Auto takeoff	↗	↗	↗		Perform rad search activities	↗	↗	↗	
Calculate target coord				↗	Perform vehicle activities	↗	↗	↗	
Capture video	↗	↗	↗		Perform vehicle data comm	↗	↗	↗	
Collect rad data	↗	↗	↗		Process				↗
Collect rad spectrum		↗	↗		Provide data comm w/ vehicle				↗
Combine rad data/telemetry				↗	Provide I/O w/ GCS operator				↗
Conduct BIT	↗	↗	↗		Provide video	↗	↗	↗	
Connect to GCS	↗	↗	↗		Receive cmd	↗	↗	↗	
Connect to vehicle				↗	Receive MP status				↗
Construct MP				↗	Receive rad data				↗
Create rad map				↗	Receive spectrum data				↗
Display MP status				↗	Receive telemetry				↗
Display rad data				↗	Receive video				↗
Display rad map				↗	Report MP load status	↗	↗	↗	
Display rad spectrum				↗	Send cmd				↗
Display radionuclide				↗	Send rad data	↗	↗	↗	
Display target coord				↗	Send spectrum data		↗	↗	
Display telemetry				↗	Send telemetry	↗	↗	↗	
Display video				↗	Send video	↗	↗	↗	
Follow search pattern	↗	↗	↗		Store rad data				↗
Initiate search				↗	Store spectrum data				↗
Load MP	↗	↗	↗		Store target coord				↗
Loiter	↗	↗	↗		Store telemetry				↗
Navigate waypoints	↗	↗	↗		Store video				↗
Perform autopilot functions	↗	↗	↗		Trigger self-destruct actuator	↗	↗	↗	
Perform controlled movement	↗	↗	↗		Write MP				↗

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Design Considerations

There are several avenues for system design based on the established CONOPS and system decomposition. These include similar and dissimilar componentry as well as factors that could attribute to certain design decisions such as payload type, processing capabilities, and the operating environment. In order to evaluate the system componentry, the three vehicle systems and the ground control station were assessed. A comparison of subsystem components and their equivalent to other systems is shown in Table 8, identifying hardware that can use similar components, hardware that is similar but likely use different components, and hardware that is dissimilar.

Similar Componentry

After a rudimentary comparison, it is evident that there are multiple overlapping components in the payload, navigation, and power modules, as well as the self-destruct package. Due to the assumed simplicity of the system concept and maximizing existing COTS and GOTS hardware, equivalent components should be selected in order to duplicate the capability of each component within the overarching system. This creates redundancy throughout the system, enabling the cannibalization of one vehicle system in order to make another system fully operational. For instance, similar modem components should be incorporated for transmitting telemetry data, payload data, and video stream. Redundant hardware facilitates the interchange of system components with little to no re-programming if operational constraints arise. This can be crucial to operators if they are limited on spare parts or if geographically separated from the main operating location by providing the ability to troubleshoot a subsystem when hardware becomes inoperable.

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Table 8. Comparison analysis of subsystem componentry

	Component	Fixed-Wing	Multirotor	Ground	GCS
NAVIGATION	Autopilot				
	Autopilot Modem				
	GPS/Compass				
	Pitot Sensor				
	Distance Sensor				
PAYLOAD	Camera				
	Gimbal				
	Payload Modem				
	Radiation Detector				
	Video Transmitter				
	Spectrum Collector				
POWER	Battery				
	Fuel Tank				
	Gas Generator				
	Ignition				
	Ignition Power Switch				
	Optical Kill Switch				
	Power Distribution Board				
	Wiring				
SD	Self-Destruct Package				
VEHICLE	Electronic Speed Controller				
	Air Frame				
	Propeller				
	Servo				
	Articulator Arm				
	Ground Vehicle Chassis				
	Motor				
	Multirotor Frame				
GCS	Antenna Tracker				
	GCS Computer				
	GCS Software				
	GPS Base Station				
	Radiation Processing/Mapping Software				
	Video Receiver				

	Similar component, could be same
	Similar component, likely different
	Different component

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The decision to swap components from one system to another is driven by mission and scenario need. For example, intelligence identifies a single building as the target location for a radiological source. This would not require the use of a fixed-wing UV since a large area search is not needed. The components of the fixed-wing UV can be cannibalized in order to ensure mission execution with the other two system vehicles. On the contrary, a large area search requires a fixed-wing UV for initial detection of the radiological material. However, the fixed-wing UV can be disassembled after initial detection is complete, the search area has been narrowed, and when follow-on search and identification can be managed by the multirotor or ground vehicle. Hardware redundancy provides the flexibility to prioritize and execute mission needs when necessary.

Hardware Variations

There are also multiple componentry differences amongst the vehicle systems and the ground control station. Modules with major variations from other systems include power production, the ground control station, and the vehicle itself. As is anticipated, the vehicle chassis will be dissimilar for the various UVs. This includes the vehicle propulsion system, which consists of the motors (electric and gasoline-fueled), servos, propellers, and wheel tracks. The last distinctive vehicle component is an articulator arm on the ground vehicle, which can be used for object manipulation and as an extra mounting point for vehicle payloads.

In order to meet the system's intent of searching large areas as well as carrying payloads in excess of 15 pounds (6.8 kilograms), the power plants for the different vehicles cannot be restricted to battery-powered systems. Other options to be considered

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include small combustion engines and hybrid-electric motors. The fixed-wing vehicle is required to accomplish an initial search to localize where radiological material is located, with the potential to continue operations as a surveillance asset. Due to the potential for long-duration flights, this capability is best supported using a combustion engine in lieu of batteries to drive the propeller. A gasoline engine will enable flight times of several hours and increases the required size of the vehicle, which is beneficial for payload capacity. Battery-powered fixed-wing vehicles can achieve flight durations over 1 hour but will not be able to carry equivalent payload weights with comparable endurance times to gasoline-powered systems. Comparatively, a battery-powered multirotor system would not have the endurance to cover all potential source locations within a 3 square kilometer area for collection of a gamma spectrum. A hybrid-electric system would provide greater endurance and offers an increased payload capacity compared to battery-powered multirotor vehicles. Battery-powered systems of the desired sizing are typically limited to 30-minute flight times, which is insufficient for carrying detector payloads to the farthest sites of a large search area. Additionally, batteries can take 30 minutes to an hour for recharging if spare batteries are unavailable, which can hamper the ability to execute consecutive sorties. Endurance estimates supporting the above discussion can be found later in Chapter IV. Opting for fuel-based power systems is ideal for providing longer endurance due to a higher energy density compared to battery technology, which can be visualized in Figure 14. Utilizing liquid fuels for the fixed-wing and multirotor UVs will increase flight durations, area coverage, and maximum allowable payload, optimizing performance of these systems and providing optionality for other uses such

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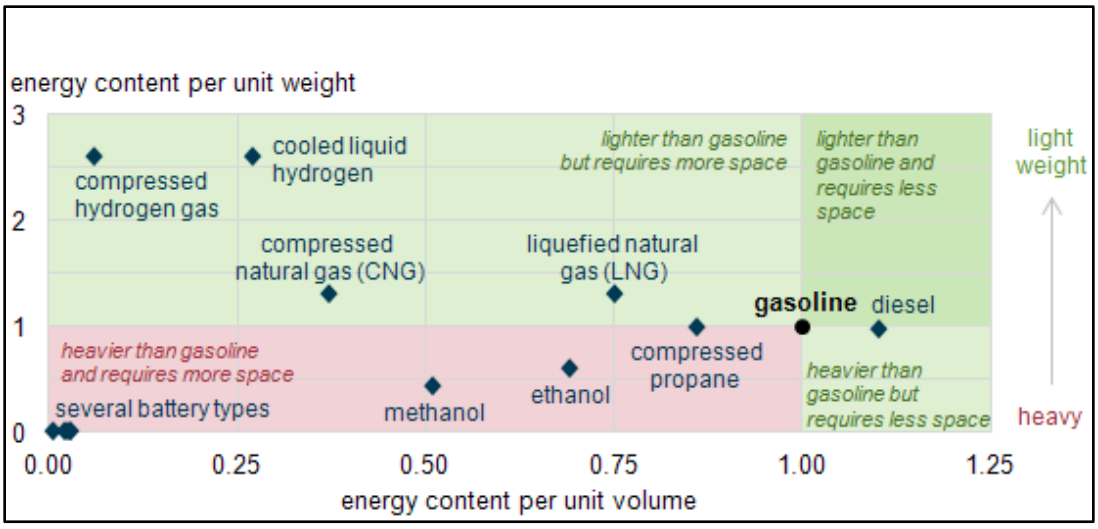


Figure 14. Energy density comparison of several transportation fuels (indexed to gasoline = 1) [35]

as surveillance missions.

In addition to the detector payloads, additional payloads should be included on vehicles to assist with navigation and surveillance. Light detection and ranging (LiDAR) or other distance measuring sensors should be incorporated on the multirotor to provide accurate navigation when flying around buildings and other potential obstacles. This will provide more accurate radiation measurements and enhanced safety by decreasing the likelihood that a collision occurs. Additionally, the fixed-wing UV could benefit from a higher quality video camera compared to cameras installed on the other vehicles. The fixed-wing's optionality to provide aerial surveillance would benefit from high-quality video and would better support ground operators.

Physical Limitations and Imposed Design

System components are constrained to the mission needs listed in the CONOPS and limited to the operational requirements of the mission area. Two important

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limitations to highlight are the restrictions on system mass and the extended endurance required to cover a 3 square kilometer search area. The two limitations drive the sizing of each subsystem vehicle, their power plants, and the quantity of vehicles utilized in the system. A minimum of three unmanned vehicles (fixed-wing, multirotor, and ground), a ground control station, and the accompanying storage, power, communications, and maintenance equipment must be containable in a truck and trailer for system deployment. Additionally, due to the nature of radiation emissions discussed in Chapter II, detector payloads are more likely to detect gamma radiations when closer to the radiological source material. This negates the viability of using large unmanned vehicles that operate at higher altitudes such as the RQ-1 Predator and MQ-9 Reaper that are categorized as DoD UAS Group 4 and Group 5 systems (Table 3).

On-board processing has been removed from the conceptualized design in the physical architecture. This capability requires additional vehicle power and produces unwanted heat, which would reduce mission endurance and could present overheating issues in warmer operating environments. Additionally, an on-board processor introduces the risk of leaking sensitive information regarding system software and vulnerabilities to adversarial forces if captured or ditched in a contested area. This will be discussed in more detail later in Chapter IV.

Power

As discussed previously, power production can be an issue for the fixed-wing and multirotor platforms. This is dependent on payload selection for the system and the required flight endurance for the individual vehicles. A liquid-fuel engine for the fixed-

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wing would increase the size of the vehicle but would greatly improve the endurance and the payload capacity. Similarly, a hybrid-electric motor for the multirotor would have a comparable effect. However, using combustion engines would increase the complexity of the system regarding mechanical components and potential maintenance. Furthermore, a deployable system may be constrained by available types of fuel. DoD Directive 4180.01 promotes the use of multiple energy sources for weapon systems and equipment, where appropriate, and becoming operational with one battlefield fuel [36]. Typical small combustion engines used on fixed-wing and multirotor vehicles consume 91 octane fuel or higher [25]. Expeditionary vehicles, aerospace generation equipment, and power generation assets are typically fueled with diesel or jet propellant-8 (JP-8). Expanding the capabilities of the system to utilize heavy fuels, if combustion engines are chosen for power generation, would provide more options for system deployment and would reduce vulnerabilities if 91 octane fuel is unavailable. Small two-stroke gasoline engines (10 cm^3 to 100 cm^3) have been proven to run on heavy fuels with minimal degradation to peak performance power. However, this required engine modifications such as replacing carburetors with throttle body fuel injection systems and changing stock engine control units to adjustable ignition timing maps [37].

In addition to meeting endurance and payload capacity, adequate power needs to be generated or supplied on-board in order to power video cameras, navigation systems, and payloads. The largest payload consumer of power would be gas-filled detectors and semiconductor detectors, which operate at higher voltages. With this being the case, it is advisable to power these detectors with separate power supplies. Utilizing separate

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power supplies for all detector payloads would enable optionality for handheld use and would reduce the complexity and drain on the vehicle's power system. It is possible to power these systems, but this also increases the size of the combustion engine and the vehicle frame to support the engine. A good example is the Airborg H8 10K Hybrid UAS. It claims a flight endurance of 1 hour carrying a 22-pound (10-kilogram) payload, with a power output of 100 watts and built-in 5 voltage direct current (VDC) and 12 VDC wiring. The longest dimension of the vehicle is 6.4 feet (1.95 meters) and the total weight with a 22-pound payload is 110 pounds (50 kilograms) [38]. This would be sufficient voltage for the Ortec Micro-Detective, which requires 10 to 17 VDC for operation [19].

Environmental

The operating environment of this system is important to understand since operations will primarily be outside. Many common components used for unmanned vehicles are designed for use in -20° to 50° Celsius temperatures, but some components, such as the Ortec Micro-Detective, may have a smaller temperature window for operation [19], [25], [26], [39]. Other components that may be affected are batteries and circuit boards. Extreme cold weather can reduce the overall power output of a battery, whereas extreme heat can lead to physical damage. On-board processing equipment such as autopilot systems and detector payloads can also be affected by hot weather, causing damage to circuity and decreased performance. Desired operating temperatures for the system could affect component selection and design for each vehicle.

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In addition to temperature constraints, other weather constraints could affect the operational utility of the system. Visual capabilities could be limited by fog, precipitation, smog, and sunlight. Unless night vision video cameras or other imaging solutions are utilized, night operations would be dangerous or not viable. Additionally, precipitation may affect system functions, either from individual component waterproofing or physical limitations of vehicle propulsion. Lastly, flying vehicles must maintain stable flight while airborne. Strong steady and gusting winds would limit the use of flying vehicles, with the wind limits being better defined during system design.

The last environmental concern is from obstacles and human interference. The operating area may contain trees and buildings that could impede flying operations, or uneven terrain such as ditches and rocks for a ground vehicle. Design considerations should be made to mitigate these risks, such as the addition of specific payloads to see and avoid terrain or the ability to traverse uneven ground with the addition of extendable wheels or tracks. Additionally, the human element can interrupt vehicle operations. Threats can be in the form of thrown rocks, nets, vehicle theft, small arms fire, or man-portable air defense systems. There are few design decisions that can currently mitigate these threats, but technology is continuously progressing and the capability to avoid human threats may present itself in the future.

Detector Payload

In order to optimize the performance of the radiological search system, detectors for initial detection and spectrum collection should be evaluated separately. It is valid to employ multiple detector technologies due to the diversity of radiological search

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scenarios. Detector selection can vary due to several reasons: 1) detector selection can be driven by the type of area to be searched; 2) detector selection can be dictated by the size of area to be searched; 3) detector selection is limited by the vehicle it will be deployed on; and 4) detector selection can be determined by the desired mission outcome.

Gas-filled detectors are well suited for area surveying during initial searches. More specifically, the higher applied voltage in G-M detectors results in a sensitive detector, which is ideal for large area searches that may require detection from long distances [14]. Additionally, typical COTS G-M detectors have higher radiation dose rate thresholds. The high threshold enables G-M detectors to avoid detector saturation when in strong radiation fields, and therefore continue to function and provide radiation strength readings [19]. This results in a more defined geolocation of source material after the initial search. However, G-M detectors do not measure the energy of incident gamma rays, which can be important for determining health and safety concerns for responding personnel.

Scintillators can also be used for area searches but tend to have lower radiation dose rate thresholds [19]. This translates to detector saturation in strong radiation fields where G-M detectors could still be operating, resulting in a less accurate geolocation than G-M technologies. However, both scintillators and semiconductors are well suited for gamma spectrum collection because they can distinguish between different energies of incident gamma rays, allowing for the identification of radioisotopes. Scintillators are cheap and lightweight but produce low resolution spectrums. On the contrary, semiconductors are expensive and heavy due to the required cooling systems that

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maintain low operating temperatures but provide very high-resolution spectrums [21]. Equipping the system with multiple technologies gives the capability for high-resolution spectrums, but the optionality to use the less expensive and lighter scintillator in unfavorable conditions.

The vehicle type can determine payload selection. For instance, a spectrum collection payload is not ideal for deploying on a fixed-wing vehicle. Spectrum collection should be completed at a constant distance from a radioisotope and in a stable position. A fixed-wing vehicle is unable to maintain a constant distance during flight but is well-suited for searching large areas when the location of source material is unknown. The optimal payload for a fixed-wing vehicle is a G-M detector due to its sensitivity, but scintillators are also a practical option. Terrain and environmental conditions can force a fixed-wing UV to fly over one hundred meters AGL, making higher-sensitivity detectors more desirable for initial detection. For isotope identification, the current government "gold standard" for gamma spectroscopy is a liquid or electromechanically cooled high purity germanium crystal [40]. This setup provides a superior resolution spectrum compared to existing scintillator technology but may not be feasible on a multirotor or ground vehicle due to weight limitations and the operating environment.

The physical and immediate surroundings of each vehicle should also be assessed. The two main considerations for detector mounting are material interactions and susceptibility to impact. Interactions with other vehicle materials can include vibration-induced gamma counts, gamma counts produced from other on-board electronic equipment, and self-imposed shielding. Unintentional shielding can happen when an

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intervening material from a vehicle is between the detector media and the radiological source. The intervening material can weaken or alter the gamma energies incident on the detector, ultimately decreasing the potential for initial detection and degrading the accuracy of spectrum collection [19]. Similarly, shielding material may need to be utilized between the detector and other electronic hardware in order to reduce false gamma readings that occur from other types of electromagnetic radiation. The other physical consideration is the potential for detector impact. Collision with obstacles, human interactions, and harsh landings can affect detector performance and can dictate payload attachment and hardening design. Depending on the detector and the vehicle, attachment options can be limited due to size and weight. Vehicle center of gravity constraints and chassis strength will drive mounting options to ensure that vehicles safely fly and maneuver as designed. Detector hardening may also be limited due to vehicle payload capacity but should be evaluated during system design.

One last consideration for payload selection is the additional capability for the detectors to be used in a handheld configuration by the system's human operators. Situations may present themselves where the initial search, the spectrum collection, or both methods are not appropriate for unmanned vehicles. Terrain, environmental conditions, and other on-scene factors can differ from provided intelligence. Once an operational team arrives at the search location, it may be logical to modify the mission plan to conduct a portion of or the entire mission using personnel search teams. Depending on their equipping, they may need the capability to conduct searches with the same equipment deployed on the UV system. Commonly used GOTS and COTS

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handheld detectors can vary in price from $1,000 to $100,000, which is contingent on the type of technology purchased [39]. It may be more cost effective to include handheld-operable equipment in the system. This would limit the overall detector acquisition cost to the end user, avoiding the need for redundant technologies that are dedicated to either a UV system or a human operator. If handheld detectors are employed, it is essential that the detector's human interface can be bypassed in order to send data and receive commands. A commonly used COTS semiconductor detector designed for handheld use is the Ortec Micro-Detective. As previously mentioned, it utilizes an HPGe crystal to provide a spectral resolution of less than one percent. The purchase price for this equipment is upwards of $100,000 but provides the highest-quality gamma spectrum compared to other spectrum-collection technologies. With a weight of 15 pounds (6.8 kilograms), this equipment is only suitable for the ground UV and for short-duration trips with a large multirotor [19]. However, including this piece of equipment also enables the human operator to collect a high-resolution spectrum if the mission dictates. Additionally, there are many COTS handheld detectors that come equipped with G-M and scintillation technology [19]. This could increase the efficiency of a mission by completing the initial search and radioisotope identification with one vehicle trip, thus avoiding payload exchange when a high-resolution spectrum is not required. This is only practical on the ground and multirotor UVs due to the constant distance required for spectrum collection. The flexibility of equipping the UV system with handheld technology increases the probability of mission success regardless of evolving or

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unforeseen circumstances. Table 1Table 9summarizes considerations for UV detector selection in order to meet operational needs.

Table 9. Vehicle and detector compatibility selection

	Ground	Multirotor	Fixed-wing
Limitations	Terrain/obstacles Slow 2-D coverage	Endurance Payload weight	No dwell
Advantages	Dwell time/stability Manipulator arm Heavy payload	3-D coverage Accessibility Hover/land for stability	Large area coverage Long endurance Aerial surveillance
Suitable Technologies	Gas-filled Scintillator Semiconductor	Gas-filled Scintillator Semiconductor	Gas-filled Scintillator
Detector Selection Criteria	Mission requirement Desired performance Environmental conditions Permissibility		

Communication Modems & On-board Processing

As mentioned in the similar componentry assessment, comparable communication modem pairs could be used to provide redundancy and flexibility throughout the system if hardware becomes inoperable. Additionally, on-board processors have been removed from the Cameo physical decomposition to reduce power-draw, weight, heat, and to avoid sensitive data exploitation if a vehicle is lost or stolen. If vehicle on-board processors are included during system design and testing, multiple modems may not be necessary for each vehicle. However, in order to capture, combine, and encrypt multiple payload data and video feeds, a custom communication modem and processor may be required that is not available commercially or through existing government PORs.

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The development of a custom communication modem and processor will depend on the established requirements, payload selection, and discoveries during the design and testing phases. The system needs the ability to communicate amongst a GCS and multiple UVs while encrypting and combining data streams, and also providing the flexibility for future payloads to be added to the system. There may not be a component that will satisfy system demands and be available commercially. Sourced payload manufacturers may not have compatible output data and could pose problems when sending or processing different data packet types and lengths. These reasons could force a requirement for on-board processing to assist with data management before communicating from a vehicle to the GCS. The on-board processor could be integrated with a communication platform that is equipped on each UV and the GCS. This could solve issues posed by data compatibility, encryption, data combination, and time synchronization. A solution for these issues would most likely necessitate a custom-designed component in order to function properly, as well as provide the flexibility to for additional payloads and other mission areas.

Processing Software

In addition to a custom-designed communication and processing package, custom software will likely need to be developed. This includes software on the GCS platform as well as software for the on-board processors. Vehicle software should be capable of combining data from various payloads and the autopilot before relaying the information to the GCS. Simultaneously, the software must decipher commands received from the GCS before relaying the commands to the appropriate vehicle components. On the

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ground, GCS software provides input and output functionality to the GCS operator. The software should be able to merge pertinent data received from a vehicle autopilot, detector payload, and video camera into one visual interface. It should have the capability to display real-time radiological data, display a three-dimensional radiological strength contour map of the search area, and provide source location estimates from the combined radiation data and telemetry data (Figure 15). Additionally, the software

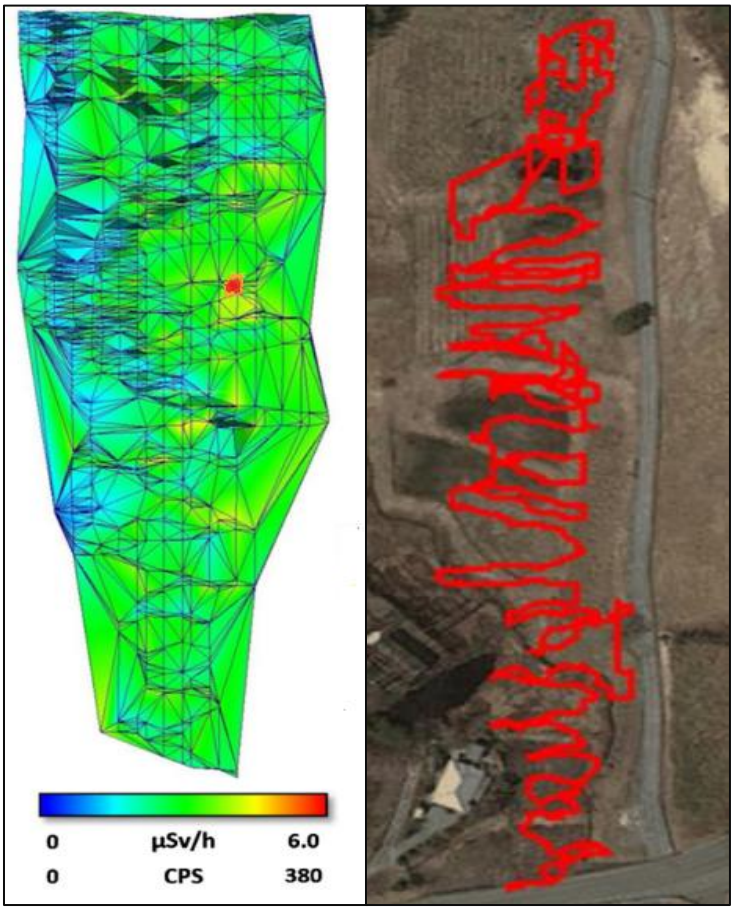


Figure 15. 3-D radiation strength map (left) of a vehicle search pattern (right) [41]

should provide real-time and planned vehicle locations on a map, similar to existing autopilot software suites. Lastly, the software should provide command options for both

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vehicle navigation and payload functions, such as starting and stopping spectrum collection, controlling camera gimbals and articulator arms, and being able to toggle between autonomous and controlled movement.

Analysis of Feasibility and Utility

After progressing through concept development, applicable scenarios, a task and physical decomposition of the system, and design considerations, the overarching query remains whether the system would be practical to employ and what utility it could provide to the radiological search mission and other mission areas. The concept system's abilities can be fundamentally evaluated through sizing and endurance estimations for multirotor and fixed-wing UVs. Ground vehicles are more forgiving with payload capacity, and therefore will not be analyzed due to the several COTS options that meet example payload requirements [42], [43], [44].

Air vehicle sizing and performance will be centered on assumptions founded upon similarly sized UAS specifications and incorporating handheld detector weights where appropriate. Assumptions are made for component sizes, efficiency ratings, air speeds, and mass fractions based on AFIT professor knowledge, existing literature, and existing COTS systems [45], [45], [46]. Mass fractions (MF) are typically tracked for vehicle payloads and for power sources (i.e. battery, fuel), and provide thresholds for vehicle estimates. The mass fractions for unmanned vehicles typically fall within the same range, with the fuel mass fraction ranging from 0.2 to 0.3 and the payload ranging from 0.1 to 0.3 [45]. Mass fractions can be estimated using Equation 2.

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$$MF_{component} = \frac{W_{component}}{W_{takeoff}} \quad (2)$$

Incorporating handheld detectors would be the worst-case scenario for payload weight and size due to the additional weight from ruggedized cases and integrated power supplies, but it also gauges the feasibility of employing handheld detectors on UV platforms. Custom-designed detectors can be a fraction of the weight but typically do not include power sources, hardening, or user interfaces for handheld operation. Example payloads will be used for multirotor sizing, whereas fixed-wing vehicles will use mass fractions and total takeoff weight to determine system endurance.

Electric Multirotor Sizing

Multirotor sizing is estimated from derived power equations related to current draw and battery capacity that can maintain the vehicle in a constant hover. The power required for each prop (P_{prop}) is dependent on vehicle mass (*m),* the area and efficiency of the prop (A_{prop}, η_{prop}), the number of motors (n_{motors}), and the density of air (ρ_{air}) (Equation 3) [45], [46].

$$P_{prop} = \frac{2 \cdot A_{prop} \cdot \rho_{air}}{\eta_{prop}} \cdot \left(\sqrt{\frac{m \cdot g}{2 \cdot A_{prop} \cdot \rho_{air} \cdot n_{motors}}} \right)^3 \quad (3)$$

The power required for each prop to maintain hover determines the current required for each motor (I_{motor}), which also depends on the battery voltage ($V_{battery}$) and the motor efficiency (η_{motor}) (Equation 4) [46].

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$$I_{motor} = \frac{P_{prop}}{V_{battery} \cdot \eta_{motor}} \quad (4)$$

The total current (I_{total}) required for vehicle operation is found using the total number of motors (n_{motors}) and additional current requirements ($I_{auxilary}$) (Equation 5) [46].

$$I_{total} = I_{motor} \cdot n_{motors} + I_{auxilary} \quad (5)$$

In order to determine the UV's endurance (E), the usable battery capacity (C_{usable}) has to be calculated by using the rated capacity of the battery (C_{rated}), the efficiency of the battery ($\eta_{battery}$), the permissible battery discharge depth (f_{usable}), and the number of batteries ($n_{batteries}$) (Equations 6-7) [46].

$$C_{usable} = C_{rated} \cdot \eta_{battery} \cdot f_{usable} \cdot n_{batteries} \quad (6)$$

$$E = \frac{C_{usable}}{I_{total}} \quad (7)$$

Sizing was calculated for electric DoD UAS Group 1 and Group 2 multirotor vehicles. The Group 1 multirotor was estimated to carry a FLIR IdentiFINDER R400-NG, which has a NaI(Tl) scintillator for dose rate measurement and radioisotope identification and a G-M tube for high radiation field dose rate equivalence. This payload adds 1.2 kilograms to the overall mass with dimensions of 24.9 centimeters × 9.4 centimeters × 7.6 centimeters and an 8-hour runtime on internal batteries [19]. A Tarot T960 hexacopter frame with Tarot 5008-340KV motors were used for mass and power estimates. Including two 10 ampere-hour 6-cell lithium polymer (LiPo) batteries to the

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system, the overall mass is 9 kilograms, which is within the threshold for Group 1 UAS. Hovering at this weight produces an overall endurance of 20 minutes. A summary of the input data and results can be found at Table 10.

Table 10. Group 1 electric multirotor endurance estimate

Payload mass [kg]	1.2
Mass w/out batteries/payload [kg]	5.3
Gravity [m/s²]	9.86
Air density [kg/m³]	1.2
Prop diameter [in]	18
Prop diameter [m]	0.46
Prop efficiency	0.8
Motor efficiency	0.8
# battery cells	6
Rated battery capacity [Ah]	10
Battery voltage [volts]	22.2
Battery mass [kg]	1.32
# batteries	2
Battery efficiency	0.9
Permissible battery discharge	0.8
Usable battery capacity [Ah]	14.4
# motors	6
Motor mass [g]	168
Auxiliary current [A]	5
Total mass [kg]	9
Power required per prop [W]	115.9
Current required per motor [A]	6.5
Total current [A]	44.2
Endurance [min]	**19.6**

The Group 2 multirotor was estimated to carry an Ortec Micro-Detective-DX, which uses an HPGe semiconductor and electromechanical Stirling-cycle cooler for dose rate measurement and high-resolution identification. This payload adds 6.8 kilograms to

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the overall mass with dimensions of 37.3 centimeters × 14.6 centimeters × 27.9 centimeters and a 5-hour runtime on its lithium-ion battery pack [19]. A Tarot T960 hexacopter frame with T-Motor-U7-420KV motors were used for mass and power estimates. Including three 10 ampere-hour 6-cell LiPo batteries to the system, the overall mass is 16.7 kilograms, which is 6 kilograms below the Group 3 UAS threshold. However, it should be noted that the total mass exceeds the recommended 15-kilogram design threshold for the frame [47]. This estimate, although not advisable for design purposes, provides a best-case operating endurance using the lightweight frame and heavy payload. Even with these risky operating parameters, hovering at this weight only produces an endurance of 13 minutes. A summary of the data and results can be found at Table 11.

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Table 11. Group 2 electric multirotor endurance estimate

Payload mass [kg]	6.8
Mass w/out batteries [kg]	5.9
Gravity [m/s²]	9.86
Air density [kg/m³]	1.2
Prop diameter [in]	18
Prop diameter [m]	0.46
Prop efficiency	0.8
Motor efficiency	0.8
# battery cells	6
Rated battery capacity [Ah]	10
Battery voltage [volts]	22.2
Battery mass [kg]	1.32
# batteries	3
Battery efficiency	0.9
Permissible battery discharge	0.8
Usable battery capacity [Ah]	21.6
# motors	6
Motor mass [g]	255
Auxiliary current [A]	5
Total mass [kg]	16.7
Power required per prop [W]	285.3
Current required per motor [A]	16.1
Total current [A]	101.4
Endurance [min]	**12.8**

Hybrid-electric Multirotor Sizing

Group 1 and Group 2 electric multirotors provide short endurance flights, which limits their application to cover small search areas. Therefore, an estimate was completed of a Group 2 hybrid-electric multirotor that uses a gasoline generator to charge a LiPo battery to power the motors. The gasoline provides a higher specific energy while the battery provides a simpler and more reliable method for throttling power to the six

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electric motors. The same Ortec Micro-Detective-DX payload was used, but this time a GAIA 160 Elite Pro 2.4 kilowatt hybrid-electric drone was used as a baseline system [48]. The same power equation (Equation 3) was used to determine the power required per prop, which was then totaled for the entire system. The gas generator can supply a constant 2.4 kilowatts of power at a fuel burn rate of 2.5 liters per hour. This allows for an endurance of 58 minutes when flying with 3 liters of fuel and retaining 20% of fuel at the end of mission. Results from the estimation are detailed in Table 12.

Table 12. Group 2 hybrid-electric multirotor endurance estimate

Payload mass [kg]	6.8
Mass fraction payload	0.30
Generator system mass [kg]	4.2
Mass w/out payload [kg]	13.7
Gas density [kg/L]	0.76
Fuel capacity [L]	3
Mass of fuel [kg]	2.3
Mass fraction fuel and batteries	0.2
Gravity [m/sec^2]	9.86
Air density [kg/m^3]	1.2
Prop diameter [in]	29
Prop diameter [m]	0.74
Prop efficiency	0.8
Motor efficiency	0.8
# battery cells	6
Rated battery capacity [Ah]	5
Battery voltage [volts]	22.2
Battery mass [kg]	0.85
# batteries	2
# motors	6
Auxiliary current [A]	5
Total mass [kg]	22.8
Power required per prop [W]	282.8
Power required system [W]	2232
Fuel burn rate (2.4kW) [L/hr]	2.5
Endurance [min]	**57.6**

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Fixed-wing Sizing

Fixed-wing sizing was completed for a Group 1 electric vehicle and a Group 2 gasoline-powered vehicle. The maximum takeoff weights ($W_{takeoff}$) for the electric and gasoline UVs are the maximum allowable for Group 1 and Group 2 vehicles, which are 9 kilograms and 25 kilograms respectively. Vehicle airspeeds (v) were varied for both vehicles so high and low endurance estimates can be compared. The lift-to-drag ratios (L/D) were also varied in order to provide endurance ranges. The endurance equation is similar to the multirotor endurance equation, but the battery power equation incorporates the takeoff weight, the vehicle air speed, the lift-to-drag ratio, and the summated propulsion efficiencies ($\eta_{propulsion}$) from the electronic speed controller, the propeller, and the motor (Equations 8-9) [45].

$$E = \frac{C_{usable} \cdot V_{battery}}{P_{battery}} \tag{8}$$

$$P_{battery} = \frac{W_{takeoff} \cdot v}{L/D \cdot \prod \eta_{propulsion}} \tag{9}$$

For the fixed-wing vehicles, specific payloads were not chosen for mass. Instead, a mass fraction of 15% of the takeoff weight was used for the allowable payload mass in order to estimate the endurance. The endurances for the Group 1 electric vehicle range from 41 to 69 minutes when flying at a constant angle of attack at the given cruise airspeeds. A summary of the estimated endurances and ranges can be seen in Table 13.

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Table 13. Group 1 electric fixed-wing endurance estimate

Airspeed [m/s]	16	20	16	20
L/D	6	6	8	8
Mass fraction battery	0.3	0.3	0.3	0.3
Mass fraction payload	0.15	0.15	0.15	0.15
Battery mass allowable [kg]	2.73	2.73	2.73	2.73
Payload mass allowable [kg]	1.36	1.36	1.36	1.36
Total mass [kg]	9	9	9	9
Gravity [m/s²]	9.86	9.86	9.86	9.86
Prop efficiency	0.8	0.8	0.8	0.8
Motor efficiency	0.8	0.8	0.8	0.8
# battery cells	6	6	6	6
Rated battery capacity [Ah]	10	10	10	10
Battery voltage [volts]	22.2	22.2	22.2	22.2
Battery mass [kg]	1.32	1.32	1.32	1.32
# batteries	2	2	2	2
Battery efficiency	0.9	0.9	0.9	0.9
Permissible battery discharge	0.8	0.8	0.8	0.8
Usable battery capacity [Ah]	14.4	14.4	14.4	14.4
Power required thrust [W]	239.0	298.8	179.3	224.1
Power required from battery [W]	373.5	466.9	280.1	350.1
Endurance [hr]	0.9	0.7	1.1	0.9
Endurance [min]	**51.4**	**41.1**	**68.5**	**54.8**

The endurance estimate for gasoline engine requires the brake specific fuel consumption ($BSFC$) (Equation 10). A representative vehicle that is under the 25-kilogram Group 2

$$E = \frac{L/D \cdot \eta_p}{v \cdot BSFC} \cdot ln\left(\frac{1}{1-MF_{fuel}}\right) \tag{10}$$

threshold is the Silver Fox, which has a $BSFC$ of 395 grams per kilowatt-hour [49]. The estimated endurances for a gasoline-powered vehicle using this $BSFC$ range from 12 to 24 hours with a payload near 2 kilograms (Table 14).

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Table 14. Group 2 gasoline fixed-wing endurance estimate

Airspeed [m/s]	20	30	20	30
L/D	6	6	8	8
Mass fraction fuel	0.25	0.25	0.25	0.25
Mass fraction payload	0.15	0.15	0.15	0.15
Fuel [kg]	3.25	3.25	3.25	3.25
Payload [kg]	1.95	1.95	1.95	1.95
Total mass [kg]	13.0	13.0	13.0	13.0
Prop efficiency	0.8	0.8	0.8	0.8
BSFC [g/kW-hr]	395	395	395	395
Endurance [hr]	**17.7**	**11.8**	**23.6**	**15.8**

Feasibility for Current Radiological Search Operations

At a minimum, the conceptualized system would serve useful for a portion of current operations. Executing the entire operation from the initial search through completing source disposal is unlikely. This is due to the potential unfavorable scenarios and environmental conditions that could be encountered, especially when weighing the limited performance of certain vehicles such as the electric multirotor endurance and payload capacity. Incorporating the system into a portion of operations is very feasible. For instance, conducting an initial search of a large area would be extremely useful for responding personnel, especially if the terrain is difficult to navigate by foot or is not accessible by vehicle. Once the initial search area has been decreased, unmanned platforms could provide an excellent asset for surveillance by providing immediate feedback to personnel on the ground. However, confirmation activities using the unmanned system may have limited applicability. In most permissible scenarios, human operators are best suited to finish ground operations including spectrum collection and follow-on activities. Non-permissible environments may warrant the full utilization of

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the radiological search system, especially when strong sources or nefarious activity and entrapments are involved. Nevertheless, utilizing the system in place of human operators is dependent on system-mitigated hazards and efficiently accomplishing the tasks expected of human teams.

When considering the estimated endurances for the vehicle power plant configurations, there are performance constraints for some vehicles and optionality for others. The fixed-wing is able to execute the mission using both electric and gasoline power plants. The endurance and payload capacity are much higher for the gasoline engine, but the overall size of the vehicle is increased. The larger size could decrease vehicle maneuverability, forcing the vehicle to fly at a higher and safer operating altitude. This is not ideal for detecting radiation. Therefore, detector sensitivity, operating altitude, and airspeed should be assessed when selecting the fixed-wing vehicle and detector payload. On the other hand, multirotor vehicles are limited to hybrid-electric setups in order to provide sufficient endurance while carrying a detector payload. This would supply enough power to ingress, collect a spectrum, and egress from any estimated source location. Battery-powered multirotors offer limited endurance and are too risky for incorporating into the radiological search system.

An important aspect of evaluating system feasibility is the cost of the system, which depends on design decisions and other factors that are not the focus of this research. Regardless of having a tangible price, the same comparison needs to be made concerning the cost of the system against the utility it provides the user. The procurement cost and recurring costs will not be worthwhile for some agencies based

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upon their scope of responsibility and the probability that they will have to respond to a lost or stolen radiological source. The typical small-town police department would not benefit from this system as both the probability of response is low and there is most likely a federal or state asset that is the principal agency for this type of emergency response. Agencies that would benefit from this system would be those responsible for large metropolitan areas, have a high-threat environment including radiological material, cover high-density areas of NRC Category 1 and Category 2 radioactive materials, and those that are deemed principal responding agencies per governing policy. State and local agencies that could realistically benefit from an unmanned search system include large metropolitan area police departments and high-volume ports. Federal applicability ties directly to existing policy and emergency response plans that define who is responsible for specific emergency scenarios and jurisdictional areas, such as the Federal Bureau of Investigation, the DOE and national laboratories, the Department of Homeland Security, and the DoD. For example, the Radiological Assistance Program (RAP) under the DOE is one of many organizations formed to assist with radiological emergency responses. The United States is split into nine geographic regions that are covered by separate RAP teams [50]. These teams could benefit from an unmanned radiological search system as part of their equipment suite to cover the array of radiological response missions they are responsible for.

The last issue that this system would introduce is logistical requirements on the owning organization. Like the initial procurement cost of the system, the cost for maintenance and replacement parts should be measured against the utility of the system.

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Maintenance issues can be time consuming and costly, which depends on the complexity of the system and the necessity to procure specialty tools or equipment. If maintenance is completed by the owning organization, maintenance hours on this system would decrease hours spent on other serviced equipment and potentially impact other mission areas. Increased manpower or dedicated maintenance technicians may be necessary, which also increases the overall cost. If a separate maintenance contract is determined to be the optimal route, this requires continual funding to ensure the system maintains operational readiness. The aforementioned costs will help decision-makers determine the realistic acquisition and implementation of this system.

Utility to Other Missions

It is crucial to look at the applicability and extension of the radiological search system to other mission areas. Expanding the operational reach of the system to other mission areas would also increase the overall value for government and private entities. This increase in the asset's value could result in more emphasis on mission application, funding, maintenance, and development of future systems and system payloads. Providing a niche-solution to the radiological search mission will only attract niche customers. An infrequently used equipment set makes it challenging for the end user to reorient on system functionality and could lead to mechanical maintenance issues due to inactivity. Therefore, expanding the applicability of the system should be beneficial in terms of utility and cost effectiveness. Some consequences of expanding the mission coverage could include optional sizing of ground and air vehicles, the inclusion of a

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water-borne platform, and a more flexible vehicle architecture that can interface with numerous payloads.

In order to promote a flexible system that can apply to other missions, some modifications will need to be made. The system architecture is currently geared toward a radiological search mission with three specific vehicle options that all serve a certain purpose and accomplish certain tasks. There is some flexibility built into the system with separate modems for autopilot, video, and payloads. However, the promoted sizing for both the vehicle chassis and the power plant configurations are geared toward lifting a 6.8-kilogram payload for the multirotor and ground UVs as well as providing increased endurance for the fixed-wing UV by integrating a combustion engine. These narrowed solutions serve the purpose of meeting the intent established in the CONOPS. In order to provide a more comprehensive system, a new CONOPS and system architecture should be developed with a more holistic approach to incorporate current and emerging missions. As previously discussed, this would necessitate the customization of some hardware components such as the communication modem and processor suite in addition to on-board and GCS software. These additions would provide the capability for multiple vehicles to interchange payloads and the ability to reprogram system software to be compatible with a variety of components and data types.

Summary

The radiological search system has been characterized starting with the system CONOPS and resulting in the physical framework to meet the capabilities and assumptions determined by the CONOPS. Following the characterization of the system,

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a feasibility analysis considered the potential benefits and disadvantages that the system presents and must be evaluated when determining the overall utility of the system to the mission area. The analysis determined that the system could apply to current radiological search operations but may be limited to certain portions of the mission and constrained to specific organizations. Lastly, it was concluded that the system could be applied to other missions, but it may need to be modified to provide enhanced flexibility and a more refined product.

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V. Conclusions and Recommendations

Overview

Within the counter-WMD mission space, radiological and nuclear terrorism is an imminent and constant threat to United States national security. Developing and employing new technologies is crucial for safeguarding this nation, and a radiological search system is a potential solution to assist and strengthen the radiological search mission space. It would provide more execution options to responding personnel and the ability to remove the human element from hazardous situations.

Review of Findings

A CONOPS was developed by incorporating mission needs and constraints for radiological search operations. Utilizing the radiological search CONOPS, use cases and a functional decomposition were derived that account for the necessary tasks to complete radiological search missions. A physical architecture was created in order to allocate physical components to satisfy task completion. After completing the hierarchical decomposition, it is evident that the system necessitates a multidimensional construct with multiple vehicle platforms and distinct detector payloads that are governed by scenario or mission criteria. Each detector technology can be optimally applied to select portions of the radiological search mission, such as initial search operations or gamma spectrum collection. Similarly, certain vehicle platforms are ideal for or are limited to specific segments of the mission. In order to cover the gamut of radiological search mission tasks, the system needs multiple vehicle options and interchangeable detector

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payloads with an adaptable system framework. The conceptual system was found to be feasible in terms of constructability and operability based upon currently available technologies, but it may have limited application to the mission area. Hybrid-electric power plants would be a necessity for multirotor endurance and payload capacity, whereas fixed-wing vehicles could safely operate with battery or gasoline-powered options. In order to maximize the utility and effectiveness of the system to other DoD mission areas, the system needs to be expanded to provide more optionality for payload integration, vehicle selection, and software flexibility. This includes a universal system architecture and software suite that can adapt to emerging technologies and mission areas.

Study Limitations

The research was scoped to cover system application to radiological and nuclear material search and spectroscopy activities in the next two to five years. Assumptions guided the creation of the CONOPS, as user requirements for the system do not exist. The research did not incorporate consequence management surveying following accidents or terrorism activity involving nuclear or radiological materials. Content was limited to publicly available information and did not dwell at a higher-level of classification. Tactics, techniques, and procedures for the system were not covered, as the focus was characterizing the system and its operational feasibility and utility of the system to the radiological search mission. Lastly, research was limited by funding and time constraints.

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Future Research

There are multiple avenues for future research involving unmanned systems to accomplish radiological search missions. Options align with a continuation of the Systems Engineering "V" concept by conducting a detailed system design, developing custom hardware or software for the vehicles and GCS, or completing a cost analysis of system procurement and lifecycle operating costs for the end user. Utilizing a decision-based engineering design framework will provide rigor to the engineering design process and ensures that value theory is applied to system development [51]. These additional areas would provide more tangible findings and insight to the system's utility when weighed against acquisition and recurring costs.

Another research opportunity is refining or building a new architecture to expand the radiological search system to multiple mission areas. The application of the system to other missions was briefly discussed in Chapter IV. This would include additional ground and air vehicles, waterborne vehicles for maritime operations, a custom communication and processing package, and custom system software for both the GCS and UVs. An extended application to current mission areas with the flexibility to cover emerging missions would greatly increase the utility and value of the system.

In Chapter IV's design considerations, employing handheld detectors on system vehicles was considered for increasing the flexibility of the overall system and avoiding a mission stoppage if conditions change. It would be beneficial to compare commonly used handheld detectors to COTS and GOTS detectors designed for vehicle applications. Detectors can be evaluated on performance in different radiation field configurations,

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vehicle emplacement options and limitations, integration with system hardware and software, and expected procurement and lifecycle costs.

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Appendix A. Subsystem Physical Allocation Matrices

Table 15. Fixed-wing vehicle physical allocation matrix

Legend Allocated - ↗		Navigation Module					Payload Module						Power Module										Self-Destruct		Vehicle				
	System Summary	Module Summary	Autopilot	Autopilot Modem	GPS/ Compass	Pitot sensor	Module Summary	Camera	Gimbal	Payload Modem	Radiation detector	Video transmitter	Module Summary	Battery	Fuel tank	Gas generator	Ignition	Ignition power switch	Optical kill switch	Power distribution board	Wiring	Module Summary	Self-destruct package	Module Summary	Airframe	ESC	Propeller	Servo
Analyze spectrum data																													
Auto land	↗	↗											↗											↗					
Auto takeoff	↗	↗											↗											↗					
Calculate target coord																													
Capture video	↗						↗	↗					↗																
Collect rad data	↗						↗				↗		↗																
Collect rad spectrum																													
Combine rad data/telemetry																													
Conduct BIT	↗	↗	↗										↗																
Connect to GCS	↗	↗		↗			↗			↗		↗	↗																
Connect to vehicle																													
Construct MP																													
Create rad map																													
Display MP status																													
Display rad data																													
Display rad map																													
Display rad spectrum																													
Display radionuclide																													
Display target coord																													
Display telemetry																													
Display video																													
Follow search pattern	↗	↗											↗											↗					
Initiate search																													
Load MP	↗	↗	↗	↗																									

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Legend Allocated - ↗		Navigation Module					Payload Module						Power Module									Self-Destruct		Vehicle				
	System Summary	Module Summary	Autopilot	Autopilot Modem	GPS/ Compass	Pitot sensor	Module Summary	Camera	Gimbal	Payload Modem	Radiation detector	Video transmitter	Module Summary	Battery	Fuel tank	Gas generator	Ignition	Ignition power switch	Optical kill switch	Power distribution board	Wiring	Module Summary	Self-destruct package	Module Summary	Airframe	ESC	Propeller	Servo
Loiter	↗	↗											↗											↗				
Navigate waypoints	↗	↗											↗											↗				
Perform autopilot functions	↗	↗	↗	↗									↗											↗				
Perform controlled movement	↗	↗											↗											↗				
Perform GCS activities																												
Perform rad measurement	↗						↗				↗		↗															
Perform rad search activities	↗	↗	↗	↗			↗	↗		↗	↗	↗	↗											↗				
Perform vehicle activities	↗	↗	↗	↗			↗	↗		↗	↗	↗	↗											↗				
Perform vehicle data comm	↗	↗	↗	↗			↗			↗			↗															
Process																												
Provide data comm w/ vehicle																												
Provide I/O w/ GCS operator																												
Provide video	↗						↗	↗				↗	↗															
Receive cmd	↗	↗		↗			↗			↗			↗															
Receive MP status																												
Receive rad data																												
Receive spectrum data																												
Receive telemetry																												
Receive video																												
Report MP load status	↗	↗	↗	↗									↗															
Send cmd																												
Send rad data	↗						↗			↗			↗															
Send spectrum data																												
Send telemetry	↗	↗		↗									↗															
Send video	↗						↗					↗	↗															
Store rad data																												
Store spectrum data																												
Store target coord																												
Store telemetry																												
Store video																												
Trigger self-destruct actuator	↗	↗	↗	↗									↗									↗	↗					
Write MP																												

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Table 16. Ground vehicle physical allocation matrix

Legend Allocated - ↗		Navigation Module				Payload Module							Power Module				Self-Destruct		Vehicle					
	System Summary	Module Summary	Autopilot	Autopilot Modem	GPS/Compass	Module Summary	Camera	Gimbal	Payload Modem	Radiation detector	Spectrum collector	Video transmitter	Module Summary	Battery	Power distribution board	Wiring	Module Summary	Self-destruct package	Module Summary	Articulator arm	ESC	Ground vehicle chassis	Motor	Servo
Analyze spectrum data																								
Auto land	↗	↗											↗						↗					
Auto takeoff	↗	↗											↗						↗					
Calculate target coord																								
Capture video	↗					↗	↗						↗											
Collect rad data	↗					↗				↗			↗											
Collect rad spectrum	↗					↗					↗		↗											
Combine rad data/telemetry																								
Conduct BIT	↗	↗	↗										↗											
Connect to GCS	↗	↗		↗		↗			↗			↗	↗											
Connect to vehicle																								
Construct MP																								
Create rad map																								
Display MP status																								
Display rad data																								
Display rad map																								
Display rad spectrum																								
Display radionuclide																								
Display target coord																								
Display telemetry																								
Display video																								
Follow search pattern	↗	↗											↗						↗					
Initiate search																								
Load MP	↗	↗	↗	↗																				

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Legend Allocated - ↗		Navigation Module				Payload Module							Power Module				Self-Destruct		Vehicle					
	System Summary	Module Summary	Autopilot	Autopilot Modem	GPS/Compass	Module Summary	Camera	Gimbal	Payload Modem	Radiation detector	Spectrum collector	Video transmitter	Module Summary	Battery	Power distribution board	Wiring	Module Summary	Self-destruct package	Module Summary	Articulator arm	ESC	Ground vehicle chassis	Motor	Servo
Loiter	↗	↗											↗						↗					
Navigate waypoints	↗	↗											↗						↗					
Perform autopilot functions	↗	↗	↗	↗									↗						↗					
Perform controlled movement	↗	↗											↗						↗					
Perform GCS activities																								
Perform rad measurement	↗					↗				↗	↗		↗											
Perform rad search activities	↗	↗	↗	↗		↗	↗		↗	↗	↗	↗	↗						↗					
Perform vehicle activities	↗	↗	↗	↗		↗	↗		↗	↗	↗	↗	↗						↗					
Perform vehicle data comm	↗	↗	↗	↗		↗			↗				↗											
Process																								
Provide data comm w/ vehicle																								
Provide I/O w/ GCS operator																								
Provide video	↗					↗	↗					↗	↗											
Receive cmd	↗	↗		↗		↗			↗				↗											
Receive MP status																								
Receive rad data																								
Receive spectrum data																								
Receive telemetry																								
Receive video																								
Report MP load status	↗	↗	↗	↗									↗											
Send cmd																								
Send rad data	↗					↗			↗				↗											
Send spectrum data	↗					↗			↗				↗											
Send telemetry	↗	↗		↗									↗											
Send video	↗					↗						↗	↗											
Store rad data																								
Store spectrum data																								
Store target coord																								
Store telemetry																								
Store video																								
Trigger self-destruct actuator	↗	↗	↗	↗									↗				↗	↗						
Write MP																								

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Table 17. Multirotor vehicle physical allocation matrix

Legend Allocated - ↗		Navigation Module					Payload Module							Power Module										Self-Destruct		Vehicle			
	System Summary	Module Summary	Autopilot	Autopilot Modem	Distance Sensor	GPS/Compass	Module Summary	Camera	Gimbal	Payload Modem	Radiation detector	Spectrum collector	Video transmitter	Module Summary	Battery	Fuel tank	Gas generator	Ignition	Ignition power switch	Optical kill switch	Power distribution board	Wiring	Module Summary	Self-destruct package	Module Summary	ESC	Multirotor frame	Propeller
Analyze spectrum data																													
Auto land	↗	↗												↗											↗				
Auto takeoff	↗	↗												↗											↗				
Calculate target coord																													
Capture video	↗						↗	↗						↗															
Collect rad data	↗						↗				↗			↗															
Collect rad spectrum	↗						↗					↗		↗															
Combine rad data/telemetry																													
Conduct BIT	↗	↗	↗											↗															
Connect to GCS	↗	↗		↗			↗			↗				↗															
Connect to vehicle																													
Construct MP																													
Create rad map																													
Display MP status																													
Display rad data																													
Display rad map																													
Display rad spectrum																													
Display radionuclide																													
Display target coord																													
Display telemetry																													
Display video																													
Follow search pattern	↗	↗												↗											↗				
Initiate search																													
Load MP	↗	↗	↗	↗																									

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Legend Allocated - ↗		Navigation Module					Payload Module							Power Module										Self-Destruct		Vehicle			
	System Summary	Module Summary	Autopilot	Autopilot Modem	Distance Sensor	GPS/Compass	Module Summary	Camera	Gimbal	Payload Modem	Radiation detector	Spectrum collector	Video transmitter	Module Summary	Battery	Fuel tank	Gas generator	Ignition	Ignition power switch	Optical kill switch	Power distribution board	Wiring	Module Summary	Self-destruct package	Module Summary	ESC	Multirotor frame	Propeller
Loiter	↗	↗												↗												↗			
Navigate waypoints	↗	↗												↗												↗			
Perform autopilot functions	↗	↗	↗	↗										↗												↗			
Perform controlled movement	↗	↗												↗												↗			
Perform GCS activities																													
Perform rad measurement	↗						↗				↗	↗		↗															
Perform rad search activities	↗	↗	↗	↗			↗	↗		↗	↗	↗	↗	↗												↗			
Perform vehicle activities	↗	↗	↗	↗			↗	↗		↗	↗	↗	↗	↗												↗			
Perform vehicle data comm	↗	↗	↗	↗			↗			↗				↗															
Process																													
Provide data comm w/ vehicle																													
Provide I/O w/ GCS operator																													
Provide video	↗						↗	↗					↗	↗															
Receive cmd	↗	↗		↗			↗			↗				↗															
Receive MP status																													
Receive rad data																													
Receive spectrum data																													
Receive telemetry																													
Receive video																													
Report MP load status	↗	↗	↗	↗										↗															
Send cmd																													
Send rad data	↗						↗			↗				↗															
Send spectrum data	↗						↗			↗				↗															
Send telemetry	↗	↗		↗										↗															
Send video	↗						↗						↗	↗															
Store rad data																													
Store spectrum data																													
Store target coord																													
Store telemetry																													
Store video																													
Trigger self-destruct actuator	↗	↗	↗	↗										↗									↗	↗					
Write MP																													

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Table 18. Ground control station physical allocation matrix

Legend Allocated - ↗	**System Summary**	Antenna tracker	Autopilot Modem	GCS computer	GCS software	GPS base station	Payload Modem	Radiation processing & mapping software	Video receiver
Analyze spectrum data	↗							↗	
Auto land									
Auto takeoff									
Calculate target coord	↗							↗	
Capture video									
Collect rad data									
Collect rad spectrum									
Combine rad data/telemetry	↗			↗	↗			↗	
Conduct BIT									
Connect to GCS									
Connect to vehicle	↗		↗				↗		
Construct MP	↗			↗	↗				
Create rad map	↗			↗				↗	
Display MP status	↗			↗	↗				
Display rad data	↗			↗				↗	
Display rad map	↗			↗				↗	
Display rad spectrum	↗			↗				↗	
Display radionuclide	↗			↗				↗	
Display target coord	↗			↗				↗	
Display telemetry	↗			↗	↗				
Display video	↗			↗					↗
Follow search pattern									
Initiate search	↗			↗	↗				
Load MP									

1604 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Legend Allocated - ↗	**System Summary**	Antenna tracker	Autopilot Modem	GCS computer	GCS software	GPS base station	Payload Modem	Radiation processing & mapping software	Video receiver
Loiter									
Navigate waypoints									
Perform autopilot functions									
Perform controlled movement									
Perform GCS activities	↗	↗	↗	↗	↗	↗	↗	↗	↗
Perform rad measurement									
Perform rad search activities									
Perform vehicle activities									
Perform vehicle data comm									
Process	↗			↗	↗			↗	
Provide data comm w/ vehicle	↗	↗	↗	↗	↗		↗	↗	
Provide I/O w/ GCS operator	↗			↗	↗			↗	↗
Provide video									
Receive cmd									
Receive MP status	↗	↗	↗						
Receive rad data	↗	↗					↗		
Receive spectrum data	↗	↗					↗		
Receive telemetry	↗	↗	↗						
Receive video	↗	↗							↗
Report MP load status									
Send cmd	↗	↗	↗	↗	↗		↗	↗	
Send rad data									
Send spectrum data									
Send telemetry									
Send video									
Store rad data	↗			↗					
Store spectrum data	↗			↗					
Store target coord	↗			↗					
Store telemetry	↗			↗					
Store video	↗			↗					
Trigger self-destruct actuator									
Write MP	↗		↗	↗	↗				

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Appendix B. System Use Cases

Description:
This Use Case encompasses deployment of the Rad Search System vehicle(s) and ingress to the search area.

Preconditions:
Successful completion of Perform Setup Use Case
GPS Lock

Primary Flow:
1. Ground Control Station Operator initiates Launch mode through Ground Control Station
2. Ground Control Station changes Vehicle mode to Launch
3. Vehicle enters Launch mode
4. Vehicle transmits telemetry to Ground Control Station(s)
5. Ground Control Station(s) receives and displays telemetry data
6. Ground Control Station(s) stores telemetry data
7. Ground Crew launches Vehicle
8. Vehicle establishes controlled movement or stable flight
9. Vehicle maneuvers toward search area
10. Ground Control Station Operator observes received data on Ground Control Station
11. Once Vehicle arrives at Search Insertion point, it enters Search mode
12. End Use Case

Alternate Flow:
At any time:
  a. If bad Vehicle health, Ground Control Station Operator enters RTL command on Ground Control Station
  b. Ground Control Station sends RTL command to Vehicle
  c. Vehicle enters RTL mode
At any time:
  a. Operator initiates <<include>> Plan Mission Use Case
  b. Vehicle ingresses to new Search Insertion point
At any time:
  a. If vehicle compromise is evident, execute <<extend>> Perform Self-Destruct Use Case

Postconditions: Vehicle arrives at Search Insertion point and enters Search mode

Involves:
GNSS
Ground Control Station Operator
Ground Crew

Figure 16. Deploy and ingress use case

1606 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Description:
This Use Case covers the RTL actions required to return the vehicle to home location or specified location with recovery.

Preconditions: Vehicle has entered RTL mode

Primary Flow:
1. Vehicle maneuvers toward home/recovery point
2. Vehicle arrives at home/recovery point
3. Vehicle executes auto-land maneuver
4. Ground Control Station Operator and Ground Crew recovers Vehicle
5. End Use Case

Alternate Flow: At any time:
a. If bad vehicle health, Ground Control Station Operator enters RTL command on Ground Control Station
b. Ground Control Station sends RTL command to Vehicle
c. Vehicle enters RTL mode
At any time:
a. Ground Control Station Operator initiates Plan Mission Use Case
b. Vehicle ingresses to new Search Insertion point
At any time:
a. If vehicle compromise is evident, execute <<extend>> Perform Self-Destruct Use Case

Postconditions: Vehicle is safely recovered by Ground Crew

Involves:
GNSS
Ground Control System Operator
Ground Crew

Figure 17. Egress and recover use case

1607 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Description:
This Use Case covers confirmation activities

Preconditions: Target has been located and a Vehicle has entered Confirmation mode

Primary Flow:
1. Vehicle transmits telemetry data, rad data, and video to Ground Control Station(s) and Off-Board C2
2. Ground Control Station(s) receives and displays telemetry data, rad data, and video
3. Ground Control Station(s) stores telemetry data, rad data, and video
4. Vehicle navigates to and hovers or remains near target
5. Ground Control Station sends collect rad spectrum data command
6. Vehicle receives and initiates rad spectrum collection
7. Vehicle transmits rad spectrum data
8. Ground Control Station(s) receives, stores, and displays rad spectrum data
9. Ground Control Station Operator terminates rad spectrum collection
10. Ground Control Station processes rad spectrum data and displays radionuclide identification
11. Ground Control Station Operator initiates RTL
12. Ground Control Station sends RTL command to Vehicle
13. Vehicle enters RTL mode
14. End Use Case

Alternate Flow:
At any time:
a. If bad vehicle health, Ground Control Station Operator enters RTL command on Ground Control Station
b. Ground Control Station sends RTL command to Vehicle
c. Vehicle enters RTL mode
At any time:
a. If vehicle no longer required due to deployed sensor package, Ground Control Station Operator enters RTL command
b. Ground Control Station sends RTL command to Vehicle
c. Vehicle enters RTL mode
At any time:
a. Ground Control Station Operator initiates <<include>> Plan Mission Use Case
b. Vehicle ingresses to new Search Insertion point or Confirmation coordinates
At any time:
a. If vehicle compromise is evident, execute <<extend>> Perform Self-Destruct Use Case
b. Vehicle self-destructs

Postconditions: Vehicle hovers or remains near target for > 5 minutes and rad spectrum is stored and displayed on Ground Control Station(s) with suspected radionuclide identification; Vehicle enters RTL mode

Involves:
GNSS
Off-Board C2 Operator
Target

Figure 18. Perform confirmation use case

1608 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Description:
This Use Case covers execution of search patterns

Preconditions: Vehicle arrives at insertion point and has transitioned to Search mode; Mission Plan is loaded by GCS

Primary Flow:
1. Vehicle transmits telemetry data, rad data, and video to Ground Control Station(s) and Off-Board C2
2. Ground Control Station(s) receives and displays telemetry data, rad data, and video
3. Ground Control Station(s) continuously combines telemetry and rad data and displays as a radiation strength map
3. Ground Control Station(s) stores telemetry data, rad data, and video
4. Vehicle follows search pattern according to Mission Plan
5. Ground Control Station Operator and Off-Board C2 monitor rad data, navigation data, and video
6. Vehicle completes search pattern according to Mission Plan
7. Ground Control Station determines target(s) coordinates from received rad data and telemetry data
8. Ground Control Station Operator commands change to Confirmation mode
9. Ground Control Station sends Confirmation mode change
10. Vehicle enters Confirmation mode
11. End Use Case

Alternate Flow:
At any time:
  a. If bad vehicle health, Ground Control Station Operator enters RTL command
  b. Ground Control Station sends RTL command to Vehicle
  c. Vehicle enters RTL mode
At any time:
  a. If vehicle no longer required due to deployed sensor package, Ground Control Station Operator enters RTL command
  b. Ground Control Station sends RTL command to Vehicle
  c. Vehicle enters RTL mode
At any time:
  a. Ground Control Station Operator initiates <<include>> Plan Mission Use Case
  b. Vehicle ingresses to new Search Insertion point (may be used to further loiter or investigate target location)
At any time:
  a. If vehicle compromise is evident, execute <<extend>> Perform Self-Destruct Use Case
  b. Vehicle self-destructs

Postconditions: Target is identified through radiation sensor data and telemetry data and target coordinates are calculated and displayed on Ground Control Station(s); Vehicle transitions to Confirmation mode

Involves:
GNSS
Off-Board C2 Operator
Target

Figure 19. Perform search use case

1609 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Description:
This Use Case covers the activities required to perform commanded self-destruct.

Preconditions: Vehicle is navigating in a location away from the Ground Control Station Operator

Primary Flow:
1. Operator initiates Ditch mode on Ground Control Station
2. Ground Control Station sends Self-Destruct mode change to Vehicle
3. Vehicle initiates Self-Destruct mode
4. Vehicle processor sends command to A/P to crash
5. Vehicle processor sends command to embedded self-destruct actuator
6. Embedded self-destruct actuator initiates and destroys processor
7. Vehicle crashes
8. End Use Case

Postconditions: Vehicle is successfully crashed and system is inoperable by other personnel

Figure 20. Perform self-destruct use case

1610 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Description:
This Use Case covers the setup and mission planning for use of the Rad Search System

Preconditions:
Tasking received
Search area defined
Desired radionuclide(s) specified

Primary Flow:
1. Ground Crew and Ground Control Station Operator unpacks equipment
2. Ground Crew and Ground Control Station Operator inventories equipment
  2a. If necessary equipment missing - end Use Case
3. Ground Crew and Ground Control Station Operator assembles equipment
4. Ground Crew and Ground Control Station Operator initiate connection between Ground Control Station and Vehicle(s)
5. Ground Control Station sends connect signal to Vehicle(s)
6. Vehicle(s) makes connection to Ground Control Station
  6a. If connection fails, go to step 4. If fail 3x, end Use Case
7. Vehicle(s) begins transmission of rad data, rad spectrum data, telemetry data, and video
8. Ground Control Station displays rad data, rad spectrum data, telemetry data, and video
9. Ground Control Station stores rad data, rad spectrum data, telemetry data, and video
10. Ground Control Station Operator initiates function checks through Ground Control Station
11. Ground Control Station initiates function checks on Vehicle(s)
12. Vehicle(s) performs function checks and sends results to Ground Control Station
13. Ground Control Station displays results of function checks
14. Ground Control Station Operator confirms successful function checks.
  14a. If function check unsuccessful, go to step 10. If fail 3x, end Use Case.
15. <<Include>> Perform Mission Plan
  15a. If Mission Plan unsuccessful, repeat step 15. If fail 3x, end Use Case
16. End Use Case

Postconditions: System properly configured; mission planning complete; system ready for deployment

Involves:
Ground Control Station Operator
Ground Crew
GNSS

Figure 21. Perform setup use case

1611 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Description:
This Use Case covers actions associated with planning or re-planning a mission. It can be completed either pre-, or post-launch.

Preconditions: Vehicle has passed function checks and has established comm with Ground Control Station(s)

Primary Flow:
1. Ground Control Station Operator enters Mission Plan information into Ground Control Station
2. Ground Control Station converts Mission Plan to machine language form
3. Ground Control Station Operator initiates Write Mission Plan function on Ground Control Station
3. Ground Control Station sends machine language Mission Plan to Vehicle(s)
4. Vehicle(s) puts Mission Plan into active memory
5. Vehicle(s) sends indication of successful Mission Plan
6. Ground Station displays indication of successful Mission Plan load
7. End Use Case

Postconditions: Successful receipt of Mission Plan by Vehicle(s)

Figure 22. Plan mission use case

1612 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

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Vita

Captain Sam B. Harriger graduated from the United States Air Force Academy in 2011 where he received his commission and a Bachelor of Science in Environmental Engineering. After commissioning, Captain Harriger served in several Civil Engineering positions at Beale Air Force Base, California, including wastewater environmental compliance, aircraft beddown planning, and construction project management. He also deployed to southwest Asia, where he led five teams across seven countries providing runway rubber removal, airfield paint striping, and large area maintenance shelter construction. Captain Harriger's most recent assignments include serving as the 377th Explosive Ordnance Disposal (EOD) Flight Commander and as the EOD Section Chief at the Defense Nuclear Weapons School at Kirtland Air Force Base, New Mexico. In 2018, he was selected to attend the Air Force Institute of Technology at Wright Patterson Air Force Base, Ohio as part of the Graduate Engineering Management program. Following graduation and earning a Master of Science in Engineering Management, Captain Harriger is deploying to Africa to serve as a United Nations Staff Officer.

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Nuclear and radiological terrorism is a persistent threat to United States national security. The research and development of new technological capabilities is vital to bolstering emergency response and prevention capabilities in support of national security initiatives. This research characterized the applicable trade-space for a system of unmanned vehicles deployed for search, detection, and identification of radiological source material. Exploration included the development of a CONOPS, a functional decomposition and physical allocation, design considerations, and an analysis of feasibility and utility. The concept system comprises of a ground control station, ground vehicle, hybrid-electric multirotor, and fixed-wing vehicle with an open architecture permitting the exchange of payload components. Payload options include a Geiger-Müller detector or scintillator for large area search and a scintillator or high purity germanium semiconductor for radioisotope identification. Endurance estimates revealed that a hybrid-electric multirotor is capable of carrying a 6.8-kilogram payload for 58 minutes. Similar estimates indicated that a battery-powered fixed-wing vehicle can provide a minimum of 41 minutes of endurance with a payload mass fraction of 15% (1.36-kilogram payload), whereas a gasoline-powered vehicle with the same payload mass fraction (1.95-kilogram payload) can operate for 12 hours. Electric multirotors are limited to a maximum endurance of 20 minutes, which is insufficient for radiological search missions. The system concept proves effective to the radiological search mission and can be expanded to other mission areas through its open architecture.

15. SUBJECT TERMS
Unmanned Aerial Vehicle, Unmanned Aircraft System, Radiation Detection, Radiological Search

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ADVANCING INFORMATION COLLECTION MANAGEMENT PROFICIENCY IN THE BRIGADE COMBAT TEAM: A CASE FOR AN AUTHORIZED COLLECTION MANAGER

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements for the degree

MASTER OF MILITARY ART AND SCIENCE
General Studies

by

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B.A., George Mason University, Fairfax, VA, 2007

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2019

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In an ever-increasing complex world, the United States Army aims to modernize and innovate to meet emerging threats. This modernization is no less apparent than the changes observed in Army Information Collection resources and processes over the last thirty years. During this time, the Army has organized information collection platforms around the Brigade Combat Team without resourcing a collection manager at the Brigade Combat Team. This research seeks to determine the value of authorizing a collection manager position on the Brigade Combat Team Modified Table of Organization and Equipment. Through extensive qualitative analysis of doctrine, force management references, and professional writing from the past thirty years, this research found that the position of a collection manager provided expertise in coordinating information collection processes, producing information collection tools, and integrating information collection systems to support the commander's decision making.

15. SUBJECT TERMS
Military Intelligence, Brigade Combat Team, BCT, Collection Management, Collection Manager, Information Collection, Intelligence, Surveillance, and Reconnaissance, ISR

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

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ABSTRACT

ADVANCING INFORMATION COLLECTION MANAGEMENT PROFICIENCY IN THE BRIGADE COMBAT TEAM: A CASE FOR AN AUTHORIZED COLLECTION MANAGER, by Graham P. Shelly, 100 pages.

In an ever-increasing complex world, the United States Army aims to modernize and innovate to meet emerging threats. This modernization is no less apparent than the changes observed in Army Information Collection resources and processes over the last thirty years. During this time, the Army has organized information collection platforms around the Brigade Combat Team without resourcing a collection manager at the Brigade Combat Team. This research seeks to determine the value of authorizing a collection manager position on the Brigade Combat Team Modified Table of Organization and Equipment. Through extensive qualitative analysis of doctrine, force management references, and professional writing from the past thirty years, this research found that the position of a collection manager provided expertise in coordinating information collection processes, producing information collection tools, and integrating information collection systems to support the commander's decision making.

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ACRONYMS

ADP	Army Doctrine Publication
AIDP-ISR	Army Intelligence Development Program-Intelligence, Surveillance, and Reconnaissance
ATP	Army Techniques Publication
BCT	Brigade Combat Team
BICC	Battlefield Information Control Center
CM&D	Collection Management and Dissemination
CMM	Collection Mission Management
COM	Collection Operations Management
CRM	Collection Requirements Management
FM	Field Manual
INSCOM	United States Army Intelligence and Security Command
ISR	Intelligence, Surveillance, and Reconnaissance
LSCO	Large Scale Combat Operations
MICO	Military Intelligence Company
MTOE	Modified Table of Organization and Equipment
S-2	Military Intelligence Staff
S-3	Operations Staff
USAICoE	United States Army Intelligence Center of Excellence
UAS	Unmanned Aerial System

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CHAPTER 1

INTRODUCTION

The United States Army is currently undertaking significant efforts to modernize for future threats while continuing efforts to combat existing threats and maintain readiness. These efforts are evident as the Army shifts from counter-insurgency based operations to Large Scale Combat Operations (LSCO) including shifting to near-peer threat emulation at the combat training centers as well as updates to Army doctrine, starting with operations. As such, the Chief of Staff of the Army, General Milley, made readiness and the future Army as two priorities Army-wide.[1] As part of realigning strategy, Lieutenant General Robert Ashley, the Army G-2, developed the *Army Intelligence 2017-2025* to support the modernization efforts across the Army. The intelligence strategy seeks to "integrate the national to tactical intelligence enterprise with multi-domain operations to provide a high degree of situation understanding"[2] with the vision of "intelligence at the speed of mission command."[3]

The 2025 intelligence vision, nested with the Army Strategic Plan, lists synchronization of information collection efforts as the first competency of focus.[4] The vision further highlights the complexity of the future operating environment where near-peer or peer adversaries have capabilities to combat the US militaries relative dominance in information collection across all operating domains.[5] The 2025 intelligence vision identifies two major objectives with direct correlation to information collection management: fostering professionalization and manage talent, and fielding superior sensors.[6] Fostering professionalization and manage talent corresponds to the skills and abilities required for collection managers (CMs) to effectively employ collection

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platforms to drive operations and support the commander's visualization. The fielding of superior sensors speaks to the growing complexity of the operational environment into a truly multi-domain operational construct where current collection platforms are ineffective against peer adversaries' anti-access and area denial capabilities. The need for knowledgeable integrators through collection management will grow as information collection capabilities continue to advance through the Army's shift from counter-insurgency focus to multi-domain operations against a peer threat. The 2025 strategy provides the framework for how Army intelligence will prepare for the future fight by prioritizing efforts that ultimately drive budgetary decision, such as the fielding of new information collection platforms.

Intelligence collection represents a significant funding investment by the United States Government to answer the critical information requirements of civilian leaders and military commanders. A 2011 Government Accountability Office report highlighted the considerable growth in intelligence collection capabilities and expenditures to the sum of $80 billion dollars for fiscal year 2010 across the intelligence community.[7] Of this figure, for fiscal year 2010, "the defense intelligence budget, known as the Military Intelligence Program," comprised $27 billion in an environment where distinct collection activities and platforms between national and tactical levels were disappearing.[8] The blurring "between military intelligence activities and national strategic intelligence activities" of the platforms and intelligence consumers demonstrates that tactical consumers benefit from greater access to information collection capabilities than previously available just as national consumers are utilizing intelligence collected from tactical level platforms.[9] Further, these funding investments have historically not included dual use programs such

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as the Air Forces Reaper, as a collection and strike platform, as well as the military personnel expenses associated with intelligence activities which in some cases significantly underestimates the actual cost.[10] The availability of information collection platforms between echelons is largely a product of protracted counter-insurgency operations from Operations Iraqi Freedom and Enduring Freedom, enabled by advances in communications capabilities to widely disseminate information. The downward push of capabilities to the tactical-level was reinforced by the dynamic shift in Army operational construct from a Corps and Division warfighter to a modular Brigade Combat Team necessary to conduct effective counter-insurgency operations, necessitating significant investment in collection capabilities. As time progressed, terms like "Intelligence, Surveillance, and Reconnaissance (ISR) Soak", came to embody the availability of a multitude of information collection platforms at the Brigade Combat Team-level. Whereas Operations Iraqi Freedom and Enduring Freedom represent the epitome of information collection capability proliferation to meet operational needs, the first true test of highly technical information collection capabilities in support of large-scale combat operations came in Operation Desert Storm.

Operation Desert Storm provides context to the development and fielding of collection platforms over the last thirty years as the most recent example of large-scale combat operations. Likewise, this time period is illustrative of the highly technological approach to information collection and justification of significant budgetary investments. Operation Desert Storm saw the introduction of two significant collection platforms, the Unmanned Aerial System (UAS) and the Joint Surveillance and Target Attack Radar System (JSTARS).[11] Both systems deployed to Operation Desert Storm as prototypes to

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support the largely imagery dominated campaign.[12] The Pioneer UAS served as a Corps level platform while the JSTARS, an Air Force platform, supported both air component and Field Army targeting and intelligence development.[13] Further, both systems were praised heavily for their contributions and leaders from 3rd Army encouraged expansion and fielding of these platforms.[14] One conclusion the 3rd Army G-2 made after Operation Desert Storm is that the advancements in collection platforms and the ability of the American Soldier to leverage that technology were critical elements of success.[15] Where Operation Desert Storm demonstrated the ability to leverage new and existing national and tactical intelligence collection platforms in large scale combat operations, it highlighted the need for training in integrating and synchronizing these systems across echelons.

Leaders from Operation Desert Storm reinforced the need for "highly-trained intelligence personnel who can orchestrate multi-echelon collection management and dissemination operations" to provide "synchronized collection, processing, and dissemination of near-real-time, tailored intelligence."[16] This identified need, borne of experience, led to updates in the Army's collection management and tactical exploitation of national capabilities course designed to leverage the new, emerging information collection platforms identified earlier. The three-week collection management and tactical exploitation of national capabilities course represented the United States Army Intelligence Center of Excellence (UASICoE) efforts to fill the capability gap.[17] This Army school solution aimed at training multi-echelon capable collection managers. While the Intelligence Center developed this broader scoped training solution, the United

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States Army Intelligence and Security Command (INSCOM) sought a smaller education program of depth.

In 1992 INSCOM started the National Systems Development Program as an advanced training program for junior military intelligence officers in integrating national collection systems to support warfighters at the division and below level.[18] INSCOM later changed the name of this program to the Army Intelligence Development Program-ISR (AIDP-ISR).[19] No direct correlation exists in the unclassified literature between lessons learned in Operation Desert Storm with the creation of the National Systems Development Program, later AIDP-ISR. The current twelve-month training program assigns graduates as a collection manager at a U.S. Army Division or Corps for a twelve to twenty-four-month utilization tour to apply skills gained in collection management.[20] The program includes a variety of Army, Joint, and national training that covers collection capabilities, collection requirements management systems, collection management fundamentals, and integrating courses.

Collection capabilities focus primarily on distinct courses in the intelligence disciplines of Signals intelligence, Geo-Spatial Intelligence, and Human Intelligence. National-level courses at the Defense Intelligence Agency, the Department of Defense Collection Management proponent, provide exposure to collection management fundamentals and the collection requirements management systems to build proficiency in actually submitting requests for collection to national collection systems. Tactical-level collection management training occurs through USAICoEs Information Collection Planners Course. Integrating courses include examples such as the US Army Space Cadre with thorough orbital dynamics instruction and the Joint Firepower Course providing

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exposure to US Air Force resources and processes. The AIDP-ISR student's instruction culminates with participation in a Division Warfighter Exercise as a member of the Division Collection Management and Dissemination (CM&D) section. This exercise introduces the student to the array of information collection platforms at the Division and BCT levels.

The operational environment grows more complex everyday. The US Army, through INSCOM and USAICoE, continues to innovate through the development and acquisition of collection capabilities. The growth of unmanned and multi-intelligence discipline collection platforms bring more sensors and capabilities to maneuver commanders than previously available.[21] INSCOM's fielding of four unique manned and unmanned aerial collection platforms, the Enhanced Medium Altitude Reconnaissance and Surveillance System, Airborne Reconnaissance Low-Enhanced, MQ-1B Warrior Alpha, and MQ-1C Gray Eagle represent a sampling of the updated and emerging capabilities at echelons above brigade that collection managers can consider in developing collection plans.[22] At the time of the 2011 Government Accountability Office report on the Department of Defense ISR efficiencies, the department was attempting to develop long-term plans for "more than 500 ISR capabilities developed to meet urgent operational requirements in Iraq and Afghanistan" as a further example of the overwhelming collection capability environment.[23] Intelligence leaders foretold of this complex environment in 1992 while contemplating force structure changes.

> The evolving force structure calls for a smaller Army, mainly a CONUS-based force. The Army of the future must be able to deter potential regional threats and conflicts globally, instead of focusing primarily on European-based threats. This mission includes deterrence not only of mid- and high- intensity conflict, but also low-intensity conflict. The evolving threats include –

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- Nuclear and conventional forces of the Commonwealth of Independent States.
- Multiple regional threats from state and non-state powers in the Middle East, Asia, Africa, and Latin America.
- International drug trafficking.
- International Terrorism.[24]

The development of the BCT-centric capability came from force modernization plans based on lessons learned from small-scale contingency operations, such as Kosovo, resulting in the desire for a formation between the traditional heavy armor and light infantry.[25] In his estimations, Chief of Staff of the Army, General Eric Shinseki, concluded that future fights would require a force structure capable of rapid deployment but enabled with enough mobility and lethality to handle the transition from forced entry to sustained combat.[26] Two fundamental components of the BCT development are the Reconnaissance, Surveillance, and Target Acquisition Cavalry Squadron and the Military Intelligence Company (MICO). These organizations were designed to provide the BCT with significant organic information collection capabilities not previously available at the Brigade-level. The Cavalry Squadron included a surveillance troop of a UAS platform, signals intelligence collectors, and chemical reconnaissance to augment the three ground reconnaissance troops.[27] Separate from the cavalry squadron, a MICO consisting of human intelligence, ISR analysis, and ISR integration platoons served as the requirements management and analytical element for the BCT's new array of ground reconnaissance, UAS, human intelligence and signals intelligence collection platforms.[28] Through further modernization, the surveillance troop disappeared with the UAS and signals intelligence platforms moved to the MICO that now resides in the Brigade Engineer Battalion. The ISR analysis and integration platoons are consolidated into an

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information collection platoon adding analysis and synchronization requirements to fewer Soldiers. This increase in responsibilities to fewer Soldiers, coupled with the number of collection platforms within the BCT, results in a lack of integration in the information collection plan. This result is borne out in numerous combat training center rotation feedback and identified trends.

Problem

Brigade Combat Teams have access to vastly more collection platform capabilities than their counterpart formations during Operation Desert Storm as the model of the most recent LSCO. Currently, no authorized collection manager position exists in the BCT to support the integrated operations and intelligence working group responsible for developing a comprehensive information collection plan. To fulfill the requirements of collection management, BCTs designate a collection manager as an additional duty.

Thesis

The Brigade Combat Team needs an authorized, primary duty collection manager on the Modified Table of Organizational Equipment (MTOE) to integrate collection management processes with information collection systems through effective information collection tools to answer the commander's requirements.

Research Purpose

The purpose of this research is to determine the benefit of authorizing a collection manager position in the BCT MTOE with advanced training in information collection management to support the BCTs information collection operations.

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Research Question

What is the value of an authorized BCT collection manager in the MTOE as BCTs prepare for offensive and defensive operations with a near-peer threat in LSCO?

Supporting Research Questions

How does the BCT doctrinally execute information collection?

How have organic collection platforms available to the BCT changed over the last three decades?

What institutional and operational knowledge is necessary for a BCT CM?

Background and Bias

The researcher served in a variety of tactical-level positions related to information collection to include reconnaissance platoon leader, surveillance troop executive officer, battalion S-2, and AIDP-ISR student. Author's AIDP-ISR training and education includes the Army's Information Collection Planners Course, Defense Intelligence Agency's Intelligence Collectors Course and Intelligence Collection Management Course. Additionally, the researcher attended in-depth education covering capabilities and requirements management systems in the Geospatial, Signals, and Human Intelligence disciplines. Beyond collection management, the author attended integrating education in joint fires and digital intelligence systems architecture. The researcher acknowledges the inherent possibility of bias towards the role of the collection manager as a graduate of the AIDP-ISR program. In light of this bias, the author intends to show a variety of viewpoints objectively regarding improvements to information collection at the BCT. Lastly, the researcher recognizes that, as a Military Intelligence Officer, the research may

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appear framed from a military intelligence perspective. However, the researcher has never served as a BCT collection manager or supervised a BCT collection manager. To address the inherent Military Intelligence lean, this research intends to include the reconnaissance communities' perspective wherever possible.

Assumptions

The main assumption of this research is that information collection platforms available to the BCT will continue to grow. This assumption is largely based on lessons learned from Operations Desert Shield, Desert Storm, Iraqi Freedom, and Enduring Freedom. From Operation Desert Storm, "the field Army focused nearly all intelligence collection and production on Corps and Division needs" demonstrating a push of collection platforms to subordinate units.[29] The next assumption presumes the audience has a general understanding of the composition of a BCT to the company level, specifically enabler companies such as the Military Intelligence Company. The last assumption is the audience has a general understanding of the information collection capabilities organic to the BCT. This assumption is necessary to keep this research at the unclassified level as discussion of specific collection platform capabilities can quickly elevate the information to higher classification levels unnecessary for this discussion.

Definitions

The primary definition, for the purposes of this research, of Information Collection, is defined in the Army's manual as "an activity that synchronizes and integrates the planning and employment of sensors and assets as well as the processing, exploitation, and dissemination systems in direct support of current and future

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operations."[30] Sensor and asset must be defined for further clarity in the research as no formal definition exists in either Army or Joint doctrine. Oxford Dictionaries defines a sensor as a "device which detects or measures a physical property and records, indicates, or otherwise responds to it."[31] Given this definition, this research considers a sensor as a technical collection platform that transmits data for processing and analysis. Sensor collection systems associate most closely with the intelligence disciplines of Geospatial (GEOINT), Signals (SIGINT), Measures and Signatures (MASINT).

Assets are more loosely defined with Oxford Dictionaries offering as "a useful or valuable thing or person."[32] Given the broad scope of the term asset, this research considers a collection asset as a human dependent collector. Asset collectors are associated with Human Intelligence, Counter-Intelligence, and Cavalry Scouts performing reconnaissance and security operations. To further clarify, Cavalry scouts are capable of utilizing sensors, such as the long-range scout surveillance system, but for this research, the scout is the asset as the data is processed and reported by the scout as combat information.

A collection platform is inclusive of a sensor or an asset or a combination of multiple sensors or assets. A collection platform also includes the means of transportation and data communication. An example of a collection platform would be a Cavalry Scout section consisting of two combat vehicles equipped with long range scout surveillance systems as the sensors and eight Cavalry Scouts as the assets.

Two terms must be clarified in the leveraging of a collection platform against an information requirement. The terms of assigning versus tasking may, at face value, appear similar but, in reality, carry different weight in collection management.

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Doctrinally, unless dictated otherwise, the Commander and the S-3 are the two tasking authorities in the BCT. Staff supports the tasking authority through assignment recommendations to free the commander and S-3 to focus on other requirements of the operations process and mission command. This distinction is critical to the base understanding of the role of the collection manager. As a manager, the collection manager is a staff member making assignment recommendations to the Commander and S-3.[33] This distinction reflects in Army Information Collection doctrine as an operations series Field Manual (FM).

The Army definition of information collection is virtually identical to the joint definition of Intelligence, Surveillance and Reconnaissance (ISR) that is "an integrated operations and intelligence activity that synchronizes and integrates the planning and operations of sensors, assets, and processing, exploitation, and dissemination systems in direct support of current and future operations."[34] That stated, ISR is also a composition of three sub-elements as the acronym suggests with distinct characteristics differentiating them from one another. To fully understand the concept of ISR, one must first understand that intelligence exists in a product sense and operational sense. The product sense starts with the difference between data, information, and intelligence. Data exists in raw form and can be collected by a sensor or asset becoming information. Intelligence is information that has been processed and exploited by a trained analyst to derive meaning from the information collected. Intelligence in an operational sense are "tasks undertaken by military intelligence units and Soldiers to obtain information to satisfy validated requirements," and associated with one or more intelligence discipline; therefore, a form of collection operation.[35] Reconnaissance collection operations are focused on "obtaining

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information about the threat or the operational environment," whereas surveillance operations are a "systematic observation of places, person, or things."[36] Think of reconnaissance as cavalry scouts observing a named area of interest to confirm or deny an aspect of the threat or operational environment and then moving on to the next named area of interest after answering the first. Surveillance in this example would be establishing a longer duration presence by the same cavalry scouts to observe a threats activity and provide continuous reporting. Coupled together, ISR provides a wholistic approach to collecting information with intelligence and non-intelligence related sensors and assets.

Joint Collection Management Functions Defined

The two functions of collection management, as defined by Joint Pub 2-01, is necessary to understand roles and responsibilities associated with collection management as a process. The first is Collection Requirements Management (CRM) where a collection manager is responsible for validating the determined information requirements as necessary for collection.[37] The second is Collection Operations Management (COM) where a collection manager is responsible for assigning a collection platform to collect the information determined through the collection requirements management.[38] An associated, but not critical function, is Collection Mission Management (CMM) which is the tactical and technical control of a sensor or asset during collection operations. To summarize collection management functions, an analyst recommends a threat's indirect fires equipment as an information requirement that supports the commander's Priority Intelligence Requirements to the senior intelligence analyst in the Brigade Intelligence Support Element. The senior analyst includes the recommended information requirement

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along with additional information requirements such as location of threat forward observers to the collection manager for assigning a collection platform to collect. In this previous example, the senior analyst performs CRM functions while the collection manager performs COM functions. CMM rests with the organization that has direct command and control of the collection platform, in the example, CMM would be the parent unit of the forward observer. The examples provided to explain the joint collection management functions applied to a brigade are for illustrative purposes to understand the functions since current U.S. Army doctrine does not differentiate the roles in a U.S. Army capacity.

Scope

The intent of this research is to be applicable to all BCT organizations as every construct of the BCT fundamentally maintains an intelligence section, MICO, and cavalry squadron. The primary audience for this research is senior Military Intelligence leaders with influence on intelligence organization force structure and training. Brigade Combat Team Commanders and Division Senior Intelligence Officers are the secondary audience for this research as a means for manning and training of military intelligence within their respective commands. Collection platform diversity over the last three decades highlights the development of technical collection platforms available to the BCT. This timeframe includes LSCO in Operation Desert Storm, and both LSCO and Counter-Insurgency in Operations Iraqi Freedom and Enduring Freedom. The intent of this timeframe is to show that collection platform diversity has grown regardless of the nature of military conflict since 1990.

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Limitations

The primary limitation of the research is the Brigade Combat Team as an echelon and combat organization. The purpose of the limitation is to focus the research on primary maneuver forces projected to be engaged in offensive and defensive operations against a near pear threat. The research is further limited to the Brigade Combat Team's intelligence warfighting function, the cavalry squadron, and the brigade operations staff section. Where necessary, the research includes discussion of division level organizations for historical context only.

Delimitations

This research does not discuss operational capabilities of specific collection platforms or intelligence disciplines due to the sensitive or classified nature of specific platforms. Further, this research does not include aggregated details of force management documents to prevent disclosure of unclassified but sensitive information. Force management information is limited to specific references to duty positions and additional skill identifiers indicating authorizations for advanced training.

Significance of the Study

This research examines the BCT information collection organizational structure, operational planning, and employment of BCT assigned collection platforms, including scouts and technical collection platforms. The U.S. Army maintains three types of brigade combat teams, each equipped with the bulk of tactical information collection assets. This research may contribute to justification of personnel decisions for the BCT as well as training recommendations to better support information collection.

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Summary

Information collection in the United States Army represents a significant investment in strategy and force management in both material and personnel. The United States Government invests significant resources to staff and equip intelligence organizations to provide information for decision makers from tactical to strategic levels.

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[2] Ibid., 6.

[3] Ibid.

[4] Ibid.

[5] Ibid.

[6] Ibid., 7.

[7] Davi M. D'Agostino, *Intelligence, Surveillance, and Reconnaissance: Actions Are Needed to Increase Integration and Efficiencies of DOD's ISR Enterprise.*. Report to Congressional Committees (Washington, DC: U.S. Government Accountability Office, 2011), 1.

[8] Ibid., 5.

[9] Ibid.

[10] Ibid., 11; Ibid., 13.

[11] John F. Stewart, Jr., *Operation Desert Storm The Military Intelligence Story: A View From the G-2 3D U.S. Army*, April 1991, in *Operation Desert Storm: Ten Years Later*, ed. William Burr and Jeffrey T. Richelson, document 5, National Security Archive Electronic Briefing Book No. 39 (Washington, DC: George Washington University, April 1991), 1, accessed 16 March 2019, https://nsarchive2.gwu.edu/NSAEBB/NSAEBB39/.

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[13] US Congress, House, Committee on Armed Services (HASC), Oversight and Investigations Subcommittee, *Intelligence Successes and Failures in Operations Desert Shield/Storm,* Report to Congressional Committees (Washington, DC: U.S. Government Printing Office, 1993), 8; "VII U.S. Corps employed the UAV." Stewart, *Operation Desert Storm The Military Intelligence Story*, 31; "[JSTARS] gave the first and continuous signs of Iraqi withdrawal from Kuwait and was the target development instrument we used for the Air Force attack of fleeing Iraqi convoys on the main road north of Al Jahra," Stewart, *Operation Desert Storm The Military Intelligence Story*, 31.

[14] Stewart, *Operation Desert Storm The Military Intelligence Story*, 1; HASC, Oversight and Investigations Subcommittee, *Intelligence Successes and Failures in Operations Desert Shield/Storm,* 8.

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[15] Stewart, *Operation Desert Storm The Military Intelligence Story*, 39.

[16] John H. Black and Kenneth A. Watras, "Collection Management/TENCAP 2000: The Revised CM/TENCAP Course," *Military Intelligence Professional Bulletin* 18, no. 2 (April-June 1992): 44.

[17] Ibid., 45.

[18] US Army Human Resources Command (USAHRC), Military Personnel (MILPER) Message Number 07-202, 03 August 2007, accessed 14 October 2018, https://www.hrc.army.mil/milper/07-202.

[19] US Army Human Resources Command (USAHRC), Military Personnel (MILPER) Message Number 11-191, 16 June 2011, accessed 28 March 2019, https://www.hrc.army.mil/milper/11-191.

[20] US Army Human Resources Command (USAHRC), Military Personnel (MILPER) Message Number 18-194, 21 June 2018, accessed 12 April 2019, https://www.hrc.army.mil/milper/18-194.

[21] Tony K. Verenna, Keith A. Haskin, Trevis C. Isenberg, Stephen A. Gasparek, and Marco A. Garavito, "Innovation and Modernization: INSCOM's Aerial Intelligence, Surveillance, and Reconnaissance," *Military Intelligence Professional Bulletin* 44, no. 3 (July-September 2018): 62.

[22] Ibid., 61-62.

[23] D'Agostino, *Intelligence, Surveillance, and Reconnaissance,* 6.

[24] Black and Watras, "Collection Management/TENCAP 2000," 44.

[25] Ted L. Martens, "The Brigade Combat Team-The Transformation Process," *Military Intelligence Professional Bulletin* 26, no. 3 (July-September 2000): 4.

[26] Ibid.

[27] Ibid., 6-7; Kevin C.M. Benson and Dana J.H. Pittard, "Armor, Cavalry, and Transformation: 'New' Cavalry for the Interim Force," *Armor Mounted Maneuver Journal* 110, no. 2 (March-April 2001): 9.

[28] Martens, "The Brigade Combat Team," 5-6.

[29] Stewart, *Operation Desert Storm The Military Intelligence Story*, 33.

[30] Headquarters, Department of the Army (HQDA), Field Manual (FM) 3-55, *Information Collection* (Washington, DC: Government Printing Office, May 2013), 1-1.

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[31] Oxford Dictionaries, "Sensor," English Oxford Living Online Dictionaries, accessed November 16, 2018, https://en.oxforddictionaries.com/definition/sensor.

[32] Oxford Dictionaries, "Asset," English Oxford Living Online Dictionaries, accessed November 18, 2018, https://en.oxforddictionaries.com/definition/asset.

[33] HQDA, FM 3-55, 2-5.

[34] Joint Chiefs of Staff (JCS), Joint Publication (JP) 2-0, *Joint Intelligence* (Washington, DC: Government Printing Office, October 2013), GL-10.

[35] Headquarters, Department of the Army (HQDA), Army Doctrine Publication (ADP) 2-0, *Intelligence* (Washington, DC: Government Printing Office, September 2018), 2-4.

[36] JCS, JP 2-0, I-11.

[37] Joint Chiefs of Staff (JCS), Joint Publication (JP) 2-01, *Joint and National Intelligence Support to Military Operations* (Washington, DC: Governemnt Printing Office, July 2017), III-19.

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CHAPTER 2

LITERATURE REVIEW

The literature for this research consists of three main categories; doctrine, professional discourse, and personnel management references. The doctrine research covers a wide span of proponents as the nature of information collection is not limited to one single warfighting function responsibility. Therefore, the doctrine literature incorporates contributions from both the intelligence and movement and maneuver warfighting functions. The doctrine literature also includes discussion on joint doctrine since current information collection operations are heavily reliant on joint collection platforms. In short, the majority of literature found for this research was centered on information collection at the BCT which aligns with the overall purpose being to determine the benefit of an authorized collection manager position in the BCT MTOE.

The military professional literature encompasses a variety of sources from the intelligence warfighting function, the movement and maneuver warfighting function, joint observations, and historical observations from Operation Desert Storm. The military intelligence literature comes primarily from *Military Intelligence Professional Bulletin* articles discussing intelligence contribution to information collection and also leader commentary on the AIDP-ISR contributions to corps and division capabilities. Reports on intelligence operations during Operation Desert Storm provides a historical component of the military intelligence literature.

Military professional literature from the movement and maneuver warfighting function includes discussions on expectations of the intelligence warfighting function support to reconnaissance and Cavalry leader involvement in information collection

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management. In all, the prevailing discussions center around experientially based recommendations to improve Army information collection with specific emphasis at the BCT-level. Further, the literature review is organized based on the supporting research questions of how the BCT doctrinally conducts information collection, collection platform development at the BCT over the last three decades, and necessary knowledge of a BCT collection manager followed by general discussions of the collection manager at the BCT. The literature review concludes with major themes found throughout the literature that informed the overall thesis and drives the research methodology.

Improving Information Collection

The majority of the professional discourse literature focuses on improving the information collection capabilities within respective units based on direct observations and experiences, mostly through combat training center rotations. Most literature made recommendations on improving coordination during collection management activities, information collection tools, or knowledge of information collection systems. None of the literature researched clearly identified a need for standardizing the collection manager position at the BCT on the MTOE. The literature represents a diverse group of contributors with many having served as a BCT collection manager in multiple capacities, although their recommendations focused on training and coordination amongst the staff that is reflected in doctrine. Some recommendations represented fundamental organizational, equipping, and operational changes at the BCT and were the minority.

The dual-hatted capacity is represented in the case with First Lieutenant Anthony Sterioti, an Information Collection Platoon Leader and BCT collection manager. Sterioti offered a concise description of the information collection process in the BCT with

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specific emphasis on the work of the collection working group and relationship with the S-3 staff.[1]

Recent doctrine updates across the Army is represented in Ms. Terri Lobdell's article on "Resetting Intelligence Doctrine". Lobdell, a key Army Civilian in the Doctrine Integration Branch at USAICoE, presents the contextual changes for FM 2-0 brought about from the release of FM 3-0, *Operations*.[2] Lobdell includes refinement of intelligence tasks, specifically Intelligence Preparation of the Battlefield and collection management, as new focus in the updated FM 2-0 with concerted efforts to maintain fundamentals such as intelligence operations within information collection and integration of national to tactical intelligence.[3]

In terms of theses, two significant studies appeared related to improving information collection or ISR, depending on the time of publishing. Major Ryan Skaggs, an Air Force officer, authored a thesis of applying mission command principles to improve agility in joint ISR.[4] As part of this thesis, Skaggs explored a notion of a dichotomy between ISR management and leadership positing the question if ISR should be managed or led.[5] Skaggs approach and research draws from doctrinal references of ISR being a managed process ultimately leading to a conclusion that ISR can be both managed and led effectively.[6] Major Aaron Sammons in 2008 focused on doctrinal and organizational changes to better serve the BCT commander's requirements. Sammons' research identified a capability gap at the BCT-level in a qualified manager endowed with the authority to direct ISR. In Sammons conclusion, the BCT needs "truly qualified officers [who] are, preferably, both educated and experienced in the direction of ISR…imbued with both the responsibility and the authority to direct ISR."[7] Sammons'

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argument directly targets the dichotomy of responsibility for information collection planning with the S-3 overall responsible for publishing orders where the S-2 contributes the lion's share of the plan.

The most consequential intelligence-focused professional discourse came from Combat Training Center Trainer's Major Nathan Adams, Captain Raymond Kuderka, Captain Andrew Eickbush, and Major Michael Childs, whose roles provided the greatest breadth of first-hand observation. Adams observed a total of eleven Combat Training Center rotations as an intelligence trainer at the Joint Readiness Training Center in Fort Polk, Louisiana.[8] In his experience, Adams provides specific details on numerous challenges within the BCT intelligence warfighting function with the most notable being synchronizing collection efforts across the staff beyond the creation of doctrinal tools.[9] Adams also identifies challenges in S-2 leadership, intelligence architecture, and asset management as areas for improvement.[10] Childs' experience stems from direct observation of fifteen rotations at the National Training Center in Fort Irwin, California from January 2011 through June 2012.[11]

Kuderka and Eickbush provided observational experience of Brigade Combat Teams and multi-national partners at the Joint Multinational Readiness Center in Hohenfels, Germany as an intelligence trainer and fires trainer respectively. Without providing context of a number of observed rotations, Kuderka and Eickbush note that, "regardless of unit type or nation of origin, units fail to plan and execute an information collection plan that supports the commander's decision-making process."[12] Kuderka and Eickbush state that ill-defined "operational framework, convoluted information collection overlays, lack of understanding organic information collection capability, prioritization of

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assets, and inadequate staff coordination" are the fundamental challenges with effective information collection planning and execution.[13]

Childs' observations, as an intelligence trainer, led to a major theme of BCTs failing to "practice effective information collection rehearsals to synchronize the brigade's reconnaissance and surveillance plan inside the intelligence warfighting function."[14] Ultimately the conclusions from Combat Training Center trainers demonstrate clear challenges within Army Information Collection planning and execution. The fact that information collection challenges in planning and execution come from across all the combat training centers cannot be overstated.

The recommendations with the most structural change came from experiences based on the permanent opposing force from the National Training Center at Fort Irwin, California. This article from a former BCT MICO Commander recommends restructuring the BCT MICO with their existing collection platforms and transferring the company to the Cavalry Squadron.[15] Wellsandt argues for transforming the MICO into a "Hunter Company", by stripping out the UAS platoon and augmenting the company with cavalry or infantry Soldiers.[16] Wellsandt's recommendation requires the entire BCT information collection structure to change as well as add material solutions in the form of ground surveillance radar, similar to what is used at the National Training Center.[17]

Outside of the Intelligence warfighting function, the cavalry community developed the concept of the Chief of Reconnaissance as a staff advisor role responsible for the integration of reconnaissance into the BCTs plans and operations. Two authors contributed to the Chief of Reconnaissance discussion by recommending a certain position in the BCT as ideal to serve as the Chief of Reconnaissance. The first

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perspective came from Captain Michael Hefti arguing that the Cavalry Squadron Headquarters and Headquarters Troop Commander is ideal. The second opinion, by Captain John Palmer, suggested the Cavalry Squadron Commander is the best suited to fulfill the role of Chief of Reconnaissance. Both authors acknowledge the lack of any information or defining qualities of the Chief or Reconnaissance in doctrine.

Hefti argues that the Cavalry Squadron Headquarters and Headquarters Troop Commander makes the ideal candidate to serve as the BCT Chief of Reconnaissance because the doctrinal role and position of the Headquarters and Headquarters Troop Commander on the battlefield is obsolete since the Forward Support Commander is now located doctrinally at the forward-trains command post.[18] Given the obsolete location, the Headquarters and Headquarters Troop Commander can serve as an ideal cavalry liaison and integrator of multiple staff sections into the reconnaissance plan dependent on being physically located at the BCT command post.[19] Hefti assumes that the obsolete location of the Headquarters and Headquarters Troop Commander relies completely on doctrinal application of the Forward Support Company Commander assuming the forward-trains command post.

Palmer takes the more common approach to the Chief of Reconnaissance by arguing that the Cavalry Squadron Commander is the best candidate because he or she already exercises command authority, is likely the most experienced reconnaissance leader in the BCT, and has access to upper tactical internet removing the requirement to be located with the BCT command post.[20] Palmer's major assumption is the Cavalry Squadron and BCT command posts will have access to upper tactical internet even though a significant planning consideration for units training today is the degradation of

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communications architecture through enemy electronic warfare employment. Palmer's thesis also assumes that the Cavalry Squadron Commander already has the authority to task all information collection assets within the BCT.[21] This assumption would likely be a point of contention with the Brigade Engineer Battalion who exercises authority over the BCT MICO. Palmer highlights a key point in information collection discussion that "no staff section is in charge of both the planning and execution of information collection" further reinforcing the nature of Army Information Collection as a collaborative effort amongst multiple participants.[22]

Colonel Dwight DuQuensnay and Major Camero Song offer two perspectives on the value that advanced collection management training offers Corps and Division echelons through the auspices of experiences with AIDP-ISR graduates. DuQuensay indicated his experience supervising an AIDP-ISR graduate as the Multi-National Force-Iraq collection manager was able to quickly integrate and synchronize Air Force ISR and Army and contract collection platforms as a "truly joint, aerial ISR force."[23] Drawing on his later Korea experience, DuQuensay likened AIDP-ISR graduates additional collection management experience similar to the planner graduates of the School of Advanced Military Studies.[24] Song, as a graduate of the AIDP-ISR program, highlights the hallmarks of the program as advancing collection management knowledge at the joint task force and national levels which is an important factor in integrating collection platforms.[25] Song further advocates for expanding the AIDP-ISR to the noncommissioned officer corps as well as bolstering all Military Intelligence professional military education on the principles of collection management.[26]

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Institutional and Operational Knowledge Necessary for a BCT CM

The Army provides advanced training in information collection through two skill identifier producing courses at two different centers of excellence. The USAICoE administers the Intelligence, Surveillance, and Reconnaissance (ISR) Synchronization Managers Course or also referred to as the Information Collection Planners Course. This course consists of five weeks of classroom training for military intelligence officers, warrant officers, and non-commissioned officers on skills to serve as a Brigade ISR Planner/Manager and produces the Q7 information collection Planner additional skill identifier.[27] Positions associated with the Q7 additional skill identifier are described as "requiring qualifications in managing the employment of organic and supporting intelligence collection assets, as well as reach back to higher headquarters and intelligence agencies for information, in order to provide the commander with effective intelligence support."[28]

The U.S. Army Armor School administers the Cavalry Leader course at Fort Benning, Georgia for Armor officer and enlisted military occupational specialties. The Cavalry Leader Course produces the C6 additional skill identifier following three weeks of training in the application of reconnaissance and security operations to include "asset synchronization, Cavalry organization employment, synchronization of operations and intelligence analysis, and tactical techniques in a myriad of reconnaissance and security scenarios."[29] The functions associated with the C6 additional skill identifier includes "planning for and employing mounted and dismounted organic assets, employment and integration of various supporting assets including UAS, logistics, Army and Air Force manned aircraft, and SIGINT/MASINT platforms."[30]

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The Defense Intelligence Agency serves as the executive agent for the Certified Collection Management Professional Certification Program while also providing web-based and in-person training on collection management.[31] Likewise, the National Geospatial Intelligence Agency administers the Geospatial Intelligence Professional Certification Program along with associated intelligence discipline specific training.[32] It is also common for intelligence discipline specific courses to include collection management instruction as a means to educate students on how to request collection platforms. Beyond institutional training, the operational force identified training needs amongst the military intelligence force at-large in intelligence synchronization.

An article on the BCT S-2 course by Major Jason Buchanan and Lieutenant Colonel Anthony Covert shows an identified gap in information collection management knowledge in the tactical military intelligence workforce. Summarizing the training efforts to close multiple knowledge gaps, Buchanan and Covert discussed how First Corps, and later the Command and General Staff College, developed a comprehensive training agenda oriented at military intelligence majors and captains.[33] In the model week of training, collection management consists of a full day of training.[34] First Lieutenant Kari LaRubio indicated the need for a BCT collection manager to be knowledgeable in the Shadow UAS that includes the systems capabilities and limitations, briefed by the UAS platoon.[35] This knowledge, in LaRubio's estimation, enables the BCT collection manager to effectively employ the Shadow UAS "within the brigade's reconnaissance plan."[36]

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How the BCT Doctrinally Executes Information Collection

Three sources of literature provide insight into information collection staffing at the BCT; force management documents, doctrine, and professional discourse. The majority of literature speaks to information collection as a broader team effort versus one individual fulfilling all the functions of collection management.

The definitive force management documentation is the MTOE but unfortunately the current data resides at the official use only-level. Additionally, MTOE data was not available for the brigade or division-level from Operation Desert Storm. More generic Tables of Organization and Equipment provide context to how these organizations were equipped and staffed. Further, the research included the Military Intelligence Battalion organic to the Division for the frame of reference of where the intelligence collection platforms existed during Operation Desert Storm. Intelligence Doctrine active during Operation Desert Storm provides background on intended employment of information collection platforms. To overcome the force management data challenge, doctrine is used to provide context between duty positions and staff proponents through integrating processes. Doctrine from 1986 to 1990 provided context for military intelligence, cavalry, and aviation collection platforms at both the division and brigade-levels. These doctrinal publications included FM 1-111, *Aviation Brigades*; FM 34-10, *Division Intelligence and Electronic Warfare Operations*; and FM 34-80, *Brigade and Battalion Intelligence and Electronic Warfare Operations*.

The Intelligence and Operations doctrine series are the primary contributors to Army information collection doctrine in the form of FM 3-55, *Information Collection*; FM 2-0, *Intelligence*; and Army Techniques Publication (ATP) 2-01, *Plan Requirements*

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and Assess Collection. Maneuver doctrine supports information collection through ATP 3-20.96, *Cavalry* Squadron; FM 3-04, *Army* Aviation; FM 3-90-2, *Reconnaissance, Security and Tactical Enabling Tasks*; FM 3-98, *Reconnaissance and Security Operations*; and FM 3-96, *Brigade Combat Team*. Joint publications commonly use the term ISR where the Army uses information collection to describe the same activity. Joint Publication 2-0 defines ISR as "an activity that synchronizes and integrates the planning and operation of sensors, assets, and processing, exploitation, and dissemination systems in direct support of current and future operations…this is an integrated intelligence and operations function."[37] This definition is identical to the Army definition of information collection presented earlier where there is no clear indicator why the terms are different.

Doctrine informs that Information Collection is a collaborative process of activities and tasks. Information collection consists of planning requirements and assessing collection, tasking and directing collection, and executing collection; which will be referred to as components since doctrine does not define if these are tasks, activities, or the overall process.[38] Information collection activities connect the components of information collection with staff responsibility, (see figure 1).[39]

FM 3-55 identifies staff roles and collaboration responsibilities for the information collection activities. Planning requirements and assessing collection are associated with the intelligence staff collaborating with the rest of the unit staff.[40] Tasking and direction belong under the purview of the operations officer, supported through the operations staff.[41] Information collection tasks and operations are categorized as reconnaissance, surveillance, security operations and intelligence operations.[42] FM 3-55 also establishes the concept of the situationally needed, Operations and Intelligence

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Working Group. This working group represents an amalgamation of staff sections whose purpose is "coordination and integration of information collection activity and provide recommendations to the commander."[43]

Conversely, FM 2-0 identifies information collection tasks as collection management, direct information collection, execute collection, and conduct intelligence-related missions and operations.[44] FM 2-0 further states that the intelligence warfighting function contributes to all tasks except execute collection.[45] Executing collection rests with the respective units carrying out the collection tasks of reconnaissance, surveillance, security and intelligence operations. FM 2-0 assumes the responsibility of collection management with the supporting tasks of develop requirements, develop collection management tools, assess collection, and update collection management tools.[46] Figure 1 below shows the connection between FM 3-55's information collection activities and FM 2-0's collection management tasks as intelligence staff functions.

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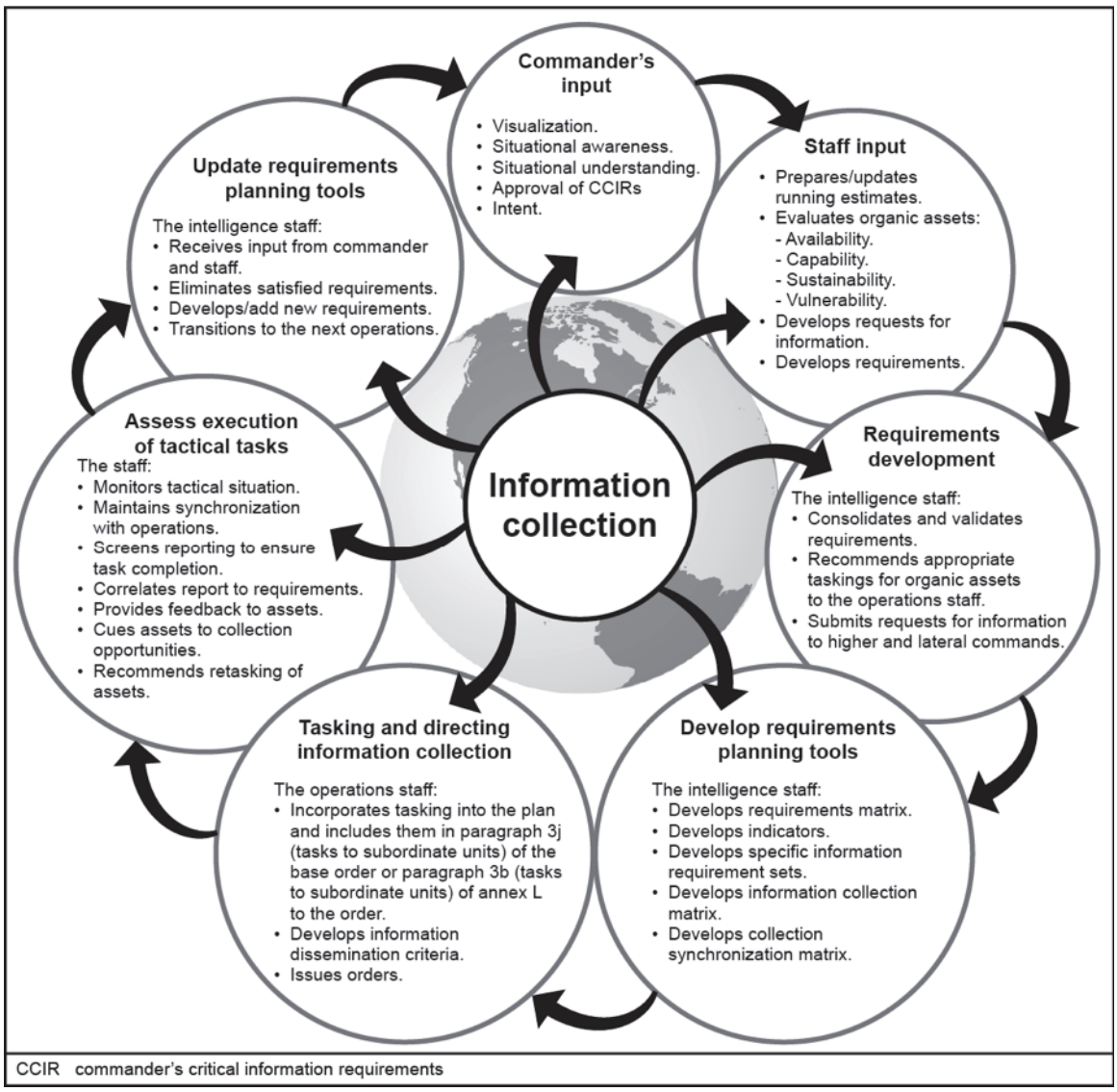


Figure 1. Information Collection Activities

Source: Headquarters, Department of the Army, Field Manual 3-55, *Information Collection* (Washington, DC: Government Printing Office, May 2013), 1-4.

ATP 2-01 serves as the intelligence series publication to further refine the intelligence warfighting functions role for information collection activities. ATP 2-01 identifies conflicting information collection tasks with FM 2-0 in the form of "plan requirements and assess collection, task and direct collection, and execute collection."[47]

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In this case, ATP 2-01 mirrors FM 3-55 with the exception that FM 3-55 does not specifically call these tasks.

FMs 3-98, *Reconnaissance and Security Operations*, and 3-90-2, *Reconnaissance, Security and Tactical Enabling Tasks* provide similar descriptions of the responsibilities for information collection at the BCT. The primary focus of these FMs is on the reconnaissance assets, namely the BCT Cavalry Squadron. One major distinction presented is the concept of the BCT Reconnaissance Cell that is not mirrored in any of the other doctrine publications. FM 3-98 further does not discuss how a BCT Reconnaissance Cell works within the context of the Operations and Intelligence Working Group that is mentioned in virtually all of the doctrine publications, except FM 3-0, FM 3-90-2 and FM 3-96. FM 3-98 indicates the purpose of the Brigade Reconnaissance Cell fulfills the employment of sensors and assets part of the information collection definition by "coordinating and synchronizing the BCT's reconnaissance operations."[48] Not directly stated, the intent of the BCT Reconnaissance Cell appears to serve an enduring function of staff coordination with a smaller cadre of staff members including S-2, S-3 Plans, Brigade Aviation Element, Tactical Air Control Party, and Fire Support Coordinator.[49] This cell differs from the often mentioned Operations and Intelligence Working Group because the working group is characterized as a "ad hoc" group focused on information collection planning which is the first part of the information collection definition.[50]

Finally, leaders writing about observations and experiences in various positions regarding information collection at the BCT provides context to in how information collection is managed and varies between BCTs. In Lobdell's article, she mentions that

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even though the previously mentioned Operations and Intelligence Working Group at the BCT and Battalion levels is optional, it does not diminish the need for close coordination between the S-2 and S-3.[51]

The concept of staff relationships to support information collection appeared multiple times. LaRubio shared insights on the interactions between BCT staff and the tactical UAS platoon. LaRubio introduced the Brigade Aviation Element as an important participant in the BCT's information collection operations with a variety of capabilities.[52] LaRubio's conclusion reinforced the common theme of relationships between staff and maneuver elements involved in information collection.[53]

The importance of relationships is the central argument in Chief Warrant Officer Two David Pierce's article on integrating the BCT S-2 and Military Intelligence Company (MICO). Pierce's assertion of relationships and early integration are important to the information collection discussion as the MICO resources are currently located under the Brigade Engineer Battalion for mission command with their operational design being the bulk of the Brigade's intelligence warfighting function workforce.[54]

Three Decades of Collection Platform Development at the BCT

The last thirty years have seen significant growth in collection platform capabilities at the tactical level. This tactical growth extends beyond the introduction and fielding of UAS to the Brigade and Battalion echelons. The transition of collection platforms in brigades that occurred included structural changes such as the Brigade Reconnaissance Troop during the Force XXI era. The Brigade Reconnaissance Troop, predating the BCT, developed from a reduction in battalion scout formations to create a reconnaissance force organic to the brigade to address a known gap in capability.[55] Major

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Todd Poindexter's thesis analyzed the development of cavalry capability at echelon over time and is shown in figure 2 below. The later transition to the BCT brought a cavalry squadron of platoons equipped with combat vehicles and many, depending on the type of BCT, outfitted with the Long-Range Scout Surveillance Systems. The Long-Range Scout Surveillance System at the BCT extended the range that scouts could observe significantly over the analog alternative of binoculars. The integration of military intelligence collection platforms in the MICO brought UAS, signals intelligence collectors, and human intelligence collectors to the BCT as well. This diversity of collection platforms in the BCT created a true ISR capability organic to the BCT.

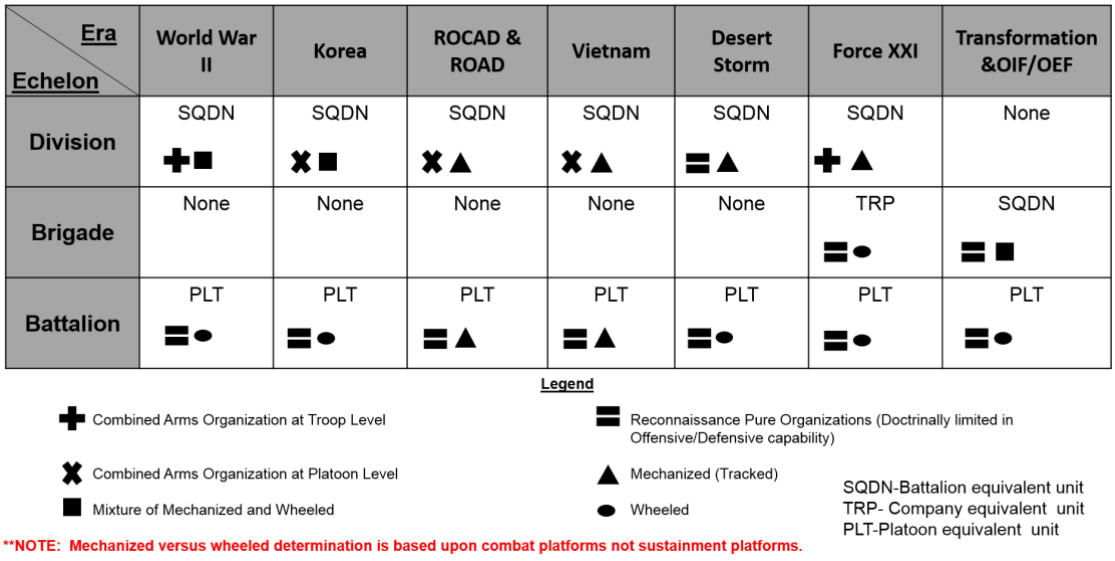


Figure 2. Example of Collection Platform Transition

Source: Todd L. Poindexter, "Transforming Mechanized Reconnaissance: How the Armored Brigade Combat Team (ABCT) Cavalry Squadron Should Be Structured For Reconnaissance and Security Operations in the near Future" (Master's Thesis, U.S. Army Command and General Staff College, Ft. Leavenworth, KS, 2014), 68.

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Several articles allude to how Operations Enduring Freedom and Iraqi Freedom influenced tactical-level information collection. The professionally accepted opinion is that prolonged rotational deployments in Iraq and Afghanistan created an over-reliance on theater collection platforms, particularly aerial.[56] The manifestation of this reliance is the lack of detailed planning for information collection assets by scheduling long blocks of collection on the Information Collection Synchronization Matrix and approaching collection dynamically.

Discussions of the BCT Collection Manager

Primarily, the literature shows doctrinal and experiential recommendations on how to most effectively employ information collection with the existing BCT force structure. No author addressed or attempted to explain why the BCT is not authorized a collection manager. Three authors addressed expanding collection manager skills to the BCT and spanned recommendations from expanding the existing AIDP-ISR program to non-commissioned officers, assign dedicated officers for ISR, and pass the responsibility to a combat arms officer supported by a subordinate military intelligence officer.[57] This recommendation came without calling for a position at the BCT but understanding that the majority of non-commissioned officers trained to the AIDP-ISR-level would serve at the BCT.

Within doctrine, there is mixed discussion of the position of the collection manager spread through a variety of publications. The collection manager is typically mentioned in one of three capacities; in Army, Joint, or generic. The preponderance of reference to the collection manager in Army doctrine was in an Army capacity. These references came in ATP 2-01, *Plan Requirements and Assess Collection*; FM 2-0,

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Intelligence; FM 3-55, *Information Collection*; ATP 3-60, *Targeting*; and ATP 6-0.5, *Command Post Organization and Operations*. The most references to the collection manager came in ATP 3-60, *Targeting*, that describes the role of the collection manager in assessing the information collection plan against systems supporting targeting and focusing on "high payoff targets that cannot be covered with available assets."[58] Curiously, the collection manager was not mentioned in ADP 2-0, *Intelligence*; and ATP 2-01.3, *Intelligence Preparation of the Battlefield*. Nor was the position mentioned in the operations series manuals of FM 3-96, *Brigade Combat Team*; FM 3-98, *Reconnaissance and Security Operations;* or FM 3-90-2, *Reconnaissance, Security, and Tactical Enabling Tasks*.

Several authors discussed the importance of the BCT collection manager without specifically mentioning a single duty position. Sterioti highlights the importance of the role the collection manager plays to building shared understanding and recommends that a properly trained officer or noncommissioned officer is critical to successful information collection operations.[59] LaRubio argues that the "Brigade information collection Manager is coordinating the eyes and ears of the BCT commander's assets"[60] further qualifying the position as requiring "continual planning and changes as the mission changes."[61] This is an example of the importance of the BCT collection manager as a duty position.

Fighting for Intelligence or Information

Lobdell highlights how the new FM 2-0 reframes intelligence operations as part of the "fight for intelligence."[62] Lobdell describes "fighting for intelligence" as an old term renewed to conjure a mental model of the contested nature of ground combat in

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LSCO, while reiterating the complexity of the multi-domain environment and capable threat profile.[63] Information collection plays a prominent role in the identified "key aspects of fighting for intelligence" with three of the six directly associated with the information collection plan and an additional nod to the importance of effective staff integration.[64]

Similarly, Lieutenant Colonel Nathan Palisca offered a cavalry perspective via defining the "Fight for Information."[65] Palisca's argument focused on formally defining the term with key stipulations of information collection with synchronized platforms in contact with an enemy, emphasizing the eight forms of contact.[66] Just like Lobdell, Palisca seeks to integrate information collection in the context of LSCO. Ultimately, both Lobdell and Palisca discuss the necessary doctrinal and institutional changes necessary to shift away from the counter-insurgency mindset that has dominated information collection over the last seventeen years.

Literature Review Summary

Ultimately there is no shortage of professional commentary on the challenges units face in conducting information collection. The challenge for Army units to manage information collection grows as the capabilities increase with de-synchronized guidance from doctrine emerging from two centers of excellence. Both the Army Intelligence and Maneuver communities indicate that there are challenges with both developing unique, and sometimes sweeping, recommendations to address the deficiencies.

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[1] Anthony J. Sterioti, "Information Collection Management in the BCT," *Military Intelligence Professional Bulletin* 41, no. 4 (October-December 2015): 46.

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[2] Terri M. Lobdell, "Resetting Intelligence Doctrine," *Military Intelligence Professional Bulletin* 44, no. 4 (October-December 2018): 9.

[3] Ibid.

[4] Ryan D. Skaggs, "Increasing Intelligence, Surveillance, and Reconnaissance (ISR) Operational Agility through Mission Command" (Master's Thesis, U.S. Army Command and General Staff College, Ft. Leavenworth, KS, 2006.), 5.

[5] Ibid., 76.

[6] Ibid., 114.

[7] Aaron D. Sammons, "Transforming Doctrine and Organization to Meet the Intelligence, Surveillance, and Reconnaissance Requirements of the Brigade Combat Team Commander" (Master's Thesis, U.S. Army Command and General Staff College, Ft. Leavenworth, KS, 2008), 76-77.

[8] Nathan Adams, "Observations from a Year as the Brigade S-2 Observer-Coach-Trainer at the Joint Readiness Training Center," *Military Intelligence Professional Bulletin* 43, no. 2 (April-June 2017): 6.

[9] Ibid., 10.

[10] Ibid., 6.

[11] Michael J. Childs, "Information-Collection Rehearsals in the Brigade Combat Team," *Armor Mounted Maneuver Journal* 121, no. 4 (September-October 2012): 30.

[12] Raymond A. Kuderka and Andrew Eickbush, "Information-Collection Failures that Lead to 'Discovery Learning'," *Armor Mounted Maneuver Journal* 125, no. 2 (April-June 2015): 32.

[13] Ibid.

[14] Childs, "Information-Collection Rehearsals in the Brigade Combat Team," 30.

[15] Bradley M. Wellsandt, "Unifying the Brigade Combat Team Information-Collection Effort," *Armor Mounted Maneuver Journal* 130, no. 1 (Winter-Spring 2018): 25.

[16] Ibid.

[17] Ibid., 25-26.

[18] Michael L. Hefti, "The Headquarters and Headquarters Troop Commander as Brigade Combat Team Chief of Reconnaissance," *Armor Mounted Maneuver Journal* 126, no. 4 (October-December 2015): 67. 39

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[19] Ibid.

[20] John F. Palmer, "The Squadron Commander as Chief of Reconnaissance," *Armor Mounted Maneuver Journal* 127, no. 3 (July-September 2016): 15.

[21] Ibid.

[22] Ibid.

[23] Dwight L DuQuesnay, "Army Intelligence Development Program-Intelligence, Surveillance and Reconnaissance (ADIP-ISR): A Senior Leader Perspective," *Military Intelligence Professional Bulletin* 43, no. 3 (July-September 2017): 16.

[24] Ibid., 18.

[25] Camero Song, "Army Intelligence Development Program - Intelligence, Surveillance, and Reconnaissance: Critical to an Army Corps," *Military Intelligence Professional Bulletin* 44, no. 1 (January-March 2018): 53.

[26] Ibid.

[27] Army Training Requirements and Resources System (ATRRS), "Information for Course: INTELL, SURVEIL & RECON (ISR) SYNCH MGR," *ATRRS Course Catalog*, 21 March 2019, accessed 21 March 2019, https://www.atrrs.army.mil/atrrscc/courseInfo.aspx?Fy=2019&sch=301&crs=3A-SI%2fASIQ7%2f243-ASIQ7&crstitle=INTELL%2c+SURVEIL+%26+RECON+(ISR)+SYNCH+MGR&phase=.

[28] Headquarters, Department of the Army (HQDA), "Officer and Enlisted Skill Identifiers," in Department of the Army Pamphlet 611-21, *Military Occupational Classification and Structure* (Washington, DC: Government Printing Office, July 2018), Table 4-3, 49-50, accessed 07 March 2019. https://www.milsuite.mil/book/groups/smartbookdapam611-21.

[29] Army Training Requirements and Resources System (ATRRS), "Information for Course: CAVALRY LEADER," *ATRRS Course Catalog*, 21 March 2018, accessed 21 March 2019, https://www.atrrs.army.mil/atrrscc/courseInfo.aspx?fy=2019&sch=171B&crs=2E-FOA-F134%2f250F46+(MC)&crstitle=CAVALRY+LEADER&phase=.

[30] HQDA, "Officer and Enlisted Skill Identifiers," Table 4-3, 36.

[31] Department of Defense (DoD), Department of Defense Instruction (DoDI) 3305.02, *DoD General Intelligence Training and Certification* (Washington, DC: Government Printing Office, May 2018), 5.

[32] Ibid., 6-7.

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[33] Jason Buchanan and Anthony Covert, "The Brigade Combat Team Intelligence Staff Officer Course," *Military Intelligence Professional Bulletin* 43, no. 2 (April-June 2017): 15.

[34] Ibid., 16.

[35] Kari C. LaRubio, "The Relationship Between the UAS Platoon and the BCT," *Military Intelligence Professional Bulletin* 41, no. 4 (October-December 2015): 53.

[36] Ibid.

[37] JCS, JP 2-0, I-11.

[38] HQDA, FM 3-55, 1-1.

[39] Ibid., 1-4.

[40] Ibid., 1-2.

[41] Ibid., 1-2.

[42] Ibid., 1-6.

[43] Ibid., 2-5.

[44] Headquarters, Department of the Army (HQDA), Field Manual (FM) 2-0, *Intelligence* (Washington, DC: Government Printing Office, July 2018), 2-12.

[45] Ibid. Refers to the Non-Intelligence Related Missions and Operations.

[46] Ibid., 2-13.

[47] Headquarters, Department of the Army (HQDA), Army Techniques Publication (ATP) 2-01, *Plan Requirements and Assess Collection* (Washington, DC: Government Printing Office, August 2014), 1-1.

[48] Headquarters, Department of the Army (HQDA), Field Manual (FM) 3-98, *Reconnaissance and Security Operations* (Washington, DC: Government Printing Office, July 2015), 1-11.

[49] Ibid., 1-11.

[50] HQDA, FM 3-55, 2-5.

[51] Lobdell, "Resetting Intelligence Doctrine," 16.

[52] LaRubio, "The Relationship Between the UAS Platoon and the BCT," 52.

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[53] Ibid., 65.

[54] David Pierce, "The Keys to Success: Integration between the Brigade Combat Team S-2 and the Military Intelligence Company," *Military Intelligence Professional Bulletin* 43, no. 2 (April-June 2017): 18.

[55] Robert S. Cameron, "Scouts Out – But Not in HMMWVs!: The Rise and Fall of the HMMWV-equipped Heavy Maneuver Battalion Scout Platoon," *Armor Mounted Maneuver Journal* 116, no. 2 (March-April 2007): 31.

[56] Kuderka and Eickbush, "Information-Collection Failures that Lead to 'Discovery Learning'," 34-35.

[57] Song, "Army Intelligence Development Program," 53; Sammons, "Transforming Doctrine and Organization to Meet the Intelligence, Surveillance, and Reconnaissance Requirements of the Brigade Combat Team Commander," 76-77; Brian Gellman, "Improving the Relevance of Tactical Intelligence in the COE" *Military Intelligence Professional Bulletin* 33, no. 2 (April-June 2007): 14-15.

[58] Headquarters, Department of the Army (HQDA), Army Techniques Publication (ATP) 3-60, *Targeting* (Washington, DC: Government Printing Office, May 2015), F-5.

[59] Sterioti, "Information Collection Management in the BCT," 48.

[60] LaRubio, "The Relationship Between the UAS Platoon and the BCT," 53.

[61] Ibid.

[62] Lobdell, "Resetting Intelligence Doctrine," 10.

[63] Ibid., 15, 12.

[64] Ibid., 15.

[65] Nathan Palisca, "What Do We Mean When We Say 'Fight For Information'?" *Armor Mounted Maneuver Journal* 128, no. 3 (Summer 2017): 42.

[66] Ibid., 42-43.

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CHAPTER 3

RESEARCH METHODOLOGY

Qualitative Content Analysis Overview

The research approach employed in this thesis is a qualitative document and narrative content analysis utilizing categorization and coding to determine the value of an authorized collection manager on the BCT MTOE as derived from professional opinions and experiences. The analysis focuses on data from a variety of professional discourse covering information collection doctrine, training, and experiences. Qualitative content analysis is ideal for this research because of the breadth of professional writing about improving U.S. Army information collection. There was no data found in a format to support effective quantitative analysis such as human subjects research surveys of leaders and Soldiers on U.S. Army information collection. The content analysis approach lends to an effective way to extract inferences and meaning in professional writing from a wide variety of authors perspectives. Dr. Steve Stemler's "Overview of Content Analysis" in the Journal *Practical Assessment, Research &* Evaluation served as the seminal source for developing this research methodology.[1]

Research information was obtained through historical searches of military professional publications, primarily U.S. Army centers of excellence, with additional searches conducted on joint military professional periodicals. The figure below shows the research process employed to answer the fundamental research question of determining the value of a MTOE BCT collection manager. (see figure 2). Specifically, two periodicals representing the intelligence and maneuver centers of excellence provided the bulk of the professional writing. The *Military Intelligence Professional Bulletin* serves as

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the quarterly forum for U.S. Army Intelligence professional discussion. The *Armor Mounted Maneuver Magazine* represents the U.S. Army reconnaissance community through the maneuver warfighting function. The content analysis supports the research question through the wide variety of perspectives collected. The supporting research questions are minimally supported by the methodology as they are largely answered through the literature review. The professional writing represents a unique perspective and experience from each author in different organizations and in different capacities all focused on improving information collection. Professional discourse falls under two categories of data in this research.[2] The first represents professional writing that directly relates to information collection at the BCT. The second represents professional writing that relates to information collection in general.

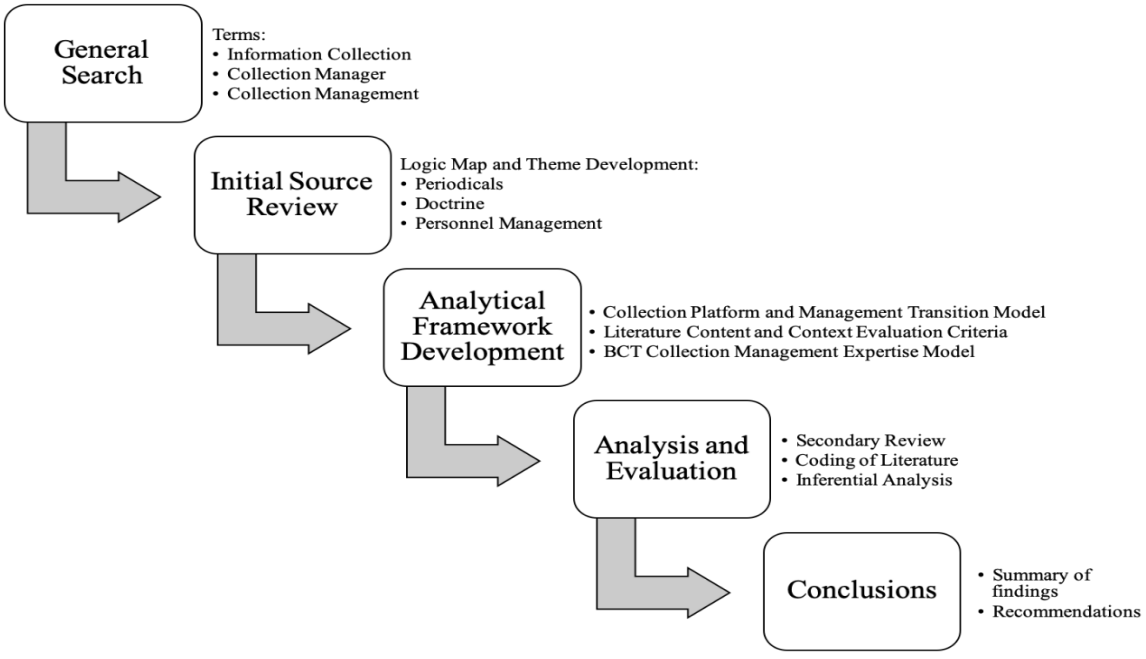


Figure 3. BCT Collection Manager Research Process

Source: Created by author.

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Coding is based on *a priori* categorization of qualities necessary for a BCT collection manager, (see figure 4).[3] The dependent variable for analysis is the BCT collection manager, annotated in the black square. The independent variables for qualitative analysis derive from the themes identified within the research as well as professional experience in the form of collection management processes, information collection tools, and information collection systems, annotated as white ovals (see figure 4). Essentially, the analytical framework was developed as a mind map from personal experience of twelve months of formal collection management training and grouped into categories of common themes identified from the research literature. Together, these variables provide the analytical framework to determine the value of a MTOE authorized collection manager in the BCT. The gray blocks within the analytical framework represents the component parts of each category theme. In several cases, these component parts consist of additional entities too detailed to graphically represent, but further explained below.

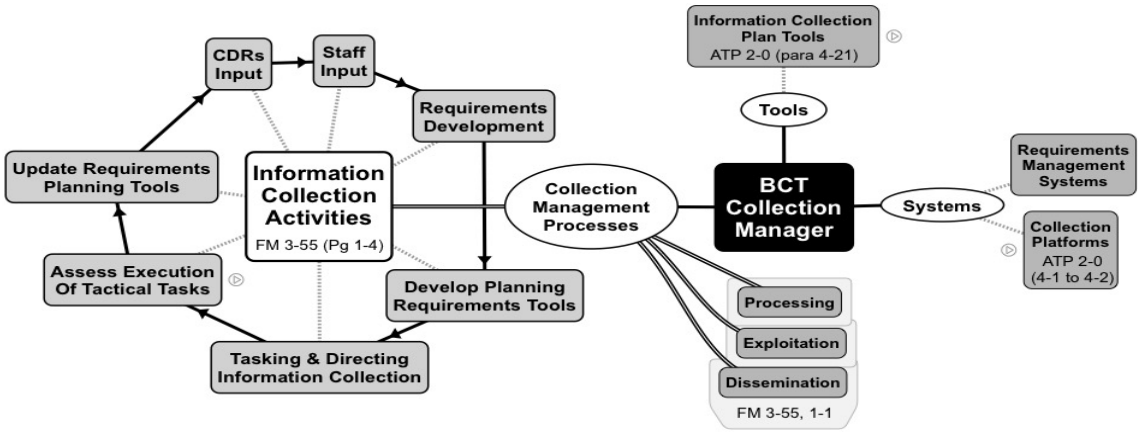


Figure 4. BCT Collection Manager Logic Map

Source: Created by author.

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The analytical framework began with knowledge and skills of the collection management processes which is a combination of the Information Collection Activities and the definition of Army information collection from doctrine. The Information Collection Activities clearly include the essential concepts of planning and employment of sensors and assets as the information collection definition states. The next quality is knowledge and skills of tools associated with information collection. These tools are doctrinally defined as the Information Collection Matrix, Information Collection Synchronization Matrix, Information Collection Overlay, and the Information Collection Annex to the Order. The final quality of a collection manager is divided into knowledge and skills of collection systems inclusive of the collection platforms and the requirements management systems for requesting collection platforms. Knowledge of collection platform capabilities includes both assigned equipment and platforms at higher echelon.

Transition of Collection Platforms and Management

Collection platforms have diversified and transitioned over the last thirty years since Operation Desert Storm where collection management personnel and expertise has not. To show this transition, a comparison is used of collection platforms and collection management roles at echelon during Operation Desert Storm and present BCT constructs (see table 1). Overall aggregated collection platform numbers are used to maintain the content at the unclassified level. For this table, a collection platform is considered a single signals intelligence sensor, a human intelligence collection team, a ground scout platoon, attack or reconnaissance aviation platoon, and the ground control station for UAS. The ground control station is the limiting factor for UAS since a unit may only operate as many UAS aircraft as they have ground control stations, such as six RQ-7

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Shadows may be limited to three ground control stations. The echelon relationship is defined based on an assigned and typical operational control status. For example, the Division had an assigned Military Intelligence Battalion and Cavalry Squadron during Operation Desert Storm timeframe. Conversely, the current BCT structure has an assigned Cavalry Squadron and separate Engineer Battalion where the MICO is located.

Collection management roles are qualified as staff or units intended to fulfill collection management. The staff or units associated with collection management functions are identified by the joint collection management function they provide, such as CRM, COM, or CMM. Although this research is focused on the management of BCT organic collection platforms, it is necessary to acknowledge that a component of collection operations management is requesting higher-level collection platforms when organic capabilities are not available. This could be requesting a UAS capable of operating deeper in the area of operations or a collection platform providing an intelligence discipline capability not organic to the BCT. As if managing organic platforms was not challenging enough, the addition of requesting and managing collection operations of non-organic platforms can drastically increase the complexity of collection management, to say nothing of the reality that requesting capabilities requires a thorough knowledge of the capability, as well as the processing, exploitation, and dissemination requirements to make collection timely. The requesting of higher-level collection platforms as a component of collection operations management is deliberately excluded from this research as the context of LSCO presumes the availability of higher-level collection platforms for subordinate units' requests will be limited. The notion of limited request-able collection platforms is a departure from the experiences of many

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units who grew accustomed to the ISR soak in Operations Enduring Freedom and Iraqi Freedom.

Table 1. Collection Platform and Management Transition Model

Echelon	Era / Resource	Pre-Operation Desert Storm (1986-1990)	Modular BCT (2003-Present)
Division	Collection Platforms	Aggregate Quantity of Scout Platoons, Air Cavalry Platoons, Attack Aviation Platoons, and UAS ground control stations, SIGINT sensors, and HUMINT collection teams	
	CM Roles	Staff or Unit Organizations by joint collection management function	
Brigade	Collection Platforms	Aggregate Quantity of Scout Platoons, Air Cavalry Platoons, Attack Aviation Platoons, and UAS ground control stations, SIGINT sensors, and HUMINT collection teams	
	CM Roles	Staff or Unit Organizations by joint collection management function	

Source: Created by author.

The source data for analyzing collection platform and management transition came from Tables of Organization and Equipment for a Heavy Division in 1986 as well as current Army doctrine and additional skill identifier descriptions. Military Intelligence (Combat Electronic Warfare and Intelligence) Battalions as of 1986 were equipped with both collection and jamming capabilities. The analysis focuses on the collection capabilities and excludes jamming systems. The Brigade collection platforms during 1986 assumes the assigned maneuver battalions maintain operational control of their assigned scout platoons. The analysis of the pre-Operation Desert Storm Division focuses on the heavy division assuming there is more collection platform capability than light or

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airborne divisions. The current organic BCT capabilities are the total number of information collection platforms represented by the Cavalry Squadron and the MICO. Further, the analysis limits UAS consideration to the Shadow, RQ-7B, tactical UAS aircraft. This limit results in the exclusion of the Raven, Small UAS, that is fielded at the company and platoon level. This exclusion regards the Raven as a company and platoon-level platform versus the Shadow as a BCT-level platform. If the Raven was factored in, the numerical platforms at the Brigade level would certainly increase. Further, the chemical reconnaissance platoon within the brigade engineer battalion is not included as it is generally focused on the chemical threat.

Determining the Value of the Collection Manager

The key to determine the value of the collection manager requires analysis of written material against the identified themes from the literature related to how the material relates to the position of the collection manager. Each of the three major themes identified are valued against how the document or narrative relates to the collection manager by directly relating to the BCT collection manager, relating to the collection manager generically, or relating to collection management in general (see table 2). The literature evaluation criteria are limited to the professional writing from the *Military Intelligence Professional Bulletin* and *Armor Mounted Maneuver Journal*, as doctrinal references to the collection manager are reflected in the word count analysis. In total, fifteen articles serve as the data set for analysis with seven from the *Military Intelligence Professional Bulletin* and eight from *Armor Mounted Maneuver Journal*.

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Table 2. Literature Evaluation Criteria			
Literature theme derived framework content valuation:			
	Collection Management Processes Information Collection Tools Information Collection Systems		
Author	Discussion directly related to a BCT Collection Manager	Discussion generically related to a Collection Manager	Discussion related to information collection generically
Context Valuation			
Author	Single perspective of multiple direct observations or experiences	Multiple perspective direct observation or experience	Single perspective direct observation or experience

Source: Created by author.

The literature evaluation criteria identified in table 2 is not intended to grade the professional recommendations as good or bad. The evaluation criteria are intended to show how the role of the collection manager relates to the identified themes from the literature and thesis. This evaluation is necessary as no literature clearly identified a MTOE collection manager at the BCT as a recommendation for improving Army information collection. Likewise, the context valuation is designed to show which perspectives on information collection are formed from a single observation or experience, such as performing the position, from the perspective of a combat training

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center trainer with multiple direct observations over a period of time. Neither the content nor the context valuations intend to diminish the value of the opinions represented by the authors.

Collection Management Expertise in the BCT

The final method of analysis looks at the intended distribution of advanced collection management training within the BCT. The purpose of analyzing personnel management documents is to determine where positions are associated with advanced information collection training at the BCT level. The BCT level, in this analysis, focuses on positions associated with a BCT collection platform. This analysis intends to show the density of positions coded for either the Q7, Information Collection Planners Course graduate, or C6, Cavalry Leader Course graduate, additional skill identifiers (see table 3). Advanced training in collection management is annotated as the number of C6 and Q7 ASIs based on tables 4-3 and 12-2 of Department of the Army Pamphlet 611-21, *Military Occupational Classification and Structure*.

Table 3. BCT Collection Management Expertise Model

ASI	Q7 Information Collection Planner	C6 Cavalry Leader
Officer	Quantity and Distribution	
Enlisted	Quantity and Distribution	

Source: Created by author.

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Methodology Summary

The three analytical approaches identified allow for a comprehensive document and narrative analysis to show common themes as they relate to the role of the collection manager, specifically at the BCT. Additionally, the different analytical approaches allow for each type of data to be evaluated against unique criteria. Finally, the use of multiple approaches with different criteria allows the inference of relationships between doctrine, professional writing, and force management documents.

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[1] Steve Stemler, "An overview of content analysis," *Practical Assessment, Research & Evaluation* 7, no. 17 (June 2001): 1, accessed 18 March 2019, http://pareonline.net/getvn.asp?v=7&n=17.

[2] Ibid., 2.

[3] Ibid.

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CHAPTER 4

ANALYSIS

This research analyzes doctrine and professional writing from military intelligence and cavalry perspectives to determine the value of an authorized MTOE position for a BCT collection manager through the variables of collection management processes, information collection tools, and information collection systems. This analysis is accomplished through examining the transition of collection platforms over the last thirty years; content analysis of professional writing as it relates to the BCT collection manager and information collection in general; and the comparison of existing information collection management expertise in the BCT.

Collection Platforms and Management: Past and Present

Analysis of the Heavy Division Table of Organization and Equipment and doctrine from 1986 revealed a multitude of collection platforms located within the Military Intelligence Battalion and Cavalry Squadron. The Military Intelligence Battalion contributed twenty-eight of the pre-Operation Desert Storm collection platforms. These platforms included an array of ground-based communications intelligence, ground-based electronic intelligence, ground surveillance radar, and long-range surveillance teams.[1] The divisional cavalry organization of 1988 consisted of two troops of three platoons for a division total of six reconnaissance platoons that doctrinally existed in the Heavy Division Aviation Brigade.[2] The Operation Desert Storm Era Aviation Brigade for a heavy division included a cavalry squadron and two attack helicopter battalions. The Cavalry Squadron adds an additional total of four platoons of AH-1 Cobra and OH-58

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Kiowa helicopters.[3] The Attack Helicopter Battalions provide a total of six more platoons consisting of a mix of OH-58 Kiowa and AH-64 Apache aircraft.[4] In 1986, the Division Intelligence Section supported the Division Tactical Operations Center Support Element with a staffed Collection Management and Dissemination (CM&D) Section.[5] The CM&D Section was responsible for mission management that included "collection planning, tasking, and coordination" as well as "dissemination of combat information and intelligence."[6] FM 34-10 stipulates that the collection planning "converts priority intelligence requirements and information requirements into collection missions."[7] This function demonstrates that the division maintained a dedicated team of collection managers to fulfill what is now considered by joint doctrine as COM and CMM.

Current doctrinal division information collection capabilities exist entirely from the Combat Aviation Brigade. This is not to say that the Division Commander is incapable of composing a ground reconnaissance force, but more so highlights that the Division Cavalry Squadron of the Operation Desert Storm era no longer exist, as evident from Poindexter's diagram of reconnaissance capability by echelon by era mentioned in chapter two.[8] Certainly, the Division Commander can task a subordinate BCT, as in the case of 1st Stryker Brigade Combat Team, 4th Infantry Division, as a Reconnaissance and Security BCT or a subordinate BCT's cavalry squadron.[9] A healthy debate exists on how to fill the ground reconnaissance capability at the division-level considering that no dedicated division cavalry formation currently exists and certainly exceeds the scope of this research. This research focuses on the current doctrinal role of the Combat Aviation Brigade as a division capability with the first core competency being "provide accurate and timely information collection."[10] The Division's reliance on the Combat Aviation

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Brigade for primary information collection capability is evident from the organizational structure of the Combat Aviation Brigade.

The Combat Aviation Brigade maintains an Aerial Reconnaissance Squadron of twenty-four AH-64 Apache helicopters organized with twelve RQ-7 Shadow UASs. The Attack Reconnaissance Battalion consists of twenty-four AH-64 Apache helicopters with an additional company of twelve MQ-1C Gray Eagle UAS. These MQ-1C Gray Eagle UAS are often reserved for divisional control as dedicated collection platforms.[11] The key distinction between the MQ-1C Gray Eagles and the RQ-7 Shadows within the Combat Aviation Brigade lies in the fact that the RQ-7 Shadows are integrated into the Attack Reconnaissance Squadron Troops whereas the MQ-1C Gray Eagles operate as a separate company within the Attack Reconnaissance Battalion.[12] Further, Michael Brake discusses a limiting factor for UAS in his 2004 article on "BCT Intelligence Operations" where the capability of the UAS depends on the number of ground control stations as opposed to the number of aircraft. Using Brake's description of the proposed BCT MICO, this research considers half of the number of UAS as operational at any one time considering there were roughly half the number of ground control stations proposed in 2004.[13] Therefore, the operational total of UAS in the division Combat Aviation Brigade is considered to be six RQ-7 Shadows and six MQ-1C Gray Eagle UASs. The key point for the division echelon is, barring the deliberate tasking of a subordinate BCT to provide forces for information collection, the division relies primarily on the Combat Aviation Brigade for all organic information collection capabilities. The division G-2 maintains a collection management element led by a Major, as evident from the AIDP-ISR program

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who executes COM functions as well as referenced in FM 3-55, *Information Collection*.[14]

The Brigade echelon shows a significant difference in capability between the Operation Desert Storm and current BCT eras. Prior to and through Operation Desert Storm, the brigade echelon did not have any dedicated reconnaissance capability, as Poindexter's figure indicated in chapter two.[15] Similarly, FM 34-80, *Brigade and Battalion Intelligence and Electronic Warfare Operations*, provides a very generic description of the intelligence and electronic warfare capability at the Brigade level as the maneuver battalions.[16] Divisional MI BN doctrine serves as a nod to the modularity of the BCT era with conceptual employment of task-organized MI company-teams in a direct or general support role to subordinate brigades.[17] The supporting MI company-team explains why the Brigade maintained a management role over MI platforms through the Battlefield Information Control Center (BICC) even though the Brigade had no organic or permanently assigned platforms.

According to FM 34-80, *Brigade and Battalion Intelligence and Electronic Warfare Operations*, the S-2 was responsible for the reconnaissance and security plan "as the formal collection management tool" supported through the BICC.[18] The BICC fulfilled responsibilities similar to the current Brigade Intelligence Support Element through developing intelligence requirements, the reconnaissance and security plan, and then executing the approved plan.[19] In essence, the BICC served all roles of CRM, COM, and CMM much like a miniature analysis and control element coupled with a current operations element. The key takeaway here is no specific position beyond the Brigade S-

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2 is identified as responsible for collection management in the pre-Operation Desert Storm brigade.

Current BCT collection capabilities, both platforms and management responsibilities are difficult to provide in an unclassified setting. Definitive information for numbers of collection platforms and personnel in management roles exists at the official use only level through MTOEs and generically through doctrine. For this research, Brake's article on the proposed BCT MICO provides enough information for overall consideration of capabilities. Without providing the specific numbers of each MI platform, the BCT MICO provides eight collection platforms while the Cavalry Squadron contributes six total reconnaissance platoons.[20] The current Cavalry Squadron consists of three reconnaissance troops of two platoons with an additional tank company. This tank company contributes an additional three platoons presuming a hunter-killer capacity when employed with the Cavalry Squadron. Another application of the tank company in the Cavalry Squadron is serving as a brigade reserve which would reduce the overall platform count by three.

Collection management responsibilities in the current BCT vary widely depending on the source documentation. Brake mentions ISR synchronization and requirements management as responsibilities for the MICO's analysis and integration platoon, which exists now as the information collection platoon.[21] FM 3-98, *Reconnaissance and Security Operations*, discusses the previously mentioned Brigade Reconnaissance Cell which performs COM responsibilities by "allocate[ing] organic, attached, and supporting assets and enablers against the [named areas of interest] to ensure seamless and in-depth reconnaissance operations."[22] The Operations and

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Intelligence Working Group mentioned in both ATP 2-01, *Plan Requirements and Assess Collection*, and FM 3-55, *Information Collection*, is designed to "achieve a fully synchronized and integrated information collection plan" through "validat[ing] information requirements and deconflict the use of organic and attached assets."[23] Regardless of echelon, doctrine states the O&I WG is a temporary group for the sole purpose of information collection integration and coordination.[24] A fair argument can be made that the Cavalry Squadron staff itself is a collection management organization through the functions of CRM, COM, and CMM.

The development of the BCT clearly shows how the organic collection platforms available to the brigade and BCT changed over the last three decades, speaking to supporting research question two, (See table 4). This is evident by the clear increase in BCT collection platforms with a corresponding decrease in Division collection platforms that mostly represents Military Intelligence platforms followed by Reconnaissance Platoons. This transition also provides insight on how the brigade-level was and is designed for information collection, which speaks to supporting research question one. Doctrine shows that collection management responsibility rested with the Brigade S-2, and in many ways still exists today. However, current doctrine indicates that many representatives from other warfighting functions are involved in information collection management.

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Table 4. Collection Platform and Management Transitions			
Echelon	Era / Resource	Pre-Operation Desert Storm (1986-1990)	Modular BCT (2003-Present)
Division	Collection Platforms	44	24
	CM Roles	CM&D section - COM, CMM Cavalry Squadron Staff – CRM, COM, CMM	CM&D element - COM
Brigade	Collection Platforms	0	17
	CM Roles	Brigade S-2 – CRM, COM BICC – CRM, COM, CMM	ICP – CRM, COM Brigade Recon Cell – COM O&I WG – CRM, COM Cavalry Squadron Staff – CRM, COM, CMM
Note: CRM: Collection Requirements Management COM: Collection Operations Management CMM: Collection Mission Management CM&D: Collection Management and Dissemination BICC: Battlefield Information Control Center ICP: Information Collection Platoon (within the BCT MICO) O&I WG: Operations and Intelligence Working Group			

Source: Created by author.

The collection platform data is pretty clear that information collection platforms increased at the BCT level. What is less clear is who is responsible for the collection management at the BCT considering the data reflects four staff units or organizations capable of fulfilling collection management functions. From FM 2-0, collection management related responsibilities of the S-2 section are:

> Developing collection strategies; overseeing the intelligence cell's contributions to collection management; coordinating requirements with higher, lateral, and subordinate units; ensuring ongoing intelligence operations are collecting

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> information needed for anticipated decisions; and recommending changes to the information collection plan based on changes in the situation or weather.[25]

Of the aforementioned tasks, each can be categorized as a function of either CRM or COM with the key takeaway being that collection management functions do reside in the S-2 section, which applies at all echelons with an intelligence section. Battalion S-2s provide CRM for their formations, including submitting requests to the BCT for support, and COM of organic and attached collection platforms. The cavalry squadron S-2, as part of the squadron staff, identified in table 4 above, provides significant CRM functions to BCT collection platforms as the cavalry squadron typically crosses the line of departure well before any operations order is finalized, and in many instances, before the information collection plan is finished. From previous discussion in chapter two, the Brigade Reconnaissance Cell and the Operations and Intelligence Working Group are ad-hoc organizations composed of members with primary responsibilities and only when necessary. This temporary basis poses challenges in the large-scale combat operations environment since most leaders will likely be focused on their primary duties. This focus would presumably make gathering the right leaders together to effectively compose a Brigade Reconnaissance Cell or Operations and Intelligence Working Group. Conversely the information collection platoon and the cavalry squadron staff are permanent organizations, but each is limited in capability to provide collection management functions as they are doctrinally organized. The information collection platoon does not have CMM authority over any of the military intelligence collection platforms. The cavalry squadron staff does not have CMM either unless the military intelligence company is task organized under the cavalry squadron. Acknowledging the lack of a dedicated primary duty collection management responsibility, this research looks to the

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professional contributions from leaders within the Army maneuver and intelligence communities for insight in how units approach information collection management.

The Value of the Collection Manager

The professional writing in the *Military Intelligence Professional Bulletin* and *Armor Mounted Maneuver Journal* provides insights into how units are approaching information collection within the force. These perspectives are grounded in direct observations or experiences by the authors. Seventeen total articles covering tactical information collection spanning thirty years were evaluated on both content and context, (see table 5). Four of the seventeen articles directly related to a BCT collection manager when discussing the analytical variables of collection management processes, tools, and systems. An additional five articles referenced the BCT collection manager in one of the analytical variables. Of note, not all of the discussions highlighted things that collection managers do well or that units do well with regard to information collection. On the contrary, most articles focused on missing capabilities and skills while presenting possible solutions that span the range of doctrine, organization, training, material, leadership education, and personnel. Throughout the articles, three key points stood out as they relate to information collection and the analytical variables of collection management processes, tools, and systems. These three points are: information collection is a team effort; information collection leaders must know the capabilities and architecture; and most importantly, the purpose of information collection is to support the commander's decision making.

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Table 5. Professional Writing Evaluation				
Author	Content Evaluation			Context Evaluation
	Processes	Tools	Systems	
Adams	1	1	1	S-MDO
Armstrong	3	3	3	S-MDO
Black	3	3	3	S-SDO
Black and Watras	2	2	2	M-DO
Buchanan and Covert	3	3	3	M-DO
Childs	1	1	1	S-MDO
Gellman	1	2	1	S-MDO
Hefti	2	2	2	S-SDO
Kuderka and Eickbush	1	3	3	M-DO
LaRubio	1	1	1	S-SDO
Lobdell	2	3	3	Undetermined
Miseli, McLean, and Bovan	3	3	1	M-DO
Palisca	3	3	3	Undetermined
Palmer	1	3	1	S-SDO
Rudock	2	2	3	S-SDO
Sterioti	1	1	1	S-SDO
Wellsandt	1	3	3	S-MDO
Legend: 1 = Discussion directly related to a BCT Collection Manager 2 = Discussion generically related to a Collection Manager 3 = Discussion related to information collection generically S-MDO = Single Perspective of Multiple Direct Observations M-DO = Multiple Perspective of Direct Observation S-SDO = Single Perspective of Single Direct Observation				

Source: Created by author.

Information Collection is a Team Effort

No authors attempted to argue that a one-person operation could successfully integrate information collection platforms into the information collection plan. Ten of the

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seventeen articles directly addressed the integration of the intelligence warfighting function with other warfighting functions as a necessary component of successful information collection operations. These observations varied in perspective and emphasis but collectively drive to the same point; that integration is key but the leader of the effort matters. The secondary point inferred is that the lack of integration results in divergent, unsynchronized plans of maneuver and intelligence warfighting function collection platforms. The clearest example of describing the lack of integration is the frequent use of the term synchronization. Synchronization appears in most of the articles and refers collectively to the integration of multiple platforms in time and space with the overall BCT operation. As Adams described it, "failure to use information collection planning as an integrating process for multiple staff members risks wasting precious resources or missed opportunities."[26] The last contribution of the team effort approach is how units define or align collection management functions with personnel in the BCT. The frequent association of collection management functions without calling them a collection manager is represented in the Chief of Reconnaissance concept.

Palmer highlighted that no single staff section owns the "planning and execution of information collection" further elaborating on a list of personnel; the "S-2, S-3, information collection manager, cavalry squadron, military intelligence company, attached aviation units and attached UAS all have a major role in the information collection process."[27] LaRubio also includes the Brigade Aviation Element and the Staff Weather Officer as critical staff members for coordination.[28] Integration goes beyond staff members at the brigade-echelon as evident from several authors indicating coordination between echelons was critical. This point was echoed by Palisca in that the

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"cavalry squadron S-2 and S-3 must maintain a continual dialogue with the BCT S-2 and S-3."[29] Likewise, Sterioti mentions the cross-echelon coordination to identify gaps and ensure understanding between priority intelligence requirements, named areas of interest, and the event template.[30] Childs and Stertori both addressed the importance of the information collection rehearsal with Childs offering multiple combat training center observations of units failing to rehearse the information collection plan. Childs perspective of responsibilities mirrors current doctrine with the BCT S-3 or Chief of Reconnaissance chairing the information collection rehearsal with the BCT collection manager leading the rehearsal.[31] Sterioti further recommends that the intelligence warfighting function collection manager needs a "counterpart" in the BCT current operations cell who understand the plan and the platforms as continuity across the staff.[32] This larger team approach necessitates the question of who is in charge?

The easy and often default answer is the commander who does so through planning and reconnaissance guidance which Kuderka and Eickbush observed failures of commanders to drive the information requirement process.[33] Armstrong echoed the need for commander's guidance beyond how to employ the UAS.[34] Beyond the commander's role, most authors echo doctrine with the S-3 serving as the orders issuing authority and the S-2 providing the majority of planning tools to the collection plan. Doctrine presents the S-3 as the integrating authority for the information collection effort through the operations and intelligence working group, BCT reconnaissance cell, and the orders process for annex L, *Information Collection*. Kuderka and Eickbush elaborate that observations at the combat training centers extend to failures of operations staffs to fill

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the doctrinal information collection integration role by leaving the process to the battalion S-2.[35]

Two authors approached the integration problem through the lens of effective rehearsals. Childs and Armstrong both recognized that a separate information collection rehearsal was necessary as a synchronization tool following integrated planning. Childs recommends that the information collection rehearsal is conducted prior to the BCT combined arms rehearsal.[36] Ultimately both Childs and Armstrong focus on executing a rehearsal that provides a clear shared understanding and identifies intelligence gaps.[37] The key consideration for Childs and Armstrong's perspective is through observations from combat training center rotations where units have dedicated time to conduct planning prior to crossing the line of departure. Effective information collection rehearsal becomes significantly more challenging after operations begin, units are in-contact with the threat, and units are out of face-to-face coordination range. Both Childs and Armstrong focused more on just executing information collection rehearsals as opposed to addressing the nature of how to conduct rehearsals after the BCT crosses the line of departure.

Since there is no MTOE BCT collection manager position, units are free to choose who they want, and the results are represented throughout the professional discourse literature. The majority of references to the specific position of the BCT collection manager associate it with a military intelligence lieutenant who often is the information collection platoon leader as evident in nine of eleven training center rotations observed by Adams.[38] This assignment to a lieutenant led to the criticism that the collection manager either does not know ground reconnaissance, experience is limited to

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technical collection, military intelligence platforms, or is not suited to the demands of the position.[39] Adams' observations from the Joint Readiness Training Center led to a conclusion that "understanding when and how to participate in events, such as the operations synchronization meeting, and incorporating collection tasks into a daily order were often beyond the information CM's level of experience."[40] Gellman recommended the collection manager be filled by a maneuver officer who presumably is best qualified to plan for ground reconnaissance augmented with a subordinate military intelligence officer who brings the technical collection expertise.[41] The other argument for a maneuver leader leading information collection planning is the Chief of Reconnaissance, with an equally diverse recommendation on who should fill that role.

As discussed in chapter 2, Hefti and Palmer offer different recommendations who could fill the non-doctrinal role of Chief of Reconnaissance. Even though the role is non-doctrinal, it is important for the discussion as the arguments center around the fundamental collection management functions defined in chapter one; CRM, COM, and CMM. Hefti's argument for the Cavalry Squadron's Headquarters and Headquarters Troop Commander focuses on the COM functions based on this commander's expectation to understand the BCT's collection platforms and how to integrate ground reconnaissance.[42] Hefti's perspective infers that the Chief of Reconnaissance operates as a cavalry squadron advisor or liaison to the BCT staff on how to employ scouts. As previously stated, Hefti's approach presumes that the Headquarters and Headquarters Troop Commander would be co-located with the BCT planning effort to be effective. Palmer's argument centers around the Squadron Commander fulfilling COM and CMM functions for the BCT collection platforms.[43] Palmer's perspective relies on the Squadron

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Commander's command authority for tasking which would presume that the BCT would task organize the information collection platforms under the Cavalry Squadron. In either construct, the Chief of Reconnaissance fulfills COM functions and therefore is a type of collection manager, just by a different name.

Ultimately which duty position fulfills the role of BCT collection manager is for another discussion. What the literature infers through critique of past experiences in combat training center rotations and observations is the need for a BCT collection manager who can coordinate across the BCT staff and between echelons higher and lower. Further, the importance of this relational coordination cannot be stressed enough since synchronization of platforms requires collaboration with battalion, brigade, and division representatives. The professional discussion appears very clear that a military intelligence leader and a maneuver leader cannot be expected to be subject matter experts in the others platform capabilities. That said, authors did stress the need for expertise in collection platforms and architecture as necessary for successful information collection.

Knowledge in Capabilities and Architecture

The need to understand collection platform capabilities and architecture were represented in eight of the seventeen articles. All eight of these articles directly discussed knowledge in collection platforms as important. Three of the eight articles addressed information collection architecture as well as capabilities. Information collection architecture refers to how information gets from the collector to the person who needs it. Think of information collection architecture as the entire system necessary for information to flow from the sensor to processor to analyst to end user. The literature evaluation resembled a single perspective that BCT collection managers were not

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knowledgeable of the BCT collection platforms capabilities. Beyond the lack of knowledge, a few articles offered insight on how to close the knowledge in capabilities gap.

Sterioti and Lobdell both discussed the need to understand the request process for platforms where Lobdell mentioned that a significant number of platforms exist above the BCT and outside the Army.[44] LaRubio provides the platoon level perspective by stating that the collection manager needs to know the capabilities and limitations of the RQ-7 Shadow UAS to effectively employ it within the BCT's information collection plan.[45] The failure to understand information collection platform capabilities was discussed in four of the eight articles, several providing observational experience. Adams attributed an observable disconnect between the collection manager, S-2, MICO, and collectors as a failure to understand the capabilities of the platforms.[46]

Buchanan and Covert addressed the gap of knowledge in capabilities and architecture as they discussed an entire training day of the five-day BCT S-2 course was dedicated to "BCT Intelligence and Electronic Warfare Systems and Architecture."[47] The emphasis on organic capabilities followed by a day of employment considerations and collection management training sought to address perceptions of BCT S-2s, as the senior intelligence officers of their formations, unable to integrate their capabilities into the BCT fight. Lobdell, quoting Army Doctrine Publication 2-0, *Intelligence*, discusses how the intelligence architecture requires a knowledge of intelligence capabilities.[48] Adams reiterates the need for understanding intelligence architecture but also stipulates that collection managers must understand maneuver capabilities as a nod to the divergent perspectives between maneuver and intelligence communities.[49] Kuderka and Eickbush

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placed the blame of failing to utilize organic capabilities on conditioning to the enduring counter-insurgency operations in Iraq and Afghanistan.[50] Kuderka and Eickbush discussed alternative collection platforms such as Air Force Joint Terminal Attack Controllers and other forward observers, although they seem to gloss over the fact that those positions have other primary duties than information collection.[51]

Seven of the total seventeen articles addressed recommendations at closing the knowledge in capabilities gap. These recommendations were wide ranging and encompassed institutional and on-the-job training. Adams correlates units that perform successful information collection are units that also prioritize assigning three to four Soldiers to a collection management team at the BCT which is then capable of covering 24-hour operations.[52] Likewise, Sterioti recommends that an officer or non-commissioned officer be trained as the collection manager prior to any training center or deployment without providing a recommendation on what type of training.[53] Sterioti claims a direct correlation between failures to train collection management in garrison with an ineffective and unsynchronized collection plan.

Although dated, Black and Watras' discussion on the collection management course, precursor to the Q7 Information Collection Planners Course, provides insight in an institutional example of changes made to training to accommodate new requirements. Specifically, Black and Watras mention that following Operation Desert Storm, collection management students would be exposed to new fielded technologies such as UASs and JSTARS as well as integrating between battalion and army component command echelons.[54] Miseli, McLean, and Bovan propose an alternative through sending military intelligence officers to attend the C6 Cavalry Leader Course to better

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understand cavalry scout planning and integration.[55] This approach to diversifying understanding was credited by Bovan for success in a combat training center rotation.[56] Both the Q7 and C6 additional skill identifiers are discussed in greater detail later in this chapter.

The BCT S-2 course already mentioned earlier serves as another example of training by teaching the leaders of the BCT's intelligence warfighting function. This viewpoint was similarly represented by LaRubio in the form of a capabilities briefing on the RQ-7 Shadow UAS from the subject matter experts to the BCT collection manager.[57] At face value, the thought of a simple capabilities brief may seem elementary, but it belies a deeper inferred point. Understanding that there is no authorized position for a collection manager means that whoever ends up fulfilling the role has another primary job which is likely where that Soldier's attention goes. As Sterioti said "training the collection manager in garrison" is important to successful information collection management. The humble capabilities brief demonstrates that there is a wealth of resources available to the collection manager beyond formal institution training at USAICoE. After all, the AIDP-ISR program demonstrates that a significant resource exists in distance learning through the Defense Intelligence Agency and National Security Agency. Lastly, a collection manager in garrison needs only pick up the phone or walk down to see subject matter experts in the BCT information collection platforms to gain more exposure to the capabilities available.

Support the Commander's Decision Making

Thirteen of the seventeen articles discussed the purpose of information collection was to facilitate the commander's understanding and visualization to enable the

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commander to make informed decisions. This analysis does not indicate that the remaining articles argue against supporting the commander's decision making, they simply did not mention it. Two viewpoints were represented in the form of a general reminder of the purpose and an attribution of a product and process focused purpose. The general reminder perspective reiterates the importance of the information collection plan in answering priority intelligence requirements and conditions for decision points.

The attribution of a product or process focus is directed at instances where planners put too much emphasis on creating the perfect information collection plan tools, such as the Information Collection Matrix, Information Collection Synchronization Matrix, or Information Collection Overlay, that comes at the expense of detail to the collection platform. Armstrong attributes reconnaissance failure with units that focus on these products, largely dominated by the S-2 section, with no involvement by the S-3 section.[58] Childs stressed the importance of displaying the commander's priority intelligence requirements during the information collection rehearsal to remind participants what the plan is working towards.[59] Adams discusses purpose through accepting that the information collection plan is subject to change and must focus on the commander's priority intelligence requirements.[60]

Adams introduces a concept that is echoed by Palmer and Wellsandt which is the use of mission orders for tasking collection platforms.[61] Both Palmer and Wellsandt use the issue of mission order or task and purpose versus information collection tools as part of the benefit in their proposed organizational changes to place all the BCT collection platforms under the cavalry squadron.[62] In the end, doctrine provides little guidance on how to task collection platforms other than the information collection plan, which

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remains heavily dominated by S-2 produced tools. The simple answer, offered by Armstrong, puts the responsibility back to the S-3 section in the form of the "staff integrated" written Annex L with the attached appendices provided by the S-2.[63] The results of the literature evaluation analysis is a firm understanding of the overall purpose for information collection and the need for an integrated planning process through trained leaders.

Collection Management Expertise in the BCT

The final contributor to collection management within the BCT is collection management related additional skill identifiers. Specifically, the Cavalry Leader Course graduate, C6, and the Information Collection Planners Course graduate, Q7. According to officer and enlisted tables in the Department of the Army Pamphlet 611-21, *Military Occupational Classification and Structure*, the C6 additional skill identifier provides for a total of eight qualified positions at the Cavalry Troop and Cavalry Squadron Operations cell.[64] Likewise, the Q7 describes the position as "requiring qualifications in managing the employment of organic and supporting intelligence collection assets" but does not include density of positions like the C6.[65] Without providing specifics, the MTOE does reflect a very small number of Q7 positions in the BCT but they are either already factored into an existing staff or unit identified, in table 4, or positioned in a role limiting their ability to doctrinally coordinate the variety of BCT collection platforms.

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Table 6. Current BCT Collection Management Expertise Analysis		
ASI	Q7 Information Collection Planner	C6 Cavalry Leader
Officer	0* (Military Intelligence Officers and Warrant Officers)	1 per Cavalry Troop 3 per BCT Cavalry Squadron Operations Cell (Armor Captains or Majors)
Enlisted	0* (Military Intelligence Sergeant through Sergeant First Class)	1 per Cavalry Troop 1 per ABCT and SBCT Cavalry Squadron Operations Cell (Armor Master Sergeants)
*Note: BCT authorization documents provide a different amount of negligible value		

Source: Created by author from data contained in Headquarters, Department of the Army, "Officer and Enlisted Skill Identifiers" in Department of the Army Pamphlet 611-21, *Military Occupational Classification and Structure* (Washington, DC: Government Printing Office, July 2018), accessed 07 March 2019, https://www.milsuite.mil/book/groups/smartbookdapam611-21.

Summary of Analysis

The data clearly shows an increase in information collection platforms at the brigade-level with no primary responsibility for collection management over all of the BCT's information collection platforms. The professional discussions from cavalry and military intelligence leaders provides insight into the value that the collection manager provides through four necessary qualities. Foremost, a collection manager must be an integrator across the staff for effective information collection planning and execution. Secondly, the collection manager must be knowledgeable in organic and external information collection platform capabilities. Third, knowledge in capabilities can create the perfect plan, but understanding the architecture of how the information gets from the sensor to support the fourth quality, the commander's decision making, is key. The

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collection manager must always focus information collection planning and execution on the commander's priority intelligence requirements to collect timely information for analysts to produce intelligence that facilitate the commander's understanding, visualizing, and decision making. Lastly, a disparity appears to exist in how the maneuver community trains leaders for collection management functions as opposed to how the Army intelligence community approaches it. The cavalry squadron is strongly represented within the BCT for positions coded with advanced collection management training. The BCT intelligence warfighting function is not enabled with advanced collection management training to its detriment.

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[1] Headquarters, Department of the Army (HQDA), "Military Intelligence

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Battalion: Combat Electronic Warfare and Intelligence (CEWI) Heavy Division,

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34285L000," *Table of Organization and Equipment* (Washington, DC: Government Printing Office, October 1986), II-9 to II-12; Headquarters, Department of the Army (HQDA), Field Manual (FM) 34-10, *Division Intelligence and Electronic Warfare Operations* (Washington, DC: Government Printing Office, November 1986), 2-8 to 2-12.

[2] Todd L. Poindexter, "Transforming Mechanized Reconnaissance: How the Armored Brigade Combat Team (ABCT) Cavalry Squadron Should Be Structured for Reconnaissance and Security Operations in the near Future" (Master's Thesis, U.S. Army Command and General Staff College, Ft. Leavenworth, KS, 2014), 46; Headquarters, Department of the Army (HQDA), Field Manual (FM) FM 1-111, *Aviation Brigades* (Washington, DC: Government Printing Office, August 1990) 1-8.

[3] HQDA, FM 1-111, 1-8.

[4] Ibid.

[5] HQDA, FM 34-10, 3-6.

[6] Ibid.

[7] Ibid.

[8] Poindexter, "Transforming Mechanized Reconnaissance," 68.

[9] Curt Taylor and Joe Byerly, "Fighting for Information in a Complex World: Lessons from the Army's first Reconnaissance and Security Brigade Combat Team" (Raider Brigade White Paper, 1st Stryker Brigade Combat Team, 4th Infantry Division, Fort Carson, CO, September 2017), 2.

[10] Headquarters, Department of the Army (HQDA), Field Manual (FM) HQDA, FM 3-04, *Army Aviation* (Washington, DC: Government Printing Office, July 2015), 1-1.

[11] Ibid., 2-7 to 2-8.

[12] Ibid., 2-7.

[13] Michael A. Brake, "Brigade Combat Team (BCT) Intelligence Operations," *Military Intelligence Professional Bulletin* 30, no. 4 (October-December 2004): 28.

[14] USAHRC, MILPER Message; HQDA, FM 3-55, 2-5 to 2-6.

[15] Poindexter, "Transforming Mechanized Reconnaissance," 68.

[16] Headquarters, Department of the Army (HQDA), Field Manual (FM) 34-80, *Brigade and Battalion Intelligence and Electronic Warfare Operations* (Washington, DC: Government Printing Office, April 1986), 2-15 to 2-17.

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[17] HQDA, FM 34-10, 3-24 to 3-25.

[18] HQDA, FM 34-80, 3-10.

[19] Ibid.

[20] Brake, "Brigade Combat Team (BCT) Intelligence Operations," 28; Headquarters, Department of the Army (HQDA), Army Techniques Publication (ATP) 3-20.96, *Cavalry Squadron* (Washington, DC: Government Printing Office, May 2016), 1-8 to 1-9.

[21] Brake, "Brigade Combat Team (BCT) Intelligence Operations," 28.

[22] HQDA, FM 3-98, 1-11.

[23] HQDA, ATP 2-01, 2-5 to 2-6; HQDA, FM 3-55, 2-5 to 2-6.

[24] HQDA, ATP 2-01, 2-5 to 2-6; HQDA, FM 3-55, 2-5 to 2-6.

[25] HQDA, FM 2-0, 2-1 to 2-2.

[26] Adams, "Observations from a Year as the Brigade S-2 Observer-Coach-Trainer at the Joint Readiness Training Center," 9.

[27] Palmer, "The Squadron Commander as Chief of Reconnaissance," 15.

[28] LaRubio, "The Relationship Between the UAS Platoon and the BCT," 52.

[29] Palisca, "What Do We Mean When We Say 'Fight For Information'?" 42.

[30] Sterioti, "Information Collection Management in the BCT," 48.

[31] Childs, "Information-Collection Rehearsals in the Brigade Combat Team," 31.

[32] Sterioti, "Information Collection Management in the BCT," 48.

[33] Kuderka and Eickbush, "Information-Collection Failures that Lead to 'Discovery Learning,'" 34.

[34] James E. Armstrong, "Information-Collection Plan and Reconnaissance-and-Security Execution: Enabling Success," *Armor Mounted Maneuver Journal* 127, no. 3 (Summer 2017): 20.

[35] Kuderka and Eickbush, "Information-Collection Failures that Lead to 'Discovery Learning,'" 35.

[36] Childs, "Information-Collection Rehearsals in the Brigade Combat Team," 31-32.

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[37] Childs, "Information-Collection Rehearsals in the Brigade Combat Team," 33; Armstrong, "Information-Collection Plan and Reconnaissance-and-Security Execution: Enabling Success," 21.

[38] Adams, "Observations from a Year as the Brigade S-2 Observer-Coach-Trainer at the Joint Readiness Training Center," 9.

[39] Palmer, "The Squadron Commander as Chief of Reconnaissance," 15; Sterioti, "Information Collection Management in the BCT," 48; Gellman, "Improving the Relevance of Tactical Intelligence in the COE," 14; Hefti, "The Headquarters and Headquarters Troop Commander as Brigade Combat Team Chief of Reconnaissance," 68; Adams, "Observations from a Year as the Brigade S-2 Observer-Coach-Trainer at the Joint Readiness Training Center," 10.

[40] Adams, "Observations from a Year as the Brigade S-2 Observer-Coach-Trainer at the Joint Readiness Training Center," 9.

[41] Gellman, "Improving the Relevance of Tactical Intelligence in the COE," 14.

[42] Hefti, "The Headquarters and Headquarters Troop Commander as Brigade Combat Team Chief of Reconnaissance," 67.

[43] Palmer, "The Squadron Commander as Chief of Reconnaissance," 16.

[44] Sterioti, "Information Collection Management in the BCT," 48; Lobdell, "Resetting Intelligence Doctrine," 12.

[45] LaRubio, "The Relationship Between the UAS Platoon and the BCT," 53.

[46] Adams, "Observations from a Year as the Brigade S-2 Observer-Coach-Trainer at the Joint Readiness Training Center," 13.

[47] Buchanan and Covert, "The Brigade Combat Team Intelligence Staff Officer Course," 16.

[48] Lobdell, "Resetting Intelligence Doctrine," 15; HQDA, ADP 2-0, 5-8.

[49] Adams, "Observations from a Year as the Brigade S-2 Observer-Coach-Trainer at the Joint Readiness Training Center," 10.

[50] Kuderka and Eickbush, "Information-Collection Failures that Lead to 'Discovery Learning,'" 34.

[51] Ibid., 34-35.

[52] Adams, "Observations from a Year as the Brigade S-2 Observer-Coach-Trainer at the Joint Readiness Training Center," 10.

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[53] Sterioti, "Information Collection Management in the BCT," 48.

[54] Black and Watras, "Collection Management/TENCAP 2000," 44-45.

[55] Jason A. Miseli, Gregory W. McLean, and Jeremy Bovan, "Intelligence Support to a Cavalry Squadron," *Armor Mounted Maneuver Journal* 123, no. 3 (July-September 2014): 42.

[56] Ibid.

[57] LaRubio, "The Relationship Between the UAS Platoon and the BCT," 53.

[58] Armstrong, "Information-Collection Plan and Reconnaissance-and-Security Execution: Enabling Success," 21.

[59] Childs, "Information-Collection Rehearsals in the Brigade Combat Team," 32.

[60] Adams, "Observations from a Year as the Brigade S-2 Observer-Coach-Trainer at the Joint Readiness Training Center," 11.

[61] Ibid., 9.

[62] Palmer, "The Squadron Commander as Chief of Reconnaissance," 16; Wellsandt, "Unifying the Brigade Combat Team Information-Collection Effort," 25.

[63] Armstrong, "Information-Collection Plan and Reconnaissance-and-Security Execution: Enabling Success," 21.

[64] HQDA, "Officer and Enlisted Skill Identifiers" tables 4-3 and 12-2.

[65] Ibid.

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CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This research sought to determine the value of an authorized BCT collection manager on the MTOE through military intelligence and cavalry doctrine and professional writing. The value of the BCT collection manager was hypothesized as possessing knowledge and skills in collection management processes, information collection tools, and information collection systems. The research and analysis identified recommendations applicable to both senior Army Intelligence leaders and tactical leaders.

Conclusions

This research resulted in four distinct conclusions. First, the growth of information collection platforms at the BCT did not include a corresponding increase in dedicated collection management responsibilities. This increase of platforms and lack of management forces units to treat the collection manager as an additional duty or, less likely, to sacrifice other responsibilities to fill the collection manager responsibilities. It is also a fair conclusion that collection platforms will continue to develop, as stated in the *Army Intelligence 2017-2025* strategic vision, to address gaps identified against peer threats, an example being survivable UAS in a contested airspace environment. Further, it is likely that given growth in capabilities, there is unlikely to be a growth in personnel to accommodate, essentially a do more with the same or less scenario. This would likely require a position for collection management to be taken from an existing role within the staff.

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Second, the professional discussions within the Army maneuver and intelligence communities expands the qualities originally hypothesized for this research. As mentioned earlier, the original hypothesis for this research focused more on the knowledge and skills necessary for a BCT collection manager to integrate the BCT collection platforms through collection management processes and tools. Professionals clearly indicated that knowledge and skills across the process, tools, and systems is important, but does not substitute the need for a leader who can integrate multiple staff representatives and orient on the commander's needs. In essence, the professional discussion encompasses the entire thesis as a single component of a larger discussion of necessary qualities. Therefore, a leader who is capable of working across the staff represents the above center mass quality of capabilities for a successful integrator. In the context of integration, the data reflects that successful integration is less about a single person and more about a team working together to achieve an integrated information collection plan. This expansion of necessary BCT collection manager qualities was unanticipated but clearly reflects the experienced perspectives from the data pool. Relationships matter to integration and represents the quality that most leaders identified as necessary to make information collection management and synchronization successful. The challenge with successful integration then returns to how doctrine defines who is responsible for what within the staff. Doctrine leaves the responsibilities with the staff primaries, such as the S-2 and S-3, without clearly identifying the integrator.

The third conclusion is that doctrine for information collection clearly identifies tasks and requirements for information collection and collection management but does little to fix responsibility beyond the staff primary officer. The professional discussions

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were fairly clear in identifying that without fixing responsibility, the ownership falls up the chain from the staff primary to the commander. Ultimately concluding that when the commander is deep in information collection management, they are not focusing on other necessary operational requirements. This lack of specificity beyond the staff primary invokes the thought that doctrine is intentionally vague to the point of allowing the commander and staff to determine who best fills the role of an integrator for information collection management. The key point for this conclusion is that professional discussion places a high enough priority on integration that, at the very least, doctrine should clarify responsibility for integration.

The final conclusion determined that advanced collection management training is available for both intelligence and maneuver leaders, but a disparity exists in the distribution of positions associated with this advanced training in the BCT. Table six in chapter four identified that the maneuver warfighting function invests significantly more additional training in leaders at the junior officer and senior non-commissioned officer ranks than the military intelligence warfighting function. How can the intelligence warfighting function contribute through three of the four information collection tasks as defined by FM 2-0, Intelligence; as "collection management, direct information collection, and conduct intelligence-related missions and operations;" without providing dedicated requirements for advanced collection management training?[1] Related to available training, the data demonstrated that opportunities exist in cross training leaders through formal institutional training as well as garrison training.

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Senior Leader Recommendations

There are four recommendations for the Department of the Army G-2, USAICoE Commander, and INSCOM commander in concert with leaders of other centers of excellence. The first is initiate or include a dedicated collection manager position on the BCT MTOE in a force design update. As Sterioti puts it "the Brigade collection manager is the central figure in the collection plan that brings it all together" and Childs expands with "when the collection manager owns the process, develops a simple and logical agenda, compiles the right tools and gathers the right participants together, he sets the brigade up for success."[2] Further, the BCT collection manager position should be coded for at least the Q7, Information Collection Planner additional skill identifier, as well as the C6, Cavalry Leader additional skill identifier. At a minimum, the BCT staff should be authorized one position coded for each of the Q7 and C6 additional skill identifiers. The Department of the Army Pamphlet 611-21 tables for additional skill identifiers should be updated to specify an ideal number of Q7 positions within the BCT, similar to how the C6 additional skill identifier reflects. After all, the Q7, Information Collection Planner Course is the intelligence warfighting functions solution to provide advanced collection management skills. It seems puzzling that there would not be a position on the BCT staff coded for the Q7 considering this research identified a clear increase in the amount and diversity of collection platforms within the BCT.

Implied in the first recommendation is the need to determine which position on the MTOE should be the collection manager. To that requirement, this research recommends additional research to include surveys of BCT S-2s, Division collection managers, BCT S-3s, and BCT Commanders. The additional research should also explore

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data from the Information Collection Planners course as to the typical training audience and in what capacity they attend. Discussions of who should fulfill the collection manager role typically include the Information Collection Platoon leader, the MICO Commander, a senior all source warrant officer or non-commissioned officer, an assistant BCT S-2, or someone outside the intelligence warfighting function. Considering the scope of responsibility and necessary experience, a senior staff captain in either the intelligence or operations staffs would be a logical candidate to fill the collection manager role. Understanding that every staff position is likely already task saturated, the collection manager role can be reinforced through distributing requirements by the collection management functions of CRM, COM, and CMM.

The second recommendation is for the USAICoE and Maneuver Center of Excellence commands to develop information collection doctrine and organization updates collaboratively. The diversity of information collection platforms identified in chapter four demonstrates that no single warfighting function can own information collection. The appearance of a silo mentality between the maneuver and intelligence warfighting functions on who best plans their respective collection platforms creates unsynchronized collection plans. Since the release of FM 3-0, *Operations*, in 2017 and FM 2-0, *Intelligence*, in 2018, FM 3-55, *Information Collection*, is in need of an update. Updates to FM 3-55, *Information Collection*, should include incorporation of the collection management functions of CRM, COM, and CMM to highlight the integrated staff approach of planning and executing information collection. Additionally, FM 3-55, *Information Collection,* should include a description of the role of the MTOE BCT collection manager.

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The third recommendation is for senior Military Intelligence Corps leaders to update tables 4-3 and 12-2 of Department of the Army Pamphlet 611-21, *Military Occupational Classification and Structure*. The updates to the tables should reflect the coding of BCT positions as collection managers. Further, the tables should reflect a desired objective of at least one Q7 Information Collection Planner on the BCT staff. The tables should also adjust to reduce the restriction to military intelligence branches only and allow maneuver leaders to earn the additional skill identifier.

The fourth recommendation is for the INSCOM commander to expand the Army Intelligence Development Program-Intelligence, Surveillance, and Reconnaissance track to include an abbreviated program of instruction for non-commissioned officers for assignment to BCTs for collection management. This expansion already occurred to accommodate warrant officers. If further research on which position best fits the collection manager results in a warrant officer identified, then the AIDP-ISR could easily expand to accommodate more students.

BCT and Division Leader Recommendations

At the tactical-level, BCT leaders should purposefully assign at least one leader as the BCT collection manager if not a small three to four-member collection management team. Absent of a formally authorized position, the BCT CM's appointment should be as a primary duty to allow them to focus on preparing through training and building relationships across the staff. Prospective collection managers should be leaders capable of working effectively between staff sections and able to lead key processes and events at the BCT-level. BCT leaders must prioritize advanced collection management training of either the Q7 Information Collection Planner or C6 Cavalry Leader for any leader filling

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collection management functions. A staff captain in the S-2 section is a logical starting point for consideration as the collection manager. The S-2 captain likely has the requisite knowledge of information collection platforms, at least the military intelligence systems, as well as basic institutional training in information collection planning tools. The S-2 captain may be better able to integrate with other staff sections for collaborative planning. This recommendation certainly acknowledges that there is not a plethora of extra staff members to easily assign the collection manager role without the risk of losing focus in other requirements. The data reflects how important the collection manager is to enable effective decision making.

BCT S-2s, Division collection managers, and G-2s should develop training plans for subordinate collection managers that includes capabilities, limitations, and employment considerations of information collection platforms at every echelon. collection manager training should also include thorough instruction in mission command system architecture. collection managers should understand how information is moved from collection platform to analyst to the commander. The information collection planning and execution effort should be trained and planned just as the analytical effort within the unit training plan. These training plans should include capabilities briefs, site visits, leader professional development sessions, web-based training, institutional training, and practical exercise application in a field environment.

Lastly, BCT S-2s should build standing operating procedures and counseling within the intelligence staff and influence the entire BCT staff with identifying the collection management functions of CRM, COM, and CMM. By incorporating these collection management functions, the staff may be able to better integrate through better

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understanding of distributed responsibilities. An example would be specifying that the BCT S-2 operations officer in the command post fulfills COM functions by monitoring and providing awareness to the staff of what collection platforms are active and where they are collecting. Likewise, this position could also be identified to maintain the current information collection matrix to facilitate COM should a tasked collection platform become unavailable and require re-tasking of a different platform. Each staff section could also identify a position to serve as their respective CRM to facilitate the consolidation of generated information requirements.

Ultimately these recommendations represent practical actions that senior leaders and tactical leaders can take to improve information collection within the Army and their formations. The operational environment is only growing more complicated, the architecture to support information movement is growing more complex, and the capabilities to gather the information is increasing. The goal of delivering "intelligence at the speed of mission command" is only achievable effectively if the collected information gets to an analyst to produce intelligence to support the commander's decision making. To do that, information collection must be managed and integrated through a dedicated team effort at the BCT.

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[1] HQDA, FM 2-0, 2-12.

[2] Sterioti, "Information Collection Management in the BCT," 48; Childs, "Information-Collection Rehearsals in the Brigade Combat Team," 34.

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A STUDY OF HOW UNMANNED AERIAL VEHICLE SYSTEMS CAN IMPROVE OVER-THE-HORIZON TARGETING AND STRIKE MISSIONS

by

Chadwick J. Boyd, Roderick E. Harris, Christopher L. Kleparek, and Joshua W. Taylor

March 2020

Advisor: Bonnie W. Johnson

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This capstone project studied the mission utility of using unmanned aerial vehicle (UAV) systems to accomplish the over-the-horizon mission by modeling a variety of UAV capabilities and evaluating their contribution. An Excel probabilistic model of the mission was created to determine the optimized weapon loadout and swarm configuration, which assumed the electronic countermeasures (ECM) UAV to have the highest probability of enemy engagement due to its lead formation position and large radar signature. An ExtendSim simulation added a time element to the study. Both the model and simulation revealed that a maximum air-to-air and strike weapon loadout, which is four weapons for each role, yields the highest probability of success at the lowest probability of a UAV casualty. A maximum air-to-air and strike loadout was found to produce success and UAV casualty probabilities of 98 and 3 percent, respectively. A comparative cost analysis assessed the financial viability of substituting UAVs for manned platforms. The analysis found the unit and per-flight hour cost, for all UAV platforms except those that fulfill the ECM role, to be less than the cost for manned counterparts. However, the use of the ECM UAV eliminates the potential for a flight crewmember casualty.

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Chadwick J. Boyd, Roderick E. Harris, Christopher L. Kleparek, and Joshua W. Taylor

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

A/A	air-to-air
BREM	Battle Readiness Engagement Management
CONOPS	concept of operations
DoDAF	Department of Defense Architecture Framework
DOE	design of experiments
ECM	electronic countermeasures
M&S	modeling and simulation
NPS	Naval Postgraduate School
OTH	over-the-horizon
OTH-T	over-the-horizon targeting
OTH-S	over-the-horizon strike
OV	operational view
RCS	radar cross-section
SSM	swarm strike model
SSS	swarm strike simulation
SV	system view
UAV	unmanned aerial vehicle
VB	Visual Basic

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EXECUTIVE SUMMARY

Naval Air Warfare Center, Weapons Division, China Lake, is developing an automated decision aid for over-the-horizon targeting (OTH-T) and strikes (OTH-S), called the Battle Readiness Engagement Management (BREM) system. The BREM system, which is currently in the research and development phase, is envisioned as a decision aid to military decision makers by evaluating different OTH courses of action based on game theory and artificial intelligence. The BREM project has developed a prototype OTH targeting and strike game for evaluating a wide range of challenges, actions, and outcomes based on complex "real world" conflicts.

The BREM game's initial scope includes air-launched OTH smart weapons and similar adversarial threats. The primary area of interest of this project is to expand the BREM scope to include the utilization of unmanned aerial vehicles (UAVs). The unmanned platform has the potential to redefine the battlespace by augmenting many existing capabilities, such as carrying offensive missile payloads and electronic warfare pods, as well as providing OTH sensor surveillance and defensive capabilities. Operating multiple UAVs in a swarm allows for a mix of UAVs with specialized payloads, to further shape the battlespace.

Research began with developing a concept of operations (CONOPS). The CONOPS consists of the baselined interactions, strategies, and configurations for how a system of UAV systems can provide capabilities for OTH missions. With the incorporation BREM, the goal is to achieve the highest chance of mission success while using the fewest amount of resources. To do so, inputs such as the operation scenario, available resources, and threat data feed into a decision matrix. At this point, the decision matrix serves as the brains of the system, autonomously generating an optimized plan of attack. This plan will consist of the number of UAVs required for the mission, which type will be most effective, loadout configurations for each unit, and the strategy for executing the mission.

Establishing this functionality served as a launching point for architectural analysis. The DOD Architecture Framework (DoDAF) 2.02 was utilized as a guideline for capturing

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the overall architecture. The UGN team was able to capture and illustrate many factors of the OTH mission: physical assets, the interaction of external systems, the flow of functionality, internal systems, internal communications, and functional allocation. The in-depth knowledge acquired from these DoDAF models fueled the development of modeling and simulation parameters.

The goal of the modeling and simulation effort was to quantify the effectiveness of various factors of an OTH strike mission. Modeling focused on two critical probabilities: the probability of striking the OTH target and the probability of a swarm UAV being hit. Both are driven by factors such as UAV selection, UAV performance, and enemy proficiency. Simulation enabled the UGN team to reinforce the data collected with modeling. The same performance parameters were used, but simulation provided a better representation of a live combat scenario (i.e., not targeting downed targets). Through modeling and simulation, the strike UAV was found to be the critical UAV platform for the successful engagement of the OTH target. In addition, loss of the strike UAV had the most detrimental impact on the success probability of the OTH strike mission.

This UGN team is convinced the results of the modeling and simulation effort can aid in developing further analyses to unlock new capabilities to be implemented in the OTH mission. An Excel application and ExtendSim model will be the near-term deliverables provided to support BREM development. This data provides a sufficient baseline, but the UGN Team recommends the swarm size analysis be repeated using real-world probabilities for UAV effectiveness and reliability.

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I. INTRODUCTION

The over-the-horizon (OTH) mission is one of the most challenging engagements for modern weapons systems. The mission engagement is driven by the complexity of data transfer of target information due to the break in the line of sight from the horizon, as well as sensor error budgets from long mission execution times. The mission is further strained by the limits of weapons loadouts and adversarial counter-tactics. The complexities of the OTH mission area present a decision space that can benefit from automated decision aids to support human warfighting decision makers. Automated decision aids could support the selection of sensors for target data support and the selection of available weapons.

The Naval Air Warfare Center, Weapons Division, China Lake, is developing an automated decision aid for OTH missions, called the Battle Readiness Engagement Management (BREM) system (Nagy 2019). The BREM system, which is currently in the research and development phase, is envisioned as a decision aid to military decision makers by developing and evaluating different OTH courses of action. The BREM system incorporates game theory and machine learning to develop OTH courses of action and evaluate these options based on expected consequences and predicted adversarial responses (Johnson 2019). The BREM system will develop battle plans to determine when and how to use kinetic and non-kinetic weapons to support various OTH targeting and strike missions. The BREM program is using an incremental learning approach to ensure readiness in the successful execution and management of missions involving complex planning. This learning approach includes de-escalation tactics while also recommending the selection of available weapons, communications, and sensors that yield the highest likelihood of mission success. The BREM system is focused on leveraging the increased readiness provided by the system to reduce casualties and maximize results.

The BREM system's initial scope includes air-launched smart OTH weapons and similar adversarial threats. One area of interest is an expansion of the BREM system to include the contribution of unmanned aerial vehicles (UAVs) to the OTH mission. This capstone project studied the mission utility of adding UAVs to the OTH mission by modeling a variety of UAV capabilities in conjunction with the BREM system. The study

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looked at the use of different types of UAVs (missile payload, electronic countermeasure [ECM] pod, sensor, defensive, etc.) in different configurations and combinations (single UAVs to swarms of UAVs) using modeling and simulation to evaluate probabilities of mission success. The study supports the incorporation of UAVs as contributors to OTH mission operations into the BREM system decision space.

A recent NPS systems engineering student team developed an operational scenario and conceptual design architecture for the BREM system with a focus on weapons selection and determining salvo size and weapons trajectories (Fava et al. 2019). The student team compared the use of a future BREM system in an operational scenario to a purely human decision process. This showed how a BREM system may be incorporated into future OTH missions and how the automated decision-making capability could be leveraged across platforms to enable autonomous OTH multi-mission engagement.

This capstone project built upon the foundation laid by the previous NPS systems engineering student study (Fava et al. 2019) to model and analyze the contribution of UAVs to the OTH mission domain. The goal of this project is to provide an understanding of the operational utility of adding UAV capabilities to OTH missions. In addition, this capstone project aims to support the implementation of the UAV OTH decision space within the BREM gaming system. The capstone project team has conducted a systems engineering modeling and simulation analysis to capture the functions, architecture, data flow, event sequences, and concepts of operation used in various combinations and configurations of UAVs to assess the factors involved in improving OTH missions.

A. PROBLEM STATEMENT

The OTH mission presents a complex and stressing military decision domain for tactical decision makers. The complexity of this mission arises from incomplete and often inaccurate knowledge of the battlespace; the speed, kinematics, autonomy and destructive capabilities of modern strike weapons; unknown aspects of the adversary; unpredictable consequences of tactical decisions; adversarial means of obfuscation, countermeasures, and counterstrikes; and the general complexities of the operational environment including the beyond-line-of-sight distances. The complexities of the OTH mission area present a

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decision space that can benefit from automated decision aids to support human warfighting decision makers. The Navy is developing the BREM system as an automated OTH decision aid; however, BREM is not complete and currently lacks the consideration of naval UAV assets as contributors to the OTH mission space. This capstone study addresses this need by analyzing the potential contributions of UAVs to the OTH mission and supporting the implementation of adding this knowledge to the BREM decision aid system.

B. CAPSTONE PROJECT OBJECTIVES

The primary objective of this capstone project was to study the mission utility of adding UAVs to the OTH mission by modeling a variety of UAV capabilities in conjunction with the BREM game system. The study looked at the use of different types of UAVs (such as those with payload, ECM, sensor, and air-to-air defensive capabilities) in various configurations and combinations (single UAVs to swarms of UAVs) using modeling and simulation to evaluate probabilities of mission success. An additional objective of the study was to support the incorporation of UAVs into the BREM mission planning game system.

C. SCOPE, ASSUMPTIONS, AND CONSTRAINTS

The focus of this project was the application of a systems engineering analysis process to study the potential contribution of UAV capabilities for the OTH mission. Therefore, the scope of the project included:

- naval UAV assets
- OTH targeting and strike missions
- BREM as a decision aid under development
- modeling and simulation methods of performance assessments

The assumptions and constraints for this project were generated based upon the need for defining some of the mission parameter unknowns. These assumptions were used

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to reduce the complexity and bound mission parameters for the probabilistic analysis of systems performance. The assumptions are as follows:

- The OTH mission is not dependent on a single surface ship type for the OTH swarm mission execution
- OTH targets have a maximum return fire capability of four rounds.
- The performance of the return fire threats will be susceptible to electronic countermeasures ECM.
- The target tracking of the return fire threats is radar-based.
- The minimum UAV selection for the swarm engagement includes at least one strike UAV.

D. METHODOLOGY

The team developed a tailored system engineering analysis approach, as shown in Figure 1. As with a traditional "Vee" systems engineering process, definition and decomposition occurred as the project traversed down the left side, and testing and integration occurred as the project continued up the right side. This approach began with concept development, which included the development of a concept of operation (CONOPS). The CONOPS was then used to transition into the architectural analysis and the development of functional and architectural models based on the Department of Defense Architecture Framework (DoDAF). After completing the functional/architectural analysis, these models were used to create parameters for a mission execution simulation. After simulation development, the team evaluated the model evaluation and studied the analysis results.

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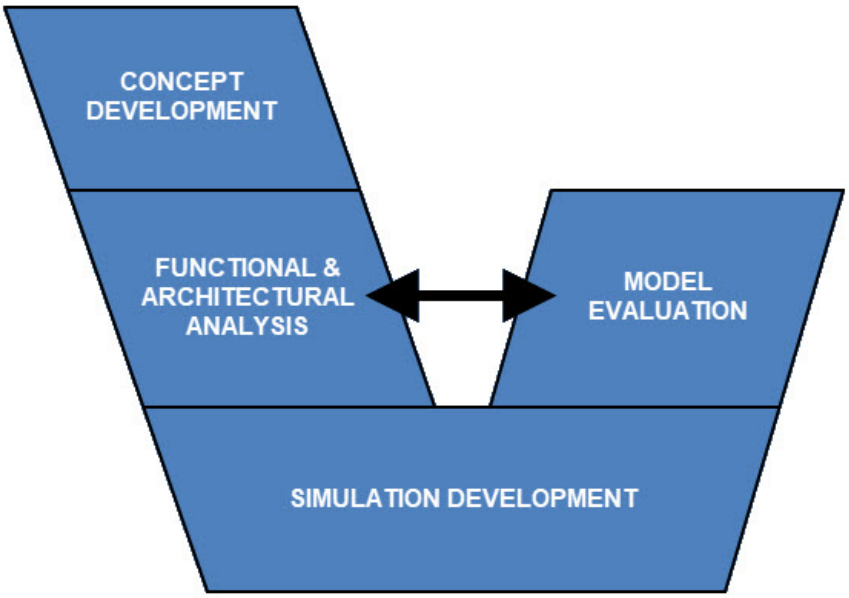


Figure 1. Modified Systems "V"

E. TEAM ORGANIZATION

Each team member had an identified set of roles and responsibilities that enabled the successful completion of the project. The fulfilled responsibilities are identified as follows:

Team Lead—Rod Harris

- Responsibilities: setup meeting agendas, kept meetings on track, kept workload distributed, kept team members accountable for attendance and deliverables

Lead Editor—Joshua Taylor

- Responsibilities: reviewed and submitted all deliverables, supported tracking, review, and accountability of deliverables

Systems Development Lead—Chris Kleparek

- Responsibilities: Ensured the systems engineering processes were being utilized, posted meeting minutes and actions to the Sakai team resource site, tracked-and-closed actions

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Modeling and Simulation Lead—Chadwick Boyd

- Responsibilities: strategically organized architecture, modeling, and simulation solutions to ensure project objectives were achieved

Specialists, Analysts—All

- Responsibilities: remained accountable and diligent for completing tasking

F. CAPSTONE REPORT ORGANIZATION

The purpose of this report is to capture the analysis and results of the project execution. The report follows the systems engineering approach previously described. Chapter II presents the team's OTH UAV concept of operations (CONOPS). Chapter III contains the team's architectural analysis that describes the OTH UAV system of systems and functional architecture. Chapter IV describes the team's modeling and simulation analysis and performance analysis results. Chapter V reflects on the report's findings, identifies contributions, highlights potential benefits, and outlines future work to be undertaken by successive efforts.

Reflecting on Chapter I, the problem and scope of the project was defined and the underlying assumptions and constraints were identified to aid the reader in realizing the goal for this project. In addition, the team organization, project methodology, and report organization were introduced to provide the reader with a better understanding of the team element undertaking this project. Moving into Chapter II, the CONOPS, types of UAVs, operational scenarios, and battle strategies will be discussed to provide the foundation for the modeling and simulation effort.

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II. CONCEPT OF OPERATIONS FOR UNMANNED AERIAL VEHICLES TO SUPPORT OVER-THE-HORIZON MISSIONS

The team developed a concept of operations (CONOPS) as a basis for developing a model and simulation (M&S) of UAV operations to support the OTH mission. The CONOPS details the operation of UAV systems of systems (SoS) in conjunction with the BREM decision aid system during an over-the-horizon targeting (OTH-T) and strike (OTH-S) mission. The CONOPS consists of the baselined interactions, strategies, and configurations for how a UAV SoS can provide capabilities for OTH missions. Establishing a CONOPS serves as a launching point for more in-depth content of the project: it provides the information necessary to develop architectural DoDAF models (Chapter III) and serves as the basis for parameter selection and M&S development (Chapter IV and V).

A. CONCEPT OF OPERATIONS DESCRIPTION

This CONOPS provides details of how UAVs could operate in conjunction with BREM decision aid system to improve OTH missions. Figure 2 illustrates this operational concept. Adding blue force UAVs as a SoS to the OTH mission can improve situational awareness, threat targeting, communication, countermeasures, and both defensive and offensive OTH actions. The role of the BREM system, as a decision aid, is to determine how a UAV SoS can best support the gathering of threat data and battle strategies (such as formations, loadout selection, resource management) to improve OTH missions. This CONOPS focuses on the successful utilization of blue force assets to neutralize a present threat, whether engaged in an offensive or defensive combat scenario.

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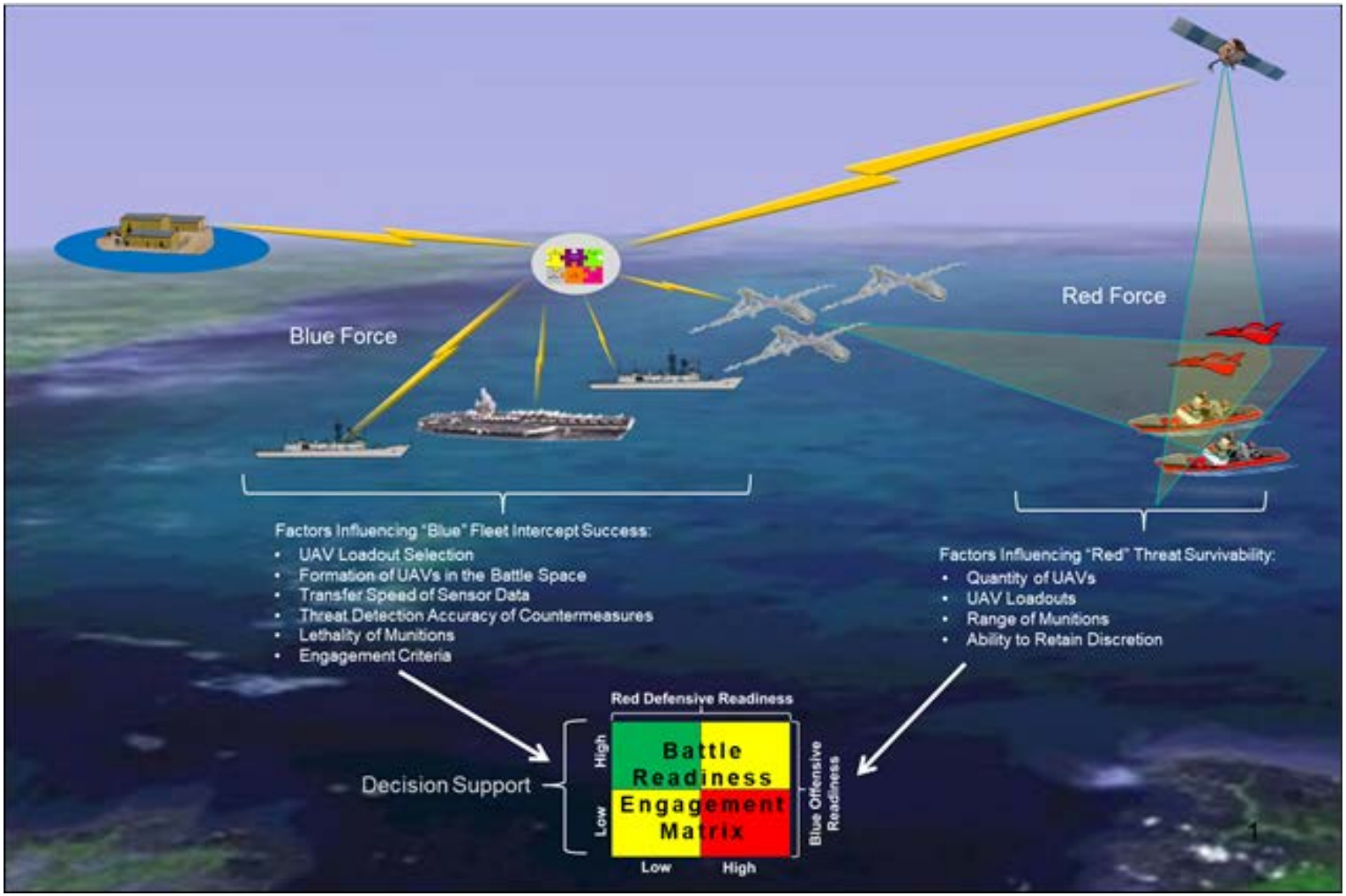


Figure 2. OV-1: Operational Concept for BREM and UAV SoS for OTH Missions

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The CONOPS details the structure of the UAV system of systems (SoS) and its relationship to the BREM system. The CONOPS is based on information that is leveraged from Department of Defense weapon system experience and research detailing stochastic game theory, battle simulations, capabilities-based planning, and systems development. The CONOPS considers current capabilities for UAVs, radar, communications, and weapon systems.

As illustrated in Figure 2, the OTH mission domain includes blue force assets such as a naval strike group that can perform strike missions against a red force. The red force may defend itself with countermeasures and warfare strikes such as missile launches from ships and aircraft. The BREM system is shown in the figure as a colored cube representing this decision aid system that develops OTH courses of action (COA) and also evaluates the risk level of each COA—as green, yellow, or red. This CONOPS describes the use of the BREM system to determine how a UAV SoS could best support the blue force's OTH mission. The BREM tool would be used to deliver an estimation of the probability of success of COAs involving the engagement conditions of a given scenario. The engagement conditions include the following: types and quantity of blue force UAVs present, types and quantity of red force UAVs present, radar detection rates, ECM success rates, missile neutralization rates, and missile intercept rates.

The BREM is a tool used to illustrate this desired readiness condition. Mission success, represented as a green condition, is achievable through the informed use of available resources. Suggestions regarding resource allocation will aid decision makers in determining the actions required to maximize the probability of mission success while minimizing friendly casualties. Figure 3 depicts a high-level flow chart of BREM functionality. The system will take the mission scenario, analyze current resources and threat data (such as quantity, weaponry, vulnerabilities), and generate an optimal plan of attack. This plan will consist of the number of UAVs required for the mission, which type will be most effective, loadout configurations for each unit, and the strategy for executing the mission. This strategy will consist of communication, UAV coordination, reporting of sensor data, firing of weaponry, deployment of countermeasures, and all other functions required for mission success.

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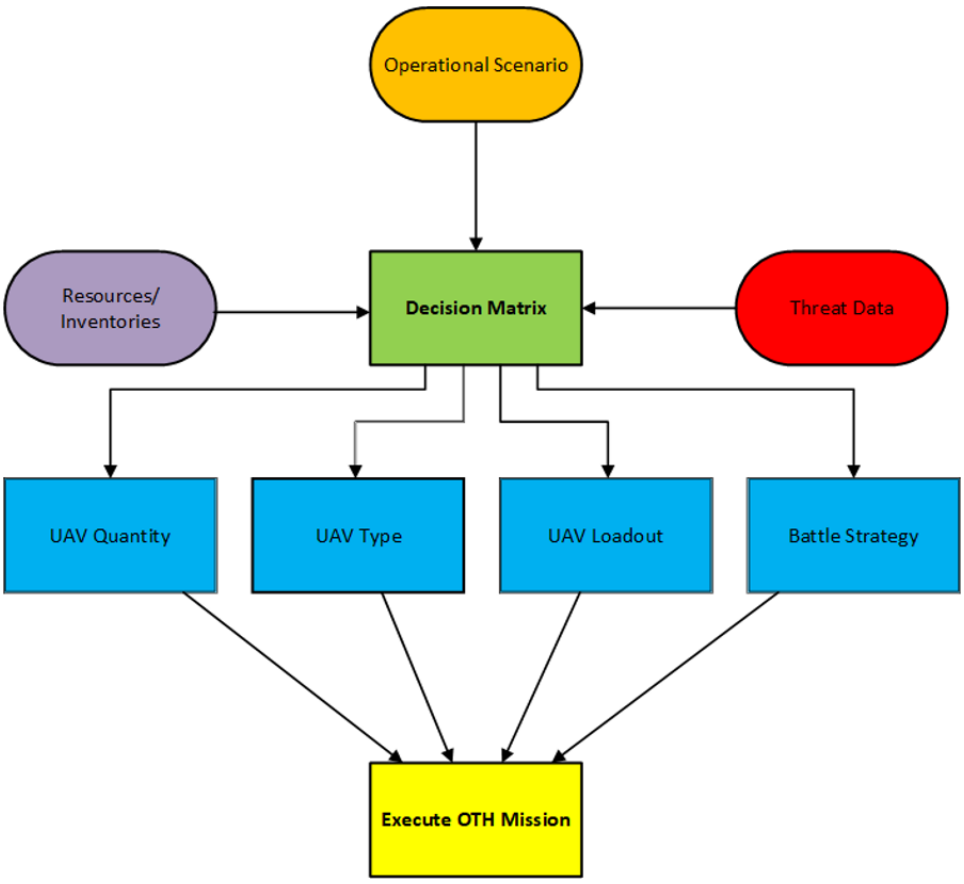


Figure 3. Operational Flow Chart

B. TYPES OF UNMANNED AERIAL VEHICLES

1. Sensor-Enabled Unmanned Aerial Vehicles

Sensor-enabled UAVs support the target and threat detection and tracking data needs for the blue force. This type of UAV supports the OTH-T mission. This information may then be used to support UAVs capable of electronic countermeasures (ECM), air-to-air (A/A) strikes, or air to ground target strikes. The sensor-enabled UAVs improve target and threat data fidelity and provide data used for battle state assessments.

2. Air-to-Air Defense Unmanned Aerial Vehicles

Equipped with antiballistic missiles, A/A defense UAVs are capable of countering incoming missiles. These UAVs are responsible for the completion of the inbound missile

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target OTH-S missions. The capability to combat incoming threats reduces the probability of damage to a UAV in the swarm and increases the likelihood of mission success.

3. Strike Unmanned Aerial Vehicles

Strike enabled UAVs are capable of engaging and neutralizing enemy targets. These UAVs support the offensive attack portion of the OTH mission. This type of UAV's probability of kill success contributes directly to the overall OTH mission success.

4. Electronic Countermeasures Unmanned Aerial Vehicles

UAVs equipped with ECM are capable of jamming the electronics of enemy threats, thereby reducing the red force's probability of successful attacks against the blue force. ECM UAVs target the red force's radar homing systems. Effective use of ECM UAVs will reduce the likelihood of damage to the blue forces and will increase the blue force's probability of OTH mission success.

C. OPERATIONAL SCENARIOS

1. Unmanned Aerial Vehicle Strike Mission

The OTH strike mission occurs when an OTH target is identified. During this event, the user-supplied target location and identification will be used by the BREM decision aid system to assess the number of assets to deploy to meet and predicted probability of success. In the event that a strike UAV is selected to support this mission, the strike UAV must acquire, track and engage the target. The engagement will be consummated with a missile deployment. Mission success will depend on the strike UAV probability of survival as well as the probability of a successful missile intercept by the red force.

2. Unmanned Aerial Vehicle Sensor Mission

The surveillance mission requires a percentage of radar coverage for a specified area based upon the user inputs. User-supplied radar capabilities are used by the BREM decision support system to generate the number of sensor-enabled UAVs required to maintain the desired domain coverage. The sensor-enabled UAV mission success will be dependent on the radar quality of sensor-enabled UAVs in support of the OTH target

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acquisition and track. The OTH target track data is sent to the OTH strike UAV to improve its probability of missile intercept success.

3. Unmanned Aerial Vehicle Missile Intercept Mission

The OTH missile intercept mission requires allocation of an intercept missile loadout based on the user assessment of the OTH target's return fire salvo size. This mission occurs during an inbound missile threat. During this event, the A/A UAVs must launch missiles to intercept the enemy missile. Significant factors influencing the success of this type of mission is the number of inbound missiles, the number of A/A UAVs, the velocity of an inbound missile, distance from an inbound missile, detection distance, target acquisition time, missile inventory, and missile intercept rate. The mission success will be assessed as a probability of intercepting inbound missiles.

4. Unmanned Aerial Vehicle Electronic Countermeasure Mission

The ECM mission requires a specific jamming energy output based on user input regarding the OTH target's return fire capability. The jamming performance factors include distance and angle to incoming threats, as well as, the ECM UAV position in relation to the target of the inbound threat. The ECM UAV mission success improves the UAV survivability by decrementing the intercept performance of inbound threat missiles.

5. Over-the-Horizon Unmanned Aerial Vehicle Target Mission

The OTH UAV target mission occurs when there is in inbound non-weaponized UAV threat. An example of this type of mission would be an enemy UAV equipped with cameras dedicated to retrieving intelligence. During this type of mission, strike UAVs must be employed to neutralize the enemy threat. Major factors influencing the success of this type of mission are the number of strike UAVs, enemy UAV velocity, missile kill-rate, missile inventory, missile velocity, and distance from an inbound missile.

6. Over-the-Horizon Unmanned Aerial Vehicle Swarm Mission

The UAV swarm mission relies on the efforts of each type of UAV in the SoS: sensor-enabled, air-to-air, strike, and ECM. The swarm mission simulates two opposing

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swarms of UAVs, and mission success is defined by the complete neutralization of the enemy UAVs. During this mission, blue force UAVs must defend their team from inbound missiles and attack the opposing force. This mission is composed of independent OTH Missile Intercept Missions and OTH UAV Target Missions. In addition, ECM UAVs are employed to help defend the blue force by reducing the blue force casualty rate during the engagement with the red force.

7. Communications

a. Ship-to-Ship Communications

The firing ship can receive data from support ships that include incoming threat data. The threat data covers the target states, such as position (altitude and range), velocity, and target type (such as maneuvering or sea skimming). The firing ship can also send and receive data about BREM states. The BREM data will be used to support weapons selection decisions.

b. Sensor-Enabled Unmanned Aerial Vehicle-to-Ship Communications

The firing ship can receive data from support sensors that include incoming threat data. The threat data covers the target states, such as position (altitude and range), velocity, and target type (such as maneuvering or sea skimming). Sensors will also communicate environmental data for mission support.

c. Ship-to-Unmanned Aerial Vehicle Communications

The firing ship can send data to the UAVs that include incoming threat data. The threat data covers the target states such as position (altitude and range), velocity, and target type (such as maneuvering or sea-skimming) as well as environmental data such as the presence of radar jamming.

d. Unmanned Aerial Vehicle-to-Ship Communications

The UAV released for intercept engagement will communicate the status of target acquisition, target tracking, and target kill to the firing ship.

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e. UAV-to-UAV Communications

In a swarm UAV engagement, the UAVs will communicate the status of target acquisition and target track to the other UAVs. The UAVs may also transmit threat data required for target tracking.

D. MISSION BREAKDOWN

The BREM OTH scenario is a battle group mission. It includes the identification and tracking of an incoming threat or OTH target as well as the identification of the likely target. The nominal scenario starts with sensor support systems, shipboard or external, picking up a likely threat or OTH target. The threat/target information is delivered to the battle group, where the threat/target is identified as the OTH target. At this point, a target track is established using the available sensor. The sensors may be down-selected based on expected intercept complexity. The down select option allows the sensor resource to be reallocated to other tasks or shut down to prevent overuse. Once the track/position is established, target data is sent to the battle group. Based on the target data, the firing ship is selected from within the battle group. The firing ship then determines which UAV or UAV group to use for the intercept engagement. After UAVs are released, the continuation of UAV support with target state data is determined and supported if needed. The sensor systems continue to track the engagement. If the intercept/OTH mission fails, the scenario iterates until the threat is neutralized.

E. BATTLE STRATEGIES

Once the threat has been identified using a ship's radar sensing system, the BREM program selects the optimal ship to launch the unique UAV or UAV swarm with the highest probability of destroying the target. Unique UAVs are on board each vessel with different weapon selections, flight characteristics, and missile inventory. It is up to the BREM program to leverage the ship's position with the UAV information to defend against or attack the enemy. This program must also consider swarm engagement approaches and future engagements in the battle theater space. Table 1 lists types of BREM input and output, and scenario manager functions.

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Table 1. BREM Input, Output, and Scenario Manager Functions

Input	Ship positioning (coordinates in the battle theater)
	UAV loadout (quantity for each variety on each ship, UAV weapon inventory)
	Remaining missions (number of probable future engagements
	Ship sensor data (number of threats, threat positions)
	UAV sensor data (number of threats, threat positions)
	Target (threat ID, trajectory, speed)
Output	UAV selection (ship selection, UAV team selection, weapon usages, lethality determination)
	Engagement decision (single UAV vs multiple, engagement success rate)
Scenario Manager Functions	User may select alternative UAVs to engage or create a new class of UAV
	Evaluate new engagement success rate under new theater space criteria

The engagement decision system utilizes three sets of decision factors (surface ship and UAV selection factors, event decision factors, and target decision factors) to develop the optimal battle strategy output.

Surface Ship and Unmanned Aerial Vehicle Selection Decision Factors

The position represents the coordinates of the ship in the battle theater. Each ship in the battle theater can launch its own set of UAVs teams at approaching threats and targets. The UAV loadout to be launched depends on the UAVs remaining on each ship. The multiple loadout values represent the remaining UAVs (of varying capabilities) available to execute battle tasks such as payload delivery, missile attacks, EW, and surveillance. The ship's UAV reserves are critical to ship and UAV selection. The remaining missions is another variable that is unique to each vessel.

The remaining missions are the expected number of future mission engagements based on the total number of missions allocated minus the number of missions executed. If

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a ship is likely to engage at least three more times in the theater space, there must be the appropriate resource allocation for each engagement. The resource allocation must account for missiles, UAVs, and UAV capabilities. The BREM program may require events such as payload drop-offs and ship-to-ship UAV transfers to maintain the optimal readiness condition. The fourth and final variable that is unique to each ship is the available sensor data. This sensor data is used to detect incoming threats and enemy UAVs. Due to each ship's unique positioning, each will encounter differing battle events.

1. Event Decision Factors

The target threat level represents the likelihood (*p)* of the threat to cause damage. This factor will be used in the UAV selection decision, and more specifically, the UAV quantity decision. Although the user of the BREM program may manipulate the target threat level, the default value will be set at 0.5. By increasing the threat level, the optimal position in the BREM will require a more significant swarm or attack force to neutralize the target. By decreasing the value below 0.5, non-violent approaches are preferred to reduce the likelihood of future casualties.

2. Target Decision Factors

Before selecting the appropriate means of engagement, the target attributes need to be identified and processed. Factors such as the position, trajectory, speed, and maneuverability of the target will be used to determine the optimal means of neutralization, counterattack, or surveillance approach. The ship and UAV selection are heavily dependent upon these factors. If an inbound threat is approaching a ship containing a UAV team or a non-weaponized UAV, the ship selection becomes critical to incepting the inbound threat. In this type of scenario, if a nearby UAV is in flight, it will be considered to intercept new threats.

Reflecting on Chapter II, the CONOPS, types of UAVS, operational scenarios, and battle strategies were discussed to provide the foundation for the modeling and simulation effort. Moving into Chapter III, the operational and system architecture will be defined to illustrate the relationships required between the swarm assets for mission execution.

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III. ARCHITECTURAL ANALYSIS OF A SYSTEM OF UNMANNED AERIAL VEHICLE SYSTEMS IN SUPPORT OF THE OVER-THE-HORIZON MISSION

The capstone team performed an architectural analysis of the UAV SoS for the OTH mission. The team developed architectural views based on the Department of Defense Architectural Framework (DoDAF) to capture both operational and system views of the UAV SoS. This analysis was performed to aid in the refinement and maturation of the CONOPS, to inform the UAV SoS swarm size performance analysis, and support the UAV modeling and simulation.

A. DEVELOPMENT OF BREM SYSTEM ARCHITECTURE

The architectural analysis for the OTH mission focused on describing the UAV SoS functions and architecture. The analysis generated a system architecture for the proposed OTH mission using model-based system engineering (MBSE) tools. The identification of internal and external system interactions resulting from the architectural analysis supports the future BREM system as well as the team's M&S analysis.

With the understanding of how the system is expected to operate, who is involved, and what are the assumptions and parameters of the system as developed in the CONOPS, the architecture analysis took a top-MBSE approach. This approach utilized the DODAF 2.02 as a guideline for capturing the overall architecture. The team selected Innoslate's model-based systems engineering software Innoslate to develop the DoDAF viewpoints. Knowledge of the system and parameters generated were input into Innoslate, which was then used to generate various views of the system to show operational and system-level interactions.

Utilization of the Innoslate tool offered various ways to depict the interaction of systems and subsystems, both internal and external, involved in the execution of the OTH mission. The DODAF was used to model the core functions of the BREM system as well as the various interactions between internal and external systems required for swarm operation. The overarching DODAF views focused on for this architecture of the system

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were the operational and systems viewpoints. We chose these viewpoints to illustrate the system-to-system operation as well as the execution and exchange of information between assets. When examining the views, we recommend approaching them from the perspective of an external, high-level user as many of the finer system-related details have yet to be considered.

The following are specific viewpoints developed and brief reasoning for selection:

- OV-1: High-Level Operational Concept Graphic—Offers the high-level graphical depiction of the system's operational concept
- OV-5a Physical Context Hierarchy—Captures the physical assets of the OTH mission
- External Systems Diagram (IDEF0)—Captures the functional decomposition of the mission environment and the interaction between external systems required for the execution of the BREM swarm mission.
- OV-5b: Operational Activity Model and sub-assembly decompositions—Defines the relationship between the external systems and the OTH mission as well as the internal relationships captured in the IDEF0 format
- OV-6c: Event Trace Description—Captures the sequence of events required for the OTH mission
- SV-1: Systems Interface Description—Identifies the internal systems associated with the OTH mission
- SV-2: Communications Network Diagram—Captures the intra-swarm communications required for the execution of the OTH mission
- SV-4a Functional Hierarchy—Captures the functional allocations for the OTH mission

The knowledge gained during the development of the diagrams that support the system architecture and design will aid the modeling and simulation development.

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B. OPERATIONAL ARCHITECTURE

The operational architecture view (OV) describes the operations of the system and the connections among the system and subsystems. The OV allows for evaluation of operational requirements, evaluation of interoperability issues, and system baseline. The decision was made to focus on the system analysis through the development of an OV-1, OV-5a Physical Context Diagram, OV-5b F1 External System Diagram and F2/F3 Sub-Functions decompositions, and the OV-6c Event Trace Diagram. These operational viewpoints are described in Table 2.

Table 2. DoDAF Operational Architecture for OTH Mission

DoDAF Operational Viewpoints Developed for the OTH UAV SoS	
OV-1: High-Level Operational Concept Graphic	Offers the high-level graphical depiction of the system's operational concept (Note—this is located in Chapter II of this report)
OV-5a Physical Context Hierarchy	Captures the physical assets of the OTH mission
External Systems Diagram (IDEF0)	Captures the functional decomposition of the mission environment and the interaction between external systems required for the execution of the BREM swarm mission
OV-5b: Operational Activity Model and sub-assembly decompositions	Defines the relationship between the external systems and the OTH mission as well as the internal relationships captured in the IDEF0 format
OV-6c: Event Trace Description	Captures the flow of the functions performed by each UAV during the mission execution

1. OV-5a: Hierarchy Diagram—Physical Context Diagram

The hierarchy diagram outlines the decomposition of the physical assets allocated to the BREM swarm mission execution. The physical hierarchy includes the system decompositions, as shown in Figure 4. The battle group contains the UAV swarm that will be responsible for mission execution. The UAV decompositions capture the asset's specific needs for each of the UAV configurations. The analysis used to develop this diagram reinforced that the system's assets are captured and allocated to operational activities, which are represented in the system's architecture views (SV).

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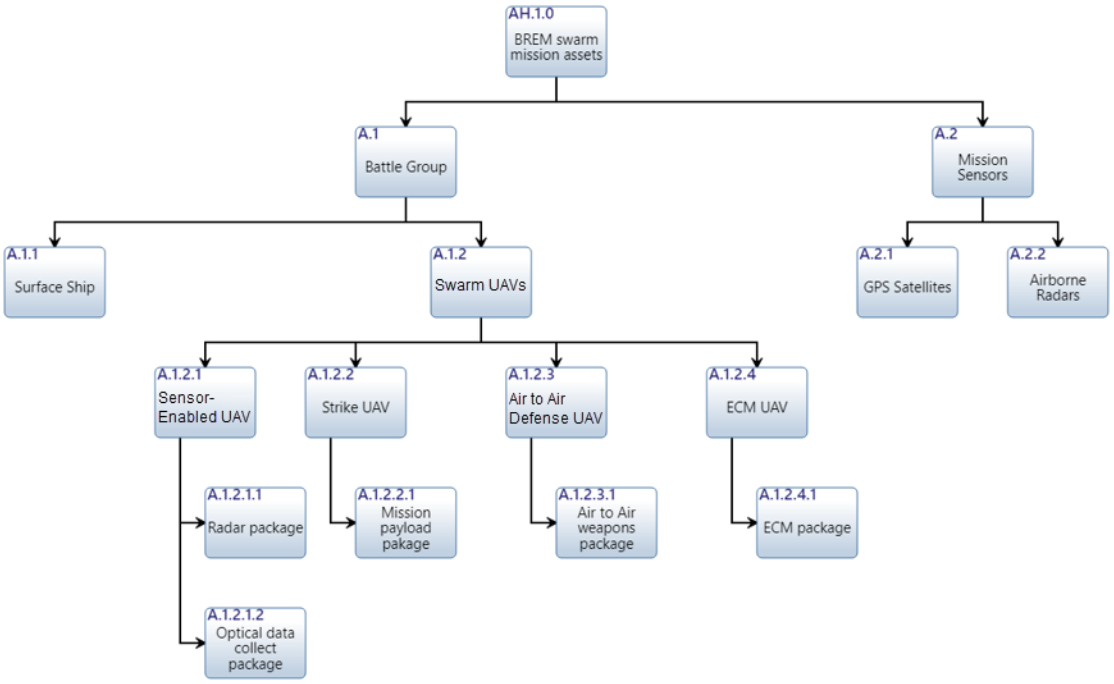


Figure 4. OV-5a: Physical Context Hierarchy

2. OV-5b: Operational Activity Diagrams

The operational activities models describe the interactions and relationships of the various system required to execute the OTH mission. These diagrams, shown in Figures 5 through 10, establish the functional architecture and identify the interactions between swarm assets and external conditions. As the team developed the architecture, each of the functional decomposition levels where labeled. The Level F-1 External System Diagram is the top of the systems architecture, the Level F-2 Execute Mission Diagram is a decomposition of the execute OTH mission function from the F-1 diagram, and Level F-3 Sub-Function decompositions of the OTH mission are captured in the remaining diagrams.

3. Level F-1 External System Diagram IDEF0

The External System Diagram (Level F-1) depicts the functions of the external systems as an SoS architecture. It also illustrates the data flow between each of the external systems. External systems include the OTH mission support systems that will not be decomposed as part of the swarm UAV architecture. The diagram aids in understanding

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the cooperative nature of the external systems and the architecture of the SoS utilized in the OTH mission execution.

The external systems captured in the external systems diagram include GPS satellites, airborne tracking radars, and surface ships. These systems provide functions such as; GPS target tracking, radar target tracking, mission parameters, and launching the swarm UAVs. These functions are required for the execution of the mission but cannot be accomplished by the swarm UAVs. In this architecture, the swarm UAVs are responsible for the execution of the OTH mission functions. These functions will be decomposed in the throughout architecture. The operational relationships for these systems are shown in Figure 5.

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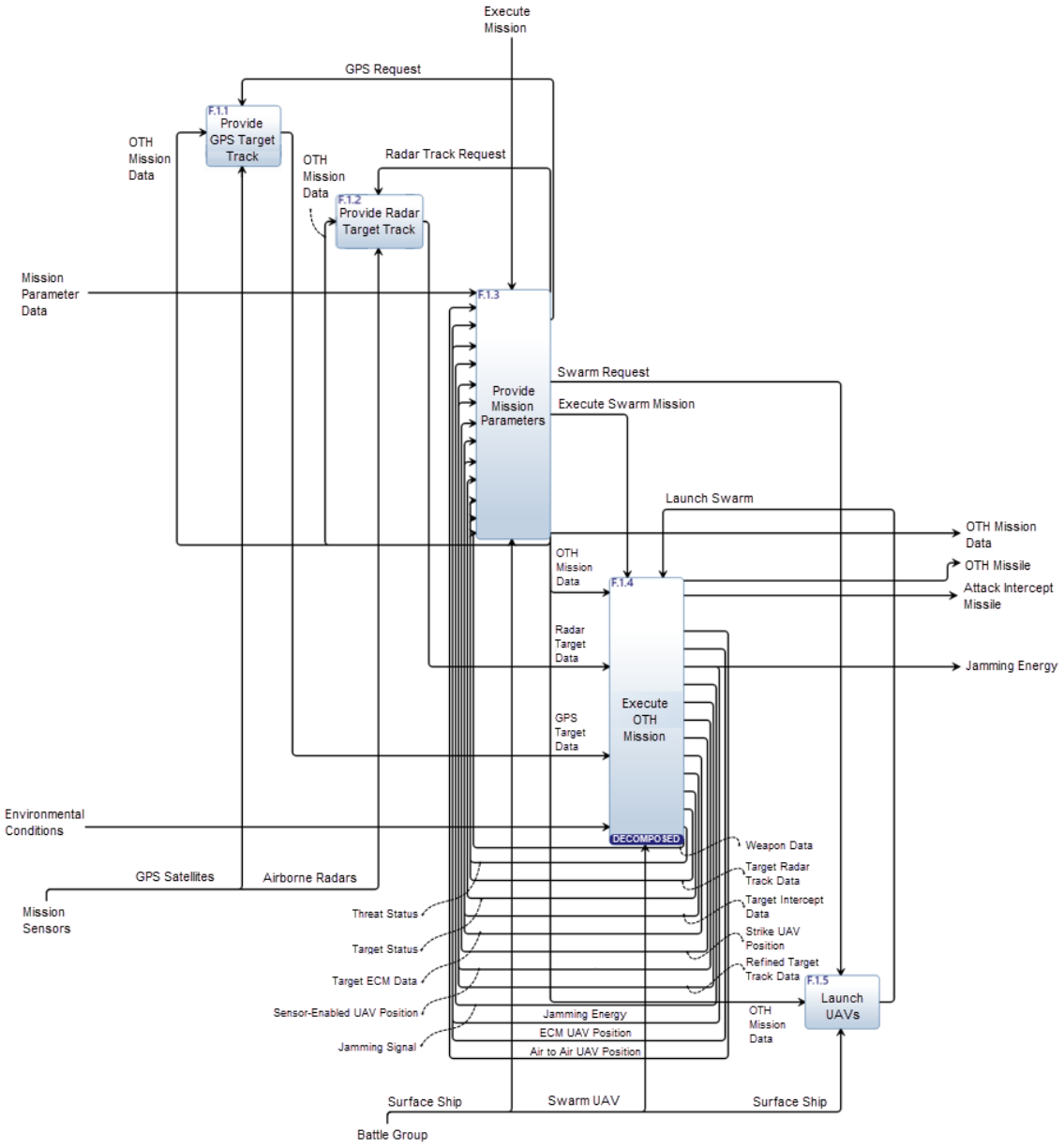


Figure 5. IDEF0: External System Diagram—External Mission Elements

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4. Level F-2 IDEF0 Sub-function Execute Mission Diagram

The interactions between the swarm assets required for mission execution are shown in Figure 6.

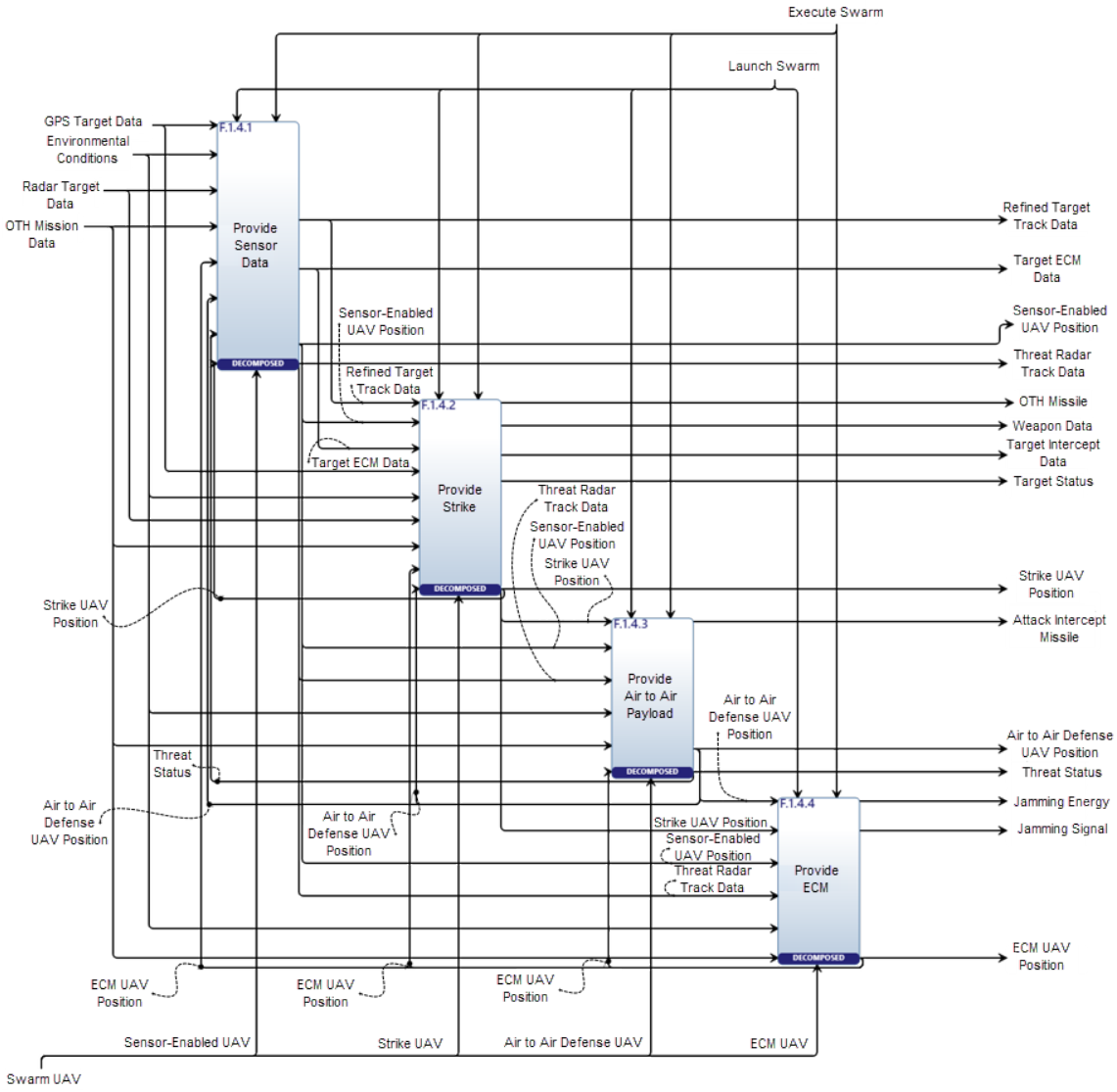


Figure 6. OV-5b: Execute Mission Context Diagram

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5. Level F-3 IDEF0 Sub-function Decompositions

The BREM Swarm Execute Mission diagram was decomposed to its sub-functions to provide a better understanding of the UAV sub-systems. All of the UAV decompositions have a fly UAV function by necessity and for completeness, but the UAV functional decomposition focused on the unique UAV configuration functions needed to support the mission execution. This approach dictates the specifics for the command and control of the UAV concerning flight operations as they were combined into the single function by design. Note each UAV possesses a communications function responsible for receiving and transmitting data to elements external to the UAV. The communications function was also bundled to capture the need for an encrypted data link.

6. Level F-3 IDEF0 Sub-function of Sensor-Enabled Unmanned Aerial Vehicle

The decomposition of the sensor-enabled UAV operation describes the interfaces and functions that enable the mission execution to have radar sensor capability. The sub-functions include producing radar energy, detecting radar energy, identifying incoming threats, and determining target location. These functions describe the sensor-enabled UAV capability to produce refined target measurements as well as threat data that will be used by other UAVs in the swarm. They also identify the radar signals needed to support the sensor-enabled UAV functions within the swarm. See Figure 7 for a depiction of the interactions between sensor-enabled UAV's sub-functions.

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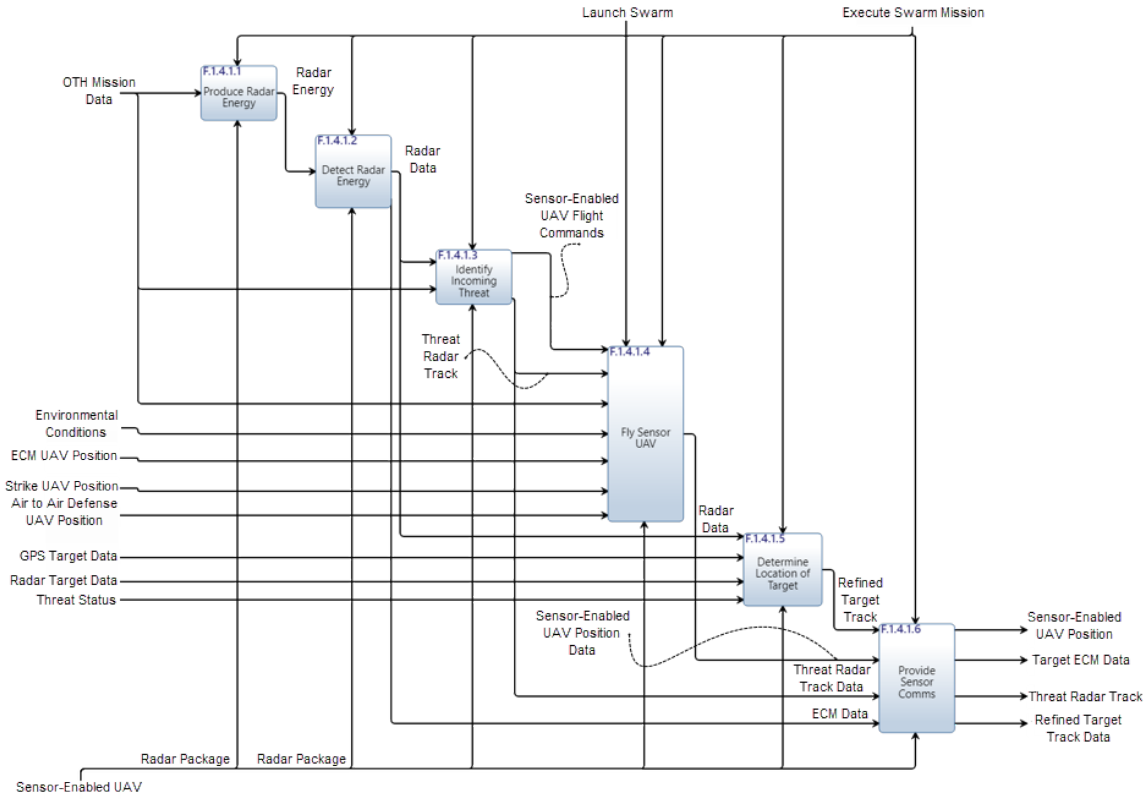


Figure 7. OV-5b for Sensor-Enabled UAV System Sub-functions IDEF0

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7. Level F-3 IDEF0 Sub-function of Strike UAV

The decomposition of the strike UAV operation describes the interfaces and functions that enable the mission execution to have strike capability. The sub-functions are track target, identify target intercept, launch ordinance, and provide kill assessment. These functions describe the strike UAV capability needed to complete the OTH strike part of the mission. While the swarm is designed to increase the overall mission success, the strike UAV is solely responsible for the delivery of ordinance to the mission target. See Figure 8 for a depiction of the interactions between the strike UAV's sub-functions.

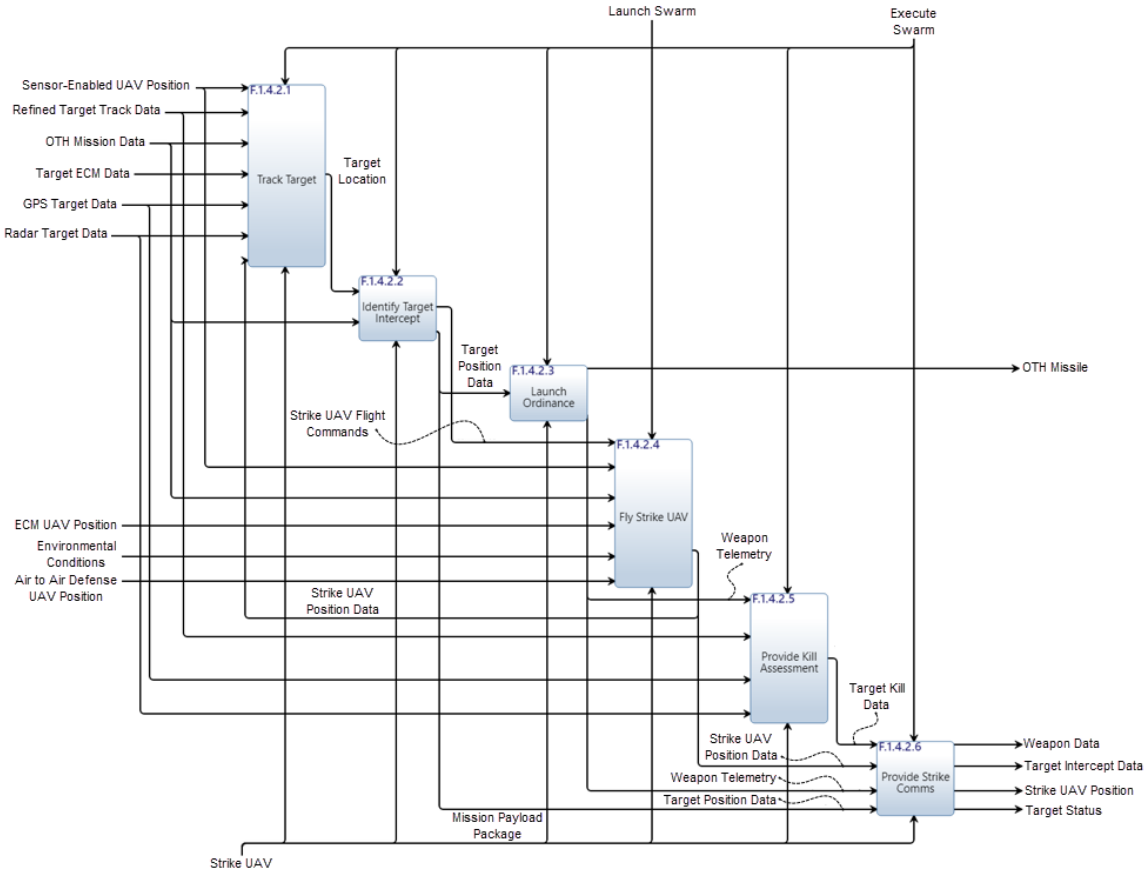


Figure 8. OV-5b for Strike UAV System Sub-functions IDEF0

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8. Level F-3 IDEF0 Sub-function of Air-to-Air Defense Unmanned Aerial Vehicle

The decomposition of the air-to-air defense UAV operation describes the interfaces and functions that enable the mission execution to have an air-to-air defensive capability. The sub-functions are track inbound threat, identify threat intercept point, launch a missile, and assess threat status. These functions describe the air-to-air defense UAV capability needed to provide the swarm with an air-to-air intercept operation. By eliminating possible threats to the swarm, the overall mission success is improved. See Figure 9 for a depiction of the interactions between the air-to-air defense UAV's sub-functions.

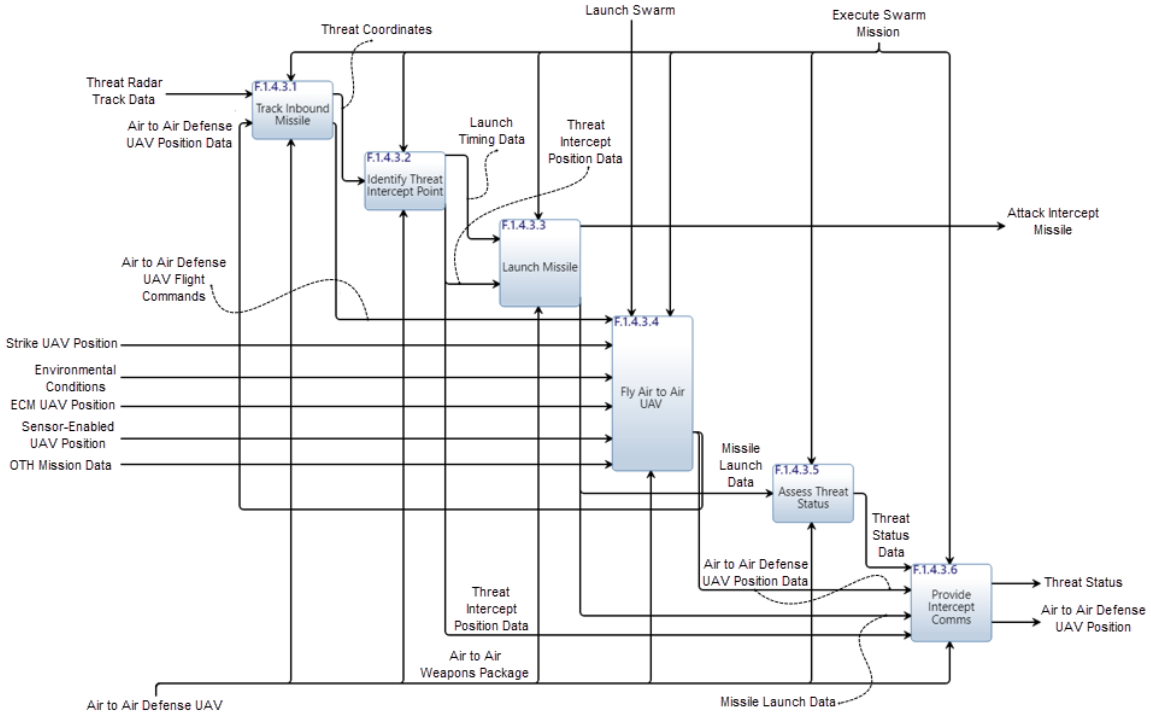


Figure 9. OV-5b for Air-to-Air Defense UAV System Sub-functions IDEF0

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9. Level F-3 IDEF0 Sub-function of ECM UAV

The decomposition of the electronic countermeasure (ECM) UAV operation describes the interfaces and functions that enable the mission execution to have an ECM defensive capability. The sub-functions include calculating the jamming position and providing the jamming signal. These functions describe the ECM UAV capability needed to provide the swarm with a radar jamming operation. A jamming capability within the swarm can reduce the probability of success for an incoming threat. Decreasing the likelihood of success that a UAV in the swarm is damaged will help improve the probability of success for the overall mission. See Figure 10 for a depiction of the interactions between the ECM UAV's sub-functions.

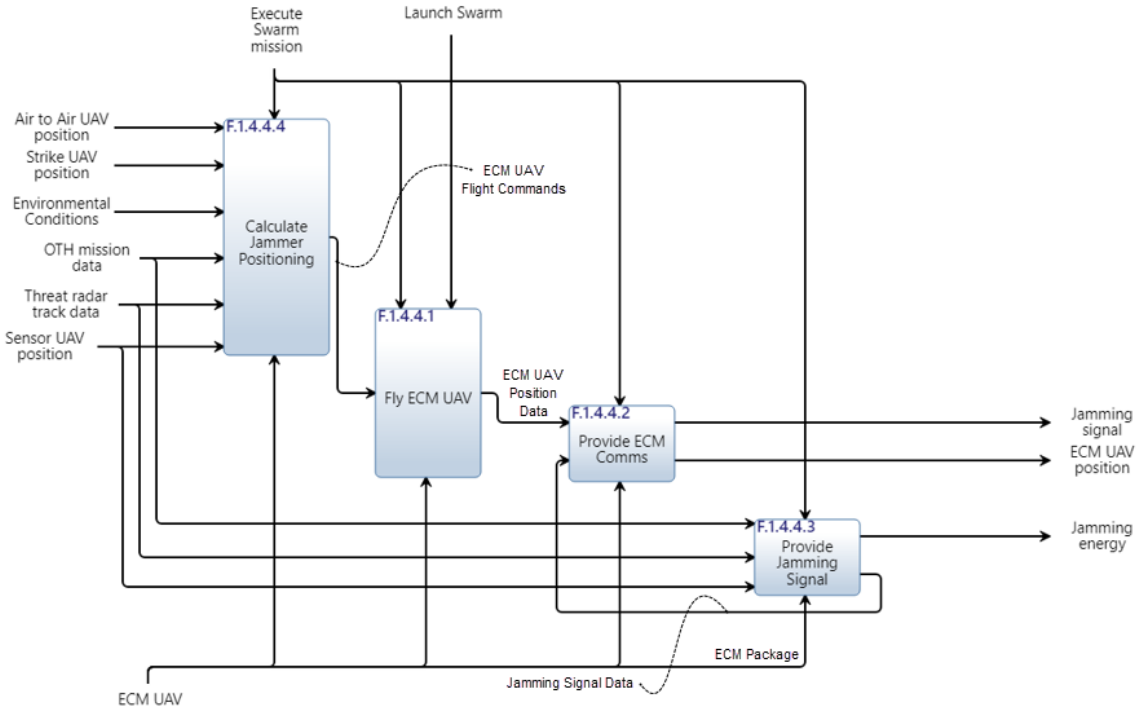


Figure 10. OV-5b for ECM UAV System Sub-functions IDEF0

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The F-3 level of decompositions provides an understanding of the individual UAV capabilities supported through the UAV functional decompositions. This breakdown aided in identifying the sensor, strike, air-to-air, and ECM functions needed to develop the swarm capability. After several iterations of the decomposition, the UAV sub-functions can provide further fidelity in the development of the system architecture. They help define the swarm capabilities as needed to support the mission execution from a unique UAV mission package.

10. OV-6c: Event Trace Description

The OV-6c diagram traces the actions that occur in a given scenario or sequence of events. It provides a time-ordered examination of the resource flow for the swarm scenario as well as the tracing of actions in a critical sequence of events. The mission execution capability is modeled by the set of activities and their attributes. The event trace description captured focuses on the sequence of events completed by the swarm during the execution of the OTH strike mission. It establishes the inter-swarm events by describing the UAV to UAV interactions needed for the execution of the OTH mission. This event trace will be leveraged for the development of the modeling and simulation part of the project. The event trace diagram is shown in Figure 11.

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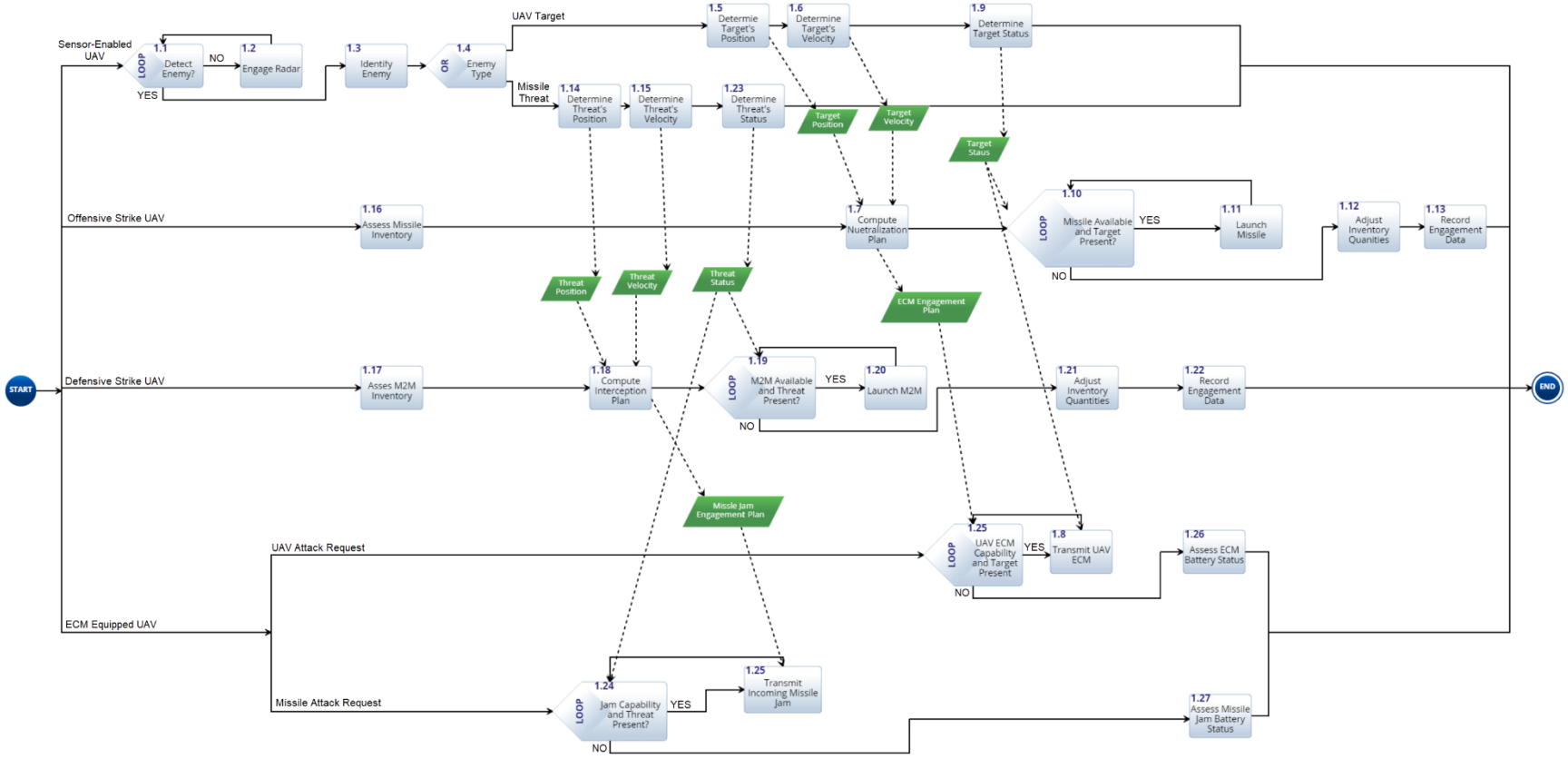


Figure 11. OV-6c Event Trace Description

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C. SYSTEM ARCHITECTURE

Systems architecture view (SV) describes the system of concern and the connections among the system and subsystems in context with the operational view. The SV allows for evaluation of system operational requirements, evaluation of interoperability issues, and system baselining. As a group, we decided to showcase our system through the use of an SV-1, SV-2, and SV-4 diagram.

1. SV-1: Systems Interface Description

The SV-1 in Figure 12 visualizes the interconnections between the system and its subsystems. The SV-1 depicts the sharing of information between the battlegroup assets. Note the surface ship is acting as a vital node in the relay of this information. The surface ship collects data from GPS satellites, airborne radars, and the UAV swarm. In return, the surface ship relays collected information to each asset as needed. Together, each asset, including the surface ship, is more aware of potential threats in the battlespace than any one asset would be otherwise.

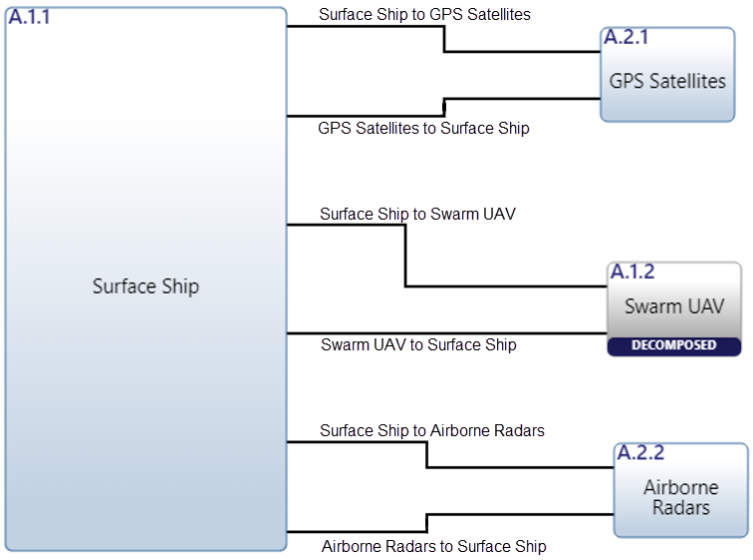


Figure 12. SV-1: Systems Interface Description

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2. SV-2: Communications Network Diagram

The SV-2 depicted in Figure 13 details the lines of communication between the swarm assets. Note each UAV is connected to the other three UAVs through a secure data link, which allows information sharing to prevent UAV isolation should any UAV be lost to an incoming threat. The network design also allows information to be relayed between UAVs to maintain situational awareness even when assets are spread across the battlespace.

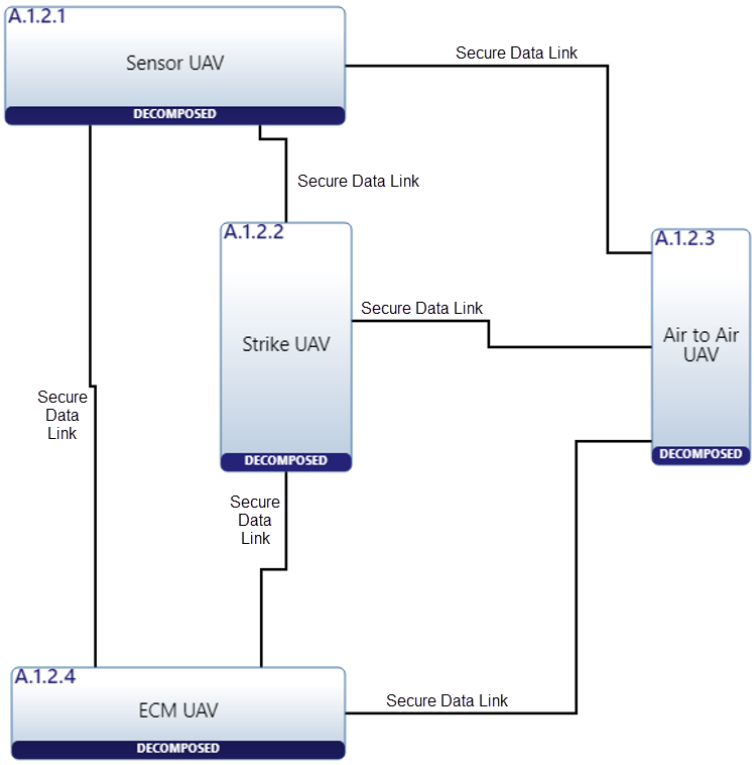


Figure 13. SV-2: Communications Network Diagram

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3. SV-4: Functional Hierarchy

The SV-4a depicted in Figure 14 details the functional relationships required to support the over-the-horizon mission. Execution of the over-the-horizon mission is supported by the principle functions of the UAVs, which include providing sensor data, strike capability, air-to-air payload, and electronic countermeasures. Each principle function is decomposed to identify the required subfunctions.

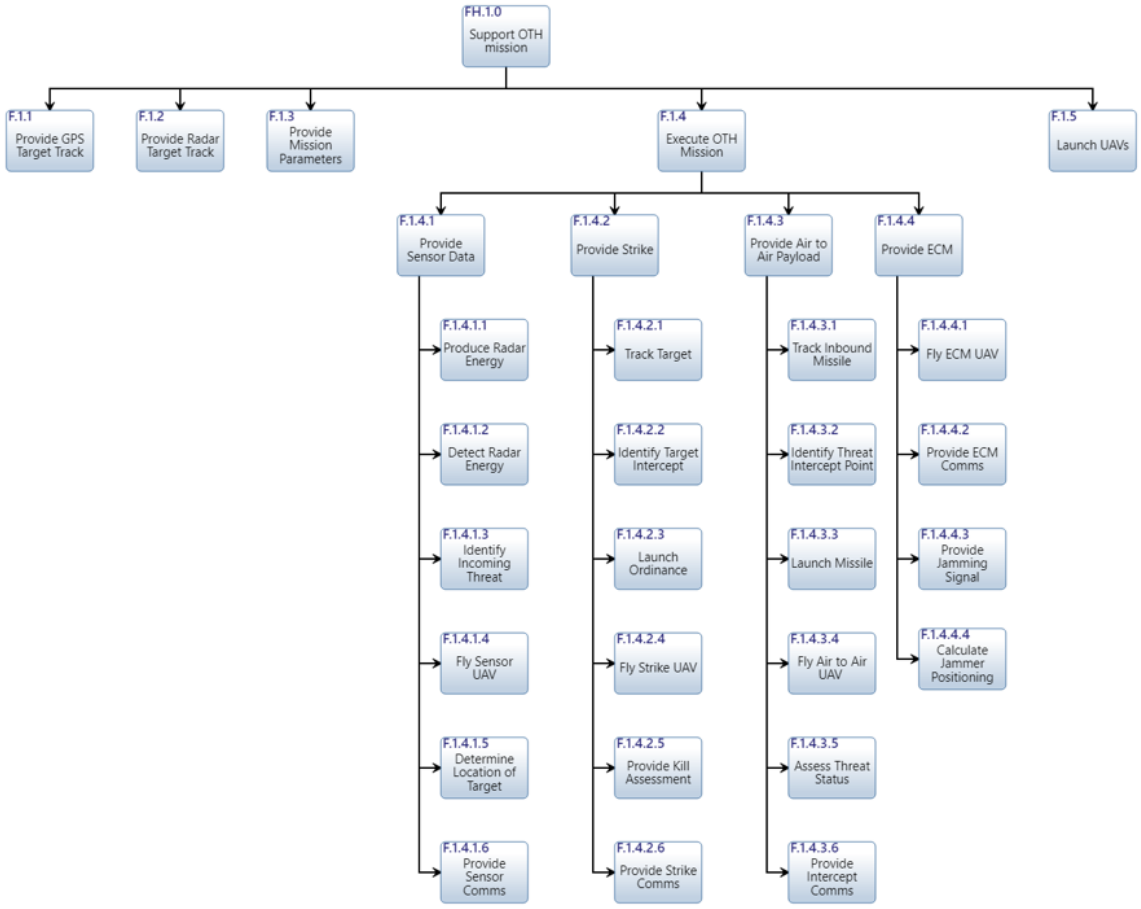


Figure 14. SV-4a: Functional Hierarchy

Reflecting on Chapter III, the operational and system architecture defined to illustrate the relationships required between the swarm assets for mission execution. Chapter IV will culminate the buildup of previous chapters with the modeling and simulation of the OTH mission execution by the UAV swarm.

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IV. MODELING, SIMULATION, AND, OTH MISSION ANALYSIS

This chapter describes the modeling and simulation (M&S) analysis of the system of UAV systems (referred to as the "swarm") for the OTH mission. It includes a look at cost factors for the utilization of UAVs in the execution of the OTH mission. The chapter contains an overview of the M&S effort and a description of the OTH mission analysis methods employed. The purpose of the model, as well as the model's limitations, will be discussed and followed by a review of the data derived from the model; a similar discourse will follow for simulation development. The execution of the OTH mission using UAVs will then be assessed from a cost-effectiveness standpoint with manned platforms.

A. PURPOSE OF THE MODELING, SIMULATION AND MISSION ANALYSIS

The goal of the M&S and mission analysis was to study the operational benefits of adding UAVs to the OTH mission. The M&S analysis assessed the individual UAV performance factors that are drivers for the OTH mission success. A blue force versus red force OTH mission scenario was modeled. The blue force was equipped with four different types of UAVs: sensor-enabled, air-to-air (A/A), electronic countermeasure (ECM), and strike. The red force consisted of a ship that could return fire with its own set of OTH weapons. The red force ship was the OTH target of the blue force. Mission success consisted of eliminating the red force ship. The performance values of the blue force's individual UAV types were varied, and different combinations and configurations of UAVs were modeled. The cost of the UAV mission implementation was assessed as well.

1. Modeling and Simulation Approach

The approach for the M&S effort is shown in Figure 15. A single scenario for the OTH target mission execution was captured. Then a probabilistic model called the swarm Strike Model (SSM) and the Swarm Strike Simulation (SSS) was developed to represent an instance of the scenario. The results from the SSM and the SSS were compared to establish confidence in the M&S effort. The performance data was then used to analyze the

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execution of the OTH scenario. This analysis was used to provide evidence for making recommendations about the use of UAV for OTH mission execution.

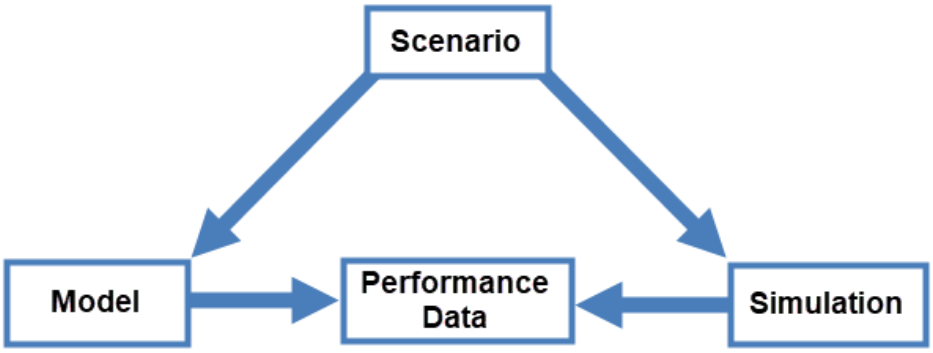


Figure 15. Modeling and Simulation Scenario

2. Modeling and Simulation Scenario

A mission scenario was chosen that represented a blue force OTH strike using a variety of UAV assets onto a red force ship, referred to as the "OTH target." The red force was equipped with its own OTH weapons to fire at the blue force UAVs. Figure 16 is an illustration of the scenario.

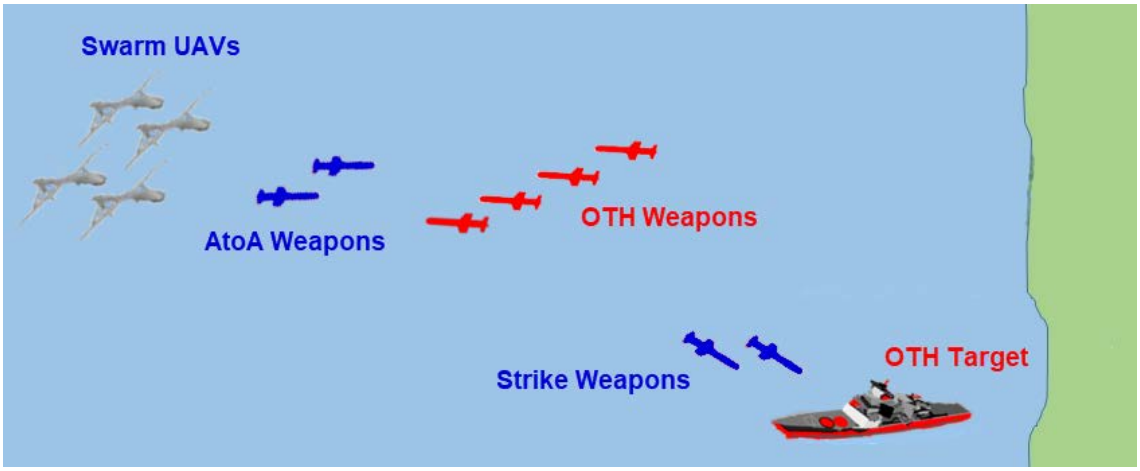


Figure 16. UAV Swarm Engagement Scenario

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The M&S efforts leveraged the UAV types described in the CONOPs and the UAV functional descriptions in the DoDAF architectures. In the mission scenario, the red force "OTH target" can fire on the swarm UAVs during the execution of the OTH-S mission. The scenario outcomes capture the OTH target kill as well as the number of swarm UAVs lost to hostile fire. Successful swarm engagement is defined by the elimination of the OTH target while minimizing swarm UAVs lost to hostile fire. Two critical probabilities were leveraged to evaluate the OTH-S mission success: the probability of striking the OTH target and the probability of a swarm UAV being hit. These two probabilities were central to the series of experiments executed to determine the impact of swarm configurations and UAV performance parameters on engagement success.

The scenario shown in Figure 16 was used to develop the M&S capability. The scenario captures the engagement of the swarm by hostile OTH weapons, as shown in the middle of Figure 16. The inbound threats may be intercepted by the A/A UAV's weapon loadout. The remaining OTH weapons, if any, may be defeated by the jamming energy of the ECM UAV when the ECM UAV is included in the swarm configuration. Any OTH weapons that survive intercept and jamming attempts will have the opportunity to kill a swarm UAV. If the Strike UAV survives the OTH weapons engagement, the UAV will release the strike weapons on the OTH target, as shown in the lower right of Figure 16. The strike weapons will be aided by the sensor-enabled UAV when present in the swarm. Elimination of the OTH target is considered a mission success. Note the scenario detailed above assumes the OTH target environment does not include any factors inhibiting swarm performance.

3. Modeling, Simulation, and Data Analysis Tools

The SSM used for assessing the OTH mission was developed in Excel. This model uses several of the built-in Excel functions including the random number generator and the Binomial Inverse Function, which returns the inverse of the Cumulative Binomial Distribution for a given number of independent trials. These functions allow for probabilistic evaluation of the OTH engagements. The SSM also used the Visual Basic (VB) software in Excel to automate the generation and collection of the swarm

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configuration data. The SSM's VB script runs every allowable swarm configuration and captures the probabilities affecting mission success for each run.

Confidence in the SSM was increased upon comparing the results from the SSM to those obtained from the SSS. The SSS created for this purpose, which was developed in ExtendSim, captures a time-based execution of the OTH mission scenario. The ExtendSim functions for normal distribution time delays, random number generation, and probabilistic branch selection were used to produce the metrics required for comparable assessment of the OTH scenario.

The M&S effort used both the Excel and Minitab statistical analysis tools to assess data generated. Excel was used to calculate the variance and confidence intervals for the data produced by the SSM. The statistical tools in Minitab were used to generate the design of experiments for the UAV performance parameter analyses. Minitab was also used to generate the main effects analysis using the data from the design of experiments (DOE) executions. The role of each tool in the M&S effort is summarized by the flowchart shown in Figure 17.

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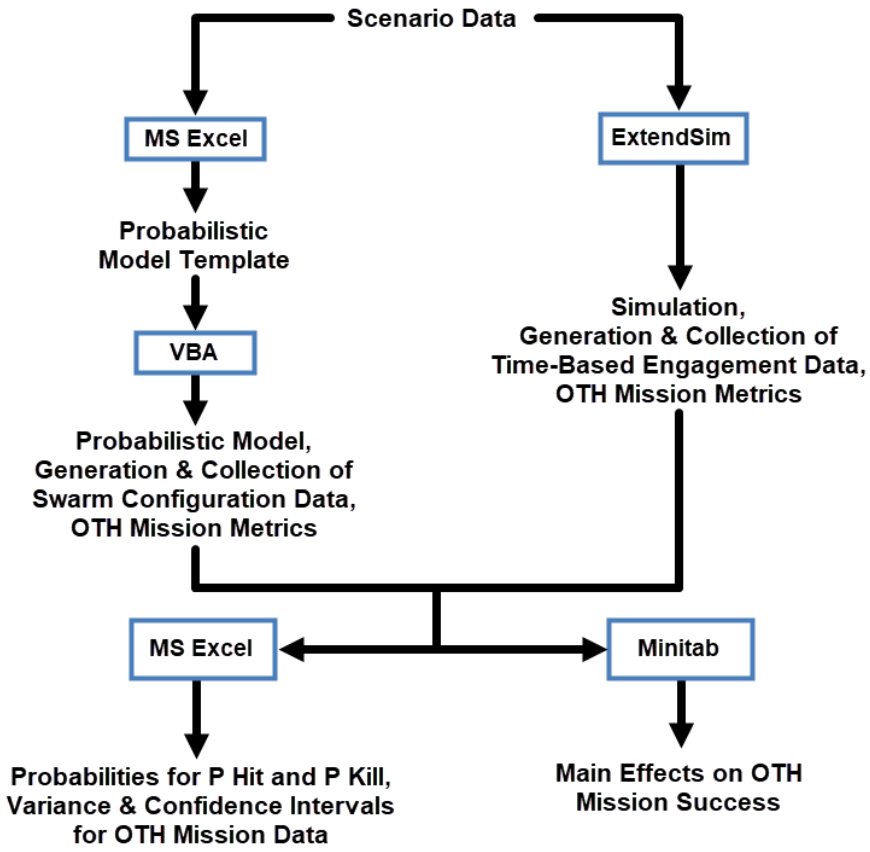


Figure 17. Modeling and Simulation Flowchart

4. Assumptions and Constraints

Several assumptions were made at the onset of the project. For instance, the scenario assumes a single hit to a swarm UAV, the OTH target, or OTH weapon will result in a kill of the targeted asset. In addition, the OTH target position is assumed known prior to swarm launch and will not loiter outside the effective range of the swarm. Note the current SSM and SSS builds neglect adverse effects in the OTH target environment, such as severe weather and geographical influences. Swarm UAV reliability is also neglected.

Both SSM and SSS are constrained to a single OTH target engagement per scenario execution. The OTH weapon performance, percent of kills per engagement, is defined in terms of threat probability of kill (threat P_k) in both the SSM and SSS. Threat P_k in the M&S was held constant at 70 percent throughout scenario execution. The SSM was constrained to having a maximum of five of each UAV type in the mission. This was done

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to manage the complexity of the SSM in relation to its capability for assessing swarm sizes. One functional constraint is that the SSM does nothing to prevent the OTH weapons from targeting the same UAV multiple times. The SSS was developed to have a single configuration of each UAV in the swarm during the scenario execution. This was done to manage the complexity of the SSS and focus on the assessment of the UAV specific performance factors.

5. Modeling and Simulation Capabilities

The M&S effort developed both the SSM and the SSS as a means to provide more fidelity in the OTH mission analysis. A full comparison of the SSM versus the SSS capabilities is shown in Table 3.

Table 3. M&S Capability Comparison

Capability	Modeling	Simulation
UAV performance factors	Included	Included
Swarm UAV configurations	Variable	1 each
OTH target	Single	Single
OTH target weapons loadout	Variable	Set to 4
OTH weapons targeting order	Based on RCS	Based on RCS
OTH weapons targeting fidelity	Low	Medium
OTH weapon performance	Set to 70%	Set to 70%

The low assessment for the SSM targeting fidelity reflects a limitation inherent to the model that allows the continued targeting of a downed UAV. The model's targeting fidelity is further reduced by the instantaneous assessment of all engagements, which negates the effects of volley timing and follow-on target selection. The SSS targeting fidelity was assessed as medium due to the inclusion of a timing component. The timing component allowed for the downing of the A/A or ECM UAV at mission onset. The loss of these UAVs decreased the swarm's defensive capabilities and the OTH weapons were able to target another UAV with a greater kill probability. The SSS targeting fidelity was not assessed as high due to the complexity preventing multiple swarm configurations to be

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readily assessed. As such, only one UAV of each type was represented in the swarm configuration for the simulation effort.

B. DESCRIPTION OF THE MODEL

1. Model Parameters

Weapon performance values are integral to the UAV performance analysis and drive the target kill assessment. The success of a weapon's engagement is quantified by the probability of target intercept, the probability of target elimination upon intercept, and the overall weapon reliability. Factors affecting the performance of assets assigned to the Strike and A/A UAVs are accounted for in their respective success probabilities. Factors affecting the probability of effectiveness for the sensor-enabled and ECM UAVs are accounted for in each UAV's net contribution to the swarm. The sensor-enabled UAV's probability of effectiveness reflects the UAV's ability to enhance the intercept of A/A UAV's intercept of OTH weapons as well as the Strike UAV's probability of OTH target hit. Likewise, the EMC UAV's probability of effectiveness reflects the UAV's ability to degrade the performance of inbound OTH weapons. The M&S efforts did not account for factors affecting UAV reliability, thereby allowing for an engagement success value of 1. Known reliability events could be integrated by multiplying the engagement probabilities by the reliability value of the swarm UAV.

Using the CONOPs and system architecture developed for the OTH mission as a foundation, the team developed the SSM for the swarm OTH engagement scenario. The SSM allows for the assessment of swarm size and selection of UAV assets as well as analysis of individual UAV performance. These metrics are captured in the SSM and expressed in terms of probability of relative success.

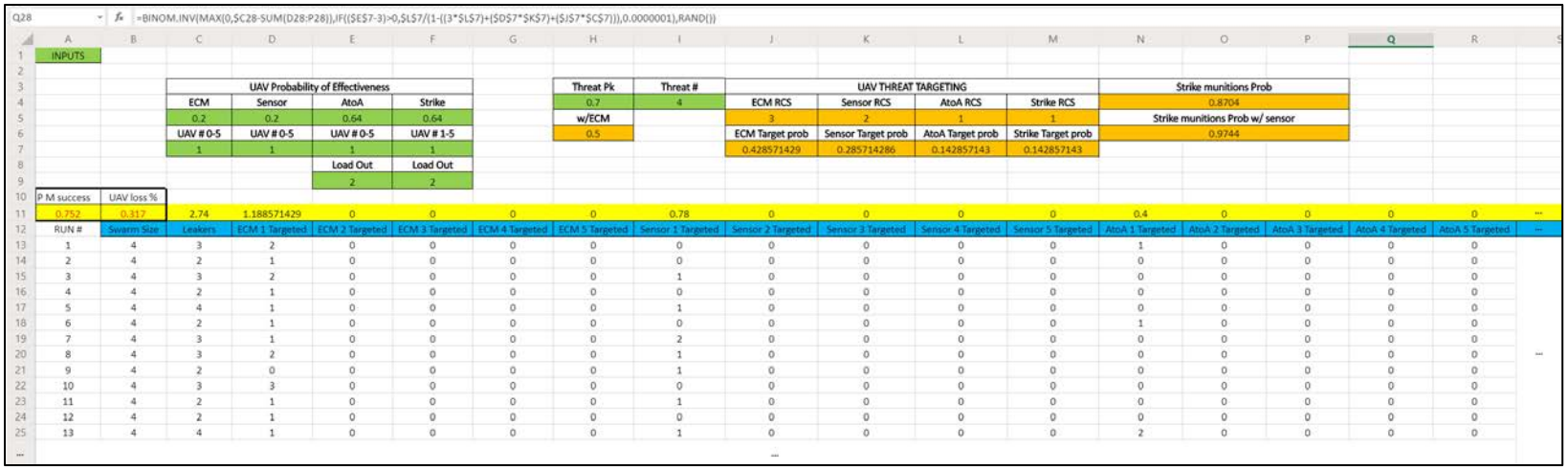
There are several probability factors included in the SSM, such as the probabilities for targeting order for OTH weapons. The UAV targeting probabilities are based on assumptions developed from a radar cross-section (RCS) analysis of the UAVs. An inbound OTH weapon is expected to target the ECM UAV with the sensor-enabled UAV being the next likely target. The remaining OTH weapons would give the A/A and strike

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UAVs equal priority. The ECM UAV is thought to be the priority target for the OTH weapons as the UAV's escort jamming capability is most effective with the UAV in front of the swarm. The ECM UAV is likely the first UAV targeted by the OTH weapons due to its jamming signal transmission and lead formation position. The sensor-enabled UAV's employment of radar to enhance the OTH firing solution also generates considerable radar signature thereby placing the UAV next OTH weapon's targeting order. The A/A and strike UAVs have a similar configuration and asset loadout, which allows the UAVs to share the lowest position in the targeting order.

The probability that a hostile force would target and eliminate a swarm UAV is dependent on the engagement values and performance of the OTH weapons. Successful engagement of the A/A weapons reduces the number of inbound threats. Likewise, the employment of the ECM UAV function minimizes the probability that a hostile threat will be successful in killing a swarm UAV. Once the probability of a successful OTH weapon engagement has been evaluated, and the fallout of the intercept attempt realized, the number of UAV casualties per scenario execution is used to determine the probability of the UAV hit (P_{Hit}) metric. Next, the SSM predicts the success of the OTH target kill using the remaining strike UAVs weapons available. The OTH target kill success is used in the calculation of the probability of success ($P_{Success}$) metric. An excerpt from the SSM is shown in Figure 18.

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Q28 =BINOM.INV(MAX(0,$C28-SUM(D28:P28)),IF(($E$7-3)>0,$L$7/(1-((3*$L$7)+($D$7*$K$7)+($J$7*$C$7))),0.0000001),RAND())

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	INPUTS																	
2																		
3			UAV Probability of Effectiveness					Threat Pk	Threat #	UAV THREAT TARGETING				Strike munitions Prob				
4			ECM	Sensor	AtoA	Strike		0.7	4	ECM RCS	Sensor RCS	AtoA RCS	Strike RCS	0.8704				
5			0.2	0.2	0.64	0.64		w/ECM		3	2	1	1	Strike munitions Prob w/ sensor				
6			UAV # 0-5	UAV # 0-5	UAV # 0-5	UAV # 1-5		0.5		ECM Target prob	Sensor Target prob	AtoA Target prob	Strike Target prob	0.9744				
7			1	1	1	1				0.428571429	0.285714286	0.142857143	0.142857143					
8					Load Out	Load Out												
9					2	2												
10	P M success	UAV loss %																
11	0.752	0.317	2.74	1.188571429	0	0	0	0	0.78	0	0	0	0	0.4	0	0	0	0
12	RUN #	Swarm Size	Leakers	ECM 1 Targeted	ECM 2 Targeted	ECM 3 Targeted	ECM 4 Targeted	ECM 5 Targeted	Sensor 1 Targeted	Sensor 2 Targeted	Sensor 3 Targeted	Sensor 4 Targeted	Sensor 5 Targeted	AtoA 1 Targeted	AtoA 2 Targeted	AtoA 3 Targeted	AtoA 4 Targeted	AtoA 5 Targeted
13	1	4	3	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0
14	2	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	3	4	3	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0
16	4	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	5	4	4	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
18	6	4	2	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
19	7	4	3	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0
20	8	4	3	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0
21	9	4	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
22	10	4	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	11	4	2	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
24	12	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	13	4	4	1	0	0	0	0	1	0	0	0	0	2	0	0	0	0

Figure 18. Swarm Strike Model Excerpt

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The orange boxes shown in Figure 18 highlight the calculated values used in the execution of the scenario. These values are not altered by direct input; however, several values are linked to input values and may vary as a result. The targeting probability values, shown below the probability cells, are mathematically defined by RCS in the targeting process.

The UAV performance inputs and OTH weapons performance parameters are shown in Table 4. These values are also shown in the light green boxes of Figure 18. In addition to these values, the table captures the allowable range for the SSM inputs.

Table 4. Swarm Strike Model Input Parameters

UAV Probability of Effectiveness				
	ECM	Sensor	A/A	Strike
Range	0.01-0.99	0.01-0.99	0.01-0.99	0.01-0.99
	Swarm Configuration			
	ECM	Sensor	A/A	Strike
Range	0-5	0-5	0-5	1-5
	UAV Weapons		OTH Weapons	
	Strike Loadout	A/A Loadout	Threat Pk	Threat Load-out
Range	0-4	0-4	0.7	0-4

The range values shown in Table 4 were used to calculate asset-specific probabilities. While the full range shown in Table 4 is allowed in the SSM execution, the probability of effectiveness for a given platform is bounded by operational effectiveness parameters as well as reliability factors. These bounds were defined by the performance assessments conducted on each UAV platform. The number of weapons a UAV may carry is not mathematically restrained in the SSM; the values shown reflect the range considered for the scenario assessment. Once the SSM functionality was confirmed, a study of the output variance was conducted to assess the consistency of the results.

The data in Table 5 shows the variance in the SSM outputs for $P_{Success}$ and P_{Hit}.

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Table 5. Swarm Strike Model Output Variance

Model	**100 runs**		**200 runs**		**350 runs**		**500 runs**	
Sample	$P_{Success}$	P_{Hit}	$P_{Success}$	P_{Hit}	$P_{Success}$	P_{Hit}	$P_{Success}$	P_{Hit}
1	0.740	0.335	0.750	0.318	0.746	0.304	0.704	0.319
2	0.720	0.315	0.720	0.315	0.717	0.319	0.738	0.313
3	0.720	0.300	0.760	0.286	0.703	0.331	0.740	0.322
4	0.730	0.290	0.725	0.324	0.731	0.305	0.726	0.324
5	0.740	0.293	0.700	0.300	0.766	0.320	0.714	0.321
6	0.770	0.308	0.770	0.311	0.723	0.339	0.720	0.326
7	0.820	0.305	0.720	0.311	0.723	0.354	0.746	0.328
8	0.700	0.343	0.745	0.336	0.709	0.325	0.748	0.313
9	0.720	0.310	0.715	0.326	0.743	0.327	0.744	0.309
10	0.710	0.328	0.740	0.300	0.706	0.317	0.736	0.319
11	0.740	0.300	0.760	0.314	0.726	0.335	0.734	0.316
12	0.720	0.288	0.720	0.331	0.686	0.338	0.718	0.318
13	0.840	0.303	0.740	0.331	0.746	0.315	0.728	0.319
14	0.740	0.323	0.760	0.320	0.737	0.323	0.732	0.331
15	0.780	0.333	0.740	0.305	0.726	0.326	0.706	0.319
16	0.680	0.328	0.775	0.290	0.729	0.317	0.738	0.317
17	0.730	0.315	0.695	0.323	0.751	0.312	0.692	0.309
18	0.700	0.298	0.725	0.296	0.706	0.328	0.744	0.328
19	0.780	0.295	0.780	0.301	0.737	0.320	0.750	0.317
20	0.740	0.310	0.715	0.319	0.731	0.329	0.756	0.314
Variance	1.58E-03	2.57E-04	6.04E-04	1.98E-04	3.66E-04	1.38E-04	2.91E-04	3.71E-05
Mean	0.741	0.311	0.738	0.313	0.727	0.324	0.731	0.319
95% CI +/-	0.019	0.007	0.012	0.007	0.009	0.005	0.008	0.003
99% CI +/-	0.025	0.010	0.016	0.009	0.012	0.008	0.011	0.004

The number of model trials was gradually increased from 100 to 500 runs per engagement. All inputs for the SSM were held constant during the increase of trial runs. A selection of 20 samples was collected at the higher trial count for statistical analysis. As shown in Table 5, the observed variance decreases as the number of trial runs increases per

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engagement. The variances were then used to calculate the 95 and 99 percent confidence intervals. The benefit of adding additional trial runs on $P_{Success}$ output decreases significantly from 350 to 500 runs. Based on the minimal difference in obtained data and the increased time required to run the SSM, a run size of 350 was selected for the remaining analyses.

2. Model Runs for UAV Performance Factors

The SSM established six UAV performance factors. The ECM and sensor performance, as well as loadout, A/A, and strike weapon performance, were assigned values of estimated effectiveness on a scale from zero to one; a value of zero represents no effect and a value of one would be completely effective. For instance, an effective range of 0.20 to 0.50 was estimated for the ECM UAV while the sensor UAV was assigned an effective range of 0.20 to 0.50. Using the six UAV performance factor inputs to the SSM, a 2-level factorial design of experiments (DOE), with a 1/8 fraction and a single center point per cube, was developed. The performance modeling inputs and outputs for the DOE are captured in Table 6.

Table 6. UAV Performance Modeling DOE

P_{ECM}	P_{Sensor}	$P_{A/A}$	P_{Strike}	Strike Loadout	A/A Loadout	$P_{Success}$	P_{Hit}
0.20	0.50	0.64	0.64	4	1	0.723	0.391
0.20	0.50	0.64	0.84	1	4	0.831	0.182
0.20	0.20	0.84	0.64	4	4	0.946	0.086
0.20	0.20	0.84	0.84	1	1	0.697	0.351
0.50	0.20	0.64	0.64	1	4	0.760	0.091
0.50	0.20	0.64	0.84	4	1	0.849	0.208
0.35	0.35	0.74	0.74	3	3	0.931	0.152
0.50	0.50	0.84	0.64	1	1	0.809	0.170
0.50	0.50	0.84	0.84	4	4	0.983	0.029

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Referring to Table 6, the ECM P-value relates to the degradation in the performance of an inbound OTH weapon as caused by the ECM UAV. On the offensive, the sensor performance (Sensor P) value represents the enhancement of the strike weapon's performance afforded by the sensor-enabled UAV. The A/A and strike performance (Strike P) values represent the probability of hit for each weapon in the A/A and strike UAV loadout. The strike and A/A loadout values capture the total number of weapons in the swarm as equipped by the respective UAV platform.

The swarm configuration was maintained at one UAV of each configuration to ensure that multiple UAVs of the same platform did not weigh the performance parameters. The OTH weapons loadout was set to four to present a stressing engagement for the swarm. The results of the DOE were evaluated in Minitab. The main effects for the probability of OTH hit ($P_{Success}$) and the probability of UAV hit (P_{Hit}) are captured in Figures 19 and 20.

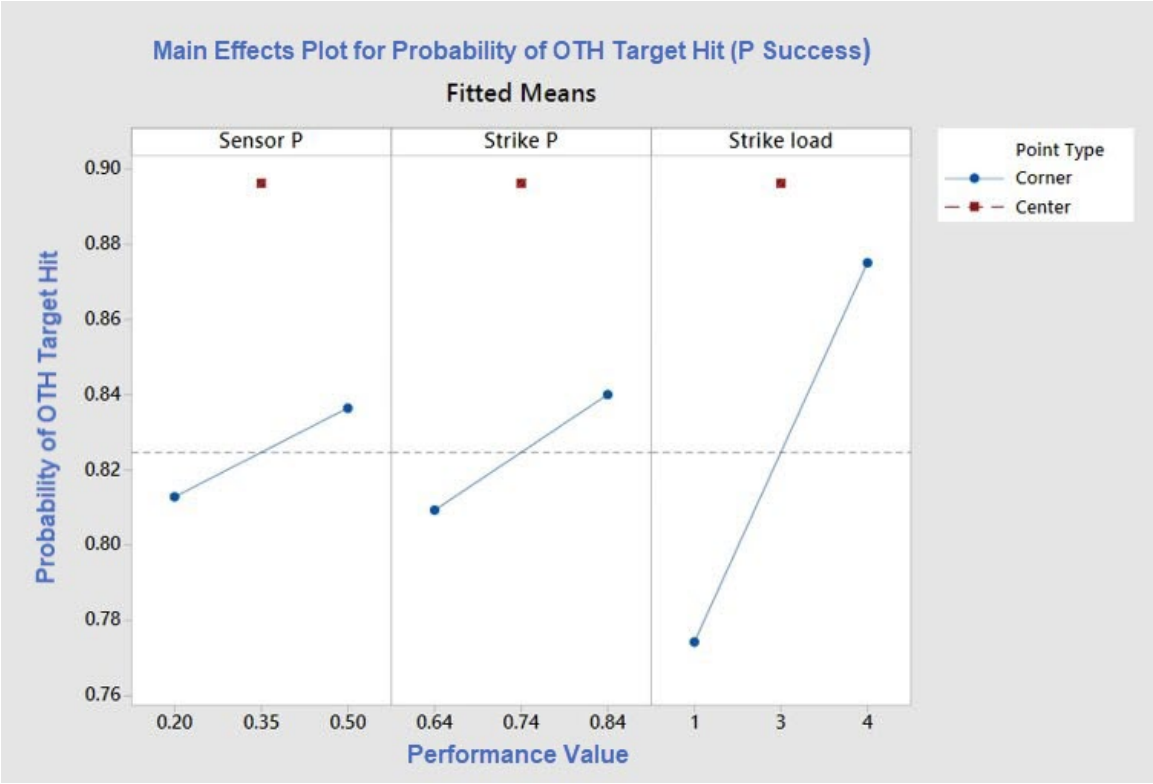


Figure 19. Engagement Probability of Success Main Effects

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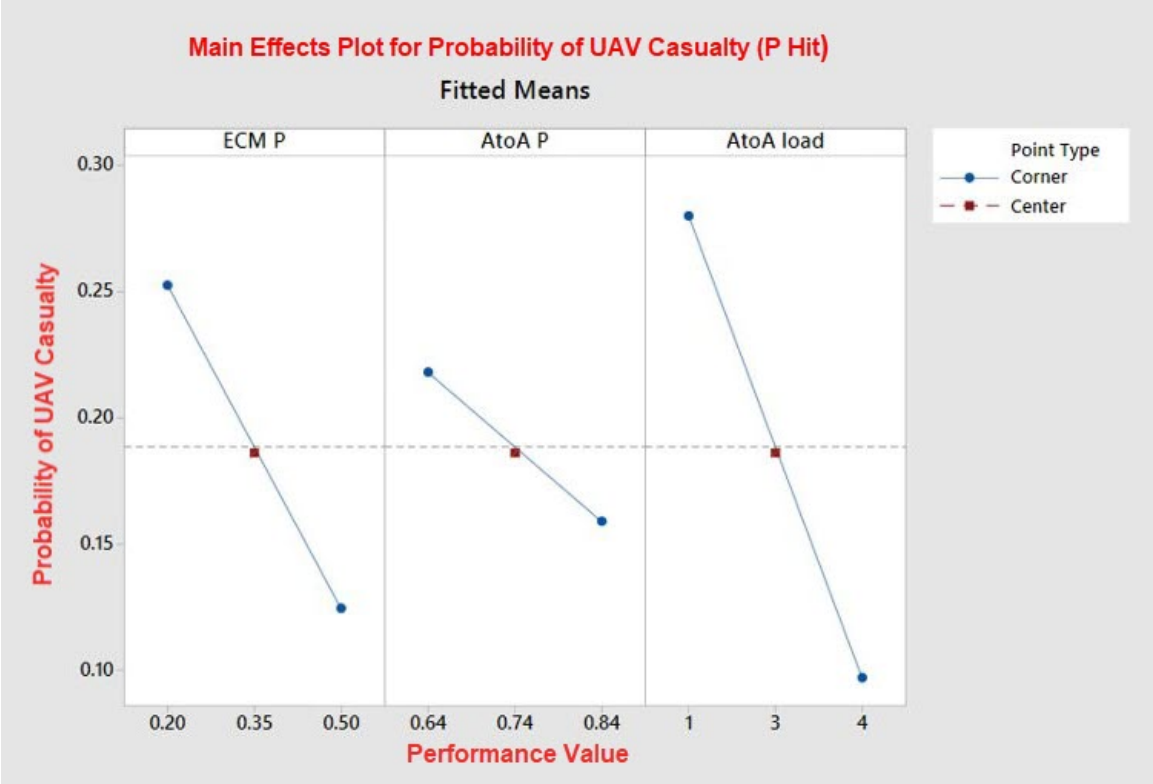


Figure 20. Engagement Probability of Hit Main Effects

The slope of the line in the main effects plots captures the impacts of the UAV performance factors on the engagement criteria. The plots show that increasing the strike loadout has the most significant impact on the probability of OTH hit. While increasing the A/A loadout has the most significant impact on the probability that a UAV is hit. The overall engagement was evaluated, and the SSM is predicting that UAV survivability is driving $P_{Success}$ for the OTH engagement.

3. Model Runs for Swarm Configurations

Utilizing the swarm configuration capability of the SSM, a two-level factorial DOE with a 1/8 fraction and a single center point per cube, for the swarm size was developed in the Minitab software tool. The model inputs and outputs for the swarm size DOE, shown in Table 7, cover the analysis of a mission where the OTH target has a loadout of four weapons.

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Table 7. Swarm Size and Configuration Modeling Design of Experiments with a Red Force with a Return Fire Capability of Four Weapons

ECM UAV	Sensor UAV	A/A UAV	Strike UAV	$P_{Success}$	P_{Hit}
5	5	0	1	0.914	0.173
0	0	5	5	1.000	0.003
0	0	0	1	0.006	0.994
0	5	0	5	1.000	0.246
5	0	0	5	0.997	0.180
5	5	5	5	1.000	0.001
5	0	5	1	0.803	0.002
0	5	5	1	0.963	0.004

The data shown in Table 8 has the inputs and outputs for the analysis of a mission where the OTH target has no return fire capability.

Table 8. Swarm Size and Configuration Modeling Design of Experiments with a Red Force with No Return Fire Capability

ECM UAV	Sensor UAV	A/A UAV	Strike UAV	$P_{Success}$
5	5	0	1	0.969
0	0	5	5	1.000
0	0	0	1	0.834
0	5	0	5	1.000
5	0	0	5	1.000
5	5	5	5	1.000
5	0	5	1	0.883
0	5	5	1	0.963

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The combination of each of the UAV configuration numbers equates to the total swarm size for the engagement. The performance inputs remained constant at 0.2 for the ECM and sensor, while the A/A and strike weapons performance values were set to 0.64. The A/A and strike loadouts were set to two each. The swarm size was evaluated for an OTH weapons loadout of zero, or non-stressing, and loadout of four, a highly stressing engagement. The results of the DOE were evaluated in Minitab. The following three figures capture the main effects for the probability of OTH hit ($P_{Success}$) based on the red force OTH loadouts of zero (shown in Figure 21) and four (shown in Figure 22) as well as the probability of UAV hit (P_{Hit}) for an OTH loadout of four (shown in Figure 23).

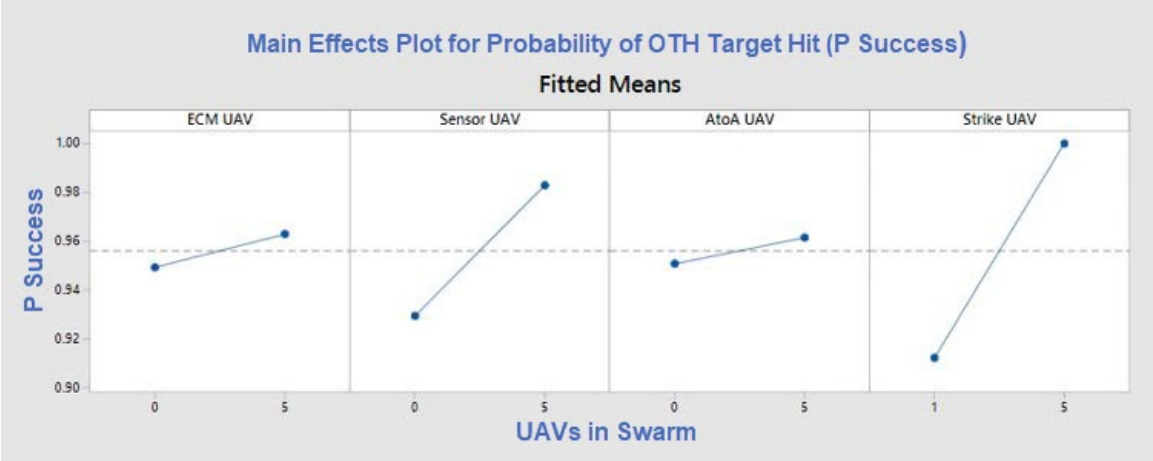


Figure 21. Probability of Success Main Effects for Red Force with No Return Fire Capability

The main effects plots for the modeling parameters show the strike UAV is the performance driver for the scenario in which the red force has no return fire capability. The A/A and ECM UAVs have a negligible impact in this scenario since there are no OTH weapons to act upon.

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The main effects plot in Figure 22 shows all UAV configurations are significant in the scenario where the red force can return fire using four weapons. As seen in Figure 22, increasing the number of strike UAVs has the most significant positive impact on mission success. A swarm consisting of five strike UAVs provide additional opportunities for engagement of the OTH target. However, a UAV swarm consisting solely of strike UAVs is more susceptible to casualties and is not ideal.

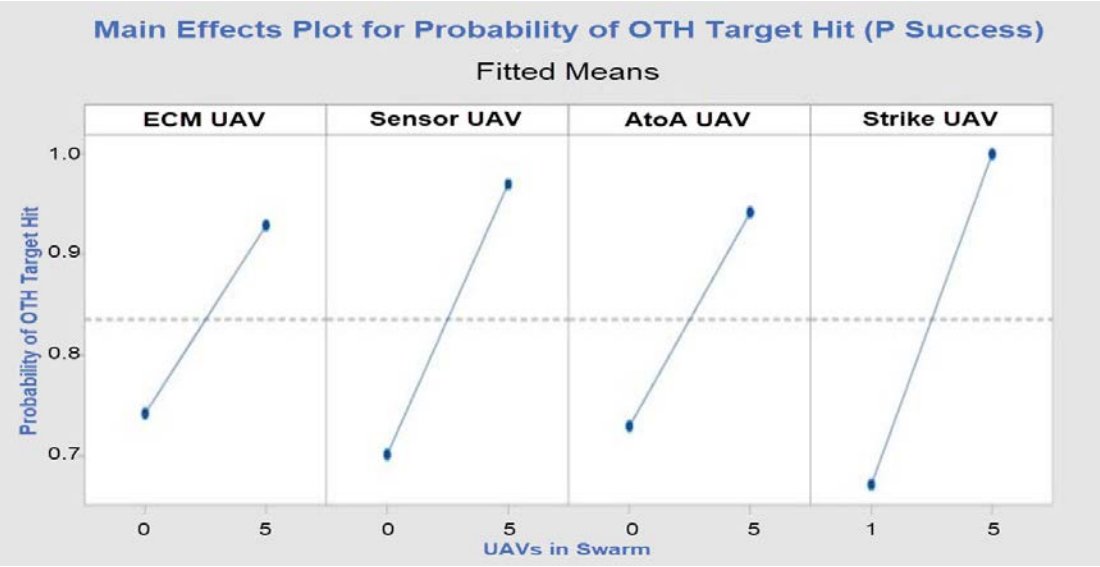


Figure 22. Probability of Success Main Effects for Red Force with Four Return Fire Weapons

The main effects plots in Figure 23 show that the UAV hit (P_{Hit}) performance driver for the four fire OTH engagement is the A/A UAV. The sensor and strike UAVs have an equivalent impact on P_{Hit} due to the constant OTH weapons having an increasing number of targets. However, increasing the number of A/A UAVs has the most significant positive impact on the P_{Hit} criteria for mission execution.

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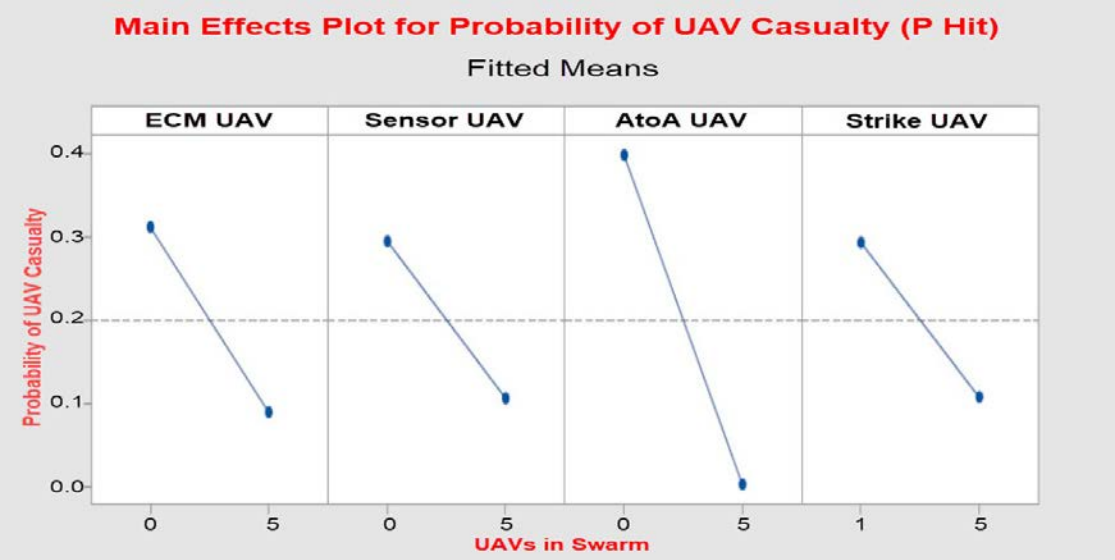


Figure 23. Probability of Hit Main Effects against Red Force with a Return Fire Capability of Four Weapons

4. Lookup Table Model of Swarm Configurations

The SSM was also used to produce a table of swarm configurations as a lookup table for the execution of a set of OTH engagements, as shown in Table 9. This table was developed by evaluating the OTH return fire capability shown in the threat column. The swarm configurations were chosen by maximizing the probability of OTH hit ($P_{Success}$) while minimizing the values of UAV hit (% UAV loss) and reducing the UAVs committed to each engagement to ensure the highest number of missions could be completed.

Table 9. Swarm Configuration for OTH Engagement

Threat No.	ECM No.	Sensor No.	A/A No.	Strike No.	$P_{Success}$	P_{Hit}	Swarm Size
0	0	1	0	1	0.986	0.000	2
1	1	1	1	1	0.963	0.014	4
2	0	1	1	2	0.971	0.119	4
2	1	1	2	1	0.963	0.021	5
3	0	1	2	2	0.974	0.081	5
3	1	1	1	2	0.974	0.175	5
4	0	1	2	2	0.969	0.170	5
4	1	1	1	2	0.966	0.260	5

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The data in Table 9 represents the recommended swarm sizes for deployment against OTH targets that have a known return fire capability. For an OTH target without return fire capability, the SSM is predicting that a swarm configuration of one sensor and one strike UAV will have a 98% probability of target kill. The prediction for the stressing scenario includes two swarm configurations with good probabilities for the scenario metrics of $P_{Success}$ and P_{Hit}. The determining factor in using one swarm configuration over another is made when planning the likelihood of follow on missions. Choosing to deploy a swarm consisting of a single A/A UAV allows an additional OTH mission to be accomplished using an A/A UAV in the swarm.

C. SIMULATION ANALYSIS

The SSS executes the single OTH target engagement with the same mission performance parameter outputs as the SSM. The UAV performance simulation the SSS for the OTH engagement was developed to increase the fidelity of the performance data analysis. The OTH engagement in the SSS was developed in two parts. The first part captures the incoming fire of the OTH weapons. The second part evaluated the engagement of the OTH target based on the surviving swarm UAVs. The SSS includes functionality that disables the targeting and capabilities of UAVs that have been hit by the OTH salvo.

The SSS is shown in Figure 24 was used to conduct an additional assessment of the UAV performance factors. This data was used to build confidence in the modeling results as well as provide further evaluation of the scenario success drivers based on UAV performance factors.

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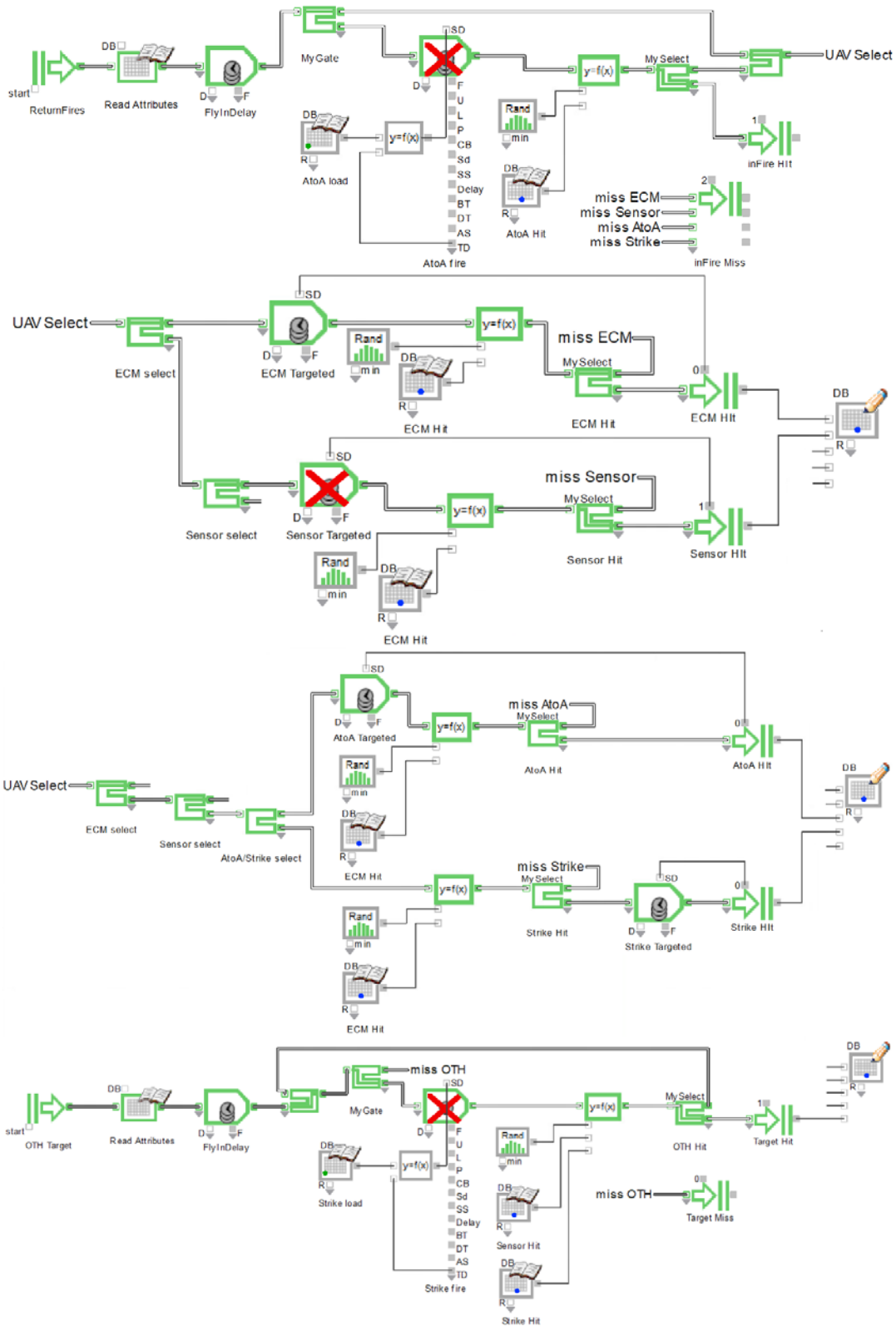


Figure 24. Swarm Strike Simulation

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When the SSS functionality matured, 20 runs of data were collected using the same performance parameters as the model data from Table 5. This data is shown in Table 10. The variance from the SSS for the $P_{Success}$ is smaller than the SSM which shows that the simulation has a more repeatable assessment of $P_{Success}$. The variance from the SSS for the P_{Hit} is larger than the SSM which shows that the model has a more repeatable assessment of P_{Hit}. The P_{Hit} variation could be due to the higher fidelity implementation of the UAV targeting in the SSS.

Table 10. Swarm Strike Simulation Output Variance

Simulation	**350 runs**	
Sample	$P_{Success}$	P_{Hit}
1	0.711	0.333
2	0.683	0.368
3	0.674	0.356
4	0.683	0.368
5	0.694	0.359
6	0.674	0.356
7	0.689	0.354
8	0.680	0.353
9	0.686	0.379
10	0.666	0.345
11	0.697	0.371
12	0.677	0.346
13	0.674	0.334
14	0.709	0.379
15	0.671	0.356
16	0.689	0.364
17	0.703	0.341
18	0.686	0.359
19	0.674	0.342
20	0.697	0.351
Variance	1.620E-04	1.761E-04
Mean	0.686	0.356
95% CI +/-	0.006	0.006
99% CI +/-	0.008	0.008

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The run data from the variance assessment was used to compare the mission performance outcomes ($P_{Success}$ and P_{Hit}) averages using the Excel t-test function with unequal variances. The t-test data in Table 11 shows that the SSM and SSS are producing different results for the mission outcomes. This was expected, as the refinement provided by the SSS should have a significant impact on the mission outcome.

Table 11. Swarm Strike Simulation UAV Performance DOE

P Success t-Test: Two-Sample Assuming Unequal Variances		
SSM/SSS 90% confidence		
	SSM	*SSS*
Mean	0.727	0.686
Variance	3.660E-04	1.620E-04
Observations	20	20
Hypothesized Mean Difference	0.000	
df	33	
t Stat	8.003	
P(T ≤ t) one-tail	1.5566E-09	
t Critical one-tail	1.308	
P(T ≤ t) two-tail	3.1133E-09	
t Critical two-tail	1.692	
P Hit t-Test: Two-Sample Assuming Unequal Variances		
SSM/SSS 90% confidence		
	SSM	*SSS*
Mean	0.324	0.356
Variance	1.376E-04	1.761E-04
Observations	20	20
Hypothesized Mean Difference	0.000	
df	37	
t Stat	-7.983	
P(T ≤ t) one-tail	7.2422E-10	
t Critical one-tail	1.305	
P(T ≤ t) two-tail	1.4484E-09	
t Critical two-tail	1.687	

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Now that the SSS fidelity has been assessed, the OTH mission can be analyzed. This was done through the execution of the performance DOE parameters from the modeling assessment shown in Table 6. The DOE parameters were run through the SSS with 350 executions per row. Table 12 shows both the DOE inputs and outputs for the UAV performance in the SSS.

Table 12. Swarm Strike Simulation UAV Performance DOE

P_{ECM}	P_{Sensor}	$P_{A/A}$	P_{Strike}	A/A Loadout	Strike Loadout	$P_{Success}$	P_{Hit}
0.20	0.50	0.64	0.64	1	4	0.651	0.414
0.20	0.50	0.64	0.84	4	1	0.800	0.193
0.20	0.20	0.84	0.64	4	4	0.951	0.089
0.20	0.20	0.84	0.84	1	1	0.606	0.419
0.50	0.20	0.64	0.64	4	1	0.774	0.087
0.50	0.20	0.64	0.84	1	4	0.837	0.192
0.35	0.35	0.74	0.74	3	3	0.897	0.156
0.50	0.50	0.84	0.64	1	1	0.797	0.181
0.50	0.50	0.84	0.84	4	4	0.980	0.036

The performance results from the SSS reinforce the performance analysis from the SSM. This increases the confidence that the analysis and findings from the modeling effort are useful. The DOE analysis from Minitab produced the same main effects results that were observed in the modeling analysis. These effects are shown in Figures 25 and 26.

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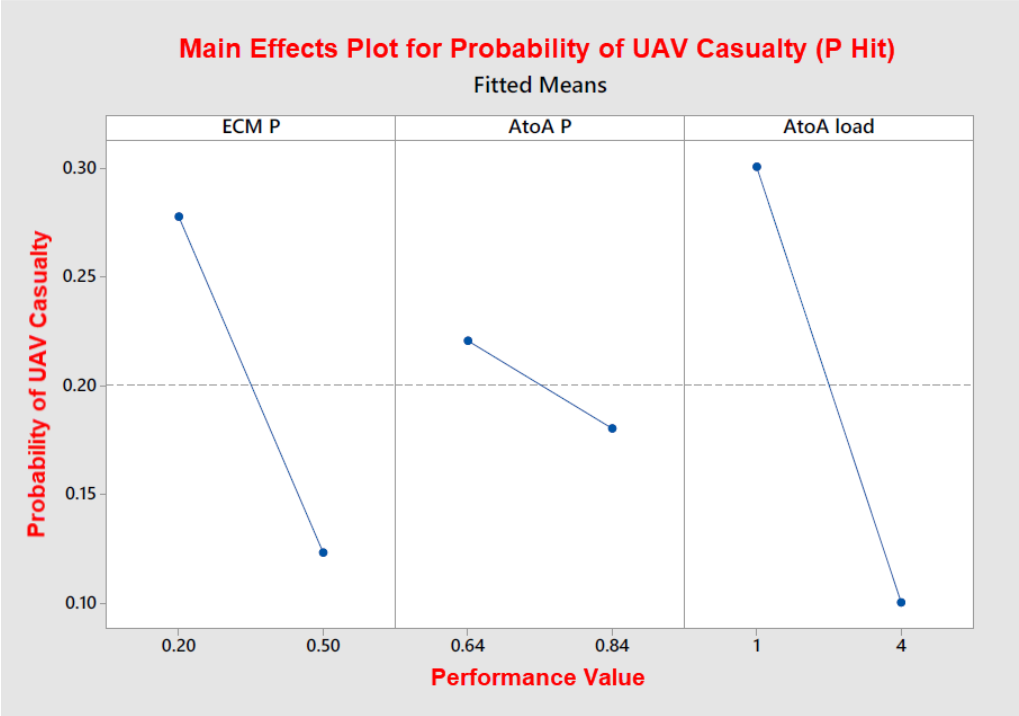


Figure 25. Swarm Strike Simulation Probability of Hit Main Effects Plot

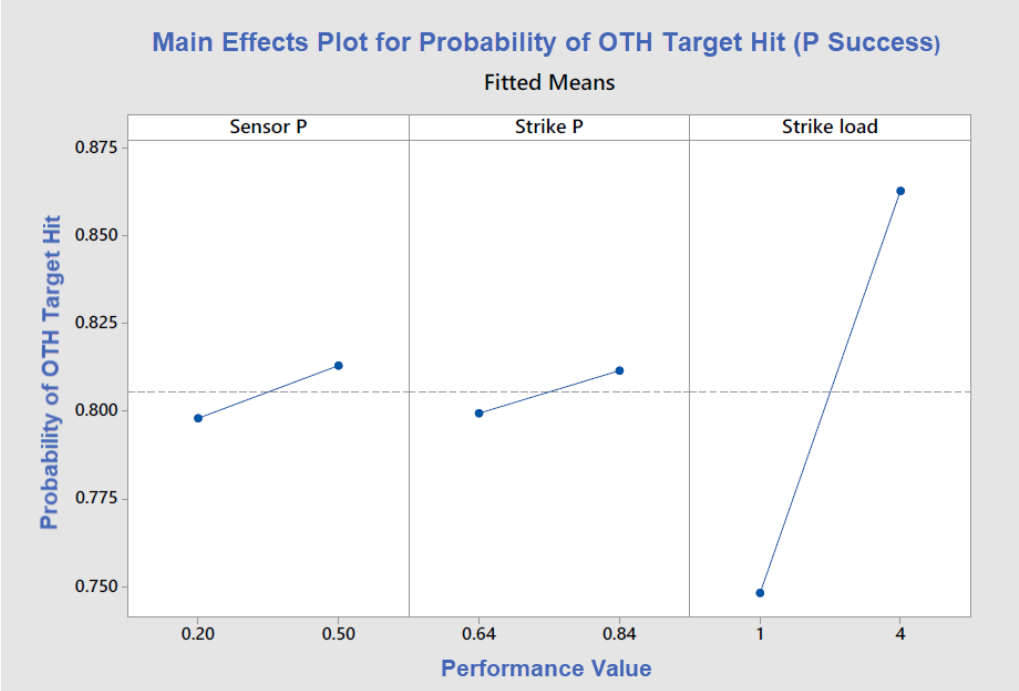


Figure 26. Swarm Strike Simulation Probability of Success Main Effects Plot

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This simulation could be utilized to further explore the UAV performance through the addition of an extended time delay for the engagements, which was not captured in this data. If the time between the release of the OTH weapons was lengthened to the point where an A/A UAV was hit, the swarm capability to intercept the next weapon would be reduced. This could result in changes to the performance driver analysis.

The M&S effort produced data that was well-matched and provided confidence that the scenario is producing believable results. It also provided the performance assessments for this project. Based on the development and assessment of the M&S tool, a usable table of swarm configurations was developed. The UAV performance factors that were identified as scenario success drivers helped identify critical UAV capabilities within the swarm. The data and analyses developed can be used to help inform the development of a BREM swarm capability.

D. COST ANALYSIS

With the move towards the usage of UAVs for combat, it is important to look at the cost implications. In a 2012 study, the average unit cost for a Lockheed Martin F-22 Raptor was approximately $186M (Boyle 2012). In addition, the average yearly cost for operations and support for each aircraft was approximately $11.5M with each flight hour costing the military $11.5K (Boyle 2012). Likewise, the Lockheed Martin F-35 Lighting II has an estimated unit cost of $91M with an average yearly operations and support cost of $5M per aircraft (Boyle 2012); current estimates expect the Lighting II's cost per flight hour to be reduced to $25K (McCarthy 2018). The premier electronic attack platform, the Boeing EA-18G Growler, costs an estimated $70M per unit (Defense Acquisition Management Information Retrieval 2017) with an average yearly operations and support cost per aircraft of approximately $6M; the cost to operate the Growler per flight hour is $25K (Defense Acquisition Management Information Retrieval 2017). With the high unit and operational and support costs, it is worth considering the cost-benefit of tasking UAV platforms to fulfill these critical roles.

From the same 2012 study, the unit cost for a General Atomics MQ-1C Gray Eagle was cited at $26.5M with an average yearly operations and support cost of $8M per unit,

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per year (Boyle 2012). Similarly, the General Atomics MQ-9 Reaper was reported to have a per-unit cost of $6.5M per unit with operations and support cost of $3M per unit, per year; the per flight hour cost for the Reaper is estimated at $3.25K (Boyle,2012). Likewise, the Northrop Grumman RQ-4 Global Hawk's has an average unit cost was $103M with an operations and support cost of $15.6M per unit, per year; the per flight hour cost for the Global Hawk is estimated at $31K (Boyle 2012). Table 13 summarizes unit and flight-hour costs.

Table 13. Cost Comparison of Manned and Unmanned Platforms

Mission Role	Strike/A/A				Sensor/ECM	
Platform	F-22 (M)	F-35 (M)	MQ-1C (U)	MQ-9 (U)	EA-18G (M)	RQ-4 (U)
Unit Cost ($M)	186	91	26.5	6.5	70	103
Flight Hour Cost ($K)	11.5	25	-	3.25	25	31
(M) – manned platform, (U) – unmanned platform						

A comparison of the costs of aerial vehicles shows an especially large variance between the unit cost. Both the MQ-1C Gray Eagle and MQ-9 Reaper are used specifically for combat, like the F-22 Raptor and F-35 Lightning II. The F-22 and F-35 may be equipped with an ECM system. Similarly, the MQ-1C Gray Eagle and MQ-9 Reaper have an available ECM payload (Air Force Technology n.d.). When comparing the UAVs to the manned combat vehicles, the conclusion becomes clearer. The average unit cost of the two conventional manned aircraft is $132M. Conversely, the two combat-capable UAVs average $19M per unit. The RQ-4 Global Hawk is primarily used for its reconnaissance capabilities which makes it a great selection for the sensor-enabled UAV. On a similar note, the EA-18G Growler is strictly purposed for electronic warfare, surveillance, and reconnaissance. Evaluated strictly on cost, the UAV option is less favorable. Although the RQ-4 Global Hawk exceeds the EA-18G Growler in unit cost, O&S cost, and flight-hour costs, its deployment eliminates the risk of service member casualties.

Reflecting on Chapter IV, the foundation provided by previous chapters allowed for the modeling and simulation of the OTH mission execution by the UAV swarm. The

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follow-on analyses found consensus in that OTH mission success is most affected by weapon stores (A/A and strike munitions). Also, the comparative cost analysis for manned versus unmanned platforms found the unmanned platform alternatives to be less costly, save for the ECM function, while eliminating the risk to service members that would otherwise be fulfilling platform role. Moving into Chapter V, the findings of this project will be further discussed with the contributions and potential application benefits identified. The chapter will conclude with a look towards future work that would aid in the further development of the BREM project.

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V. FINDINGS AND FUTURE WORK

A. FINDINGS

The team used a modified system engineering approach to study the operational utility of adding a swarm of UAVs for the OTH mission. The approach was based on the traditional systems engineering "vee" with a focus on the development of a CONOPs and system architecture, and modeling and simulation (M&S) analysis. The team developed the SSM and ran scenarios to conduct three sets of analyses. The analyses centered on the execution of the OTH mission and included a UAV performance analysis, a swarm size analysis, and a swarm configuration analysis.

The CONOPs development process identified specific UAV configurations for use in the swarm. The process also captured the functional description of the UAV configurations and related the performance of the respective UAV platform as a member of the swarm. The CONOPs itself described the basics of swarm configuration as it relates to executing the OTH mission. The CONOPs also began the development of the BREM swarm mission definitions and the OTH mission scenarios.

The architecting processes that followed the CONOPS development further matured the CONOPs by establishing the system of systems definitions for the BREM swarm. The team produced a series of operational and system views that identified UAV configuration data and communications needs. The architecture aided in describing the need for support assets in the execution of the BREM swarm mission.

The team conducted an M&S effort as a quantitative approach for assessing swarm success during the execution of the OTH strike scenario. The SSM, developed in Microsoft Excel, took a probabilistic approach to capture and evaluate the OTH strike scenario. The SSS used a similar approach to scenario execution but added fidelity to the weapon engagements and was developed in ExtendSim9. The scenario utilized in the M&S effort was developed using the information captured in the CONOPs. The quantitative approach of the M&S effort established performance metrics for the various UAV configurations. The effort also allowed for the capture of swarm size and configuration on OTH mission

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success. To this end, mission success was evaluated using the probability the swarm would kill the OTH target contrasted against the probability of a loss of a swarm UAV.

A DOE was developed for the UAV performance using the M&S metrics and analysis was completed using the SSM. The results from each of the DOEs were evaluated for main effects drivers. In the UAV performance modeling analysis, the strike loadout was identified as the driving parameter for the OTH hit probability. The analysis also revealed the A/A loadout to be the main driver of the probability that an incoming threat would hit a UAV. The swarm performance assessment was repeated using the SSS with comparable results.

The swarm size assessment and configuration analysis used a standard set of UAV performance values. A DOE was developed for the swarm size assessment and completed using the SSM. The analysis found the strike UAV configuration to be the critical UAV platform for the successful engagement of the OTH target. In addition, loss of the strike UAV was most detrimental to the success of the OTH strike mission. Successive runs of the SSM were completed to obtain the data used in swarm configuration analysis. The swarm configuration analysis provided the probability of an OTH kill as well as the probability of UAV loss for the various configurations. The team produced a table of recommended swarm configurations that depend on the number of red force return fire weapons. When the red force return fire loadout is known, the look-up table (contained in Table 9) shows the minimum number and type of UAV swarm that produces a high probability of success and a low probability of being hit.

The cost analysis for utilizing current UAV technology in the execution of the OTH mission showed that a swarm implementation would likely increase the cost. However, two factors could drive the decision in favor of the use of a UAV swarm for OTH missions. The first is that delivering more UAVs in more mission areas will reduce the unit cost. The second is that as the UAV technology matures with the higher demand, the cost of delivering UAVs will be reduced. These factors, in addition to the casualty risk associated with OTH mission execution, push the decision in favor of utilizing UAVs.

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B. CONTRIBUTIONS

The modified systems approach completed during this capstone project produced several contributions to the BREM system. The project developed a CONOPs and architecture for the OTH mission that can be utilized in the pursuit of enabling swarm mission capability. In addition, the usable swarm configuration could be used as a lookup table by surface ship combat systems for the execution of the BREM swarm missions. The results of the M&S effort can aid in developing further analyses to unlock new capabilities to be implemented in the OTH mission. The method, data, and tools established by this project could be leveraged to develop similar analyses of existing naval capabilities.

C. POTENTIAL BENEFITS

A practical and near-term benefit of the study will be an Excel application and ExtendSim model to support BREM development and to be used for this project's analysis as well as future analyses. The Excel application will have an interface in which the user may input information regarding the UAVs, coordinates, weaponry, and opposing forces. The application is expected to output the strategic positioning and predictive engagement strategy. The ExtendSim program is expected to mirror the results of the Excel application and provide graphs and visuals to help illustrate.

The results of the project's analysis will provide recommendations and lessons-learned for implementing the addition of UAVs into the BREM automated mission planning decision aid. The M&S of a variety of UAV combinations and configurations for OTH missions will provide an understanding of the operational utility of UAVs for this mission domain. The analysis results will inform the stakeholders of the benefits of integrating the UAVs to the existing BREM gaming system. The stakeholders may also leverage the project towards further development of, and insight into, the BREM functionality as well as UAV capability.

UAV system developers at the forefront of the BREM project will benefit greatly from the project. The results of this study will support the autonomous decision-making component of BREM by adding the potential operational utility of UAVs to the OTH mission. The objective of BREM is consistently to stay in the optimal battle condition of

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the matrix, leading to the highest probability of battle success. With the addition of UAV capabilities and strategies, the BREM will have the potential to achieve even more significant improvements in battle-readiness for OTH missions.

D. FUTURE WORK

The team recommends the swarm size and configuration modeling analysis be repeated using real-world data for UAV effectiveness and reliability. For a baseline, the UAV probabilities could be given F/A-18 performance metrics for similar missions as it is equipped with a sensor package that is similar in concept to the sensor-enabled UAV. In addition, the F/A-18 also features an escort jamming capability that matches the ECM UAV functionality. Lastly, the F/A-18 load outs could be leveraged for the A/A and strike mission package probabilities. By using the F/A-18 data, a better-informed analysis could be completed for the mission effectiveness of the BREM swarm UAVs. The use of measured or predicted values for known UAV reliability could also increase the fidelity of the modeling analysis.

The team also recommends the OTH mission, as completed by manned platforms, should be analyzed to establish a comparative baseline. The data provided by the baseline analysis would allow for a comparative analysis between manned and unmanned assets. In addition, an analysis of manned and unmanned platforms may yield a higher mission probability than either platform on its own.

Further work could be directed towards evaluating the impact of changing the UAV targeting priority during the execution of the OTH scenario. For instance, the ECM and sensor-enabled UAVs could effectively remain outside the OTH engagement range if the ECM UAV supported the swarm as a stand-off jammer with the sensor-enabled UAV acting as a loitering sensor. Removing two UAVs from the engagement area would concentrate on inbound threats, which may increase the probability of successful interception by the A/A weapons. The resulting changes to the OTH targeting methodology would likely necessitate the iteration of the UAV performance drivers and swarm size analyses.

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Another area of development would be enhancing the OTH scenario to reflect a dynamic environment. The addition of swarm UAV countermeasures, environmental factors, and OTH target capabilities would add a layer of fidelity to the SSM. The inclusion of swarm countermeasures would further enhance UAV survivability. Environmental factors affecting UAV and weapon performance would provide insight into optimal swarm configurations for varying environmental conditions of real-world scenarios. Predicting and acknowledging the capabilities of the OTH target are vital to reflect the complex environment accurately in which the strike weapons must operate. Each of these factors necessitates iteration of the UAV performance drivers and swarm size analyses to enable a more versatile swarm configuration.

Further engagement cost analysis would prove beneficial. Dependent on the acceptable level of risk, it would be advantageous to know which UAV configuration yields the greatest probability of success at the lowest cost. This information would provide engagement decision makers with the best cost-benefit analysis. In turn, this would support the allocation of defense spending towards the areas that have the greatest impact on OTH engagement success probability.

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SYSTEMS ENGINEERING CAPSTONE REPORT

A STUDY OF HOW UNMANNED AERIAL VEHICLE SYSTEMS CAN IMPROVE OVER-THE-HORIZON TARGETING AND STRIKE MISSIONS

by

Chadwick J. Boyd, Roderick E. Harris, Christopher L. Kleparek, and Joshua W. Taylor

March 2020

Advisor: Bonnie W. Johnson

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13. ABSTRACT (maximum 200 words)

This capstone project studied the mission utility of using unmanned aerial vehicle (UAV) systems to accomplish the over-the-horizon mission by modeling a variety of UAV capabilities and evaluating their contribution. An Excel probabilistic model of the mission was created to determine the optimized weapon loadout and swarm configuration, which assumed the electronic countermeasures (ECM) UAV to have the highest probability of enemy engagement due to its lead formation position and large radar signature. An ExtendSim simulation added a time element to the study. Both the model and simulation revealed that a maximum air-to-air and strike weapon loadout, which is four weapons for each role, yields the highest probability of success at the lowest probability of a UAV casualty. A maximum air-to-air and strike loadout was found to produce success and UAV casualty probabilities of 98 and 3 percent, respectively. A comparative cost analysis assessed the financial viability of substituting UAVs for manned platforms. The analysis found the unit and per-flight hour cost, for all UAV platforms except those that fulfill the ECM role, to be less than the cost for manned counterparts. However, the use of the ECM UAV eliminates the potential for a flight crewmember casualty.

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Chadwick J. Boyd, Roderick E. Harris, Christopher L. Kleparek, and Joshua W. Taylor

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ABSTRACT

This capstone project studied the mission utility of using unmanned aerial vehicle (UAV) systems to accomplish the over-the-horizon mission by modeling a variety of UAV capabilities and evaluating their contribution. An Excel probabilistic model of the mission was created to determine the optimized weapon loadout and swarm configuration, which assumed the electronic countermeasures (ECM) UAV to have the highest probability of enemy engagement due to its lead formation position and large radar signature. An ExtendSim simulation added a time element to the study. Both the model and simulation revealed that a maximum air-to-air and strike weapon loadout, which is four weapons for each role, yields the highest probability of success at the lowest probability of a UAV casualty. A maximum air-to-air and strike loadout was found to produce success and UAV casualty probabilities of 98 and 3 percent, respectively. A comparative cost analysis assessed the financial viability of substituting UAVs for manned platforms. The analysis found the unit and per-flight hour cost, for all UAV platforms except those that fulfill the ECM role, to be less than the cost for manned counterparts. However, the use of the ECM UAV eliminates the potential for a flight crewmember casualty.

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LIST OF ACRONYMS AND ABBREVIATIONS

A/A	air-to-air
BREM	Battle Readiness Engagement Management
CONOPS	concept of operations
DoDAF	Department of Defense Architecture Framework
DOE	design of experiments
ECM	electronic countermeasures
M&S	modeling and simulation
NPS	Naval Postgraduate School
OTH	over-the-horizon
OTH-T	over-the-horizon targeting
OTH-S	over-the-horizon strike
OV	operational view
RCS	radar cross-section
SSM	swarm strike model
SSS	swarm strike simulation
SV	system view
UAV	unmanned aerial vehicle
VB	Visual Basic

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EXECUTIVE SUMMARY

Naval Air Warfare Center, Weapons Division, China Lake, is developing an automated decision aid for over-the-horizon targeting (OTH-T) and strikes (OTH-S), called the Battle Readiness Engagement Management (BREM) system. The BREM system, which is currently in the research and development phase, is envisioned as a decision aid to military decision makers by evaluating different OTH courses of action based on game theory and artificial intelligence. The BREM project has developed a prototype OTH targeting and strike game for evaluating a wide range of challenges, actions, and outcomes based on complex "real world" conflicts.

The BREM game's initial scope includes air-launched OTH smart weapons and similar adversarial threats. The primary area of interest of this project is to expand the BREM scope to include the utilization of unmanned aerial vehicles (UAVs). The unmanned platform has the potential to redefine the battlespace by augmenting many existing capabilities, such as carrying offensive missile payloads and electronic warfare pods, as well as providing OTH sensor surveillance and defensive capabilities. Operating multiple UAVs in a swarm allows for a mix of UAVs with specialized payloads, to further shape the battlespace.

Research began with developing a concept of operations (CONOPS). The CONOPS consists of the baselined interactions, strategies, and configurations for how a system of UAV systems can provide capabilities for OTH missions. With the incorporation BREM, the goal is to achieve the highest chance of mission success while using the fewest amount of resources. To do so, inputs such as the operation scenario, available resources, and threat data feed into a decision matrix. At this point, the decision matrix serves as the brains of the system, autonomously generating an optimized plan of attack. This plan will consist of the number of UAVs required for the mission, which type will be most effective, loadout configurations for each unit, and the strategy for executing the mission.

Establishing this functionality served as a launching point for architectural analysis. The DOD Architecture Framework (DoDAF) 2.02 was utilized as a guideline for capturing

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the overall architecture. The UGN team was able to capture and illustrate many factors of the OTH mission: physical assets, the interaction of external systems, the flow of functionality, internal systems, internal communications, and functional allocation. The in-depth knowledge acquired from these DoDAF models fueled the development of modeling and simulation parameters.

The goal of the modeling and simulation effort was to quantify the effectiveness of various factors of an OTH strike mission. Modeling focused on two critical probabilities: the probability of striking the OTH target and the probability of a swarm UAV being hit. Both are driven by factors such as UAV selection, UAV performance, and enemy proficiency. Simulation enabled the UGN team to reinforce the data collected with modeling. The same performance parameters were used, but simulation provided a better representation of a live combat scenario (i.e., not targeting downed targets). Through modeling and simulation, the strike UAV was found to be the critical UAV platform for the successful engagement of the OTH target. In addition, loss of the strike UAV had the most detrimental impact on the success probability of the OTH strike mission.

This UGN team is convinced the results of the modeling and simulation effort can aid in developing further analyses to unlock new capabilities to be implemented in the OTH mission. An Excel application and ExtendSim model will be the near-term deliverables provided to support BREM development. This data provides a sufficient baseline, but the UGN Team recommends the swarm size analysis be repeated using real-world probabilities for UAV effectiveness and reliability.

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I. INTRODUCTION

The over-the-horizon (OTH) mission is one of the most challenging engagements for modern weapons systems. The mission engagement is driven by the complexity of data transfer of target information due to the break in the line of sight from the horizon, as well as sensor error budgets from long mission execution times. The mission is further strained by the limits of weapons loadouts and adversarial counter-tactics. The complexities of the OTH mission area present a decision space that can benefit from automated decision aids to support human warfighting decision makers. Automated decision aids could support the selection of sensors for target data support and the selection of available weapons.

The Naval Air Warfare Center, Weapons Division, China Lake, is developing an automated decision aid for OTH missions, called the Battle Readiness Engagement Management (BREM) system (Nagy 2019). The BREM system, which is currently in the research and development phase, is envisioned as a decision aid to military decision makers by developing and evaluating different OTH courses of action. The BREM system incorporates game theory and machine learning to develop OTH courses of action and evaluate these options based on expected consequences and predicted adversarial responses (Johnson 2019). The BREM system will develop battle plans to determine when and how to use kinetic and non-kinetic weapons to support various OTH targeting and strike missions. The BREM program is using an incremental learning approach to ensure readiness in the successful execution and management of missions involving complex planning. This learning approach includes de-escalation tactics while also recommending the selection of available weapons, communications, and sensors that yield the highest likelihood of mission success. The BREM system is focused on leveraging the increased readiness provided by the system to reduce casualties and maximize results.

The BREM system's initial scope includes air-launched smart OTH weapons and similar adversarial threats. One area of interest is an expansion of the BREM system to include the contribution of unmanned aerial vehicles (UAVs) to the OTH mission. This capstone project studied the mission utility of adding UAVs to the OTH mission by modeling a variety of UAV capabilities in conjunction with the BREM system. The study

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looked at the use of different types of UAVs (missile payload, electronic countermeasure [ECM] pod, sensor, defensive, etc.) in different configurations and combinations (single UAVs to swarms of UAVs) using modeling and simulation to evaluate probabilities of mission success. The study supports the incorporation of UAVs as contributors to OTH mission operations into the BREM system decision space.

A recent NPS systems engineering student team developed an operational scenario and conceptual design architecture for the BREM system with a focus on weapons selection and determining salvo size and weapons trajectories (Fava et al. 2019). The student team compared the use of a future BREM system in an operational scenario to a purely human decision process. This showed how a BREM system may be incorporated into future OTH missions and how the automated decision-making capability could be leveraged across platforms to enable autonomous OTH multi-mission engagement.

This capstone project built upon the foundation laid by the previous NPS systems engineering student study (Fava et al. 2019) to model and analyze the contribution of UAVs to the OTH mission domain. The goal of this project is to provide an understanding of the operational utility of adding UAV capabilities to OTH missions. In addition, this capstone project aims to support the implementation of the UAV OTH decision space within the BREM gaming system. The capstone project team has conducted a systems engineering modeling and simulation analysis to capture the functions, architecture, data flow, event sequences, and concepts of operation used in various combinations and configurations of UAVs to assess the factors involved in improving OTH missions.

A. PROBLEM STATEMENT

The OTH mission presents a complex and stressing military decision domain for tactical decision makers. The complexity of this mission arises from incomplete and often inaccurate knowledge of the battlespace; the speed, kinematics, autonomy and destructive capabilities of modern strike weapons; unknown aspects of the adversary; unpredictable consequences of tactical decisions; adversarial means of obfuscation, countermeasures, and counterstrikes; and the general complexities of the operational environment including the beyond-line-of-sight distances. The complexities of the OTH mission area present a

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decision space that can benefit from automated decision aids to support human warfighting decision makers. The Navy is developing the BREM system as an automated OTH decision aid; however, BREM is not complete and currently lacks the consideration of naval UAV assets as contributors to the OTH mission space. This capstone study addresses this need by analyzing the potential contributions of UAVs to the OTH mission and supporting the implementation of adding this knowledge to the BREM decision aid system.

B. CAPSTONE PROJECT OBJECTIVES

The primary objective of this capstone project was to study the mission utility of adding UAVs to the OTH mission by modeling a variety of UAV capabilities in conjunction with the BREM game system. The study looked at the use of different types of UAVs (such as those with payload, ECM, sensor, and air-to-air defensive capabilities) in various configurations and combinations (single UAVs to swarms of UAVs) using modeling and simulation to evaluate probabilities of mission success. An additional objective of the study was to support the incorporation of UAVs into the BREM mission planning game system.

C. SCOPE, ASSUMPTIONS, AND CONSTRAINTS

The focus of this project was the application of a systems engineering analysis process to study the potential contribution of UAV capabilities for the OTH mission. Therefore, the scope of the project included:

- naval UAV assets
- OTH targeting and strike missions
- BREM as a decision aid under development
- modeling and simulation methods of performance assessments

The assumptions and constraints for this project were generated based upon the need for defining some of the mission parameter unknowns. These assumptions were used

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to reduce the complexity and bound mission parameters for the probabilistic analysis of systems performance. The assumptions are as follows:

- The OTH mission is not dependent on a single surface ship type for the OTH swarm mission execution
- OTH targets have a maximum return fire capability of four rounds.
- The performance of the return fire threats will be susceptible to electronic countermeasures ECM.
- The target tracking of the return fire threats is radar-based.
- The minimum UAV selection for the swarm engagement includes at least one strike UAV.

D. METHODOLOGY

The team developed a tailored system engineering analysis approach, as shown in Figure 1. As with a traditional "Vee" systems engineering process, definition and decomposition occurred as the project traversed down the left side, and testing and integration occurred as the project continued up the right side. This approach began with concept development, which included the development of a concept of operation (CONOPS). The CONOPS was then used to transition into the architectural analysis and the development of functional and architectural models based on the Department of Defense Architecture Framework (DoDAF). After completing the functional/architectural analysis, these models were used to create parameters for a mission execution simulation. After simulation development, the team evaluated the model evaluation and studied the analysis results.

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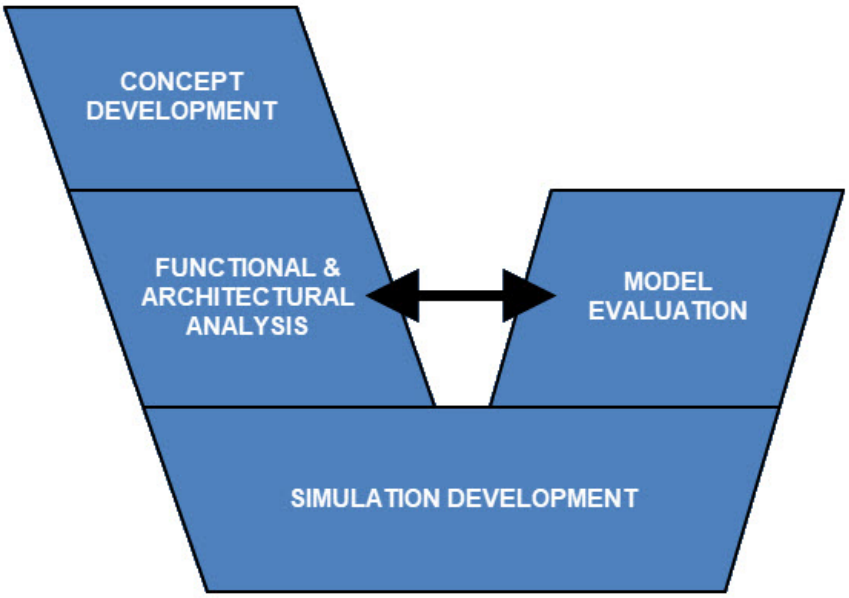


Figure 1. Modified Systems "V"

E. TEAM ORGANIZATION

Each team member had an identified set of roles and responsibilities that enabled the successful completion of the project. The fulfilled responsibilities are identified as follows:

Team Lead—Rod Harris

- Responsibilities: setup meeting agendas, kept meetings on track, kept workload distributed, kept team members accountable for attendance and deliverables

Lead Editor—Joshua Taylor

- Responsibilities: reviewed and submitted all deliverables, supported tracking, review, and accountability of deliverables

Systems Development Lead—Chris Kleparek

- Responsibilities: Ensured the systems engineering processes were being utilized, posted meeting minutes and actions to the Sakai team resource site, tracked-and-closed actions

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Modeling and Simulation Lead—Chadwick Boyd

- Responsibilities: strategically organized architecture, modeling, and simulation solutions to ensure project objectives were achieved

Specialists, Analysts—All

- Responsibilities: remained accountable and diligent for completing tasking

F. CAPSTONE REPORT ORGANIZATION

The purpose of this report is to capture the analysis and results of the project execution. The report follows the systems engineering approach previously described. Chapter II presents the team's OTH UAV concept of operations (CONOPS). Chapter III contains the team's architectural analysis that describes the OTH UAV system of systems and functional architecture. Chapter IV describes the team's modeling and simulation analysis and performance analysis results. Chapter V reflects on the report's findings, identifies contributions, highlights potential benefits, and outlines future work to be undertaken by successive efforts.

Reflecting on Chapter I, the problem and scope of the project was defined and the underlying assumptions and constraints were identified to aid the reader in realizing the goal for this project. In addition, the team organization, project methodology, and report organization were introduced to provide the reader with a better understanding of the team element undertaking this project. Moving into Chapter II, the CONOPS, types of UAVs, operational scenarios, and battle strategies will be discussed to provide the foundation for the modeling and simulation effort.

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II. CONCEPT OF OPERATIONS FOR UNMANNED AERIAL VEHICLES TO SUPPORT OVER-THE-HORIZON MISSIONS

The team developed a concept of operations (CONOPS) as a basis for developing a model and simulation (M&S) of UAV operations to support the OTH mission. The CONOPS details the operation of UAV systems of systems (SoS) in conjunction with the BREM decision aid system during an over-the-horizon targeting (OTH-T) and strike (OTH-S) mission. The CONOPS consists of the baselined interactions, strategies, and configurations for how a UAV SoS can provide capabilities for OTH missions. Establishing a CONOPS serves as a launching point for more in-depth content of the project: it provides the information necessary to develop architectural DoDAF models (Chapter III) and serves as the basis for parameter selection and M&S development (Chapter IV and V).

A. CONCEPT OF OPERATIONS DESCRIPTION

This CONOPS provides details of how UAVs could operate in conjunction with BREM decision aid system to improve OTH missions. Figure 2 illustrates this operational concept. Adding blue force UAVs as a SoS to the OTH mission can improve situational awareness, threat targeting, communication, countermeasures, and both defensive and offensive OTH actions. The role of the BREM system, as a decision aid, is to determine how a UAV SoS can best support the gathering of threat data and battle strategies (such as formations, loadout selection, resource management) to improve OTH missions. This CONOPS focuses on the successful utilization of blue force assets to neutralize a present threat, whether engaged in an offensive or defensive combat scenario.

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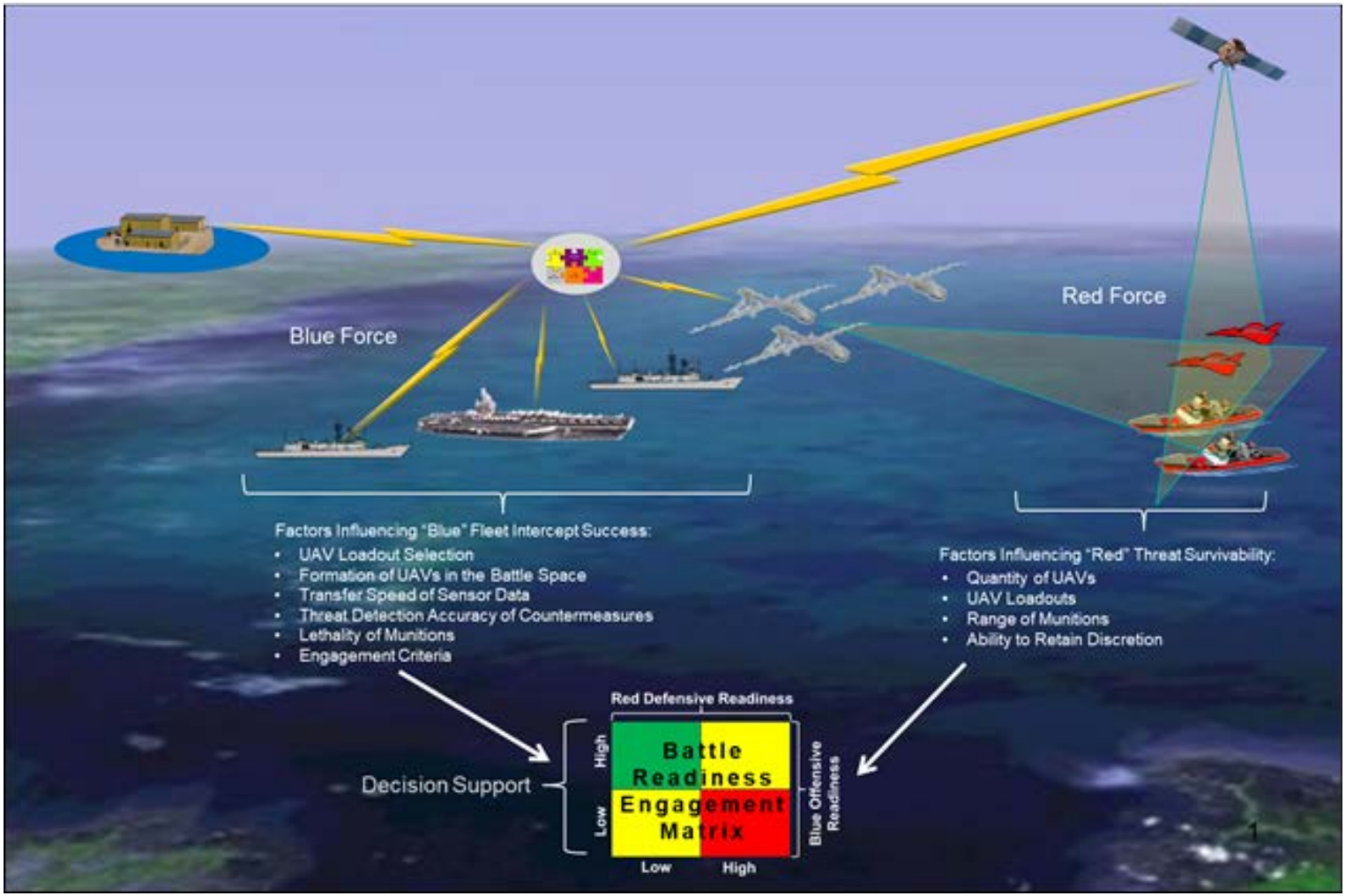


Figure 2. OV-1: Operational Concept for BREM and UAV SoS for OTH Missions

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The CONOPS details the structure of the UAV system of systems (SoS) and its relationship to the BREM system. The CONOPS is based on information that is leveraged from Department of Defense weapon system experience and research detailing stochastic game theory, battle simulations, capabilities-based planning, and systems development. The CONOPS considers current capabilities for UAVs, radar, communications, and weapon systems.

As illustrated in Figure 2, the OTH mission domain includes blue force assets such as a naval strike group that can perform strike missions against a red force. The red force may defend itself with countermeasures and warfare strikes such as missile launches from ships and aircraft. The BREM system is shown in the figure as a colored cube representing this decision aid system that develops OTH courses of action (COA) and also evaluates the risk level of each COA—as green, yellow, or red. This CONOPS describes the use of the BREM system to determine how a UAV SoS could best support the blue force's OTH mission. The BREM tool would be used to deliver an estimation of the probability of success of COAs involving the engagement conditions of a given scenario. The engagement conditions include the following: types and quantity of blue force UAVs present, types and quantity of red force UAVs present, radar detection rates, ECM success rates, missile neutralization rates, and missile intercept rates.

The BREM is a tool used to illustrate this desired readiness condition. Mission success, represented as a green condition, is achievable through the informed use of available resources. Suggestions regarding resource allocation will aid decision makers in determining the actions required to maximize the probability of mission success while minimizing friendly casualties. Figure 3 depicts a high-level flow chart of BREM functionality. The system will take the mission scenario, analyze current resources and threat data (such as quantity, weaponry, vulnerabilities), and generate an optimal plan of attack. This plan will consist of the number of UAVs required for the mission, which type will be most effective, loadout configurations for each unit, and the strategy for executing the mission. This strategy will consist of communication, UAV coordination, reporting of sensor data, firing of weaponry, deployment of countermeasures, and all other functions required for mission success.

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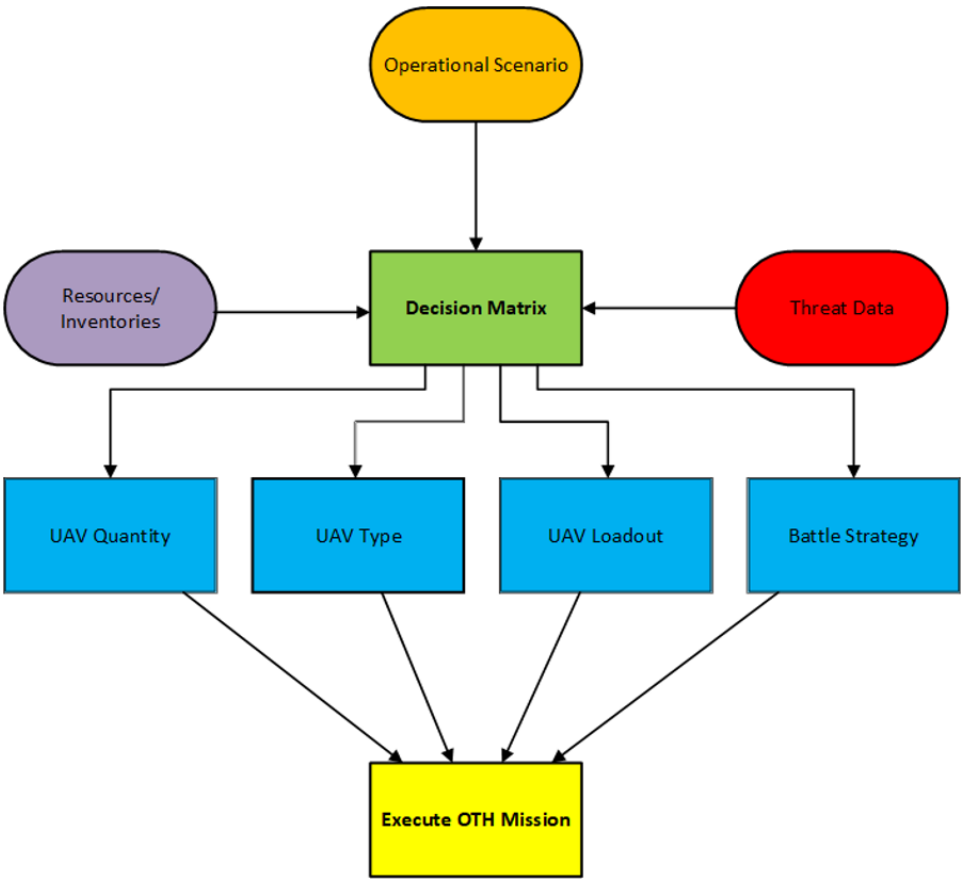


Figure 3. Operational Flow Chart

B. TYPES OF UNMANNED AERIAL VEHICLES

1. Sensor-Enabled Unmanned Aerial Vehicles

Sensor-enabled UAVs support the target and threat detection and tracking data needs for the blue force. This type of UAV supports the OTH-T mission. This information may then be used to support UAVs capable of electronic countermeasures (ECM), air-to-air (A/A) strikes, or air to ground target strikes. The sensor-enabled UAVs improve target and threat data fidelity and provide data used for battle state assessments.

2. Air-to-Air Defense Unmanned Aerial Vehicles

Equipped with antiballistic missiles, A/A defense UAVs are capable of countering incoming missiles. These UAVs are responsible for the completion of the inbound missile

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target OTH-S missions. The capability to combat incoming threats reduces the probability of damage to a UAV in the swarm and increases the likelihood of mission success.

3. Strike Unmanned Aerial Vehicles

Strike enabled UAVs are capable of engaging and neutralizing enemy targets. These UAVs support the offensive attack portion of the OTH mission. This type of UAV's probability of kill success contributes directly to the overall OTH mission success.

4. Electronic Countermeasures Unmanned Aerial Vehicles

UAVs equipped with ECM are capable of jamming the electronics of enemy threats, thereby reducing the red force's probability of successful attacks against the blue force. ECM UAVs target the red force's radar homing systems. Effective use of ECM UAVs will reduce the likelihood of damage to the blue forces and will increase the blue force's probability of OTH mission success.

C. OPERATIONAL SCENARIOS

1. Unmanned Aerial Vehicle Strike Mission

The OTH strike mission occurs when an OTH target is identified. During this event, the user-supplied target location and identification will be used by the BREM decision aid system to assess the number of assets to deploy to meet and predicted probability of success. In the event that a strike UAV is selected to support this mission, the strike UAV must acquire, track and engage the target. The engagement will be consummated with a missile deployment. Mission success will depend on the strike UAV probability of survival as well as the probability of a successful missile intercept by the red force.

2. Unmanned Aerial Vehicle Sensor Mission

The surveillance mission requires a percentage of radar coverage for a specified area based upon the user inputs. User-supplied radar capabilities are used by the BREM decision support system to generate the number of sensor-enabled UAVs required to maintain the desired domain coverage. The sensor-enabled UAV mission success will be dependent on the radar quality of sensor-enabled UAVs in support of the OTH target

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acquisition and track. The OTH target track data is sent to the OTH strike UAV to improve its probability of missile intercept success.

3. Unmanned Aerial Vehicle Missile Intercept Mission

The OTH missile intercept mission requires allocation of an intercept missile loadout based on the user assessment of the OTH target's return fire salvo size. This mission occurs during an inbound missile threat. During this event, the A/A UAVs must launch missiles to intercept the enemy missile. Significant factors influencing the success of this type of mission is the number of inbound missiles, the number of A/A UAVs, the velocity of an inbound missile, distance from an inbound missile, detection distance, target acquisition time, missile inventory, and missile intercept rate. The mission success will be assessed as a probability of intercepting inbound missiles.

4. Unmanned Aerial Vehicle Electronic Countermeasure Mission

The ECM mission requires a specific jamming energy output based on user input regarding the OTH target's return fire capability. The jamming performance factors include distance and angle to incoming threats, as well as, the ECM UAV position in relation to the target of the inbound threat. The ECM UAV mission success improves the UAV survivability by decrementing the intercept performance of inbound threat missiles.

5. Over-the-Horizon Unmanned Aerial Vehicle Target Mission

The OTH UAV target mission occurs when there is in inbound non-weaponized UAV threat. An example of this type of mission would be an enemy UAV equipped with cameras dedicated to retrieving intelligence. During this type of mission, strike UAVs must be employed to neutralize the enemy threat. Major factors influencing the success of this type of mission are the number of strike UAVs, enemy UAV velocity, missile kill-rate, missile inventory, missile velocity, and distance from an inbound missile.

6. Over-the-Horizon Unmanned Aerial Vehicle Swarm Mission

The UAV swarm mission relies on the efforts of each type of UAV in the SoS: sensor-enabled, air-to-air, strike, and ECM. The swarm mission simulates two opposing

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swarms of UAVs, and mission success is defined by the complete neutralization of the enemy UAVs. During this mission, blue force UAVs must defend their team from inbound missiles and attack the opposing force. This mission is composed of independent OTH Missile Intercept Missions and OTH UAV Target Missions. In addition, ECM UAVs are employed to help defend the blue force by reducing the blue force casualty rate during the engagement with the red force.

7. Communications

a. Ship-to-Ship Communications

The firing ship can receive data from support ships that include incoming threat data. The threat data covers the target states, such as position (altitude and range), velocity, and target type (such as maneuvering or sea skimming). The firing ship can also send and receive data about BREM states. The BREM data will be used to support weapons selection decisions.

b. Sensor-Enabled Unmanned Aerial Vehicle-to-Ship Communications

The firing ship can receive data from support sensors that include incoming threat data. The threat data covers the target states, such as position (altitude and range), velocity, and target type (such as maneuvering or sea skimming). Sensors will also communicate environmental data for mission support.

c. Ship-to-Unmanned Aerial Vehicle Communications

The firing ship can send data to the UAVs that include incoming threat data. The threat data covers the target states such as position (altitude and range), velocity, and target type (such as maneuvering or sea-skimming) as well as environmental data such as the presence of radar jamming.

d. Unmanned Aerial Vehicle-to-Ship Communications

The UAV released for intercept engagement will communicate the status of target acquisition, target tracking, and target kill to the firing ship.

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e. UAV-to-UAV Communications

In a swarm UAV engagement, the UAVs will communicate the status of target acquisition and target track to the other UAVs. The UAVs may also transmit threat data required for target tracking.

D. MISSION BREAKDOWN

The BREM OTH scenario is a battle group mission. It includes the identification and tracking of an incoming threat or OTH target as well as the identification of the likely target. The nominal scenario starts with sensor support systems, shipboard or external, picking up a likely threat or OTH target. The threat/target information is delivered to the battle group, where the threat/target is identified as the OTH target. At this point, a target track is established using the available sensor. The sensors may be down-selected based on expected intercept complexity. The down select option allows the sensor resource to be reallocated to other tasks or shut down to prevent overuse. Once the track/position is established, target data is sent to the battle group. Based on the target data, the firing ship is selected from within the battle group. The firing ship then determines which UAV or UAV group to use for the intercept engagement. After UAVs are released, the continuation of UAV support with target state data is determined and supported if needed. The sensor systems continue to track the engagement. If the intercept/OTH mission fails, the scenario iterates until the threat is neutralized.

E. BATTLE STRATEGIES

Once the threat has been identified using a ship's radar sensing system, the BREM program selects the optimal ship to launch the unique UAV or UAV swarm with the highest probability of destroying the target. Unique UAVs are on board each vessel with different weapon selections, flight characteristics, and missile inventory. It is up to the BREM program to leverage the ship's position with the UAV information to defend against or attack the enemy. This program must also consider swarm engagement approaches and future engagements in the battle theater space. Table 1 lists types of BREM input and output, and scenario manager functions.

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Table 1. BREM Input, Output, and Scenario Manager Functions

Input	Ship positioning (coordinates in the battle theater)
	UAV loadout (quantity for each variety on each ship, UAV weapon inventory)
	Remaining missions (number of probable future engagements
	Ship sensor data (number of threats, threat positions)
	UAV sensor data (number of threats, threat positions)
	Target (threat ID, trajectory, speed)
Output	UAV selection (ship selection, UAV team selection, weapon usages, lethality determination)
	Engagement decision (single UAV vs multiple, engagement success rate)
Scenario Manager Functions	User may select alternative UAVs to engage or create a new class of UAV
	Evaluate new engagement success rate under new theater space criteria

The engagement decision system utilizes three sets of decision factors (surface ship and UAV selection factors, event decision factors, and target decision factors) to develop the optimal battle strategy output.

Surface Ship and Unmanned Aerial Vehicle Selection Decision Factors

The position represents the coordinates of the ship in the battle theater. Each ship in the battle theater can launch its own set of UAVs teams at approaching threats and targets. The UAV loadout to be launched depends on the UAVs remaining on each ship. The multiple loadout values represent the remaining UAVs (of varying capabilities) available to execute battle tasks such as payload delivery, missile attacks, EW, and surveillance. The ship's UAV reserves are critical to ship and UAV selection. The remaining missions is another variable that is unique to each vessel.

The remaining missions are the expected number of future mission engagements based on the total number of missions allocated minus the number of missions executed. If

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a ship is likely to engage at least three more times in the theater space, there must be the appropriate resource allocation for each engagement. The resource allocation must account for missiles, UAVs, and UAV capabilities. The BREM program may require events such as payload drop-offs and ship-to-ship UAV transfers to maintain the optimal readiness condition. The fourth and final variable that is unique to each ship is the available sensor data. This sensor data is used to detect incoming threats and enemy UAVs. Due to each ship's unique positioning, each will encounter differing battle events.

1. Event Decision Factors

The target threat level represents the likelihood (*p)* of the threat to cause damage. This factor will be used in the UAV selection decision, and more specifically, the UAV quantity decision. Although the user of the BREM program may manipulate the target threat level, the default value will be set at 0.5. By increasing the threat level, the optimal position in the BREM will require a more significant swarm or attack force to neutralize the target. By decreasing the value below 0.5, non-violent approaches are preferred to reduce the likelihood of future casualties.

2. Target Decision Factors

Before selecting the appropriate means of engagement, the target attributes need to be identified and processed. Factors such as the position, trajectory, speed, and maneuverability of the target will be used to determine the optimal means of neutralization, counterattack, or surveillance approach. The ship and UAV selection are heavily dependent upon these factors. If an inbound threat is approaching a ship containing a UAV team or a non-weaponized UAV, the ship selection becomes critical to incepting the inbound threat. In this type of scenario, if a nearby UAV is in flight, it will be considered to intercept new threats.

Reflecting on Chapter II, the CONOPS, types of UAVS, operational scenarios, and battle strategies were discussed to provide the foundation for the modeling and simulation effort. Moving into Chapter III, the operational and system architecture will be defined to illustrate the relationships required between the swarm assets for mission execution.

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III. ARCHITECTURAL ANALYSIS OF A SYSTEM OF UNMANNED AERIAL VEHICLE SYSTEMS IN SUPPORT OF THE OVER-THE-HORIZON MISSION

The capstone team performed an architectural analysis of the UAV SoS for the OTH mission. The team developed architectural views based on the Department of Defense Architectural Framework (DoDAF) to capture both operational and system views of the UAV SoS. This analysis was performed to aid in the refinement and maturation of the CONOPS, to inform the UAV SoS swarm size performance analysis, and support the UAV modeling and simulation.

A. DEVELOPMENT OF BREM SYSTEM ARCHITECTURE

The architectural analysis for the OTH mission focused on describing the UAV SoS functions and architecture. The analysis generated a system architecture for the proposed OTH mission using model-based system engineering (MBSE) tools. The identification of internal and external system interactions resulting from the architectural analysis supports the future BREM system as well as the team's M&S analysis.

With the understanding of how the system is expected to operate, who is involved, and what are the assumptions and parameters of the system as developed in the CONOPS, the architecture analysis took a top-MBSE approach. This approach utilized the DODAF 2.02 as a guideline for capturing the overall architecture. The team selected Innoslate's model-based systems engineering software Innoslate to develop the DoDAF viewpoints. Knowledge of the system and parameters generated were input into Innoslate, which was then used to generate various views of the system to show operational and system-level interactions.

Utilization of the Innoslate tool offered various ways to depict the interaction of systems and subsystems, both internal and external, involved in the execution of the OTH mission. The DODAF was used to model the core functions of the BREM system as well as the various interactions between internal and external systems required for swarm operation. The overarching DODAF views focused on for this architecture of the system

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were the operational and systems viewpoints. We chose these viewpoints to illustrate the system-to-system operation as well as the execution and exchange of information between assets. When examining the views, we recommend approaching them from the perspective of an external, high-level user as many of the finer system-related details have yet to be considered.

The following are specific viewpoints developed and brief reasoning for selection:

- OV-1: High-Level Operational Concept Graphic—Offers the high-level graphical depiction of the system's operational concept
- OV-5a Physical Context Hierarchy—Captures the physical assets of the OTH mission
- External Systems Diagram (IDEF0)—Captures the functional decomposition of the mission environment and the interaction between external systems required for the execution of the BREM swarm mission.
- OV-5b: Operational Activity Model and sub-assembly decompositions—Defines the relationship between the external systems and the OTH mission as well as the internal relationships captured in the IDEF0 format
- OV-6c: Event Trace Description—Captures the sequence of events required for the OTH mission
- SV-1: Systems Interface Description—Identifies the internal systems associated with the OTH mission
- SV-2: Communications Network Diagram—Captures the intra-swarm communications required for the execution of the OTH mission
- SV-4a Functional Hierarchy—Captures the functional allocations for the OTH mission

The knowledge gained during the development of the diagrams that support the system architecture and design will aid the modeling and simulation development.

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B. OPERATIONAL ARCHITECTURE

The operational architecture view (OV) describes the operations of the system and the connections among the system and subsystems. The OV allows for evaluation of operational requirements, evaluation of interoperability issues, and system baseline. The decision was made to focus on the system analysis through the development of an OV-1, OV-5a Physical Context Diagram, OV-5b F1 External System Diagram and F2/F3 Sub-Functions decompositions, and the OV-6c Event Trace Diagram. These operational viewpoints are described in Table 2.

Table 2. DoDAF Operational Architecture for OTH Mission

DoDAF Operational Viewpoints Developed for the OTH UAV SoS	
OV-1: High-Level Operational Concept Graphic	Offers the high-level graphical depiction of the system's operational concept (Note—this is located in Chapter II of this report)
OV-5a Physical Context Hierarchy	Captures the physical assets of the OTH mission
External Systems Diagram (IDEF0)	Captures the functional decomposition of the mission environment and the interaction between external systems required for the execution of the BREM swarm mission
OV-5b: Operational Activity Model and sub-assembly decompositions	Defines the relationship between the external systems and the OTH mission as well as the internal relationships captured in the IDEF0 format
OV-6c: Event Trace Description	Captures the flow of the functions performed by each UAV during the mission execution

1. OV-5a: Hierarchy Diagram—Physical Context Diagram

The hierarchy diagram outlines the decomposition of the physical assets allocated to the BREM swarm mission execution. The physical hierarchy includes the system decompositions, as shown in Figure 4. The battle group contains the UAV swarm that will be responsible for mission execution. The UAV decompositions capture the asset's specific needs for each of the UAV configurations. The analysis used to develop this diagram reinforced that the system's assets are captured and allocated to operational activities, which are represented in the system's architecture views (SV).

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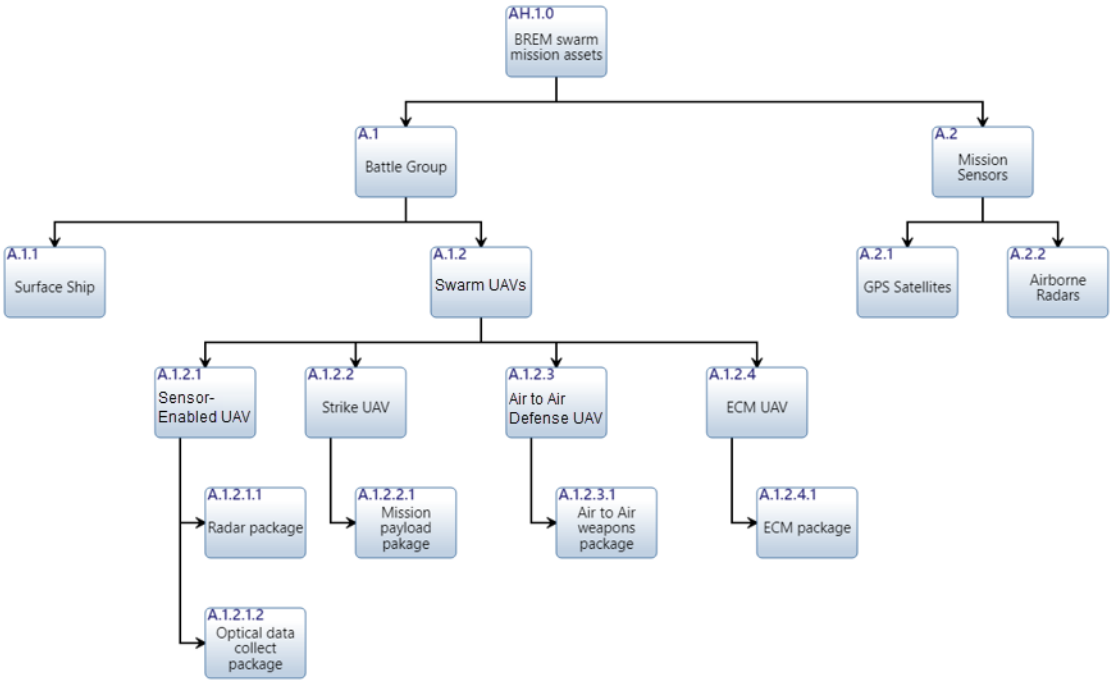


Figure 4. OV-5a: Physical Context Hierarchy

2. OV-5b: Operational Activity Diagrams

The operational activities models describe the interactions and relationships of the various system required to execute the OTH mission. These diagrams, shown in Figures 5 through 10, establish the functional architecture and identify the interactions between swarm assets and external conditions. As the team developed the architecture, each of the functional decomposition levels where labeled. The Level F-1 External System Diagram is the top of the systems architecture, the Level F-2 Execute Mission Diagram is a decomposition of the execute OTH mission function from the F-1 diagram, and Level F-3 Sub-Function decompositions of the OTH mission are captured in the remaining diagrams.

3. Level F-1 External System Diagram IDEF0

The External System Diagram (Level F-1) depicts the functions of the external systems as an SoS architecture. It also illustrates the data flow between each of the external systems. External systems include the OTH mission support systems that will not be decomposed as part of the swarm UAV architecture. The diagram aids in understanding

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the cooperative nature of the external systems and the architecture of the SoS utilized in the OTH mission execution.

The external systems captured in the external systems diagram include GPS satellites, airborne tracking radars, and surface ships. These systems provide functions such as; GPS target tracking, radar target tracking, mission parameters, and launching the swarm UAVs. These functions are required for the execution of the mission but cannot be accomplished by the swarm UAVs. In this architecture, the swarm UAVs are responsible for the execution of the OTH mission functions. These functions will be decomposed in the throughout architecture. The operational relationships for these systems are shown in Figure 5.

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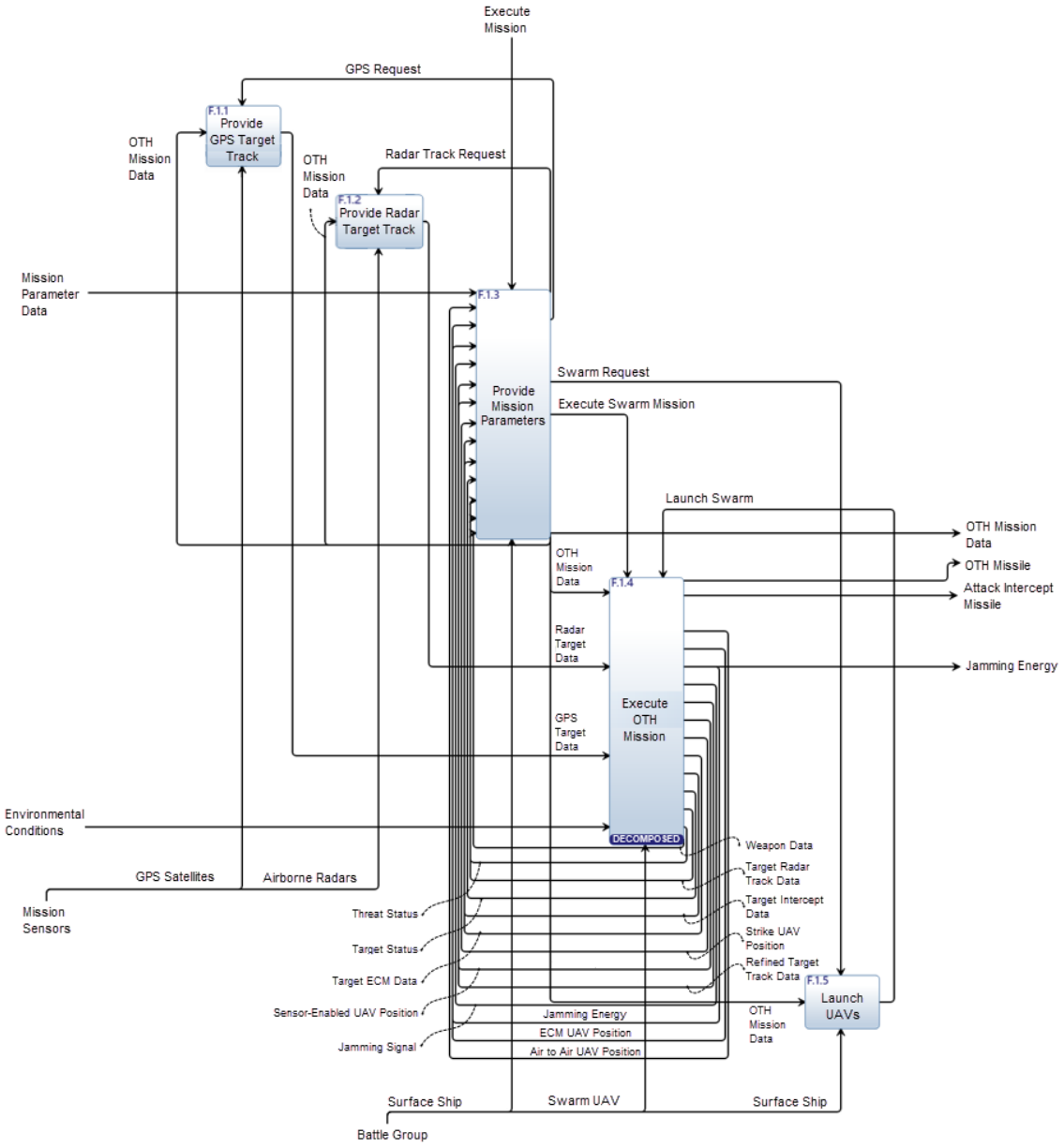


Figure 5. IDEF0: External System Diagram—External Mission Elements

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4. Level F-2 IDEF0 Sub-function Execute Mission Diagram

The interactions between the swarm assets required for mission execution are shown in Figure 6.

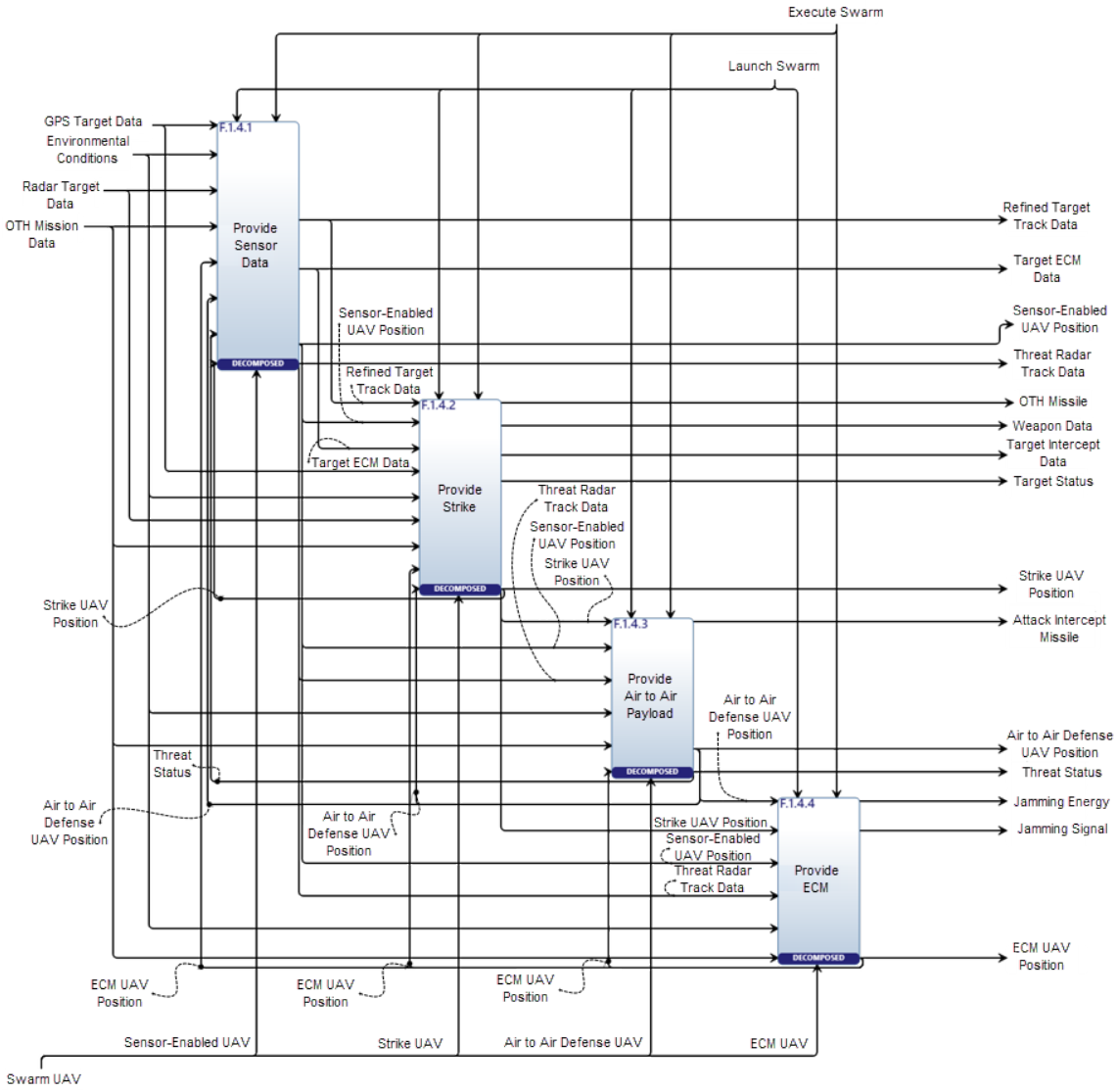


Figure 6. OV-5b: Execute Mission Context Diagram

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5. Level F-3 IDEF0 Sub-function Decompositions

The BREM Swarm Execute Mission diagram was decomposed to its sub-functions to provide a better understanding of the UAV sub-systems. All of the UAV decompositions have a fly UAV function by necessity and for completeness, but the UAV functional decomposition focused on the unique UAV configuration functions needed to support the mission execution. This approach dictates the specifics for the command and control of the UAV concerning flight operations as they were combined into the single function by design. Note each UAV possesses a communications function responsible for receiving and transmitting data to elements external to the UAV. The communications function was also bundled to capture the need for an encrypted data link.

6. Level F-3 IDEF0 Sub-function of Sensor-Enabled Unmanned Aerial Vehicle

The decomposition of the sensor-enabled UAV operation describes the interfaces and functions that enable the mission execution to have radar sensor capability. The sub-functions include producing radar energy, detecting radar energy, identifying incoming threats, and determining target location. These functions describe the sensor-enabled UAV capability to produce refined target measurements as well as threat data that will be used by other UAVs in the swarm. They also identify the radar signals needed to support the sensor-enabled UAV functions within the swarm. See Figure 7 for a depiction of the interactions between sensor-enabled UAV's sub-functions.

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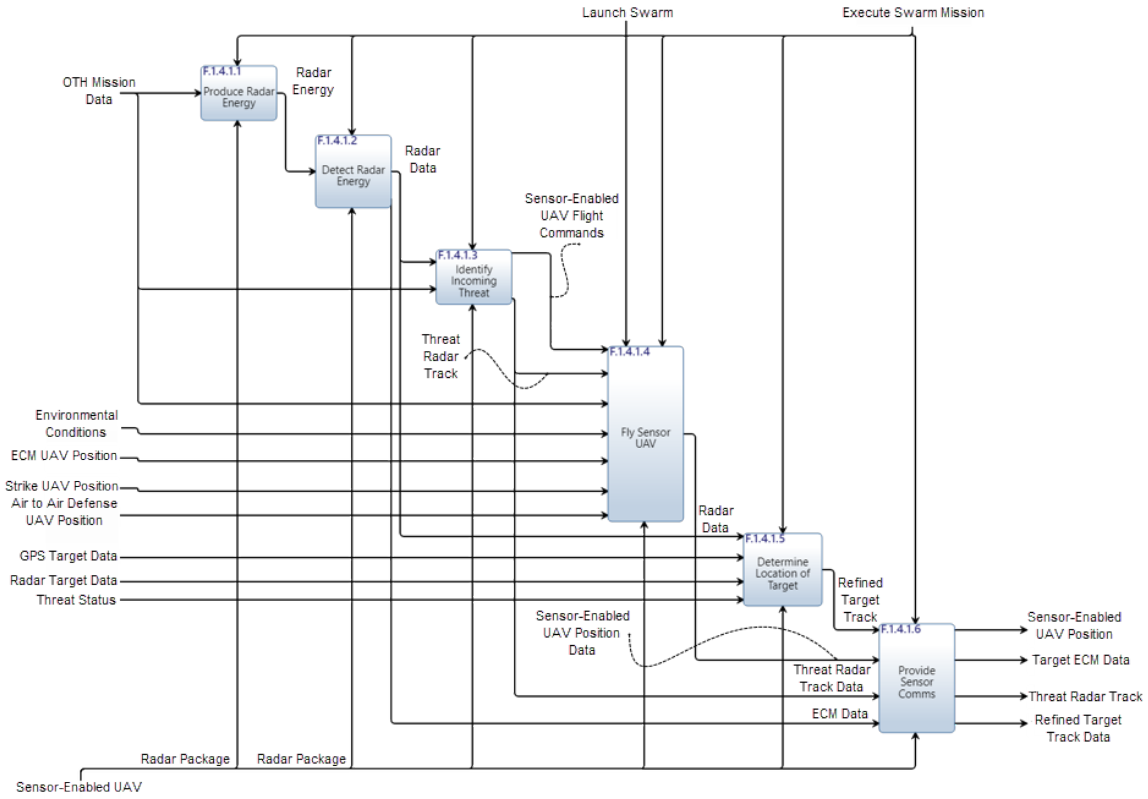


Figure 7. OV-5b for Sensor-Enabled UAV System Sub-functions IDEF0

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7. Level F-3 IDEF0 Sub-function of Strike UAV

The decomposition of the strike UAV operation describes the interfaces and functions that enable the mission execution to have strike capability. The sub-functions are track target, identify target intercept, launch ordinance, and provide kill assessment. These functions describe the strike UAV capability needed to complete the OTH strike part of the mission. While the swarm is designed to increase the overall mission success, the strike UAV is solely responsible for the delivery of ordinance to the mission target. See Figure 8 for a depiction of the interactions between the strike UAV's sub-functions.

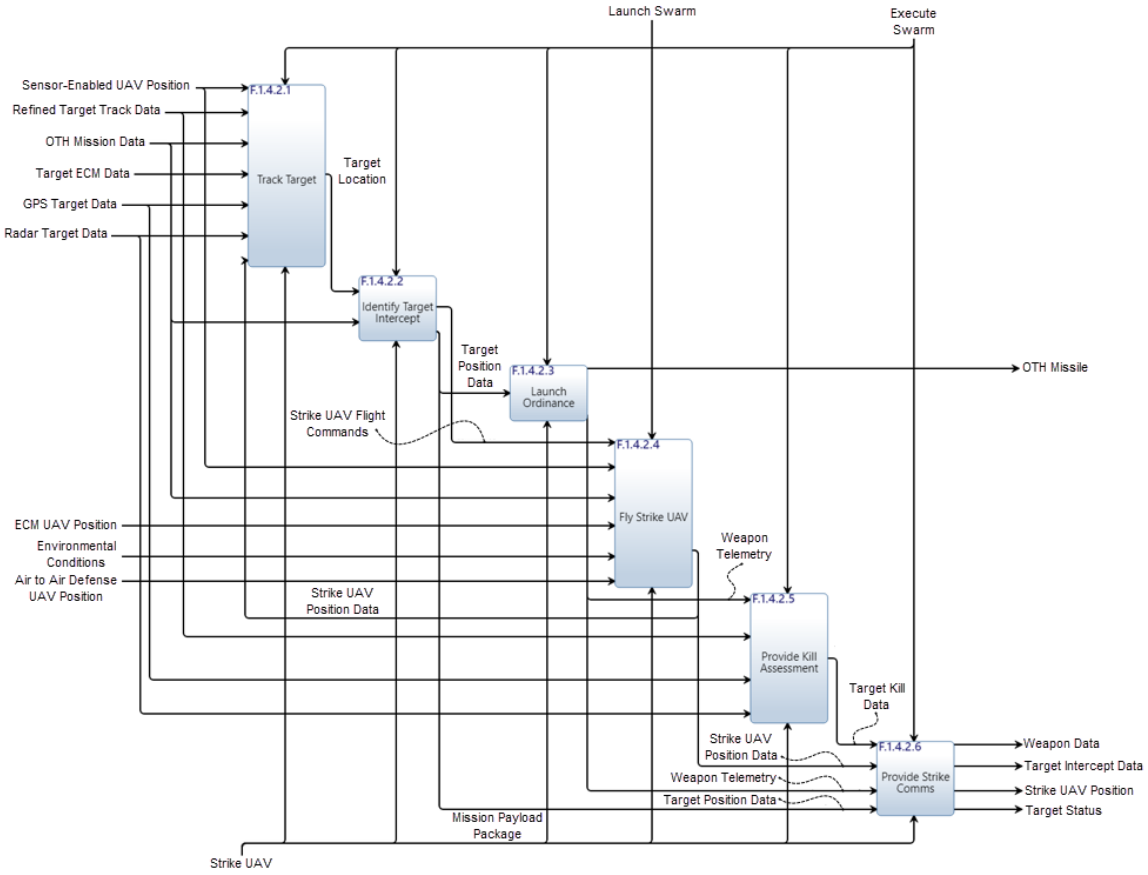


Figure 8. OV-5b for Strike UAV System Sub-functions IDEF0

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8. Level F-3 IDEF0 Sub-function of Air-to-Air Defense Unmanned Aerial Vehicle

The decomposition of the air-to-air defense UAV operation describes the interfaces and functions that enable the mission execution to have an air-to-air defensive capability. The sub-functions are track inbound threat, identify threat intercept point, launch a missile, and assess threat status. These functions describe the air-to-air defense UAV capability needed to provide the swarm with an air-to-air intercept operation. By eliminating possible threats to the swarm, the overall mission success is improved. See Figure 9 for a depiction of the interactions between the air-to-air defense UAV's sub-functions.

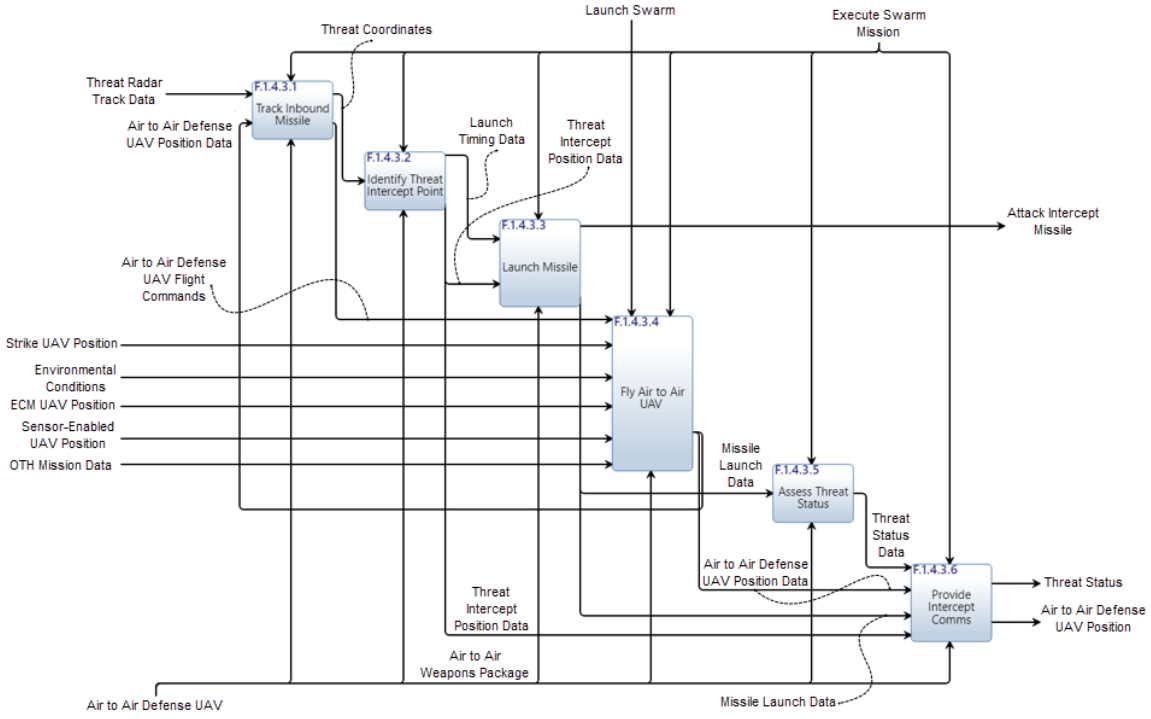


Figure 9. OV-5b for Air-to-Air Defense UAV System Sub-functions IDEF0

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9. Level F-3 IDEF0 Sub-function of ECM UAV

The decomposition of the electronic countermeasure (ECM) UAV operation describes the interfaces and functions that enable the mission execution to have an ECM defensive capability. The sub-functions include calculating the jamming position and providing the jamming signal. These functions describe the ECM UAV capability needed to provide the swarm with a radar jamming operation. A jamming capability within the swarm can reduce the probability of success for an incoming threat. Decreasing the likelihood of success that a UAV in the swarm is damaged will help improve the probability of success for the overall mission. See Figure 10 for a depiction of the interactions between the ECM UAV's sub-functions.

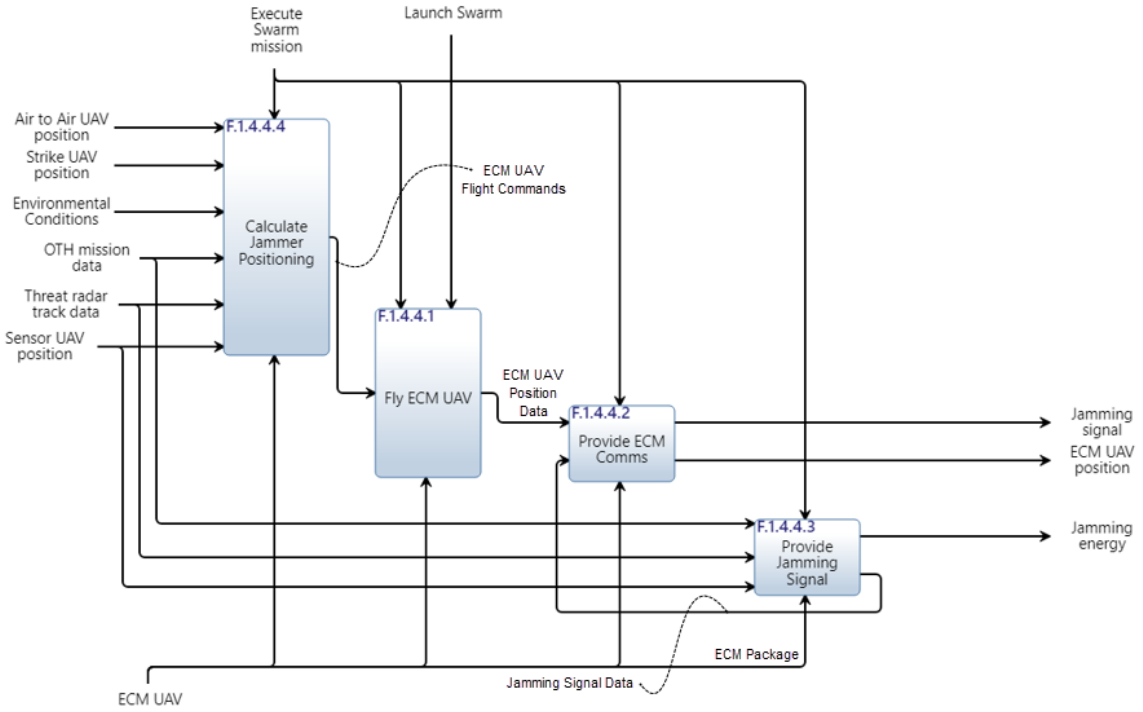


Figure 10. OV-5b for ECM UAV System Sub-functions IDEF0

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The F-3 level of decompositions provides an understanding of the individual UAV capabilities supported through the UAV functional decompositions. This breakdown aided in identifying the sensor, strike, air-to-air, and ECM functions needed to develop the swarm capability. After several iterations of the decomposition, the UAV sub-functions can provide further fidelity in the development of the system architecture. They help define the swarm capabilities as needed to support the mission execution from a unique UAV mission package.

10. OV-6c: Event Trace Description

The OV-6c diagram traces the actions that occur in a given scenario or sequence of events. It provides a time-ordered examination of the resource flow for the swarm scenario as well as the tracing of actions in a critical sequence of events. The mission execution capability is modeled by the set of activities and their attributes. The event trace description captured focuses on the sequence of events completed by the swarm during the execution of the OTH strike mission. It establishes the inter-swarm events by describing the UAV to UAV interactions needed for the execution of the OTH mission. This event trace will be leveraged for the development of the modeling and simulation part of the project. The event trace diagram is shown in Figure 11.

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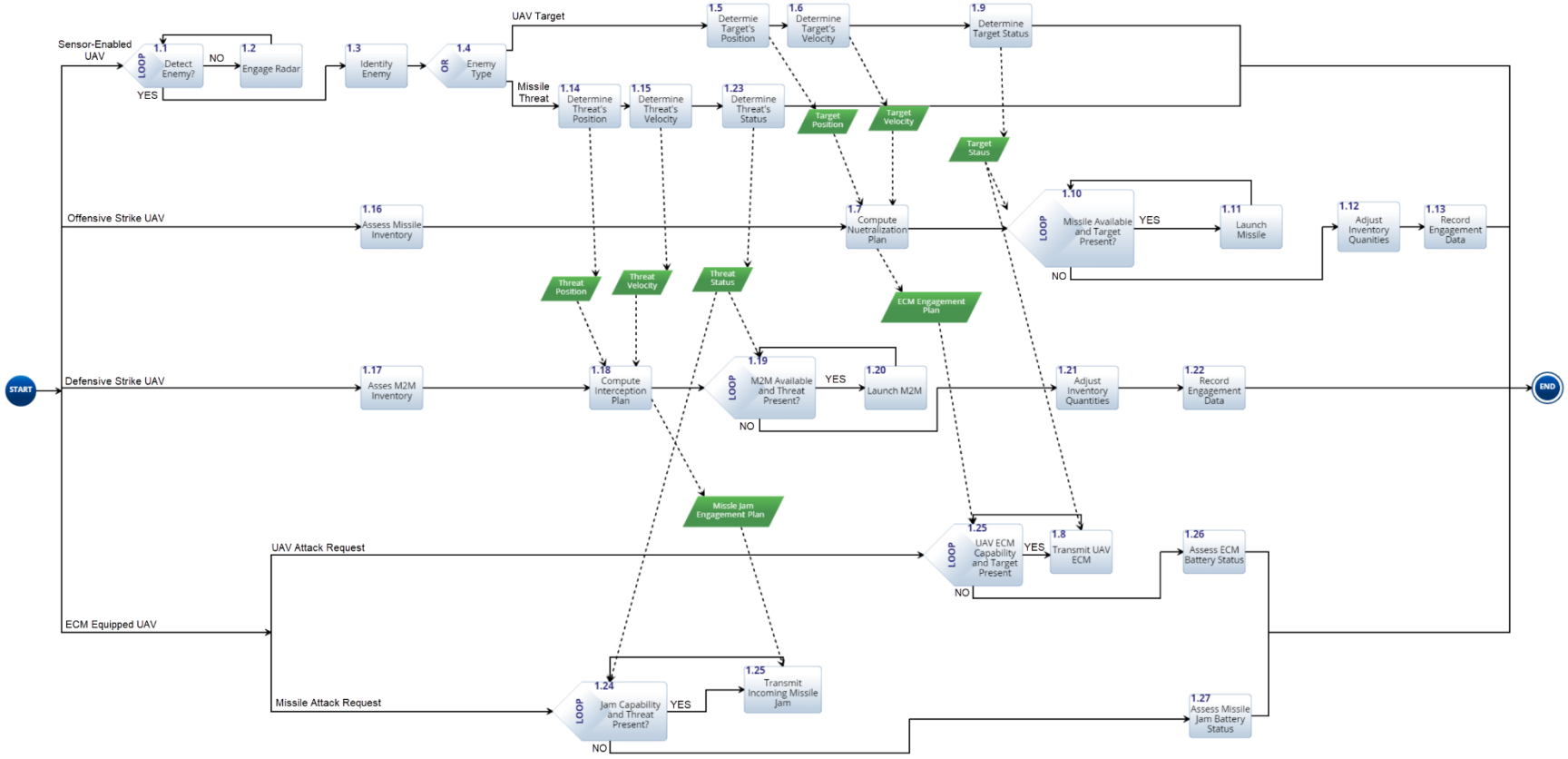


Figure 11. OV-6c Event Trace Description

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C. SYSTEM ARCHITECTURE

Systems architecture view (SV) describes the system of concern and the connections among the system and subsystems in context with the operational view. The SV allows for evaluation of system operational requirements, evaluation of interoperability issues, and system baselining. As a group, we decided to showcase our system through the use of an SV-1, SV-2, and SV-4 diagram.

1. SV-1: Systems Interface Description

The SV-1 in Figure 12 visualizes the interconnections between the system and its subsystems. The SV-1 depicts the sharing of information between the battlegroup assets. Note the surface ship is acting as a vital node in the relay of this information. The surface ship collects data from GPS satellites, airborne radars, and the UAV swarm. In return, the surface ship relays collected information to each asset as needed. Together, each asset, including the surface ship, is more aware of potential threats in the battlespace than any one asset would be otherwise.

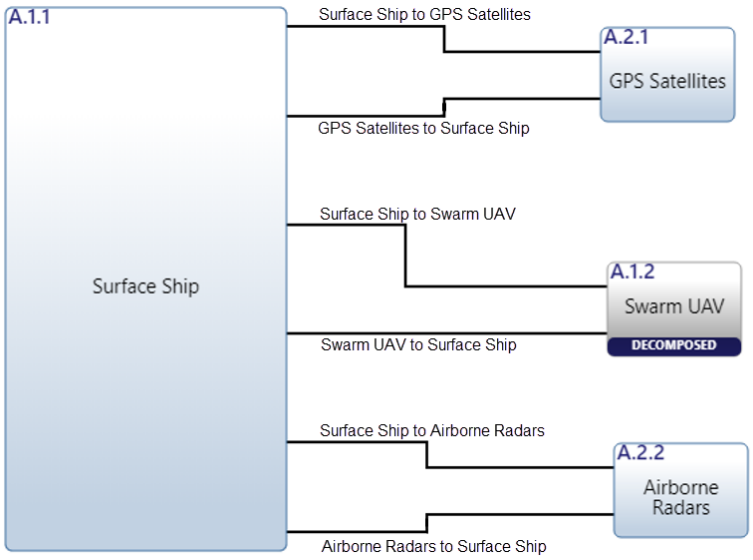


Figure 12. SV-1: Systems Interface Description

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2. SV-2: Communications Network Diagram

The SV-2 depicted in Figure 13 details the lines of communication between the swarm assets. Note each UAV is connected to the other three UAVs through a secure data link, which allows information sharing to prevent UAV isolation should any UAV be lost to an incoming threat. The network design also allows information to be relayed between UAVs to maintain situational awareness even when assets are spread across the battlespace.

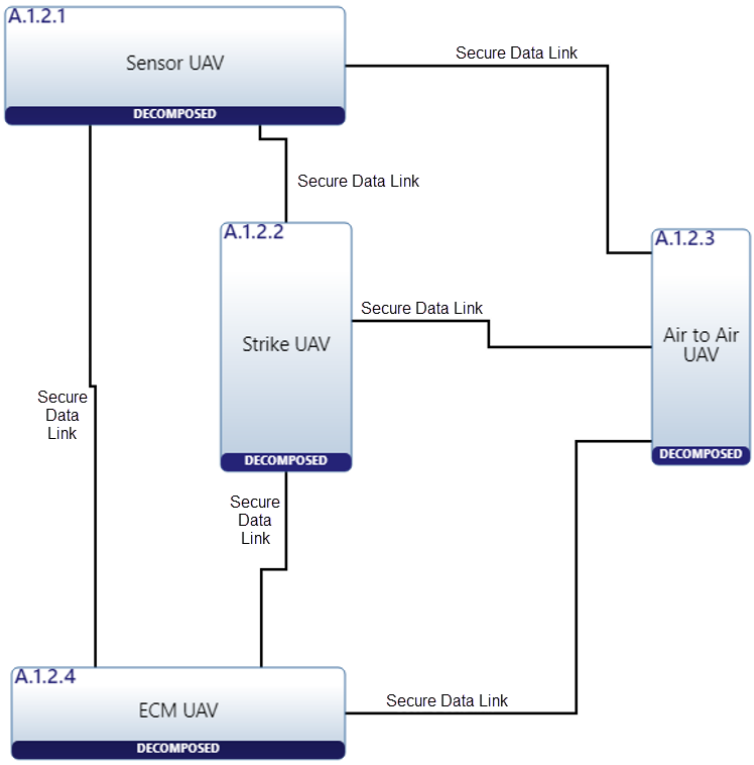


Figure 13. SV-2: Communications Network Diagram

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3. SV-4: Functional Hierarchy

The SV-4a depicted in Figure 14 details the functional relationships required to support the over-the-horizon mission. Execution of the over-the-horizon mission is supported by the principle functions of the UAVs, which include providing sensor data, strike capability, air-to-air payload, and electronic countermeasures. Each principle function is decomposed to identify the required subfunctions.

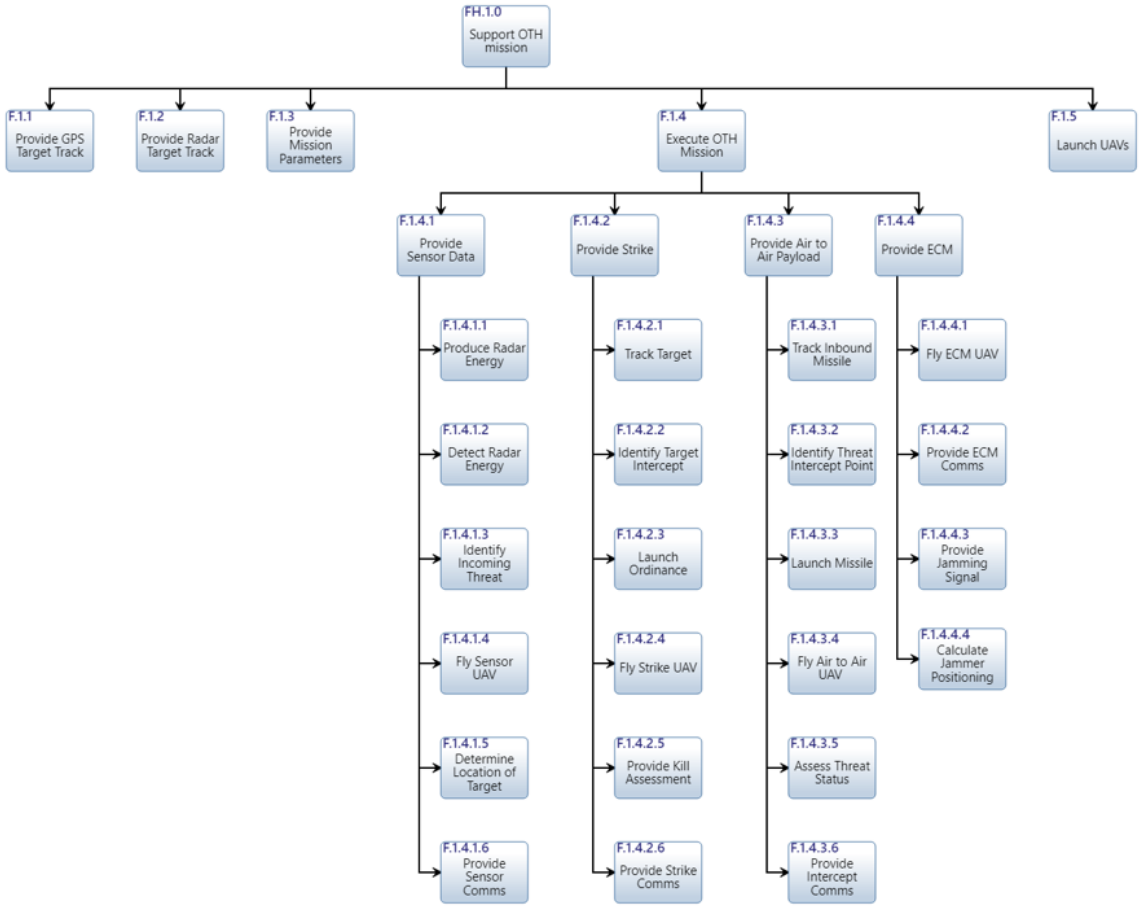


Figure 14. SV-4a: Functional Hierarchy

Reflecting on Chapter III, the operational and system architecture defined to illustrate the relationships required between the swarm assets for mission execution. Chapter IV will culminate the buildup of previous chapters with the modeling and simulation of the OTH mission execution by the UAV swarm.

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IV. MODELING, SIMULATION, AND, OTH MISSION ANALYSIS

This chapter describes the modeling and simulation (M&S) analysis of the system of UAV systems (referred to as the "swarm") for the OTH mission. It includes a look at cost factors for the utilization of UAVs in the execution of the OTH mission. The chapter contains an overview of the M&S effort and a description of the OTH mission analysis methods employed. The purpose of the model, as well as the model's limitations, will be discussed and followed by a review of the data derived from the model; a similar discourse will follow for simulation development. The execution of the OTH mission using UAVs will then be assessed from a cost-effectiveness standpoint with manned platforms.

A. PURPOSE OF THE MODELING, SIMULATION AND MISSION ANALYSIS

The goal of the M&S and mission analysis was to study the operational benefits of adding UAVs to the OTH mission. The M&S analysis assessed the individual UAV performance factors that are drivers for the OTH mission success. A blue force versus red force OTH mission scenario was modeled. The blue force was equipped with four different types of UAVs: sensor-enabled, air-to-air (A/A), electronic countermeasure (ECM), and strike. The red force consisted of a ship that could return fire with its own set of OTH weapons. The red force ship was the OTH target of the blue force. Mission success consisted of eliminating the red force ship. The performance values of the blue force's individual UAV types were varied, and different combinations and configurations of UAVs were modeled. The cost of the UAV mission implementation was assessed as well.

1. Modeling and Simulation Approach

The approach for the M&S effort is shown in Figure 15. A single scenario for the OTH target mission execution was captured. Then a probabilistic model called the swarm Strike Model (SSM) and the Swarm Strike Simulation (SSS) was developed to represent an instance of the scenario. The results from the SSM and the SSS were compared to establish confidence in the M&S effort. The performance data was then used to analyze the

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execution of the OTH scenario. This analysis was used to provide evidence for making recommendations about the use of UAV for OTH mission execution.

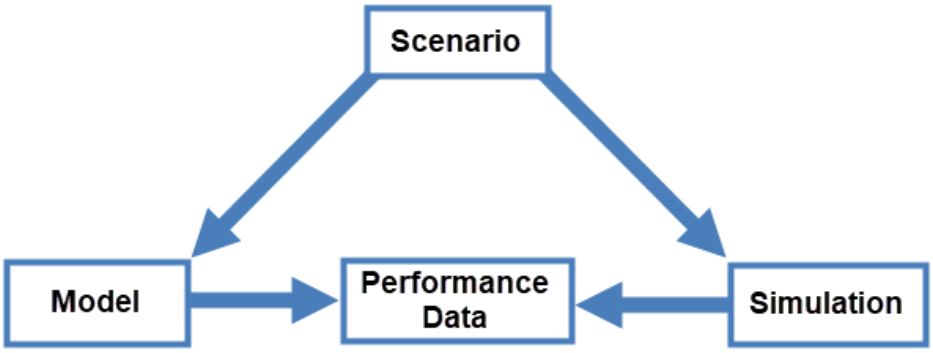


Figure 15. Modeling and Simulation Scenario

2. Modeling and Simulation Scenario

A mission scenario was chosen that represented a blue force OTH strike using a variety of UAV assets onto a red force ship, referred to as the "OTH target." The red force was equipped with its own OTH weapons to fire at the blue force UAVs. Figure 16 is an illustration of the scenario.

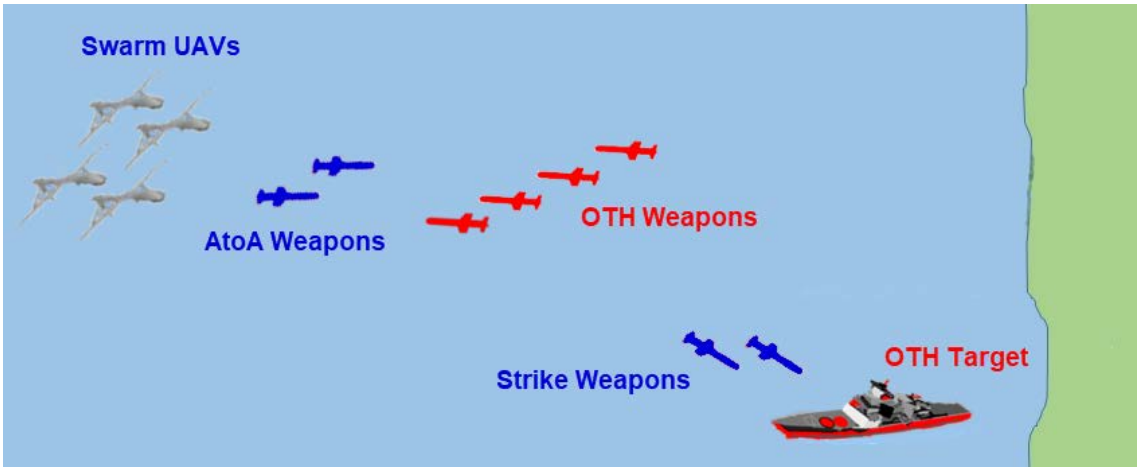


Figure 16. UAV Swarm Engagement Scenario

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The M&S efforts leveraged the UAV types described in the CONOPs and the UAV functional descriptions in the DoDAF architectures. In the mission scenario, the red force "OTH target" can fire on the swarm UAVs during the execution of the OTH-S mission. The scenario outcomes capture the OTH target kill as well as the number of swarm UAVs lost to hostile fire. Successful swarm engagement is defined by the elimination of the OTH target while minimizing swarm UAVs lost to hostile fire. Two critical probabilities were leveraged to evaluate the OTH-S mission success: the probability of striking the OTH target and the probability of a swarm UAV being hit. These two probabilities were central to the series of experiments executed to determine the impact of swarm configurations and UAV performance parameters on engagement success.

The scenario shown in Figure 16 was used to develop the M&S capability. The scenario captures the engagement of the swarm by hostile OTH weapons, as shown in the middle of Figure 16. The inbound threats may be intercepted by the A/A UAV's weapon loadout. The remaining OTH weapons, if any, may be defeated by the jamming energy of the ECM UAV when the ECM UAV is included in the swarm configuration. Any OTH weapons that survive intercept and jamming attempts will have the opportunity to kill a swarm UAV. If the Strike UAV survives the OTH weapons engagement, the UAV will release the strike weapons on the OTH target, as shown in the lower right of Figure 16. The strike weapons will be aided by the sensor-enabled UAV when present in the swarm. Elimination of the OTH target is considered a mission success. Note the scenario detailed above assumes the OTH target environment does not include any factors inhibiting swarm performance.

3. Modeling, Simulation, and Data Analysis Tools

The SSM used for assessing the OTH mission was developed in Excel. This model uses several of the built-in Excel functions including the random number generator and the Binomial Inverse Function, which returns the inverse of the Cumulative Binomial Distribution for a given number of independent trials. These functions allow for probabilistic evaluation of the OTH engagements. The SSM also used the Visual Basic (VB) software in Excel to automate the generation and collection of the swarm

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configuration data. The SSM's VB script runs every allowable swarm configuration and captures the probabilities affecting mission success for each run.

Confidence in the SSM was increased upon comparing the results from the SSM to those obtained from the SSS. The SSS created for this purpose, which was developed in ExtendSim, captures a time-based execution of the OTH mission scenario. The ExtendSim functions for normal distribution time delays, random number generation, and probabilistic branch selection were used to produce the metrics required for comparable assessment of the OTH scenario.

The M&S effort used both the Excel and Minitab statistical analysis tools to assess data generated. Excel was used to calculate the variance and confidence intervals for the data produced by the SSM. The statistical tools in Minitab were used to generate the design of experiments for the UAV performance parameter analyses. Minitab was also used to generate the main effects analysis using the data from the design of experiments (DOE) executions. The role of each tool in the M&S effort is summarized by the flowchart shown in Figure 17.

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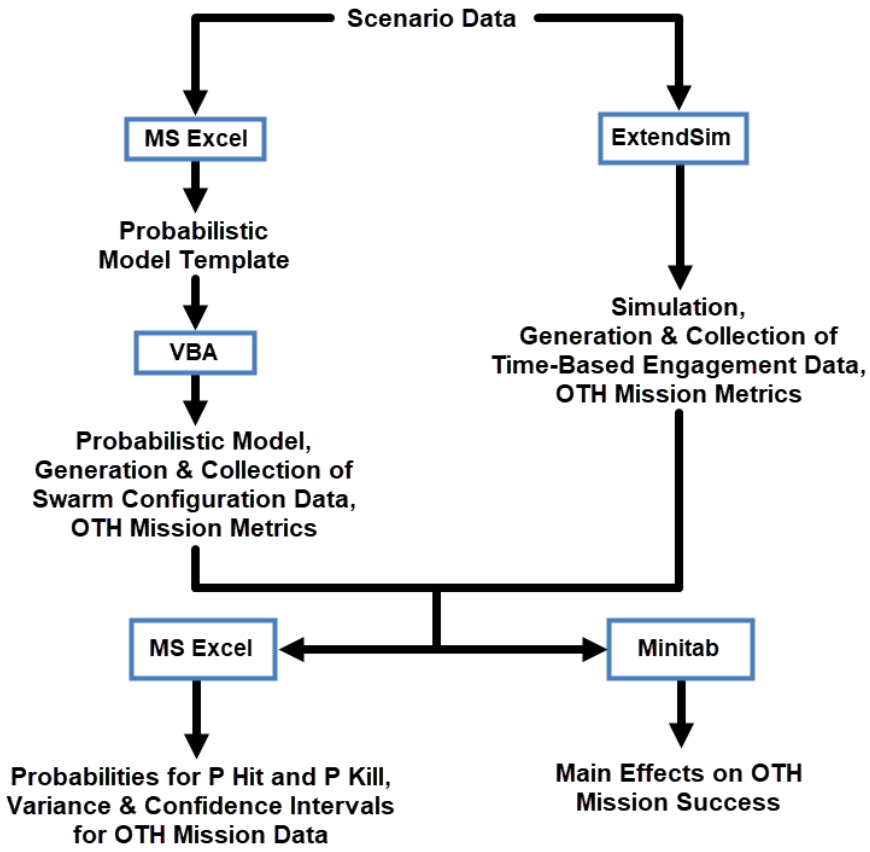


Figure 17. Modeling and Simulation Flowchart

4. Assumptions and Constraints

Several assumptions were made at the onset of the project. For instance, the scenario assumes a single hit to a swarm UAV, the OTH target, or OTH weapon will result in a kill of the targeted asset. In addition, the OTH target position is assumed known prior to swarm launch and will not loiter outside the effective range of the swarm. Note the current SSM and SSS builds neglect adverse effects in the OTH target environment, such as severe weather and geographical influences. Swarm UAV reliability is also neglected.

Both SSM and SSS are constrained to a single OTH target engagement per scenario execution. The OTH weapon performance, percent of kills per engagement, is defined in terms of threat probability of kill (threat P_k) in both the SSM and SSS. Threat P_k in the M&S was held constant at 70 percent throughout scenario execution. The SSM was constrained to having a maximum of five of each UAV type in the mission. This was done

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to manage the complexity of the SSM in relation to its capability for assessing swarm sizes. One functional constraint is that the SSM does nothing to prevent the OTH weapons from targeting the same UAV multiple times. The SSS was developed to have a single configuration of each UAV in the swarm during the scenario execution. This was done to manage the complexity of the SSS and focus on the assessment of the UAV specific performance factors.

5. Modeling and Simulation Capabilities

The M&S effort developed both the SSM and the SSS as a means to provide more fidelity in the OTH mission analysis. A full comparison of the SSM versus the SSS capabilities is shown in Table 3.

Table 3. M&S Capability Comparison

Capability	Modeling	Simulation
UAV performance factors	Included	Included
Swarm UAV configurations	Variable	1 each
OTH target	Single	Single
OTH target weapons loadout	Variable	Set to 4
OTH weapons targeting order	Based on RCS	Based on RCS
OTH weapons targeting fidelity	Low	Medium
OTH weapon performance	Set to 70%	Set to 70%

The low assessment for the SSM targeting fidelity reflects a limitation inherent to the model that allows the continued targeting of a downed UAV. The model's targeting fidelity is further reduced by the instantaneous assessment of all engagements, which negates the effects of volley timing and follow-on target selection. The SSS targeting fidelity was assessed as medium due to the inclusion of a timing component. The timing component allowed for the downing of the A/A or ECM UAV at mission onset. The loss of these UAVs decreased the swarm's defensive capabilities and the OTH weapons were able to target another UAV with a greater kill probability. The SSS targeting fidelity was not assessed as high due to the complexity preventing multiple swarm configurations to be

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readily assessed. As such, only one UAV of each type was represented in the swarm configuration for the simulation effort.

B. DESCRIPTION OF THE MODEL

1. Model Parameters

Weapon performance values are integral to the UAV performance analysis and drive the target kill assessment. The success of a weapon's engagement is quantified by the probability of target intercept, the probability of target elimination upon intercept, and the overall weapon reliability. Factors affecting the performance of assets assigned to the Strike and A/A UAVs are accounted for in their respective success probabilities. Factors affecting the probability of effectiveness for the sensor-enabled and ECM UAVs are accounted for in each UAV's net contribution to the swarm. The sensor-enabled UAV's probability of effectiveness reflects the UAV's ability to enhance the intercept of A/A UAV's intercept of OTH weapons as well as the Strike UAV's probability of OTH target hit. Likewise, the EMC UAV's probability of effectiveness reflects the UAV's ability to degrade the performance of inbound OTH weapons. The M&S efforts did not account for factors affecting UAV reliability, thereby allowing for an engagement success value of 1. Known reliability events could be integrated by multiplying the engagement probabilities by the reliability value of the swarm UAV.

Using the CONOPs and system architecture developed for the OTH mission as a foundation, the team developed the SSM for the swarm OTH engagement scenario. The SSM allows for the assessment of swarm size and selection of UAV assets as well as analysis of individual UAV performance. These metrics are captured in the SSM and expressed in terms of probability of relative success.

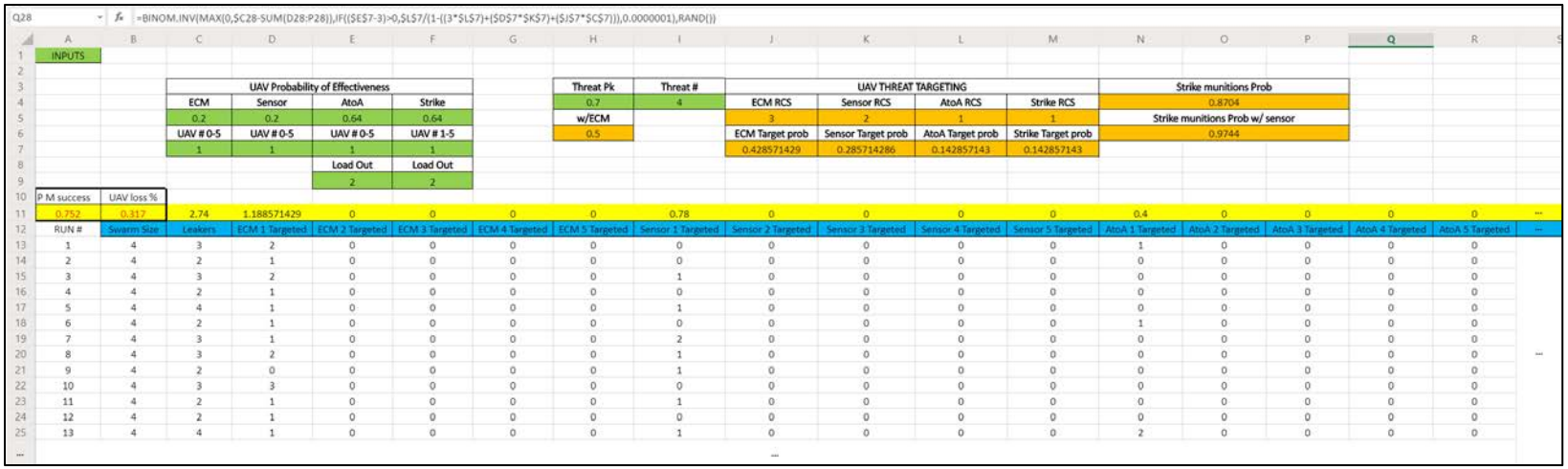
There are several probability factors included in the SSM, such as the probabilities for targeting order for OTH weapons. The UAV targeting probabilities are based on assumptions developed from a radar cross-section (RCS) analysis of the UAVs. An inbound OTH weapon is expected to target the ECM UAV with the sensor-enabled UAV being the next likely target. The remaining OTH weapons would give the A/A and strike

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UAVs equal priority. The ECM UAV is thought to be the priority target for the OTH weapons as the UAV's escort jamming capability is most effective with the UAV in front of the swarm. The ECM UAV is likely the first UAV targeted by the OTH weapons due to its jamming signal transmission and lead formation position. The sensor-enabled UAV's employment of radar to enhance the OTH firing solution also generates considerable radar signature thereby placing the UAV next OTH weapon's targeting order. The A/A and strike UAVs have a similar configuration and asset loadout, which allows the UAVs to share the lowest position in the targeting order.

The probability that a hostile force would target and eliminate a swarm UAV is dependent on the engagement values and performance of the OTH weapons. Successful engagement of the A/A weapons reduces the number of inbound threats. Likewise, the employment of the ECM UAV function minimizes the probability that a hostile threat will be successful in killing a swarm UAV. Once the probability of a successful OTH weapon engagement has been evaluated, and the fallout of the intercept attempt realized, the number of UAV casualties per scenario execution is used to determine the probability of the UAV hit (P_{Hit}) metric. Next, the SSM predicts the success of the OTH target kill using the remaining strike UAVs weapons available. The OTH target kill success is used in the calculation of the probability of success ($P_{Success}$) metric. An excerpt from the SSM is shown in Figure 18.

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Q28 =BINOM.INV(MAX(0,$C28-SUM(D28:P28)),IF(($E$7-3)>0,$L$7/(1-((3*$L$7)+($D$7*$K$7)+($J$7*$C$7))),0.0000001),RAND())

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	INPUTS																	
2																		
3			UAV Probability of Effectiveness					Threat Pk	Threat #	UAV THREAT TARGETING				Strike munitions Prob				
4			ECM	Sensor	AtoA	Strike		0.7	4	ECM RCS	Sensor RCS	AtoA RCS	Strike RCS	0.8704				
5			0.2	0.2	0.64	0.64		w/ECM		3	2	1	1	Strike munitions Prob w/ sensor				
6			UAV # 0-5	UAV # 0-5	UAV # 0-5	UAV # 1-5		0.5		ECM Target prob	Sensor Target prob	AtoA Target prob	Strike Target prob	0.9744				
7			1	1	1	1				0.428571429	0.285714286	0.142857143	0.142857143					
8					Load Out	Load Out												
9					2	2												
10	P M success	UAV loss %																
11	0.752	0.317	2.74	1.188571429	0	0	0	0	0.78	0	0	0	0	0.4	0	0	0	0
12	RUN #	Swarm Size	Leakers	ECM 1 Targeted	ECM 2 Targeted	ECM 3 Targeted	ECM 4 Targeted	ECM 5 Targeted	Sensor 1 Targeted	Sensor 2 Targeted	Sensor 3 Targeted	Sensor 4 Targeted	Sensor 5 Targeted	AtoA 1 Targeted	AtoA 2 Targeted	AtoA 3 Targeted	AtoA 4 Targeted	AtoA 5 Targeted
13	1	4	3	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0
14	2	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	3	4	3	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0
16	4	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	5	4	4	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
18	6	4	2	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
19	7	4	3	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0
20	8	4	3	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0
21	9	4	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
22	10	4	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	11	4	2	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
24	12	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	13	4	4	1	0	0	0	0	1	0	0	0	0	2	0	0	0	0

Figure 18. Swarm Strike Model Excerpt

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The orange boxes shown in Figure 18 highlight the calculated values used in the execution of the scenario. These values are not altered by direct input; however, several values are linked to input values and may vary as a result. The targeting probability values, shown below the probability cells, are mathematically defined by RCS in the targeting process.

The UAV performance inputs and OTH weapons performance parameters are shown in Table 4. These values are also shown in the light green boxes of Figure 18. In addition to these values, the table captures the allowable range for the SSM inputs.

Table 4. Swarm Strike Model Input Parameters

UAV Probability of Effectiveness				
	ECM	Sensor	A/A	Strike
Range	0.01-0.99	0.01-0.99	0.01-0.99	0.01-0.99
	Swarm Configuration			
	ECM	Sensor	A/A	Strike
Range	0-5	0-5	0-5	1-5
	UAV Weapons		OTH Weapons	
	Strike Loadout	A/A Loadout	Threat Pk	Threat Load-out
Range	0-4	0-4	0.7	0-4

The range values shown in Table 4 were used to calculate asset-specific probabilities. While the full range shown in Table 4 is allowed in the SSM execution, the probability of effectiveness for a given platform is bounded by operational effectiveness parameters as well as reliability factors. These bounds were defined by the performance assessments conducted on each UAV platform. The number of weapons a UAV may carry is not mathematically restrained in the SSM; the values shown reflect the range considered for the scenario assessment. Once the SSM functionality was confirmed, a study of the output variance was conducted to assess the consistency of the results.

The data in Table 5 shows the variance in the SSM outputs for $P_{Success}$ and P_{Hit}.

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Table 5. Swarm Strike Model Output Variance

Model	**100 runs**		**200 runs**		**350 runs**		**500 runs**	
Sample	$P_{Success}$	P_{Hit}	$P_{Success}$	P_{Hit}	$P_{Success}$	P_{Hit}	$P_{Success}$	P_{Hit}
1	0.740	0.335	0.750	0.318	0.746	0.304	0.704	0.319
2	0.720	0.315	0.720	0.315	0.717	0.319	0.738	0.313
3	0.720	0.300	0.760	0.286	0.703	0.331	0.740	0.322
4	0.730	0.290	0.725	0.324	0.731	0.305	0.726	0.324
5	0.740	0.293	0.700	0.300	0.766	0.320	0.714	0.321
6	0.770	0.308	0.770	0.311	0.723	0.339	0.720	0.326
7	0.820	0.305	0.720	0.311	0.723	0.354	0.746	0.328
8	0.700	0.343	0.745	0.336	0.709	0.325	0.748	0.313
9	0.720	0.310	0.715	0.326	0.743	0.327	0.744	0.309
10	0.710	0.328	0.740	0.300	0.706	0.317	0.736	0.319
11	0.740	0.300	0.760	0.314	0.726	0.335	0.734	0.316
12	0.720	0.288	0.720	0.331	0.686	0.338	0.718	0.318
13	0.840	0.303	0.740	0.331	0.746	0.315	0.728	0.319
14	0.740	0.323	0.760	0.320	0.737	0.323	0.732	0.331
15	0.780	0.333	0.740	0.305	0.726	0.326	0.706	0.319
16	0.680	0.328	0.775	0.290	0.729	0.317	0.738	0.317
17	0.730	0.315	0.695	0.323	0.751	0.312	0.692	0.309
18	0.700	0.298	0.725	0.296	0.706	0.328	0.744	0.328
19	0.780	0.295	0.780	0.301	0.737	0.320	0.750	0.317
20	0.740	0.310	0.715	0.319	0.731	0.329	0.756	0.314
Variance	1.58E-03	2.57E-04	6.04E-04	1.98E-04	3.66E-04	1.38E-04	2.91E-04	3.71E-05
Mean	0.741	0.311	0.738	0.313	0.727	0.324	0.731	0.319
95% CI +/-	0.019	0.007	0.012	0.007	0.009	0.005	0.008	0.003
99% CI +/-	0.025	0.010	0.016	0.009	0.012	0.008	0.011	0.004

The number of model trials was gradually increased from 100 to 500 runs per engagement. All inputs for the SSM were held constant during the increase of trial runs. A selection of 20 samples was collected at the higher trial count for statistical analysis. As shown in Table 5, the observed variance decreases as the number of trial runs increases per

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engagement. The variances were then used to calculate the 95 and 99 percent confidence intervals. The benefit of adding additional trial runs on $P_{Success}$ output decreases significantly from 350 to 500 runs. Based on the minimal difference in obtained data and the increased time required to run the SSM, a run size of 350 was selected for the remaining analyses.

2. Model Runs for UAV Performance Factors

The SSM established six UAV performance factors. The ECM and sensor performance, as well as loadout, A/A, and strike weapon performance, were assigned values of estimated effectiveness on a scale from zero to one; a value of zero represents no effect and a value of one would be completely effective. For instance, an effective range of 0.20 to 0.50 was estimated for the ECM UAV while the sensor UAV was assigned an effective range of 0.20 to 0.50. Using the six UAV performance factor inputs to the SSM, a 2-level factorial design of experiments (DOE), with a 1/8 fraction and a single center point per cube, was developed. The performance modeling inputs and outputs for the DOE are captured in Table 6.

Table 6. UAV Performance Modeling DOE

P_{ECM}	P_{Sensor}	$P_{A/A}$	P_{Strike}	Strike Loadout	A/A Loadout	$P_{Success}$	P_{Hit}
0.20	0.50	0.64	0.64	4	1	0.723	0.391
0.20	0.50	0.64	0.84	1	4	0.831	0.182
0.20	0.20	0.84	0.64	4	4	0.946	0.086
0.20	0.20	0.84	0.84	1	1	0.697	0.351
0.50	0.20	0.64	0.64	1	4	0.760	0.091
0.50	0.20	0.64	0.84	4	1	0.849	0.208
0.35	0.35	0.74	0.74	3	3	0.931	0.152
0.50	0.50	0.84	0.64	1	1	0.809	0.170
0.50	0.50	0.84	0.84	4	4	0.983	0.029

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Referring to Table 6, the ECM P-value relates to the degradation in the performance of an inbound OTH weapon as caused by the ECM UAV. On the offensive, the sensor performance (Sensor P) value represents the enhancement of the strike weapon's performance afforded by the sensor-enabled UAV. The A/A and strike performance (Strike P) values represent the probability of hit for each weapon in the A/A and strike UAV loadout. The strike and A/A loadout values capture the total number of weapons in the swarm as equipped by the respective UAV platform.

The swarm configuration was maintained at one UAV of each configuration to ensure that multiple UAVs of the same platform did not weigh the performance parameters. The OTH weapons loadout was set to four to present a stressing engagement for the swarm. The results of the DOE were evaluated in Minitab. The main effects for the probability of OTH hit ($P_{Success}$) and the probability of UAV hit (P_{Hit}) are captured in Figures 19 and 20.

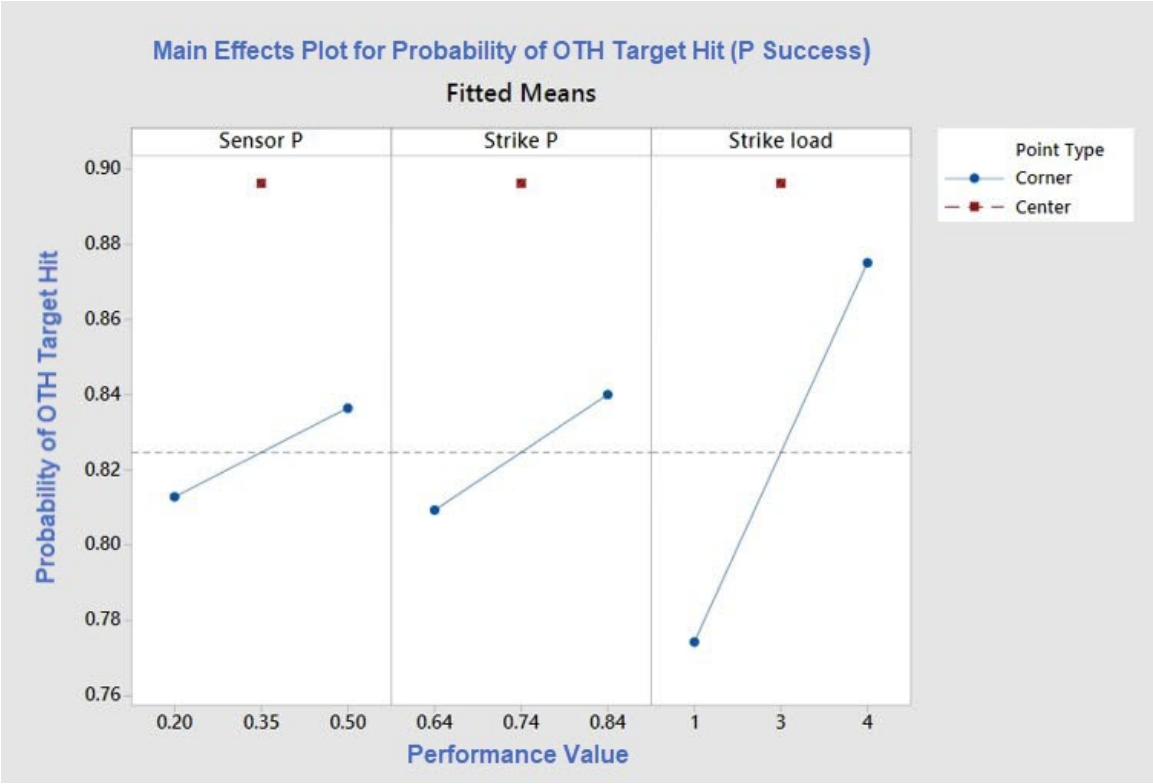


Figure 19. Engagement Probability of Success Main Effects

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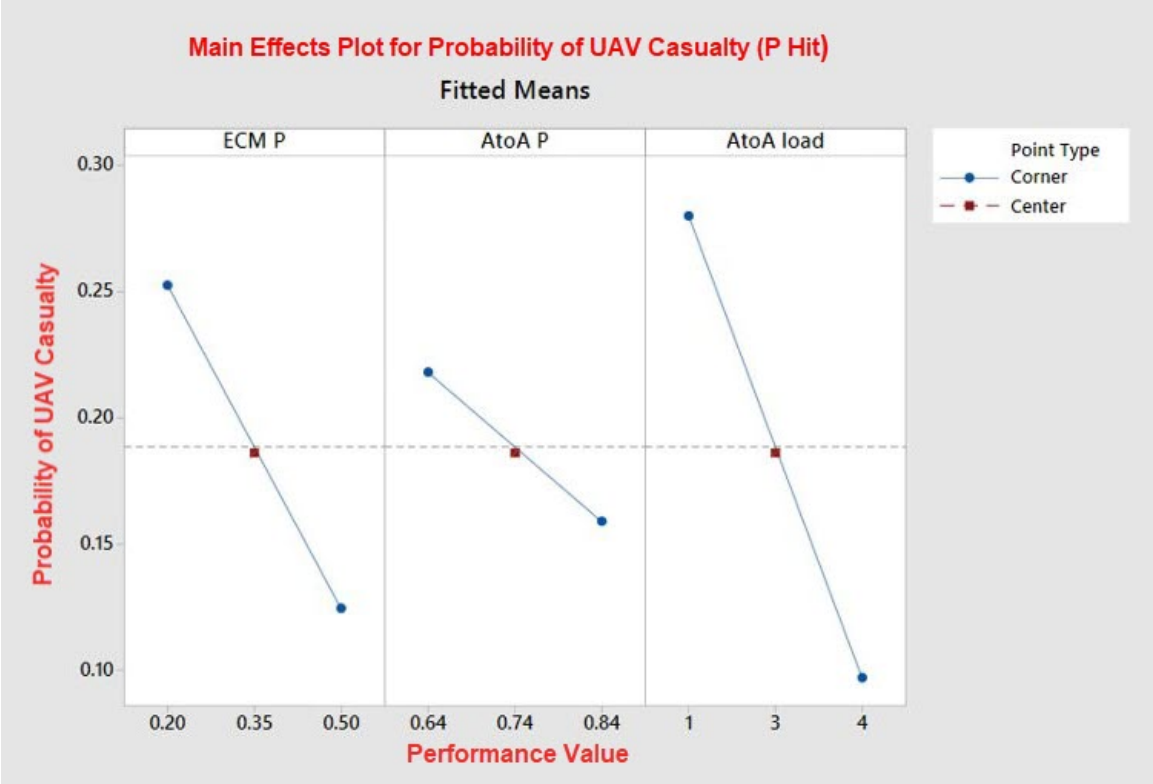


Figure 20. Engagement Probability of Hit Main Effects

The slope of the line in the main effects plots captures the impacts of the UAV performance factors on the engagement criteria. The plots show that increasing the strike loadout has the most significant impact on the probability of OTH hit. While increasing the A/A loadout has the most significant impact on the probability that a UAV is hit. The overall engagement was evaluated, and the SSM is predicting that UAV survivability is driving $P_{Success}$ for the OTH engagement.

3. Model Runs for Swarm Configurations

Utilizing the swarm configuration capability of the SSM, a two-level factorial DOE with a 1/8 fraction and a single center point per cube, for the swarm size was developed in the Minitab software tool. The model inputs and outputs for the swarm size DOE, shown in Table 7, cover the analysis of a mission where the OTH target has a loadout of four weapons.

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Table 7. Swarm Size and Configuration Modeling Design of Experiments with a Red Force with a Return Fire Capability of Four Weapons

ECM UAV	Sensor UAV	A/A UAV	Strike UAV	$P_{Success}$	P_{Hit}
5	5	0	1	0.914	0.173
0	0	5	5	1.000	0.003
0	0	0	1	0.006	0.994
0	5	0	5	1.000	0.246
5	0	0	5	0.997	0.180
5	5	5	5	1.000	0.001
5	0	5	1	0.803	0.002
0	5	5	1	0.963	0.004

The data shown in Table 8 has the inputs and outputs for the analysis of a mission where the OTH target has no return fire capability.

Table 8. Swarm Size and Configuration Modeling Design of Experiments with a Red Force with No Return Fire Capability

ECM UAV	Sensor UAV	A/A UAV	Strike UAV	$P_{Success}$
5	5	0	1	0.969
0	0	5	5	1.000
0	0	0	1	0.834
0	5	0	5	1.000
5	0	0	5	1.000
5	5	5	5	1.000
5	0	5	1	0.883
0	5	5	1	0.963

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The combination of each of the UAV configuration numbers equates to the total swarm size for the engagement. The performance inputs remained constant at 0.2 for the ECM and sensor, while the A/A and strike weapons performance values were set to 0.64. The A/A and strike loadouts were set to two each. The swarm size was evaluated for an OTH weapons loadout of zero, or non-stressing, and loadout of four, a highly stressing engagement. The results of the DOE were evaluated in Minitab. The following three figures capture the main effects for the probability of OTH hit ($P_{Success}$) based on the red force OTH loadouts of zero (shown in Figure 21) and four (shown in Figure 22) as well as the probability of UAV hit (P_{Hit}) for an OTH loadout of four (shown in Figure 23).

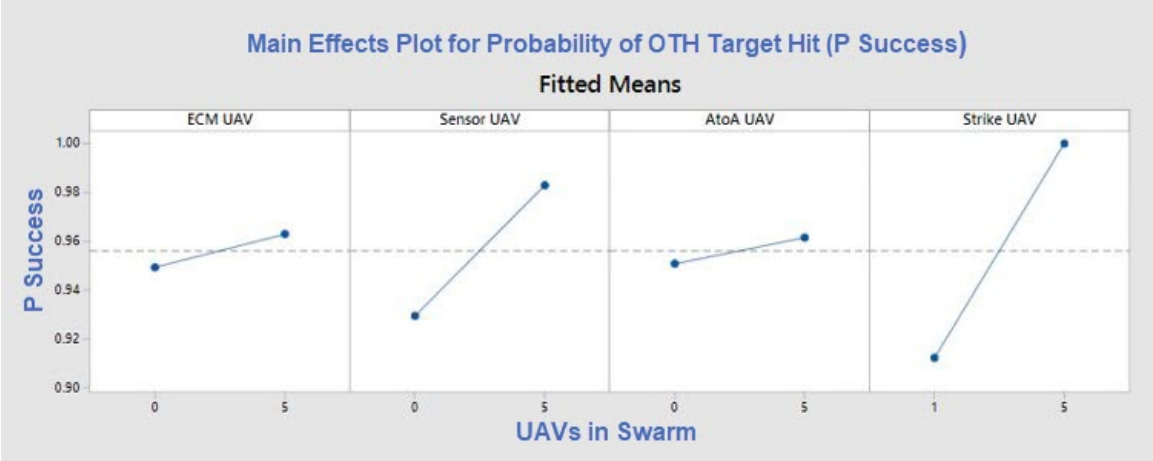


Figure 21. Probability of Success Main Effects for Red Force with No Return Fire Capability

The main effects plots for the modeling parameters show the strike UAV is the performance driver for the scenario in which the red force has no return fire capability. The A/A and ECM UAVs have a negligible impact in this scenario since there are no OTH weapons to act upon.

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The main effects plot in Figure 22 shows all UAV configurations are significant in the scenario where the red force can return fire using four weapons. As seen in Figure 22, increasing the number of strike UAVs has the most significant positive impact on mission success. A swarm consisting of five strike UAVs provide additional opportunities for engagement of the OTH target. However, a UAV swarm consisting solely of strike UAVs is more susceptible to casualties and is not ideal.

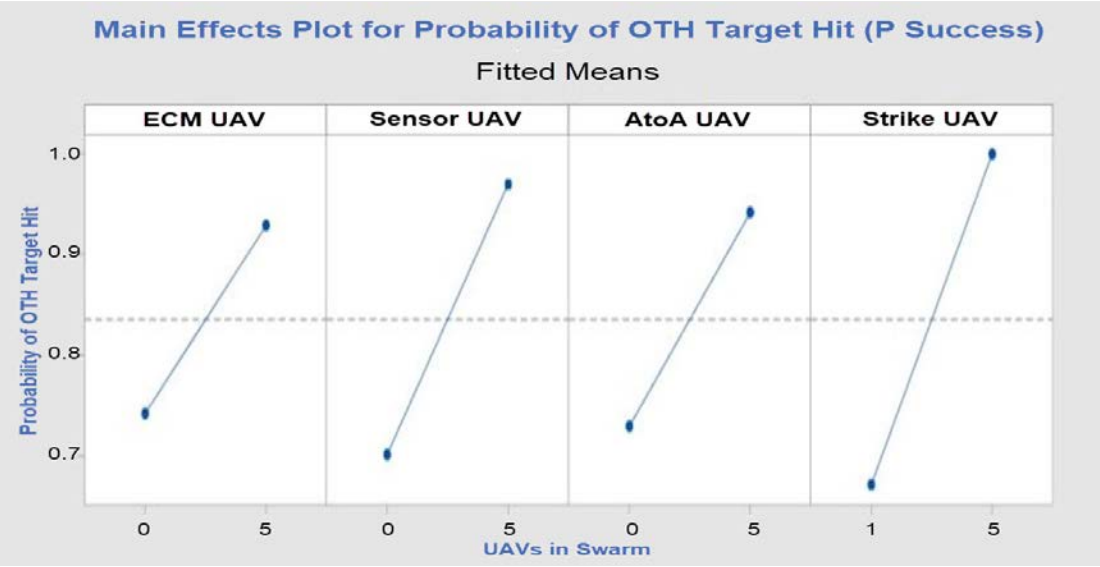


Figure 22. Probability of Success Main Effects for Red Force with Four Return Fire Weapons

The main effects plots in Figure 23 show that the UAV hit (P_{Hit}) performance driver for the four fire OTH engagement is the A/A UAV. The sensor and strike UAVs have an equivalent impact on P_{Hit} due to the constant OTH weapons having an increasing number of targets. However, increasing the number of A/A UAVs has the most significant positive impact on the P_{Hit} criteria for mission execution.

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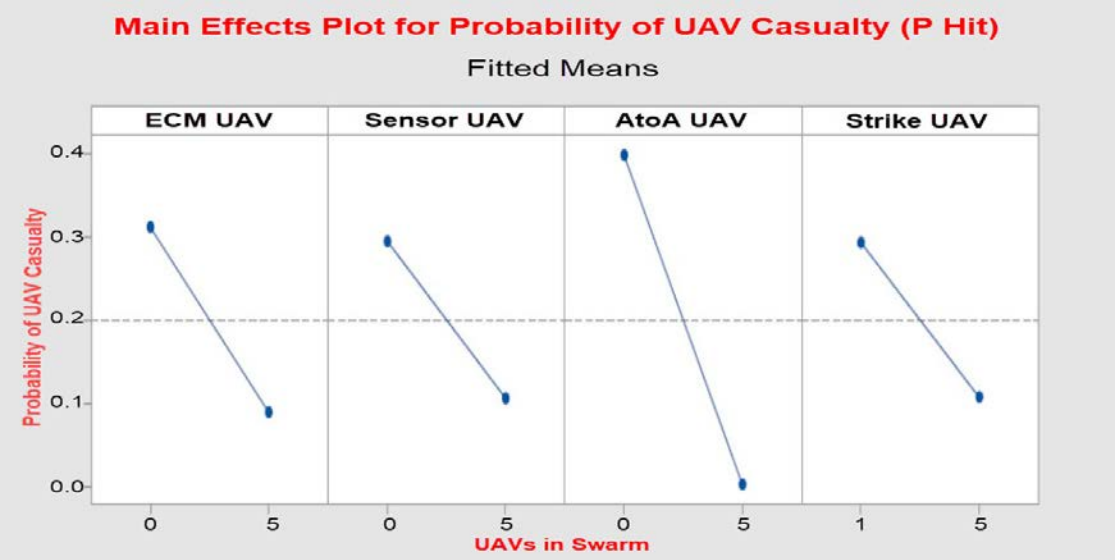


Figure 23. Probability of Hit Main Effects against Red Force with a Return Fire Capability of Four Weapons

4. Lookup Table Model of Swarm Configurations

The SSM was also used to produce a table of swarm configurations as a lookup table for the execution of a set of OTH engagements, as shown in Table 9. This table was developed by evaluating the OTH return fire capability shown in the threat column. The swarm configurations were chosen by maximizing the probability of OTH hit ($P_{Success}$) while minimizing the values of UAV hit (% UAV loss) and reducing the UAVs committed to each engagement to ensure the highest number of missions could be completed.

Table 9. Swarm Configuration for OTH Engagement

Threat No.	ECM No.	Sensor No.	A/A No.	Strike No.	$P_{Success}$	P_{Hit}	Swarm Size
0	0	1	0	1	0.986	0.000	2
1	1	1	1	1	0.963	0.014	4
2	0	1	1	2	0.971	0.119	4
2	1	1	2	1	0.963	0.021	5
3	0	1	2	2	0.974	0.081	5
3	1	1	1	2	0.974	0.175	5
4	0	1	2	2	0.969	0.170	5
4	1	1	1	2	0.966	0.260	5

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The data in Table 9 represents the recommended swarm sizes for deployment against OTH targets that have a known return fire capability. For an OTH target without return fire capability, the SSM is predicting that a swarm configuration of one sensor and one strike UAV will have a 98% probability of target kill. The prediction for the stressing scenario includes two swarm configurations with good probabilities for the scenario metrics of $P_{Success}$ and P_{Hit}. The determining factor in using one swarm configuration over another is made when planning the likelihood of follow on missions. Choosing to deploy a swarm consisting of a single A/A UAV allows an additional OTH mission to be accomplished using an A/A UAV in the swarm.

C. SIMULATION ANALYSIS

The SSS executes the single OTH target engagement with the same mission performance parameter outputs as the SSM. The UAV performance simulation the SSS for the OTH engagement was developed to increase the fidelity of the performance data analysis. The OTH engagement in the SSS was developed in two parts. The first part captures the incoming fire of the OTH weapons. The second part evaluated the engagement of the OTH target based on the surviving swarm UAVs. The SSS includes functionality that disables the targeting and capabilities of UAVs that have been hit by the OTH salvo.

The SSS is shown in Figure 24 was used to conduct an additional assessment of the UAV performance factors. This data was used to build confidence in the modeling results as well as provide further evaluation of the scenario success drivers based on UAV performance factors.

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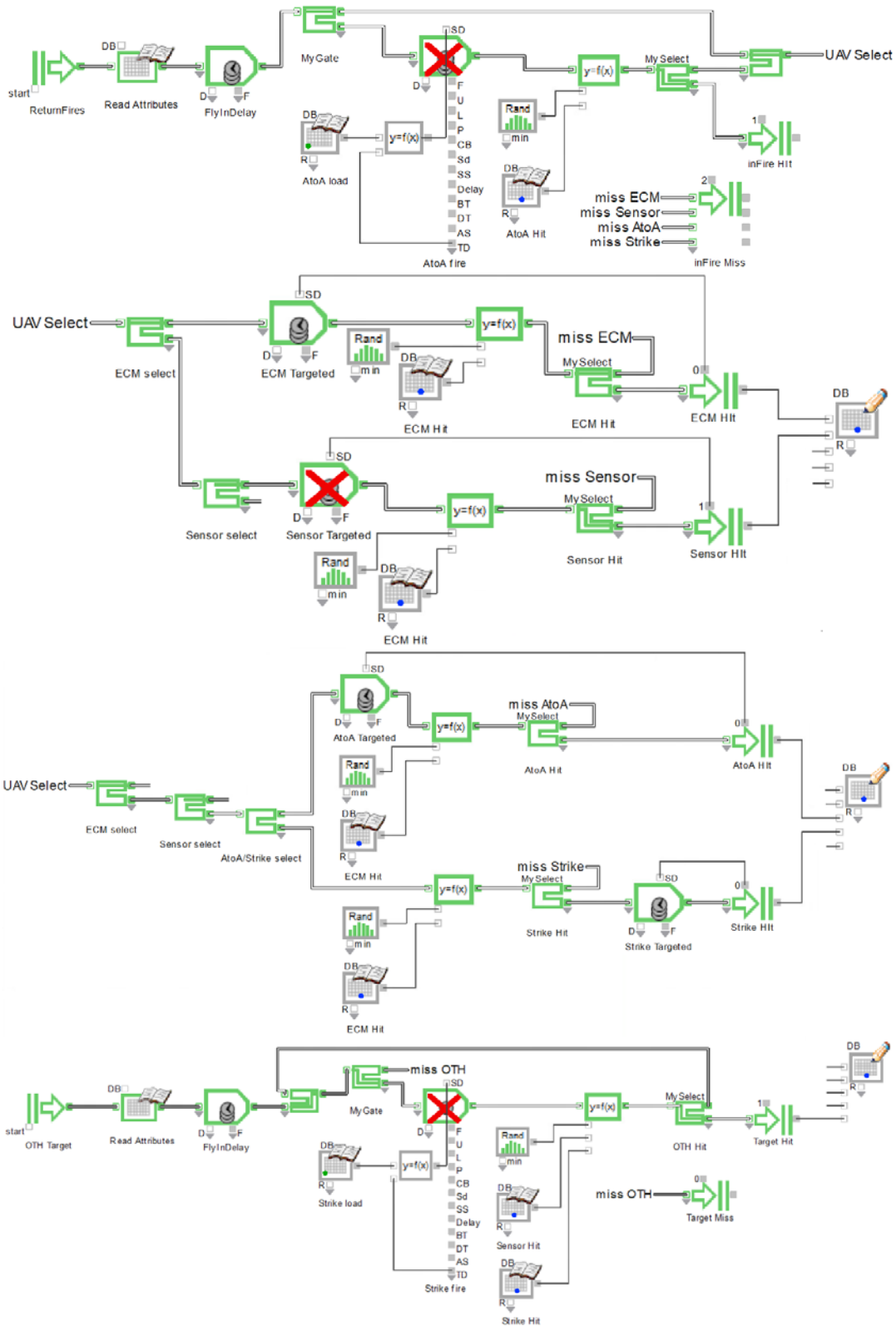


Figure 24. Swarm Strike Simulation

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When the SSS functionality matured, 20 runs of data were collected using the same performance parameters as the model data from Table 5. This data is shown in Table 10. The variance from the SSS for the $P_{Success}$ is smaller than the SSM which shows that the simulation has a more repeatable assessment of $P_{Success}$. The variance from the SSS for the P_{Hit} is larger than the SSM which shows that the model has a more repeatable assessment of P_{Hit}. The P_{Hit} variation could be due to the higher fidelity implementation of the UAV targeting in the SSS.

Table 10. Swarm Strike Simulation Output Variance

Simulation	**350 runs**	
Sample	$P_{Success}$	P_{Hit}
1	0.711	0.333
2	0.683	0.368
3	0.674	0.356
4	0.683	0.368
5	0.694	0.359
6	0.674	0.356
7	0.689	0.354
8	0.680	0.353
9	0.686	0.379
10	0.666	0.345
11	0.697	0.371
12	0.677	0.346
13	0.674	0.334
14	0.709	0.379
15	0.671	0.356
16	0.689	0.364
17	0.703	0.341
18	0.686	0.359
19	0.674	0.342
20	0.697	0.351
Variance	1.620E-04	1.761E-04
Mean	0.686	0.356
95% CI +/-	0.006	0.006
99% CI +/-	0.008	0.008

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The run data from the variance assessment was used to compare the mission performance outcomes ($P_{Success}$ and P_{Hit}) averages using the Excel t-test function with unequal variances. The t-test data in Table 11 shows that the SSM and SSS are producing different results for the mission outcomes. This was expected, as the refinement provided by the SSS should have a significant impact on the mission outcome.

Table 11. Swarm Strike Simulation UAV Performance DOE

P Success t-Test: Two-Sample Assuming Unequal Variances		
SSM/SSS 90% confidence		
	SSM	*SSS*
Mean	0.727	0.686
Variance	3.660E-04	1.620E-04
Observations	20	20
Hypothesized Mean Difference	0.000	
df	33	
t Stat	8.003	
P(T ≤ t) one-tail	1.5566E-09	
t Critical one-tail	1.308	
P(T ≤ t) two-tail	3.1133E-09	
t Critical two-tail	1.692	
P Hit t-Test: Two-Sample Assuming Unequal Variances		
SSM/SSS 90% confidence		
	SSM	*SSS*
Mean	0.324	0.356
Variance	1.376E-04	1.761E-04
Observations	20	20
Hypothesized Mean Difference	0.000	
df	37	
t Stat	-7.983	
P(T ≤ t) one-tail	7.2422E-10	
t Critical one-tail	1.305	
P(T ≤ t) two-tail	1.4484E-09	
t Critical two-tail	1.687	

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Now that the SSS fidelity has been assessed, the OTH mission can be analyzed. This was done through the execution of the performance DOE parameters from the modeling assessment shown in Table 6. The DOE parameters were run through the SSS with 350 executions per row. Table 12 shows both the DOE inputs and outputs for the UAV performance in the SSS.

Table 12. Swarm Strike Simulation UAV Performance DOE

P_{ECM}	P_{Sensor}	$P_{A/A}$	P_{Strike}	A/A Loadout	Strike Loadout	$P_{Success}$	P_{Hit}
0.20	0.50	0.64	0.64	1	4	0.651	0.414
0.20	0.50	0.64	0.84	4	1	0.800	0.193
0.20	0.20	0.84	0.64	4	4	0.951	0.089
0.20	0.20	0.84	0.84	1	1	0.606	0.419
0.50	0.20	0.64	0.64	4	1	0.774	0.087
0.50	0.20	0.64	0.84	1	4	0.837	0.192
0.35	0.35	0.74	0.74	3	3	0.897	0.156
0.50	0.50	0.84	0.64	1	1	0.797	0.181
0.50	0.50	0.84	0.84	4	4	0.980	0.036

The performance results from the SSS reinforce the performance analysis from the SSM. This increases the confidence that the analysis and findings from the modeling effort are useful. The DOE analysis from Minitab produced the same main effects results that were observed in the modeling analysis. These effects are shown in Figures 25 and 26.

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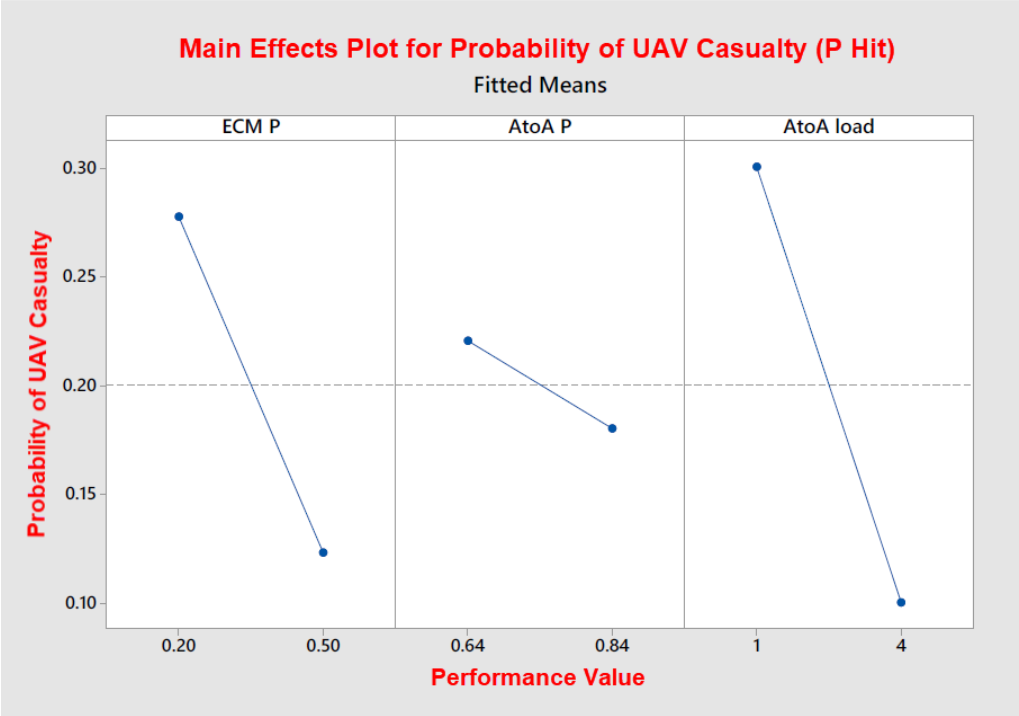


Figure 25. Swarm Strike Simulation Probability of Hit Main Effects Plot

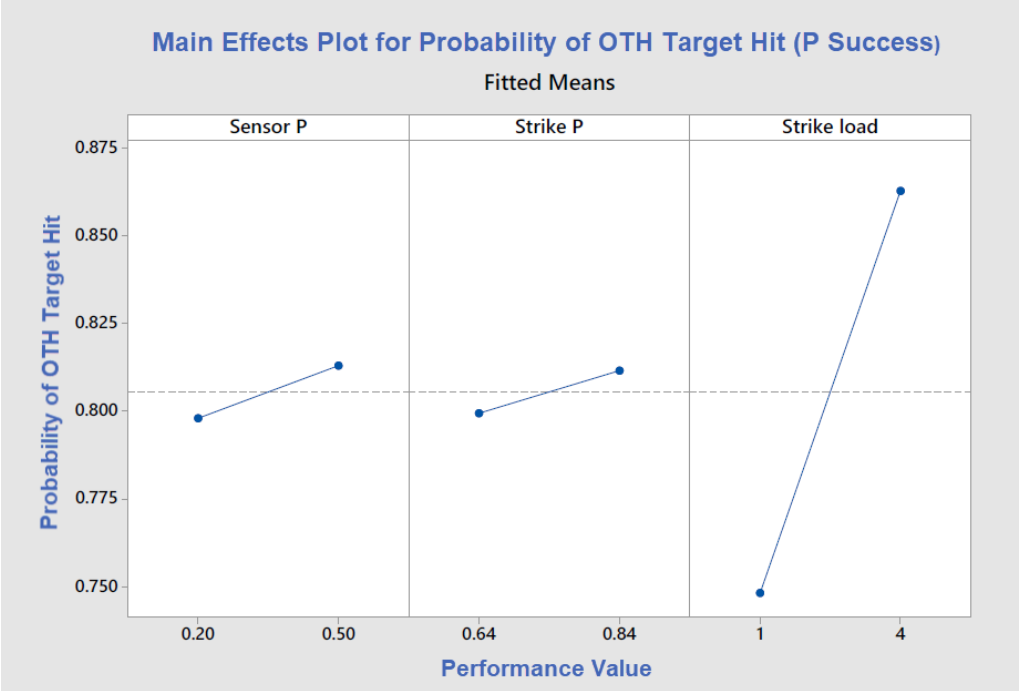


Figure 26. Swarm Strike Simulation Probability of Success Main Effects Plot

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This simulation could be utilized to further explore the UAV performance through the addition of an extended time delay for the engagements, which was not captured in this data. If the time between the release of the OTH weapons was lengthened to the point where an A/A UAV was hit, the swarm capability to intercept the next weapon would be reduced. This could result in changes to the performance driver analysis.

The M&S effort produced data that was well-matched and provided confidence that the scenario is producing believable results. It also provided the performance assessments for this project. Based on the development and assessment of the M&S tool, a usable table of swarm configurations was developed. The UAV performance factors that were identified as scenario success drivers helped identify critical UAV capabilities within the swarm. The data and analyses developed can be used to help inform the development of a BREM swarm capability.

D. COST ANALYSIS

With the move towards the usage of UAVs for combat, it is important to look at the cost implications. In a 2012 study, the average unit cost for a Lockheed Martin F-22 Raptor was approximately $186M (Boyle 2012). In addition, the average yearly cost for operations and support for each aircraft was approximately $11.5M with each flight hour costing the military $11.5K (Boyle 2012). Likewise, the Lockheed Martin F-35 Lighting II has an estimated unit cost of $91M with an average yearly operations and support cost of $5M per aircraft (Boyle 2012); current estimates expect the Lighting II's cost per flight hour to be reduced to $25K (McCarthy 2018). The premier electronic attack platform, the Boeing EA-18G Growler, costs an estimated $70M per unit (Defense Acquisition Management Information Retrieval 2017) with an average yearly operations and support cost per aircraft of approximately $6M; the cost to operate the Growler per flight hour is $25K (Defense Acquisition Management Information Retrieval 2017). With the high unit and operational and support costs, it is worth considering the cost-benefit of tasking UAV platforms to fulfill these critical roles.

From the same 2012 study, the unit cost for a General Atomics MQ-1C Gray Eagle was cited at $26.5M with an average yearly operations and support cost of $8M per unit,

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per year (Boyle 2012). Similarly, the General Atomics MQ-9 Reaper was reported to have a per-unit cost of $6.5M per unit with operations and support cost of $3M per unit, per year; the per flight hour cost for the Reaper is estimated at $3.25K (Boyle,2012). Likewise, the Northrop Grumman RQ-4 Global Hawk's has an average unit cost was $103M with an operations and support cost of $15.6M per unit, per year; the per flight hour cost for the Global Hawk is estimated at $31K (Boyle 2012). Table 13 summarizes unit and flight-hour costs.

Table 13. Cost Comparison of Manned and Unmanned Platforms

Mission Role	Strike/A/A				Sensor/ECM	
Platform	F-22 (M)	F-35 (M)	MQ-1C (U)	MQ-9 (U)	EA-18G (M)	RQ-4 (U)
Unit Cost ($M)	186	91	26.5	6.5	70	103
Flight Hour Cost ($K)	11.5	25	-	3.25	25	31
(M) – manned platform, (U) – unmanned platform						

A comparison of the costs of aerial vehicles shows an especially large variance between the unit cost. Both the MQ-1C Gray Eagle and MQ-9 Reaper are used specifically for combat, like the F-22 Raptor and F-35 Lightning II. The F-22 and F-35 may be equipped with an ECM system. Similarly, the MQ-1C Gray Eagle and MQ-9 Reaper have an available ECM payload (Air Force Technology n.d.). When comparing the UAVs to the manned combat vehicles, the conclusion becomes clearer. The average unit cost of the two conventional manned aircraft is $132M. Conversely, the two combat-capable UAVs average $19M per unit. The RQ-4 Global Hawk is primarily used for its reconnaissance capabilities which makes it a great selection for the sensor-enabled UAV. On a similar note, the EA-18G Growler is strictly purposed for electronic warfare, surveillance, and reconnaissance. Evaluated strictly on cost, the UAV option is less favorable. Although the RQ-4 Global Hawk exceeds the EA-18G Growler in unit cost, O&S cost, and flight-hour costs, its deployment eliminates the risk of service member casualties.

Reflecting on Chapter IV, the foundation provided by previous chapters allowed for the modeling and simulation of the OTH mission execution by the UAV swarm. The

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follow-on analyses found consensus in that OTH mission success is most affected by weapon stores (A/A and strike munitions). Also, the comparative cost analysis for manned versus unmanned platforms found the unmanned platform alternatives to be less costly, save for the ECM function, while eliminating the risk to service members that would otherwise be fulfilling platform role. Moving into Chapter V, the findings of this project will be further discussed with the contributions and potential application benefits identified. The chapter will conclude with a look towards future work that would aid in the further development of the BREM project.

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V. FINDINGS AND FUTURE WORK

A. FINDINGS

The team used a modified system engineering approach to study the operational utility of adding a swarm of UAVs for the OTH mission. The approach was based on the traditional systems engineering "vee" with a focus on the development of a CONOPs and system architecture, and modeling and simulation (M&S) analysis. The team developed the SSM and ran scenarios to conduct three sets of analyses. The analyses centered on the execution of the OTH mission and included a UAV performance analysis, a swarm size analysis, and a swarm configuration analysis.

The CONOPs development process identified specific UAV configurations for use in the swarm. The process also captured the functional description of the UAV configurations and related the performance of the respective UAV platform as a member of the swarm. The CONOPs itself described the basics of swarm configuration as it relates to executing the OTH mission. The CONOPs also began the development of the BREM swarm mission definitions and the OTH mission scenarios.

The architecting processes that followed the CONOPS development further matured the CONOPs by establishing the system of systems definitions for the BREM swarm. The team produced a series of operational and system views that identified UAV configuration data and communications needs. The architecture aided in describing the need for support assets in the execution of the BREM swarm mission.

The team conducted an M&S effort as a quantitative approach for assessing swarm success during the execution of the OTH strike scenario. The SSM, developed in Microsoft Excel, took a probabilistic approach to capture and evaluate the OTH strike scenario. The SSS used a similar approach to scenario execution but added fidelity to the weapon engagements and was developed in ExtendSim9. The scenario utilized in the M&S effort was developed using the information captured in the CONOPs. The quantitative approach of the M&S effort established performance metrics for the various UAV configurations. The effort also allowed for the capture of swarm size and configuration on OTH mission

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success. To this end, mission success was evaluated using the probability the swarm would kill the OTH target contrasted against the probability of a loss of a swarm UAV.

A DOE was developed for the UAV performance using the M&S metrics and analysis was completed using the SSM. The results from each of the DOEs were evaluated for main effects drivers. In the UAV performance modeling analysis, the strike loadout was identified as the driving parameter for the OTH hit probability. The analysis also revealed the A/A loadout to be the main driver of the probability that an incoming threat would hit a UAV. The swarm performance assessment was repeated using the SSS with comparable results.

The swarm size assessment and configuration analysis used a standard set of UAV performance values. A DOE was developed for the swarm size assessment and completed using the SSM. The analysis found the strike UAV configuration to be the critical UAV platform for the successful engagement of the OTH target. In addition, loss of the strike UAV was most detrimental to the success of the OTH strike mission. Successive runs of the SSM were completed to obtain the data used in swarm configuration analysis. The swarm configuration analysis provided the probability of an OTH kill as well as the probability of UAV loss for the various configurations. The team produced a table of recommended swarm configurations that depend on the number of red force return fire weapons. When the red force return fire loadout is known, the look-up table (contained in Table 9) shows the minimum number and type of UAV swarm that produces a high probability of success and a low probability of being hit.

The cost analysis for utilizing current UAV technology in the execution of the OTH mission showed that a swarm implementation would likely increase the cost. However, two factors could drive the decision in favor of the use of a UAV swarm for OTH missions. The first is that delivering more UAVs in more mission areas will reduce the unit cost. The second is that as the UAV technology matures with the higher demand, the cost of delivering UAVs will be reduced. These factors, in addition to the casualty risk associated with OTH mission execution, push the decision in favor of utilizing UAVs.

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B. CONTRIBUTIONS

The modified systems approach completed during this capstone project produced several contributions to the BREM system. The project developed a CONOPs and architecture for the OTH mission that can be utilized in the pursuit of enabling swarm mission capability. In addition, the usable swarm configuration could be used as a lookup table by surface ship combat systems for the execution of the BREM swarm missions. The results of the M&S effort can aid in developing further analyses to unlock new capabilities to be implemented in the OTH mission. The method, data, and tools established by this project could be leveraged to develop similar analyses of existing naval capabilities.

C. POTENTIAL BENEFITS

A practical and near-term benefit of the study will be an Excel application and ExtendSim model to support BREM development and to be used for this project's analysis as well as future analyses. The Excel application will have an interface in which the user may input information regarding the UAVs, coordinates, weaponry, and opposing forces. The application is expected to output the strategic positioning and predictive engagement strategy. The ExtendSim program is expected to mirror the results of the Excel application and provide graphs and visuals to help illustrate.

The results of the project's analysis will provide recommendations and lessons-learned for implementing the addition of UAVs into the BREM automated mission planning decision aid. The M&S of a variety of UAV combinations and configurations for OTH missions will provide an understanding of the operational utility of UAVs for this mission domain. The analysis results will inform the stakeholders of the benefits of integrating the UAVs to the existing BREM gaming system. The stakeholders may also leverage the project towards further development of, and insight into, the BREM functionality as well as UAV capability.

UAV system developers at the forefront of the BREM project will benefit greatly from the project. The results of this study will support the autonomous decision-making component of BREM by adding the potential operational utility of UAVs to the OTH mission. The objective of BREM is consistently to stay in the optimal battle condition of

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the matrix, leading to the highest probability of battle success. With the addition of UAV capabilities and strategies, the BREM will have the potential to achieve even more significant improvements in battle-readiness for OTH missions.

D. FUTURE WORK

The team recommends the swarm size and configuration modeling analysis be repeated using real-world data for UAV effectiveness and reliability. For a baseline, the UAV probabilities could be given F/A-18 performance metrics for similar missions as it is equipped with a sensor package that is similar in concept to the sensor-enabled UAV. In addition, the F/A-18 also features an escort jamming capability that matches the ECM UAV functionality. Lastly, the F/A-18 load outs could be leveraged for the A/A and strike mission package probabilities. By using the F/A-18 data, a better-informed analysis could be completed for the mission effectiveness of the BREM swarm UAVs. The use of measured or predicted values for known UAV reliability could also increase the fidelity of the modeling analysis.

The team also recommends the OTH mission, as completed by manned platforms, should be analyzed to establish a comparative baseline. The data provided by the baseline analysis would allow for a comparative analysis between manned and unmanned assets. In addition, an analysis of manned and unmanned platforms may yield a higher mission probability than either platform on its own.

Further work could be directed towards evaluating the impact of changing the UAV targeting priority during the execution of the OTH scenario. For instance, the ECM and sensor-enabled UAVs could effectively remain outside the OTH engagement range if the ECM UAV supported the swarm as a stand-off jammer with the sensor-enabled UAV acting as a loitering sensor. Removing two UAVs from the engagement area would concentrate on inbound threats, which may increase the probability of successful interception by the A/A weapons. The resulting changes to the OTH targeting methodology would likely necessitate the iteration of the UAV performance drivers and swarm size analyses.

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Another area of development would be enhancing the OTH scenario to reflect a dynamic environment. The addition of swarm UAV countermeasures, environmental factors, and OTH target capabilities would add a layer of fidelity to the SSM. The inclusion of swarm countermeasures would further enhance UAV survivability. Environmental factors affecting UAV and weapon performance would provide insight into optimal swarm configurations for varying environmental conditions of real-world scenarios. Predicting and acknowledging the capabilities of the OTH target are vital to reflect the complex environment accurately in which the strike weapons must operate. Each of these factors necessitates iteration of the UAV performance drivers and swarm size analyses to enable a more versatile swarm configuration.

Further engagement cost analysis would prove beneficial. Dependent on the acceptable level of risk, it would be advantageous to know which UAV configuration yields the greatest probability of success at the lowest cost. This information would provide engagement decision makers with the best cost-benefit analysis. In turn, this would support the allocation of defense spending towards the areas that have the greatest impact on OTH engagement success probability.

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THESIS

ANALYZING THE CHALLENGES AND OBSTACLES TO DEVELOPING AND FIELDING AUTONOMOUS AND SEMI-AUTONOMOUS SYSTEMS

by

Mario D. Williams and Phillyp C. Lawson

June 2020

Thesis Advisor: Robert F. Mortlock
Co-Advisor: Raymond D. Jones

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Autonomous and semi-autonomous systems operate on a system of systems (SoS) framework, utilizing their own ability to sense, perceive, analyze, and execute actions to achieve their goals. Unmanned systems present a significant challenge for the Department of Defense's (DoD) acquisition process that was established to develop and field man-in-the-loop type capabilities. The purpose of our thesis is to perform an analysis on the challenges of developing semi-autonomous and autonomous systems through the military acquisition process in order to determine best practices and trends necessary to increase the likelihood of program success.

The secondary goal of our analysis is to compare and contrast Test & Evaluation methodologies for systems with autonomous capabilities. The purpose of the test and evaluation process is to enable decision makers to manage technical risk and assess how robust and mature capabilities are prior to making a fielding decision. Autonomous systems require a rigorous test/build strategy that for most programs lead to cost overruns and schedule breaches. In addition, trying to keep pace with rapidly changing technologies outpaces the DoD's ability to field mature systems with cutting-edge technology.

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ANALYZING THE CHALLENGES AND OBSTACLES TO DEVELOPING AND FIELDING AUTONOMOUS AND SEMI-AUTONOMOUS SYSTEMS

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ABSTRACT

Autonomous and semi-autonomous systems operate on a system of systems (SoS) framework, utilizing their own ability to sense, perceive, analyze, and execute actions to achieve their goals. Unmanned systems present a significant challenge for the Department of Defense's (DoD) acquisition process that was established to develop and field man-in-the-loop type capabilities. The purpose of our thesis is to perform an analysis on the challenges of developing semi-autonomous and autonomous systems through the military acquisition process in order to determine best practices and trends necessary to increase the likelihood of program success.

The secondary goal of our analysis is to compare and contrast Test & Evaluation methodologies for systems with autonomous capabilities. The purpose of the test and evaluation process is to enable decision makers to manage technical risk and assess how robust and mature capabilities are prior to making a fielding decision. Autonomous systems require a rigorous test/build strategy that for most programs lead to cost overruns and schedule breaches. In addition, trying to keep pace with rapidly changing technologies outpaces the DoD's ability to field mature systems with cutting-edge technology.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAF	Adaptive Acquisition Framework
AI	Artificial Intelligence
ACAT	Acquisition Category
AMAS	Autonomous Mobility Applique System
APB	Acquisition Program Baseline
ASI	Autonomous Solutions Inc.
ATL	Automatic Take-Off and Landing
BDD	Binary Decision Diagrams
CRL	Carnegie Robotics Limited
COTS	commercial-off- the- shelf
DARPA	Defense Advanced Research Projects Agency
DBB	Defense Business Board
DJI	Dajing Innovations
DMSCO	Defense Modeling & Simulation Coordination Office
DOD	Department of Defense
DOT&E	Defense Operational Test and Evaluation
EMD	Engineering maturation development
EH	Explosive Hazards
FAA	Federal Aviation Administration
HRI	Human-Robot Interaction
IOT&E	Initial Operational Test & Evaluation
ISR	Intelligence Surveillance and Reconnaissance
IPT	Integrated Product Team
JAP	Joint Applied Project
LUT	Limited User Test
MDAP	Major Defense Acquisition Program
MS	Milestone
MTA	Middle Tier Acquisition
MRTFB	Major Range and Test Facility Base
M&S	Modeling and Simulation

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NASA	National Aeronautics and Space Administration
NTC	National Training Center
OT	Operational Testing
QRC	Quick Reaction Capability
RDT&E	Research Development Test and Evaluation
SAR	Selected Acquisition Report
SREHD	Stand-off robotic explosive Hazard Detection-Neutralization
SoS	System of Systems
TARDEC	Tank Automotive Research, Development and Engineering Center
T&E	Test and Evaluation
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
USDOT	U.S. Department of Transportation

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I. INTRODUCTION

Autonomous systems have gained tremendous interest and traction within the Department of Defense (DOD) over the past five years. The problem is as technology matures, the need to integrate autonomous capabilities and weapon systems becomes more of a requirement for the DOD. We will attempt to show through case studies, how the DOD is looking to develop a next generation autonomous systems capable of dominating near-peer threats. The DOD's acquisition process for autonomous systems or any other technically complex weapon system can be highly complex, and the implementation costly. As the DOD's interest for autonomous systems increases, it must take into consideration future capabilities and operational training techniques of autonomous systems. According to Parson and Ahner (2016) future capabilities of autonomous systems consist of augmenting human decisions, teaming with humans in the execution of missions, teaming with other systems for collaborative autonomous functions, and extending intelligence surveillance and reconnaissance (ISR). In the same report Parson and Ahner (2016) propose that these future capabilities will be operated in hostile environments. DOD will gain a multitude of new capabilities by implementing autonomous systems out in the field, but with the new capabilities come new challenges.

A. THE ROLE OF T&E WITHIN THE DEFENSE ACQUISITION PROCESS

According to the Parson and Ahner study (2016), the early stages of the DOD adaptation of autonomous systems have provided new challenges in conducting a proper developmental and operational test and evaluation (T&E) process. The challenges include development of requirements, the need for test infrastructure and personnel, autonomous systems test adequacy, need for safety/cybersecurity, and post-acceptance testing of autonomous systems. Figure 1 shows how these challenges line-up within the standard defense acquisition management system framework.

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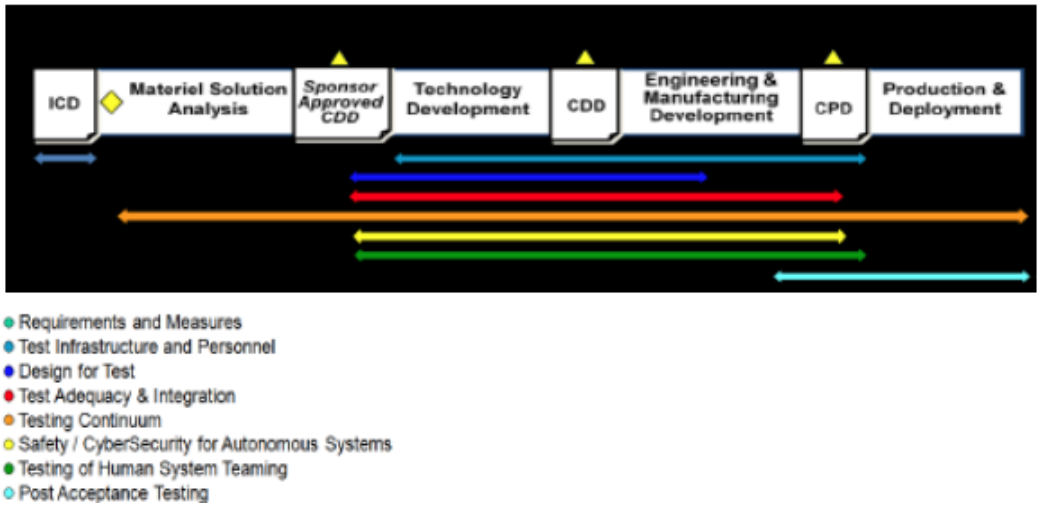


Figure 1. DOD Acquisition Life Cycle Program.
Source: Parson and Ahner (2016).

As more warfighting systems adopt autonomous systems and semi-autonomous systems, the DOD's main goal is to utilize T&E acquisition process to manage technical risks and ensure maturity of requirements are considered before final decision within the acquisition process. As technology matures the DOD and industry communities must keep pace and adapt the changes in technology to the warfighter.

B. DEFINING AUTONOMY

The *Role of Autonomy in DOD Systems* by the Defense Science Board (2012) (hereafter called *Autonomy Report)* defines an autonomous system as a system that is self-governing, with the capability for the operator to control the system without human interactions. When most people think about autonomous system, they think of software taking the place of a human interaction. Autonomous systems do not replace a human being, but rather extend an operator's effectiveness in a multitude of possibilities. The DOD indicates that the main function of autonomous systems is to reduce the cognitive burden placed on warfighter while maximizing effectiveness of any given capability. By adding autonomous systems, the *Autonomy Report* by the Defense Science Board (2012) states that the warfighter can use a DOD system or sub-system more effectively by integrating different requirements between multiple unmanned systems and software-dependent devices, thus allowing more focus on the complex decision-making process. Per

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the *Autonomy Report* by the Defense Science Board (2012) report the warfighter would gain added advantages by utilizing autonomous systems capabilities. Almost all the DOD deployed forces have been eager to use autonomous systems, particularly to counter the threat in compromised areas.

According to a 2009 report by Zilberstein, autonomous systems offer a reframing effect on society as they help decrease human workload and achieve productivity and safety. The same 2009 report, Zilberstein highlight that autonomous systems have been in operation in a great variation of forms, from special types of vacuum cleaners to space exploration vehicles. Ironically, there is no specific definition of autonomy in artificial intelligence (AI), but if a system can build and carry out a plan that achieves an assigned goal without human intervention it is considered autonomous.

The DOD sees the need for full autonomy but has incrementally implemented autonomy through semi-autonomous systems as a more feasible goal. The Zilberstein (2009) report defines semi-autonomous systems as a system that can operate autonomously under certain conditions but may require some human interactions in order to achieve its final goal.

For semi-autonomous systems to be successful, three technical approaches reported in the Zilberstein 2009 report must be considered. First, a human operator should have high competence to observe or interact with the current state of the process. Second, a human operator must have the ability to perform actions that are not available to the semi-autonomous systems (e.g., climb stairs). Third, a human operator must demonstrate a different level of competence in performing various tasks depending on certain actions (e.g., removing a stuck light bulb without breaking it) within the DOD T&E process.

C. THE IMPORTANCE OF AUTONOMOUS SYSTEMS ON THE BATTLEFIELD

In the future, autonomous systems will give warfighters numerous enhancements such as: augmenting human decision-making, teaming with humans in the execution of missions, teaming with other systems for collaborative autonomous functions, and extending situational awareness. These enhancements will allow the warfighter to operate

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a system that has a set of high-level capabilities that allow the warfighter to reply to a set of circumstances that were not pre-programmed prior to system deployment.

In addition, these enhancements will provide systems with the ability to operate in any environment without the need to preprogram software within specific boundaries, due to the artificial intelligence being able to adapt to its environment. By giving the warfighter autonomous systems capability, the number of warfighters on the battlefield will decrease, and the efficacy of each warfighter will be greater. The DOD systems that are autonomous systems or semi-autonomous systems enabled, will allow the warfighter to combat in areas not accessible in the past. As a result, we opine that the more the DOD adopts autonomous systems the less causalities will occur.

The DOD has the operational need to increase autonomous systems across air, sea and ground applications. As DOD adopts autonomy, DOD must maintain and improve a systemic approach for T&E and account for the mission needs for present and future operational environments. For industry to account for DOD mission needs, it first must understand how DOD intends to use autonomous systems.

Our plan for this JAP is to analyze test documentation, engineering reports and scientific studies to answer the research questions to follow, specifically focusing on T&E data extrapolated during the technical maturation and risk reduction phase, the engineering and maturing phase (EMD) and production and deployment phases.

The purpose of this analysis is to: 1) identify the shortcomings within the T&E methodology in comparison with industry best practices; and 2) determine corrective actions that can transition to the organic T&E test agencies in the hopes of increasing the chance of fielding autonomous systems to the warfighter. We use the case studies demonstrated in the later part of this JAP to analyze the challenges these systems face and broadly extend lessons learned from these case studies to the development of all autonomous capabilities.

In addition, we show how best practices and commercial trends can be transitioned from industry to DOD's T&E methodology. At the end of our JAP we determine if the

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current DOD T&E process or industry's T&E processes provide a better evaluation of autonomous systems by answering the following primary and secondary questions:

(1) Primary:

- What unique challenges are presented by autonomous systems to the DOD T&E and industry communities?

(2) Secondary:

- Does the DOD have the correct resources to conduct tests and evaluations of autonomous systems?

In this chapter we introduced autonomous systems, explained the role of T&E within the defense acquisition process, defined autonomy, and discussed the future importance of autonomous systems on the battlefield. As the DOD begins to adopt autonomous and semi-autonomous systems, so does industry. The following chapter provides additional information on the background of autonomy based on DOD's vision, several implementations of autonomy in current day programs and a summarization of their T&E phase as compared to the industry standard. The maturity of autonomous systems and semi-autonomous systems will cause DOD and industry communities to evaluate the challenges they will have to meet, and how to best allocate resources to conduct T&E of autonomous systems.

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II. BACKGROUND

A. DOD VISION FOR AUTONOMOUS SYSTEMS IN THE BATTLEFIELD

Beginning in 2011, the DOD published a series of Unmanned Systems Integrated Roadmaps, laying out a vision for future military technology investment, which covered advancements in sensors, communication, power, weapons, propulsion and other key enablers for future autonomous systems. The purpose of these roadmaps was to provide a reference for defense acquisition leadership to pursue science and technology initiatives that align with the overall DOD strategic guidance. The 2011 roadmap presented key technological areas that represented DOD's specific interest in artificial intelligence and machine learning, which are the key enablers for future autonomous innovations and machine human collaboration (see Figure 2).

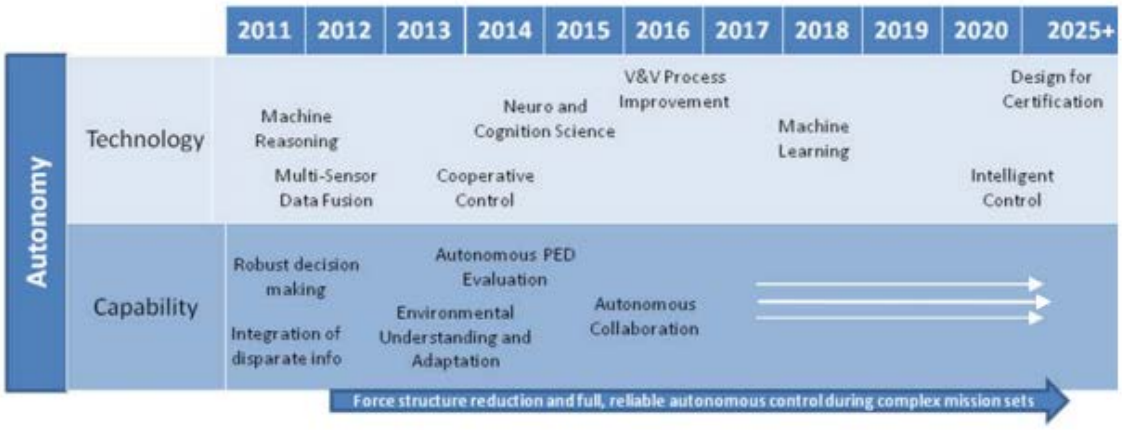


Figure 2. Defense Science Board's 2012 Autonomy Roadmap. Source: Defense Science Board (2012).

The DOD's vision behind the 2011 roadmap provides insight into the military's gamble with autonomy and the heavy reliance on artificial intelligence in future warfare (Defense Science Board, 2012).

> For unmanned systems to fully realize their potential, they must be able to achieve a highly autonomous state of behavior and be able to interact with their surroundings. This advancement will require an ability to understand

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> and adapt to their environment, and an ability to collaborate with other autonomous systems. (Scharre, 2018)

This excerpt from (Scharre, 2018) provides context to how the DOD is positioning autonomous systems in the future fight and how the military is planning to achieve overmatch against near-peer threats. Based on the current dominance of drone strikes utilized in the war on terror in the Middle East, future threats will focus on the ability to contest remotely operated systems such as drones and robotic platforms on the battlefield, rendering these capabilities useless. One option the military is planning to utilize to mitigate this is emphasizing higher levels of autonomy for the purpose of developing systems that can operate independently without the need of manned teams facilitating functionality. Additionally, the military is conducting research on drone swarm technology, which is capable of controlling hundreds of "mini-drones" required to overcome enemy threats. DOD is betting on a future of AI and unmanned systems seamlessly coordinated with manned teams influencing and dominating the battle space. AI capable of identifying threats at longer range, providing intel to ground forces and coordinating activities between unmanned and manned forces. These capabilities will enhance the military's capability in the future by reducing the warfighter's cognitive and physical load, while providing a means to improve lethality on the battlefield.

B. DOD KEY ENABLING TECHNOLOGIES FOR AUTONOMOUS SYSTEMS

The DOD *Autonomy Report* (2012) identifies six areas in artificial intelligence that have made significant improvements for autonomy: "perception, planning, learning, human-robot interaction [HRI], natural language understanding, and multi-agent coordination" (p. 31).

The report also describes how perception is key to autonomy and enables the autonomous systems to reach mission objectives. Per the DOD *Autonomy Report* (2012) perception includes sensors (hardware) and sensing (software). The hardware (sensors) includes raw inputs to sound, pressure, temperature, and lights. The DOD *Autonomy Report* (2012) explains how "perception for mission sensing is needed for mission planning,

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offering four significant benefits"(pg. 42). Planning is the steps related to how a sequence is computed or partial order of actions that changes from present circumstances to a desired circumstances. In the same report, the planning process consists of two components. The first component represents human actions, and description of world objectives and resource optimization criteria. The second component represents how the DOD learns to design software algorithms that will compute actions in sequences and assign the appropriate actions to conform the hard constraints of the problem, while optimizing the soft constraints. According to the DOD *Autonomy Report* (2012) machine learning is considered the most critical aspect of advancing intelligent autonomous systems.

The DOD *Autonomy Report* (2012*)* states HRI is new to autonomous systems. The same report defines HRI as an integrative field that interact direct human interaction compared to current usage of robots versus computers or tools. The DOD *Autonomy Report* (2012) further states that,

> HRI is a group of a bigger field that focuses on bi-directional, cognitive interactions in which the robot is a physically situated agent operating at a distance from the user, versus a computer or autopilot, thus leading to significant distinctions. (Defense Science Board, 2012)

In the same report the DOD benefits from HRI by improving performance of existing platforms, which will reduce cost for new situations.

Natural language is defined in the DOD *Autonomy Report* as the most inherent way for the user to control autonomous systems. Natural language understanding grants for a more diverse, superior operation rather than and more detailed teleoperation. As revealed in the DOD *Autonomy Report*, multi-agent coordination is applied to accomplishing a designed task for software or humans. The DOD *Autonomy Report* states that,

> Each multi-agent component is considered to have some degree of individual autonomy and the coordination may either emerge from the agents interacting or negotiating with each other directly (distributed coordination) or be explicitly directed by a planner (centralized coordination). (Defense Science Board, 2012)

In the next section, we present a brief overview of the four DOD programs of record (PORs) that we chose to analyze in this JAP. Each of the programs demonstrates one or

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multiple areas of autonomy designated by the Defense Science Board and were fully funded efforts that required a formal T&E process by the Army Evaluation Center. Each of the four PORs have a semi-autonomous systems capability that required an integrated project team (IPT) to develop non-traditional T&E methodology to verify and validate the autonomous functionality. In the next section we provide a brief synopsis of each program's development history and the implementation of their autonomous functionality.

C. DOD PROGRAMS OF RECORD WITH AUTONOMOUS FUNCTIONALITY

1. Gray Eagle

According to the *Selected Acquisition Report* (SAR) (2010) Gray Eagle or MQ-1C Unmanned Aircraft System (UAS) program is the Army's primary aerial system capable of providing reconnaissance, surveillance, security, attack and command/control missions' types for the joint force units. Gray Eagle Quick Reaction Capability (QRC) 2 Units are capable of autonomous takeoff and landing, employing hellfire missiles and tactical landings (SAR 2010). All other functionality is coordinated by an operator within a ground control station.

The SAR (2010) states that the Gray Eagle was initiated in April 2005 at milestone (MS) B and began as an acquisition category (ACAT) II program planned to replace the Hunter UAS, in response to secretary of defense requested to increase support in Iraq and Afghanistan. The SAR (2010) reports that the initial program was approved for procurement of four systems and associated equipment, but was increased to 12 systems post MS B.

The SAR (2010) states by the spring of 2008, the secretary of defense managed the deployment of prototype Gray Eagle UAS equipment to support the war in Iraq. QRC Gray Eagle systems were procured and deployed to support Operation Iraqi Freedom and Operation Enduring Freedom. Based on operational mission duration taken from both accounts, the deployed systems were capable in excess of 10,000 flight hours with zero accidents. In May of 2008, Gray Eagle was re-designated as an ACAT 1D and by March of 2010 approved for a MS C. The MS C was later rescinded and changed to March 2011

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based upon recommendation from the vice chief of staff of the Army convening a configuration steering board. Adjustments increased the allowable Gray Eagles within a platoon to 3 per company, which was a total increase from 12 to 17 Gray Eagle UAS companies. According to the SAR report PM-UAS performed a successful limited user test (LUT) in the third quarter FY 2010 and initial operational test and evaluation (IOT&E) was completed in the first Quarter FY 2012. Figure 3 is an image of a MQ-1C UAS Gray Eagle.



Figure 3. Selected Acquisition Report: MQ-1C UAS Gray Eagle. Source: SAR (2010).

2. Autonomous Mobility Applique System (AMAS)

According to the AMAS system overview, the AMAS is an Army initiative providing a low-cost/low-risk solution to retrofit an autonomous driving capability onto existing military tactical wheeled vehicles. AMAS offers driver warning/driver assist performance, leader-follower vehicles for protection operations, and waypoint following

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efficiency. The AMAS kit is composed of a three-part system of environment sensor, actuators that move the vehicle and pump the breaks and central computer that processes the sensor data and commands the drive system.

Based on the AMAS system overview, in the summer of 2014, the engineers at Tank Automotive Research, Development and Engineering Center (TARDEC) demonstrated the AMAS system at Savannah River site, in Aiken, South Carolina. The demo consisted of several types of vehicles being autonomously driven in operationally realistic scenarios. The assessment resulted in a positive recommendation to continue development. Additional progress was made in 2015 again when the driver warning/assist capability was successfully tested with soldiers. The demonstration was set up to test the collision mitigation braking, adaptive cruise control and lane keeping capability of vehicles equipped with the AMAS technology. The primary and secondary safety systems of the AMAS were successfully demonstrated, establishing AMAS's capability to reduce equipment loss and mitigate potential accidents.

In addition, the AMAS system was successfully demoed during the U.S. Army Extended Warfighter Experiment at Fort Leonard Wood, Missouri, and Fort Bliss, Texas. The EWE is a U.S. army training and doctrine command sponsored event, managed by the U.S. Army TARDEC. The event was significant for both Lockheed Martin (the initial system developer) and TARDEC as they successfully logged 55,000 miles on the system and received a recommendation to move to widespread fielding across multiple military applications. The Figure 4 is an image of an AMAS system.

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Figure 4. Autonomous Mobility Applique System Overview. Source: Lockheed Martin (2018).

3. Project Perdix

According to the Strategic Capabilities Office (SCO) (2011), Project Perdix is the name of a MIT Lincoln Laboratory initiative to use a group of micro-drones (mini unmanned aerial vehicles) for ISR missions. Project Perdix was successfully demonstrated by the SCO, in September 2014, for the DOD at the Air Force Test Pilot School, Edwards Air Force Base. The test utilized an F-16 flare canister as a transportation/ejection method and was successfully capable of launching a swarm of autonomous drones without damaging any of the drones. Over the next two years the program would transition to the SCO, Naval Air Systems command, where the military alongside MIT, demonstrated a swarm of 103 Perdix drones being deployed from an F/A-18 Super Hornet. The SCO revealed the demonstration is considered a milestone in drone swarm technology and demonstrated advanced behavior “such as collective decision-making, adaptive formation, flying, and self-healing”(pg.1). The Perdix drones can share a single collective mind for decision making and adapting to each other and the different environmental factors. The

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Perdix drones will provide the military the capability to allow a swarm of inexpensive drones to perform missions, disrupt communications and track targets of interest. The Figure 5 is an image of a single Perdix drone.

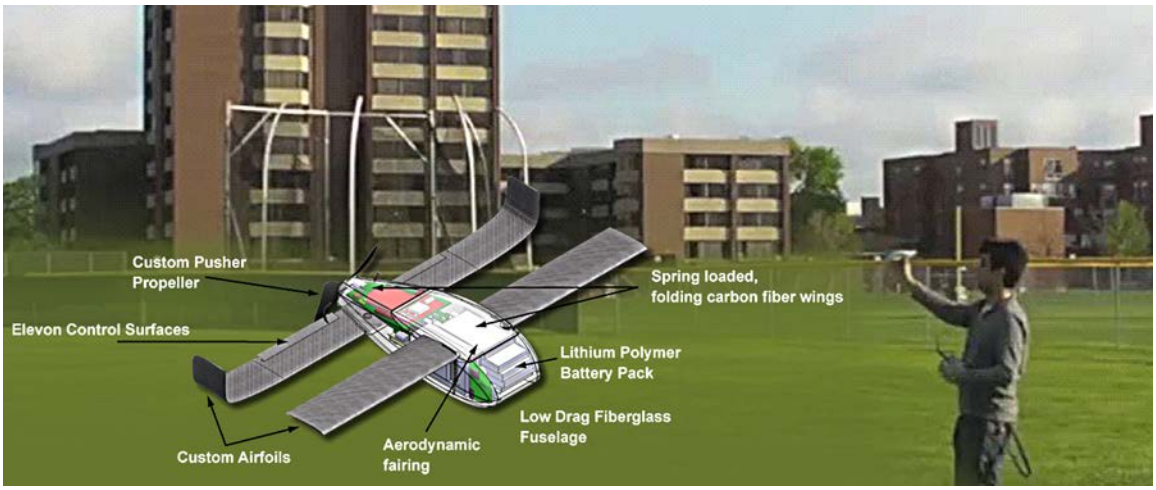


Figure 5. Project Perdix. Source: Hansman (2011).

4. Stand-off Robotic Explosive Hazard Detection-Neutralization (SREHD)

SREHD is an Acquisition Category III (ACAT III) program developed as a capability to detect, mark, and neutralize explosive hazards (EH) (e.g., landmines, improvised explosive devices, booby-traps, and unexploded explosive ordnance) in either complicated or underground environments. SREHD is capable of being mounted on unmanned ground vehicles platforms organic engineering unit.

In 2002 the Army Technology Objective initiated an effort to develop a concept to autonomously detect explosive hazards on the battlefield. Concept Phase 1 was conducted as a market survey for technology approaches to autonomous mine detection of anti-personnel and anti-tank landmines from a small surrogate robotic platform. Concept Phase 2 was a prototype design evaluation to determine the probability to detect and coverage rate autonomous capabilities against realistic threats in varying environmental conditions. SREHD formerly known as the Autonomous Mine Detection System was developed by two competitive, state-of-the-art sensor packages developed for handheld, man portable

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detection systems. CyTerra Corporation leveraged technology from the Army/Navy Portable Special Search 14 Mine Detecting Set and NIITEK Inc. was able to leverage ground penetration radar to meet the required objective. Both contractors were awarded contracts to explore technology approaches capable of autonomously detecting landmine. Concept Phase 3 was developed and assessed prototypes against mission scenarios in relevant environments. At the culmination of Phase 3, the Program Management office for Close Combat Systems awarded a contract to Carnegie Robotics Limited (CRL) for their Dismounted Standoff Explosive Hazard Detection, Marking and Neutralization approach. On 30 April 2018, PEO Ammo as the SREHD Milestone Decision Authority successfully approved a MS C decision and CRL was award an additional option to produce 16 units in support of low rate initial production (LRIP) (Test and Evaluation Master Plan, SREHD, 2018). The Figure 6 is an image of a SREHD system.



Figure 6. SREHD Shreds the handheld competition. Source: James and Chang (2017).

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III. ANALYSIS OF TEST & EVALUATION METHODOLOGIES

A. THE IMPORTANCE T&E FOR AUTONOMOUS SYSTEMS

The DOD has not developed any specific guidance for T&E of autonomous systems. Currently, autonomous systems are tested and evaluated under the same methodology as any other complex weapon system. The process starts by decomposing requirements into their basic operational intentions. Test plans are created and approved by system stakeholders, test leads evaluate system performance by executing a series of repeatable system tasks for the purpose of evaluating and verifying predictable system operational requirements.

The DOD *Autonomy Report* (2012) describes the current state of DOD's test and evaluation challenges and recommendations for T&E of autonomous systems by stating,

> Traditional test programs have been focused on repeatable performance testing, measuring a response and comparing that response to a documented performance specification. Testing perspectives need to shift to a view that is more broadly mission based and assesses the ability of the autonomous system to meet mission goals. The framework employed for testing must provide leeway to the system to adapt plans to achieve mission goals in a variety of ways that cannot necessarily be predetermined. The fact that the system's software reacts to external stimuli and makes non-scripted, but bounded, decision is particularly challenging to the test community that is more accustomed to executing testing in a fully scripted sense. The ability of the T&E community to react to this changing paradigm is limited by the understanding of how autonomous systems truly make decisions. Additionally, the DOD T&E workforce must be enhanced with new skills for robotics, artificial intelligence, networking and systems engineering for autonomous systems. (Defense Science Board, 2012)

This excerpt clearly defines the critical need for a T&E community tailored to the nuances of measuring the effectiveness and suitability of autonomous systems.

B. THE COST OF TEST & EVALUATION FOR AUTONOMOUS SYSTEMS

Autonomous systems operate on a system of systems (SoS) basis. Fundamentally, this means that a collection of resources and capabilities work together to create a more complex and enhanced capability, which offers more functionality and performance than

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the sum of its individual components. The increased amount of functionality can lead to emergent behavior that can be a challenge to the T&E community to replicate, verify and validate. The government's current verification and validation methodology ensures user requirements are evaluated based upon a predictable and expected performance envelope. The T&E community then collects, assesses and judges whether the performance measures fulfill requirements. This data collection period begins during the technical maturation and risk reduction phase and typically ends during the end of the EMD phase. The purpose of T&E within the Defense Acquisition process is to help decision makers assess the maturity of a capability and reduce the risk of failure to the system owner and users. The systems approach to test and evaluation is the principal means of demonstrating a program's readiness for deployment.

SoS T&E requires broad-scale resources based upon the complexity of the systems, missions and conditions the warfighter expects to utilize the capability. System engineers work with the T&E community to break down requirements, systems and missions into smaller pieces, which are translated into quantifiable measures. Large, exhaustive and costly experiments are conducted to inform development integrated product teams (IPT) and other system stakeholders of the overall maturity of a system and its relative timeframe to fielding.

As an example, Gray Eagle is a major defense acquisition program (MDAP) that was required to undergo IOT&E to validate its autonomous functionality. Gray Eagle's autonomous functionality includes a system capable of automatic take-off and landing (ATL) as well as a system capable of employing Hellfire missiles on a verified threat.

The information that was gathered in Table 1 and Table2, includes Gray Eagle's acquisition program baseline (APB) and the project management office (PMO) budget to fund autonomous requirements in IOT&E from September 2011 and August 2012. Using information gathered in Table 1 and Table 2, which includes Gray Eagle's acquisition program baseline (APB) and the project management office (PMO) budget to fund IOT&E from September 2011 to August 2012. We can use the established timeline in Table 1 with Gray Eagle's annual funding in Table 2 and surmise how much money was spent to validate the autonomous functionality.

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Table 1. MQ-1C Gray Eagle's Schedule. Adapted from SAR (2010) and SAR (2007).

Schedule Events				
Events	**SAR Baseline Production Estimate**	**Current APB Production Objective/Threshold**		**Current Estimate**
Milestone B	Apr 2005	Apr 2005	Apr 2005	Apr 2005
SDD (EMD) Contract Award	Apr 2005	Apr 2005	Apr 2005	Apr 2005
Critical Design Review	Feb 2006	Feb 2006	Feb 2006	Feb 2006
Milestone C	Mar 2011	Mar 2011	Mar 2011	Mar 2011
IOT&E				
IOT&E Start	Sep 2011	Jul 2012	Jul 2012	Jul 2012
IOT&E Complete	Oct 2011	Aug 2012	Aug 2012	Aug 2012
IOC	Jun 2012	Dec 2012	Dec 2012	Dec 2012
FRP Decision	Apr 2012	Jul 2013	Jul 2013	Jun 2013
FOT&E I	Aug 2012	May 2015	Nov 2015	Jun 2015
FOT&E II	May 2013	N/A	N/A	N/A

Prior to the ATL being implemented on production units, General Atomics was required to verify Gray Eagle's ability to autonomously take-off and land to ensure the safety of military test assets and a successful IOT&E. Additionally, information was gathered through a press release by General Atomics, establishing the system demonstrated 20,000 successful take-off and landings on various runways around the world (General Atomics, 2012). The (PMO's) schedule of events published in the MQ-1C Gray Eagle 2016 SAR (Table 1), confirmed Gray Eagle's IOTE was scheduled to begin in September of 2011 and ended in August of 2012. Execution of all these events required prior year planning to include the acquisition of test hardware, verification of system performance, maintenance/logistic documentation and trained operators for system demonstration before the beginning of testing in September of 2011. This schedule of events coincided with a peak operating test budget between the years of 2010 to 2012 which reflects the highest development cost during Gray Eagle's engineering maturation phase as shown in Table 2 SAR (2007).

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Table 2. MQ-1C Annual Funding Report. Adapted from SAR (2010) and SAR (2007).

Annual Funding 2040 | RDT&E | Research, Development, Test, and Evaluation, Army							
Fiscal Year	Quantity	BY 2010 $M					
		End Item Recurring Flyaway	Non End Item Recurring Flyaway	Non Recurring Flyaway	Total Flyaway	Total Support	Total Program
2005	--	--	--	--	--	--	58.8
2006	--	--	--	--	--	--	95.5
2007	--	--	--	--	--	--	127.3
2008	--	--	--	--	--	--	104.4
2009	--	--	--	--	--	--	61.6
2010	--	--	--	--	--	--	132.7
2011	--	--	--	--	--	--	114.8
2012	--	--	--	--	--	--	115.6
2013	--	--	--	--	--	--	64.1
2014	--	--	--	--	--	--	12.0
2015	--	--	--	--	--	--	41.8
2016	--	--	--	--	--	--	--
2017	--	--	--	--	--	--	11.8
Subtotal	2	--	--	--	--	--	940.4

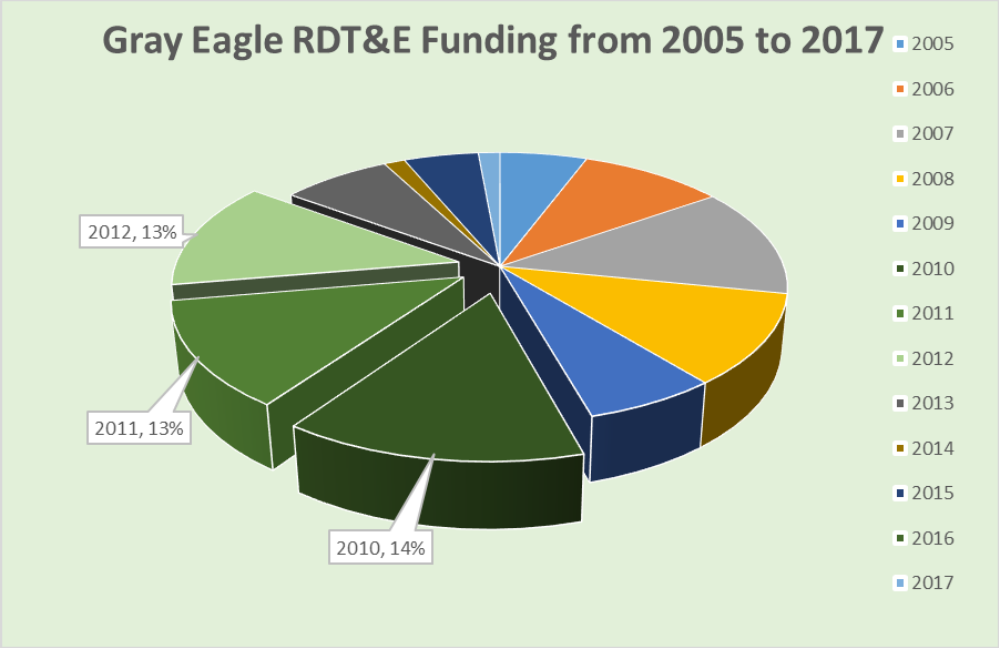


Figure 7. Gray Eagle RDT&E Funding. Adapted from SAR (2010).

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Based on the data provided, the Gray Eagle program spent the largest amount of RDT&E funds during the same period of the time in which they were verifying the system's automatic takeoff and landing capability. A one-to-one correlation to Gray Eagle's budget and IOT&E cannot be discerned from just the information researched for this JAP. There are most likely several other major factors that affect the overall increase in cost. We are assuming that since the majority of testing between 2010 to 2012 was contractor testing of the ATL semi-autonomous system, then the overall cost to verify Gray Eagle's autonomous capability in an operational environment was the cost driver during the end of the EMD phase, as referenced by both the SAR and General Atomics System AUSA announcement, (General Atomics, 2012).

C. DOD TEST & EVALUATION METHODOLOGIES

Throughout this next section, we present the research was conducted on our four (4) DOD programs of record to analyze the T&E techniques utilized throughout their system development.

1. SREHD T&E Test Methodology

SREHD's autonomous capability enables the system to independently detect and mark a broad spectrum of surface-laid and buried explosive hazards and triggering mechanisms in support of route clearance and breaching operations. SREHD is unable to neutralize explosive hazards autonomously, rather the operator is always required to provide the primary and secondary confirmations prior to a neutralization. This is to prevent accidental functioning of the munition during a route clearance mission.

The testing methodology utilized by the SREHD IPT involved various test sites that specialized in specific areas of testing in order to assure the proper standards were followed providing the evaluators the necessary information to assess autonomous performance. Both Yuma Proving Ground in Arizona and AP Hill in Virginia were used to simulate likely threat environments in which a clearance brigade would operate. During the technology demonstration phase, the contractor utilized experimental prototype systems in order to assess SREHD's autonomous surface detection capability and ability to

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independently maneuver a detection system at precise head height to maintain accuracy of probability of detection model.

Modeling and simulation (M&S) of SREHD's detection algorithm software was also utilized throughout initial development to assess how different external environmental factors could potentially impact the system's performance. This allowed the contractor to quickly evaluate changes and train the system without requiring weeks of probability detection testing.

During the EMD phase, a combination of component, subsystem, and system level testing was utilized to stress SREHD's performance over several hundred hours of testing. Operators were required to simulate a route clearance mission with the entire SREHD operational load and clear a 1.5-meter-wide lane for troops to utilize. Both surface-laid and deep-buried targets were hidden within the "lane" and SREHD was required to autonomously travel the length of the path marking and detecting possible UXOs. Test periods ended with data collectors scoring system aborts and essential function failures and required the engineering team to work with the contractor to develop a corrective action plan that would mitigate the failure and reduce future risk of failure.

2. Gray Eagle T&E Test Methodology

According to the (DOT&E,2010), test team generated thousands of hours of operational flight testing, autonomous takeoff and landing in addition to threat acquisition and threat neutralization test flights (DOT&E, 2010). Testing was conducted at Edwards Air Force Base, California, and the National Training Center (NTC), Fort Irwin, California. To date, Gray Eagle utilized computer-based simulation training for Gray Eagle operators and actual test flight in both the continental United States and outside continental United States environments.

The computer-simulated test environment is primarily used to train Gray Eagle operators with monitoring flight systems, air traffic and communication systems with other forces. In the rare instance a target requires neutralization, operators are required to authorize the use of force prior to threat engagement.

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During Gray Eagle operational testing, autonomous systems are verified and validated using continuous software checks, flight instrumentation data collection and continuous hour's flight reliability data. Since Gray Eagle is an ACAT 1D program, the low rate initial production (LRIP) quantity was requested and authorized for employment in OCONOS missions for reconnaissance. The system was able to be tested in a constrained and conflicted environment. Operators were able to fully test Gray Eagle's sensors and autonomous capabilities against foreign threats.

3. Project Perdix T&E Methodology

Project Perdix is still pre-MS A as of completion of this JAP, so there hasn't been a formal T&E master plan drafted or approved. Based upon the limited data collected on Project Perdix development, the test methodology has been to evaluate the swarm intelligence of Project Perdix, the swarm's ability to autonomously avoid obstacles and its ability to be launched from an F-16 in flight. Since the primary autonomous capability of the Perdix system is its ability to autonomously navigate low altitudes and independently control individual drones within the swarm, government experiment and testing has primarily focused on increasing the size of the swarm and increasing the complexity of the test environments.

On October 2016, the Navy successfully deployed 103 Perdix drones from three F/A-18 Super Hornets over China Lake, California. Perdix demonstrated quick maneuverability, adaptive flying formations and self-healing.

Typical testing for military-employed small UAV's consists of autonomous target tracking, flight duration and payload delivery. DOD uses White Sands Missile Range, New Mexico and Fort Bliss, Texas as its primary test facilities for new UAV's in development.

4. AMAS T&E Test Methodology

The Army's AMAS or "convoy system" is primarily tested either at Fort Leonard Wood, Missouri, Aberdeen, Maryland and Fort Bliss, Texas. The applique kit has been tested on the M915 line-haul truck, medium tactical vehicle replacement, palletized load

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system and the heavy equipment transport vehicles. Lockheed Martin has successfully logged more than 55,000 miles using the AMAS capability.

The test methodology for AMAS is primarily roadside simulations of its autonomous adaptive cruise control, assisted breaking and parking, collision avoidance and pedestrian detection. The automotive technology evaluation facility at Aberdeen Proving Ground (APG) can use plastic vehicle targets, Styrofoam mannequin pedestrians and other robotic devices to represent various scenarios to gather system characteristic data and replicate possible safety hazards. Testing is done with little to no human intervention to accurately simulate realistic operational scenarios of the AMAS system and mitigate any possible safety risk to personnel. During test events, data collectors are monitoring the AMAS capability to navigate dense urban environment in a convoy formation, braking and avoiding obstacles and its ability to warn other vehicles in the convoy of sudden changes in terrain. Data collectors measure the accuracy of the AMAS capability to correctly navigate the course based on a predetermined path pre-programed into the system versus how well it navigates the course based on real-life obstacles moving in and out of lanes. The data is then used to create models that eventually will be used to simulate the AMAS capability across different types of courses and reduce future test cost.

The goal of the AMAS test program was to transition into other programs of record for route clearance and interrogation systems. The future of the AMAS system will be fully autonomous vehicles as a counter to roadside hazards explosive operations mitigating the need of a soldier directly in harm's way.

5. DOD T&E Facilities for Autonomous Systems

Currently the military does not have dedicated test facilities positioned for unmanned autonomous systems. The major range and test facility bases (MRTFBs) are the designated core set of T&E infrastructure and associated workforce for the DOD and are preserved as national assets. The common methodology across DOD for testing unmanned systems is to utilize existing facilities and infrastructure used for manned systems.

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Typically unmanned aerial systems are tested in conjunction with the existing Army facilities. The Army's Gray Eagle utilizes Edwards Air Force Base in California and the National Training Center (NTC), Fort Irwin, California.

The SREHD payload is currently tested on route clearance lanes at Yuma Proving Ground in Arizona or in the rougher terrain of Fort AP Hill, Virginia. Test facilities are reconfigured from either existing foot trails or vehicle lanes and repurposed for SREHD payload test events.

The AMAS capability went through verification testing at Fort Leonard Wood, Aberdeen Proving Ground and Fort Bliss during its development. These test sites were originally intended to be vehicle test ranges that again were repurposed as test facilities for an autonomous capability.

6. DOD T&E Software, Simulation and Modeling Strategy for Autonomous Systems

All unmanned systems utilize advance software algorithms as the backbone their functionality and architecture. The DOD has a long running history of software-intensive programs that result in long delays in fielding, significant and cost overruns, as seen in high profile programs like the F-35 joint strike fighter (Maurer, 2019). The system engineering process within the defense acquisition environment has a solid foundation in mechanical-based designs versus software development, even though both contribute an equal measure to system functionality. This has resulted in challenges in both software development and software T&E within acquisition programs. Typical government procurement of software-intensive systems requires heavy industry investment and government oversight and requirement decomposition. Commercial off-the-shelf (COTS) software solutions remodified for government weapon system purposes are the predominant acquisition scenario for DOD software-intensive systems. COTS software solutions reduce the overall government investment cost, and quickly provide a solution mature enough to field.

DOD methodology for T&E of software-intensive systems during development is a controlled, statistically significant and iterative process. Tests are usually designed to verify performance and ensure quality attributes have been satisfied. During development

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of software-intensive systems, software is the significant driver of system maturity, to include system performance measures. System integration teams are established to iteratively validate and verify software builds prior to release.

The DOD T&E acquisition community defines software maintenance as the, "process of modifying a software system after delivery to correct faults, improve performance or adapt it to a changed environment" (Hamilton, 2017). Testing of software-intensive systems during the sustainment phase of life cycle acquisition involves verifying software systems continue to perform in accordance with requirements.

In addition to software testing, DOD also uses M&S as an additional means to test, analyze or train real world capabilities in controllable environments. The M&S Coordination Office is the DOD's central repository for providing policy to Army, Navy and Air Force Agencies (Defense Modeling & Simulation Coordination Office [DMSCO], 2019). DOD supports using M&S across the entire life cycle of its programs, but it's often used to verify metrics during the EMD life cycle phase. The data gained from simulation is used to provide confidence in design decisions prior to integration and recommendation on a critical path forward. It is DOD policy that only programs that have had their models verified and validated throughout their life cycle by an accredited organization can be used as substitutes for actual test data (Department of the Army, 2014).

D. TEST & EVALUATION METHODOLOGY FOR COMMERCIAL AUTONOMOUS SYSTEMS

Currently there is no overarching policy or industry standard for the commercial sale of autonomous systems. Unlike either the Food and Drug Administration which was stood up to protect and control food safety, tobacco products and over-the counter pharmaceutical drugs or the Federal Communications Commission, which is an agency within the government that regulates interstate communications by radio, television satellite or phone, there currently no federal agency to create, promote or oversee the safety standards for autonomous systems.

Commercial autonomous systems have been in the public sector since the 2004 defense advanced research projects agency (DARPA) challenge, where autonomous

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vehicles were tested in a series of challenges by the DARPA to self-navigate a 150-mile course in the Mojave Desert region of the United States. This event was key in pushing autonomous vehicle technology forward because the major car manufactures started investing more and more funding into research and design solutions for autonomous capabilities.

This thesis analyzes the autonomous test capability of various industries with commercial autonomous systems in order to compare similar capabilities to the four identified DOD programs. The autonomous vehicle industry, autonomous agriculture systems, and autonomous aerial systems each have their own set of separate standards and testing capabilities that sets them apart from one another.

1. Agriculture System Capability T&E Methodology

The future of agriculture is heavily dependent on producing healthier food, quicker and more efficiently than existing farming techniques of today. Farmers are more reliant on highly skilled personnel to work fields and drive machinery necessary to keep crops thriving, which can be a challenge during peak seasons. Tomorrow's farmers will be driven to utilize more autonomous machinery that will be just as safe if not safer than humans. Autonomous agriculture systems enable farmers to extend their workday to a 24-hour, non-stop operation (Edan et al, 2009, pp.1095-1128).

According to the same report Autonomous Solutions Inc. (ASI) and Case and New Holland (CNH) Industrial are the current market leaders in providing automation technology for the agriculture industry. ASI and CNH provide autonomous tractors that can autonomously seed, plant and till for broad acre and row crop farms. Per the automation agriculture report (Edan et al., 2009), state operators can collect real time data on both the health of crops and maintenance of the machinery. ASI provides the hardware and software solutions that are capable of being retrofitted into existing agricultural systems or integrated into new machines. CNH industries designs, produces and sells agriculture machinery all over the world.

ASI's test methodology, verification and validation of their autonomous agriculture equipment is done on a private proving ground built within their engineering facility (ASI

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2016). ASI can rapidly prototype, develop and test experimental autonomous equipment on a test farm environment. The test farm is pre-equipped with sensors, cameras and digital measuring equipment that enables ASI to remotely monitor their new equipment and adjust systems in real time to overcome issues and failures. Systems can be run 24/7 within a simulated environment to test maintainability and sustainability of systems prior to commercial release. After equipment is commercially released, new features can be added based on customers' specific needs and problems can be replicated to reduce customer down time. ASI's proving ground also enables them to monitor the stress of high-risk components over time and make design decisions at a higher confidence rate (Scott Garvey 2018).

During early development of CNH's autonomous tractor, ASI oversaw the intensive test program for both the tractor and planter interfaces as the system transitioned unto "real world" testing across four locations in the U.S. and Canada. CNH has partnered with Bolthouse Farms, a major carrot grower and food wholesaler to utilize the autonomous tractor alongside existing equipment. Testing was conducted to evaluate how well autonomous tractors till versus existing manned tractors. Testing has taken place across a variety of tillage applications, soil types, weather conditions and sensing and perception activities. The goal of the "real world" test was to verify that the autonomous tractor can efficiently function in any environment and provide traditional farmers an experience farming in the future with autonomous systems. The Figure 8 is an robotic tractor of the future.

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Figure 8. Forage 2017. Robotic Tractor of the Future. Source: Nielsen (2016).

(1) Drone Manufacturer T&E Methodology

Commercial drone manufacturer's T&E methodology of autonomous aerial systems is centered on assuring effective and safe operational performance in response to sudden changes in external environments (Intertek, 2016). Autonomous aerial systems are required to safely fly in fair and extreme weather conditions around the world and make independent decisions regarding the safest course of action.

Based on the severity and expense associated with testing autonomous aerial systems, private industry spends most of its resources utilizing simulation and modeling to verify and validate software systems responsible for independent behavior early in the development phase of new products. Even before metal is cut in the manufacturing of a UAV, software engineers have already verified and validated software models that simulate and correct system behavior. Industry has the capability to heavily rely on reusing

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much of their existing software code from prior products as software assurance for future products.

This method of software development minimizes the time needed to validate new features while reducing the total amount of resources needed for test and evaluation newer products. This incremental approach to T&E of autonomous software systems has turned into a reliable way of introducing new products to the commercial sector faster with minimal amount of testing required and spending. New products are scaled to work with limited features that have been thoroughly tested and as newer models are released, additional features and increased levels of autonomous behavior are added to all of the existing product lines, adding new features and capabilities. Companies such as Dajing Innovations (DJI) and 3D Robotics have used a single software platform to iterate on various products to the market within a short time frame.

Although the civilian drone market has become a booming sector for new startup businesses, BI Intelligence, a media outlet that specializes in data driven research, predicts that consumer spending will be a significantly smaller portion of the global aerial drone market in the near future. UAV systems used for military purposes will quickly dominate the market and require smaller, niche drone manufacturers to expand their portfolio. The difference in the civilian drone market as compared to the Defense industry is an order of magnitude greater. Autonomous drones manufactured for defense usually have much more complicated functionality and require substantially more development time. The Figure 9 is the amount of money being spent on development of UAVs for military defense purposes will continue to rise in relation to the amount of money being spent on commercial UAVs Business Insider Intelligence [BII] (2016).

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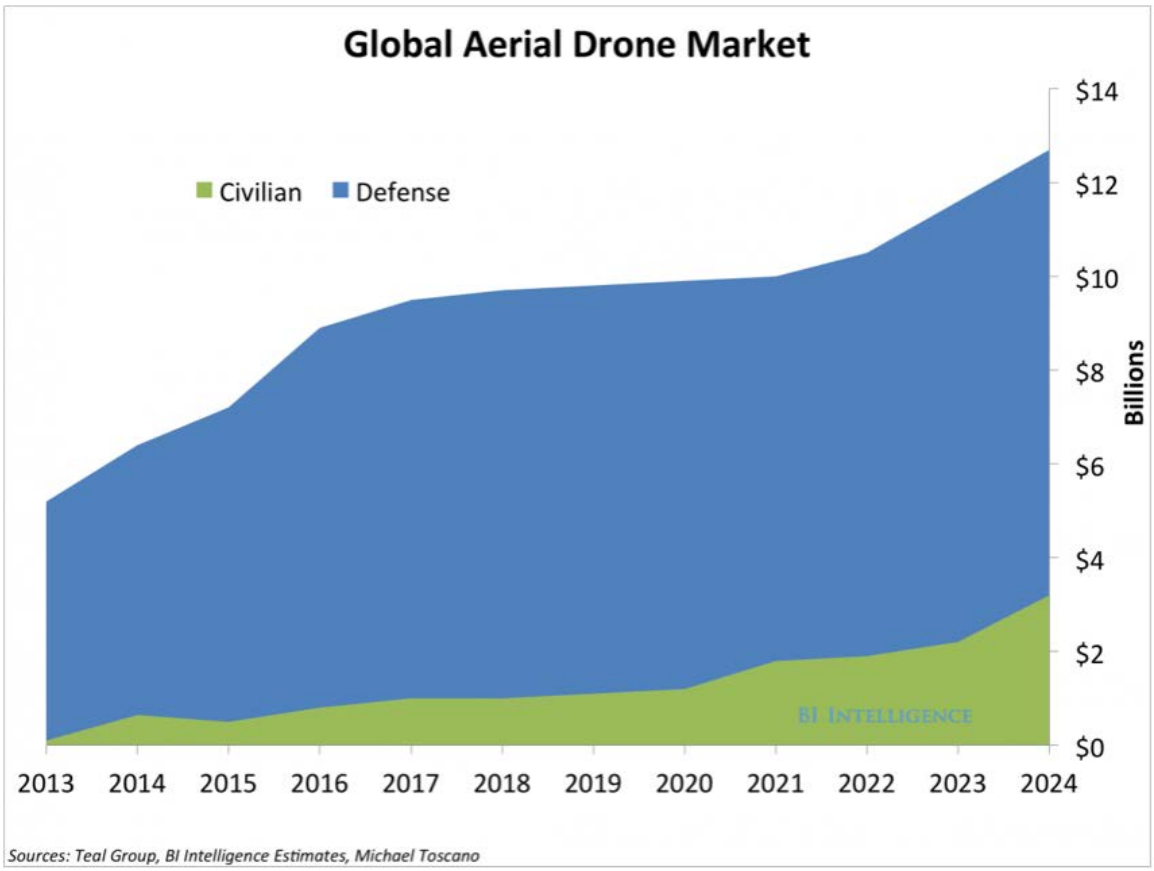


Figure 9. The Drone Report: Market, Forecasts, Regulatory, Barriers, Top Vendors, And Leading Commercial Applications.. Source: Business Insider Intelligence [BII] (2016).

(2) Industry's Autonomous Driving T&E Methodology

Comparatively, the autonomous vehicle industry has the most mature T&E methodology of all the current autonomous systems in use. Autonomous vehicles have been in use since the 2004 DARPA challenge. There are various methodologies currently in use and facilities such as the University of Michigan's Mcity facility that are dedicated to validating vehicles' autonomous software systems. The accelerated rate at which autonomous vehicles are driving on our roads is specifically due to the collaboration of the auto-industry, government, academia and technology companies who have come together in a short period of time to resolve consumer needs.

The most popular T&E method for verifying autonomous systems on vehicles is a form of accelerated testing developed by engineers (Hue Peng, director of Mcity and the

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Roger L. McCarthy Professor of Mechanical Engineering at U-M*)* at the Mcity facility requires autonomous vehicles to be rigorously tested in repeatable components based on extremely difficult real-world driving situations. According to Zhao and Peng (2017) the test method can reduce 300,000 miles of real world driving to only 1,000 miles of test data required to yield equivalent information. In the same report the goal of this test method is to analyze each vehicles' ability to make difficult decision that might result in a fatal accident. Per Zhao and Peng(2017), researchers need to be able to identify the most likely scenarios in which autonomous vehicles will make an incorrect decision and thoroughly vet software until errors can be evaluated and resolved. In the same article, Zhao and Peng (2017) noted that researchers are hoping to provide consumers up to 80 percent confidence that they are 90 percent safer in autonomous vehicles than self-driving ones.

Alongside a focus to reduce the amount of testing for autonomous vehicles, T&E engineers have also developed new methods of validating autonomous vehicle performance. Researcher Ding Zhao has stated that "Test methods for traditionally driven cars are something like having a doctor take a patient's blood pressure or heart rate, while testing for automated vehicles is more like giving someone an IQ test" (Nicole Moore, 2017). Engineers can not only determine the effects of what happens to the passenger and vehicle during an accident but also determine the best way to prevent an accident of occurring.

Verifying and validating how the autonomous systems is triggered and if the software enables the intended preventative action reliably are all part of the evaluation process during development. Autonomous vehicle proving grounds can capture real world data and creating a simulation where variables can be tweaked and changed, reducing the overall amount or real-world test data required to make design decision early on.

More recently, Toyota has adopted a similar test methodology, creating a 60-acre proving ground at Michigan Technical Resource Park in Ottawa Lake to test "Edge Cases" or extreme driving scenarios. Toyota plans to have a facility capable of simulating congested urban environments, slick surfaces and four-lane divided highways with high-speed exit and entrance ramps.

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(3) Commercial Industry Autonomous T&E Facilities

In 2013, UAV began being regulated by the U.S. Department of Transportation (USDOT) and the Federal Aviation Administration (FAA). Both agencies have partnered with private industry to designate six (6) locations across the United States designated for the T&E of UAS and providing a space where industry and private stakeholder community can conduct advance research and share information. The data being collected will be used to support future FAA policy on critical UAV safety regulations. (Federal Aviation Administration, 2013) The Figure 10 is an image of the six locations across the U.S. designated for T&E of UAS.

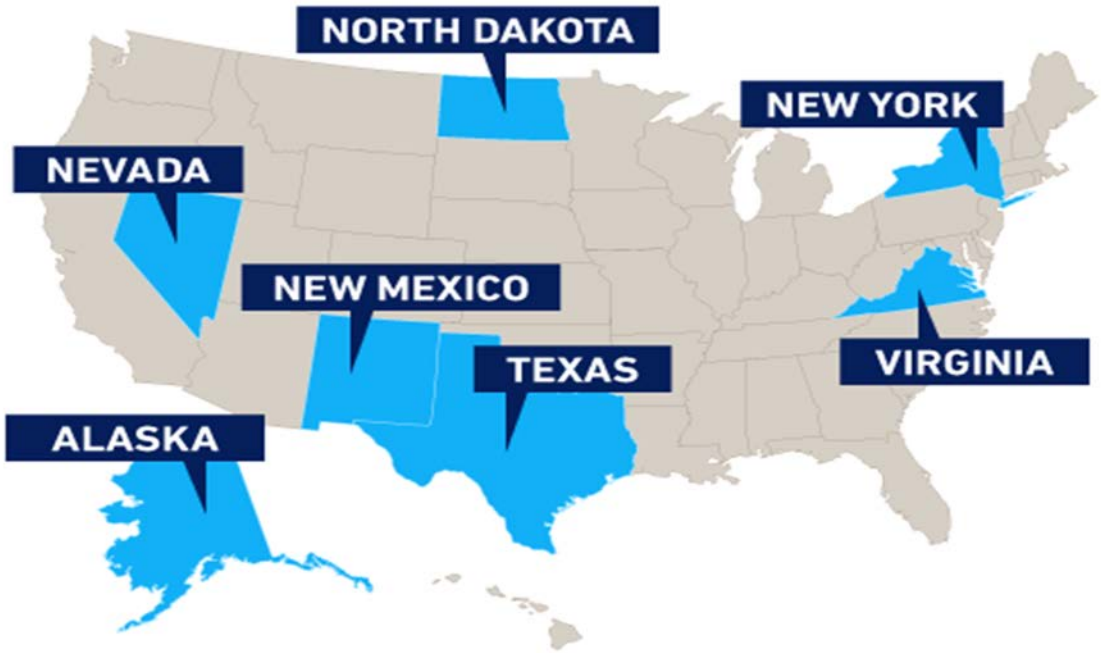


Figure 10. Federal Aviation Administration Report. Source: FAA (2013).

The auto industry has several T&E facilities across the U.S. designated for autonomous vehicles, the primary T&E facility is the Mcity Test Facility, located within the University of Michigan's Norther Campus. Mcity is a 16-acre controlled environment that is capable of simulating both urban and suburban environments prior to deploying

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experimental vehicles on public roads. Mcity was a joint venture between the Michigan Department of Transportation and the U. M. to create a space where new technologies can be safely tested. Since the development of Mcity, the U.S. Department of Transportation has designated an additional 10 proving grounds dedicated for the test and evaluation of autonomous vehicles. Locations range from the Northern Pittsburg Thomas D Larson transportation center to the southern Texas AV proving grounds and all the way to the Iowa City Area Development Group. The Department of transportation has identified these proving grounds as central hubs for the auto industry and academia to share best practices in the hopes of accelerating autonomous technologies and deploying safer cars on our roads (Mcity Test Facility, 2019). The Figure 11 is an image of Mcity test facility map.

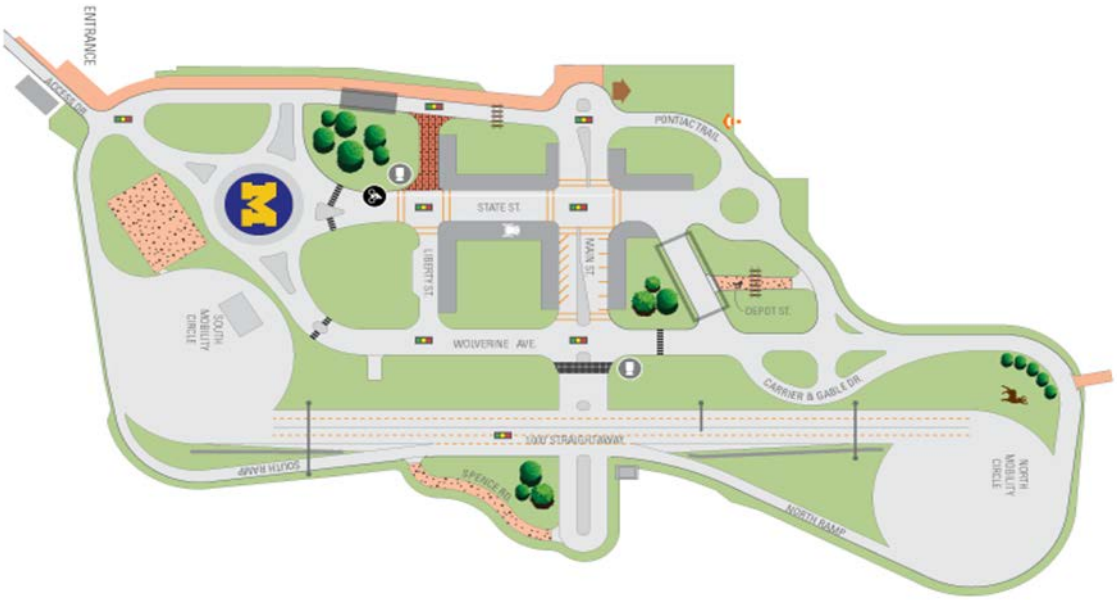


Figure 11. New Software Allows Users to Control Mcity Test Facility.
Source: University of Michigan (2019).

(4) Commercial Industry T&E Software, Simulation and Modeling Strategy for Autonomous Systems

According to Pecheur (2000) the forefront of M&S, the National Aeronautics and Space Administration (NASA) utilizes a suite of autonomous systems to support deep space exploration, from autonomous systems that work independently to keep astronauts

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on their trajectory towards their destinations, to advanced medical systems that alert ground control when astronauts' bodily vitals drastically change, or system functionality diagnoses a failure. NASA is at the forefront of utilizing autonomous software (Pecheur, 2000).

Based on the amount of unknown external factors and situations NASA systems encounter during space exploration, their systems and software engineers are required to assess a large range of situations when developing autonomous capabilities with limited information accessible. M&S is heavily relied upon as verification of autonomous applications. NASA software engineers utilize model checking, a technique that checks a program for violations or errors in every conceivable way early during the software development process. Software engineers contextualize a sub-system through a mathematic logic and analyze the model's properties during simulated situations to prove its functionality. Once a sub-system has been verified it can then be combined with multiple other structures called Binary Decision Diagrams (BDDs) and represent highly complex models that simulate entire systems. This complex model can then be used in a variety of different simulations and improved incrementally until satisfactory results are obtained.

Once a model has been validated, NASA uses analytical testing to run autonomous applications within unknown environments simulations. These unknown scenarios are simulated environment with ever-changing algorithms used to test the autonomous applications in a broad range of scenarios that have never been witnessed, a systematic exploration to identify errors within the software virtually. Analytical testing can provide a limitless amount of information prior to physical testing early in development of the hardware and at a fraction of the time and cost. Testing is done within the software in virtual simulations, parts, systems and materials can be altered reducing the overall cost of late development changes. NASA believes that analytic testing is the overall best path of increasing reliability of autonomous systems. Through the use virtual testing, NASA test evaluators can virtually simulate failure analysis and corrective action in parallel with development process.

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E. OPERATIONAL IMPACT OF AUTONOMOUS SYSTEMS

The IOT&E is the final test event for defense acquisitions systems in development and a critical milestone in a program's life cycle. Required by the DOD and by law, it's conducted near a MS C decision to substantiate the operational effectiveness and suitability of a capability in its relative environment and used as the final data point in support of a full rate production decision.

Most technically complex capabilities being fielded by the DOD face a substantial number of hurdles during an IOT&E test. Defense acquisition regulations mandate that soldiers are required to have the proper training prior to test, to operate all systems' subsystems and trouble-shooting procedures prior to the event. Technical manuals are required to be detailed enough to walk soldiers through problems during operations, reliability failures and/or inadvertent user experiences. The IOT&E test is the final exam of the developmental phase of defense acquisition. Autonomous systems must contend with those issues as well as "system" trust and "operational" trust so that operators accept autonomous systems during critical situations. System trust is the operator's trust in the system to independently perform as required and operational trust is the operator's acceptance that the autonomous system is providing a benefit to perform the assigned task over traditional un-autonomous capabilities (Zwillinger, Palmer, & Selwyn, 2014). The U.S. Air Force chief scientist Werner Dahm believes that "Human mistrust of Automation/ Autonomy" is the "major barrier that prevents the USAF from gaining more capability from autonomous systems" (Helle, Strobel, & Schamai, 2016)

In the following chapter, we continue to compare T&E activities for the purpose of identifying specific challenges and future resolutions to DOD's methodology.

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IV. ANALYSIS OF T&E METHODOLOGIES FOR AUTONOMOUS SYSTEMS

A. DOD'S T&E CHALLENGES OF AUTONOMOUS SYSTEMS AS COMPARED TO INDUSTRY BEST PRACTICES

The purpose of this JAP is to examine the current test methodologies of government programs with autonomous functionality as compared to the T&E methodologies of the private sector in order to identify successful practices that can be used as actionable changes to enhance the qualification and fielding of future DOD autonomous capabilities. This JAP utilizes the test and evaluation methodologies of four programs of records (SREHD, Gray Eagle, Project Perdix and the AMAS system) alongside similar industry systems within the automobile, agriculture, space and drone industry as a basis for comparison. The analysis section of this JAP outlines four significant weaknesses within the DOD autonomous systems T&E methodology as compared to current industry best practices. The data supporting these 4 (four) deficiencies is based upon research identified in the previous section comparing industry best practices alongside the T&E methodology of DOD programs of record.

Below we explore the following DOD T&E weaknesses

- DOD's fragmented T&E process diminishes chances of fielding autonomous capabilities
- DOD's lack of test facilities that can accommodate an autonomous capability concurrently alongside the development process
- DOD's minimal use of M&S during T&E of new systems
- DOD's inefficient Operational Testing of autonomous systems methodology

Major defense acquisition programs follow a standard development cycle; once a requirement has been established and approved by the user, those requirements are then taken by the program office and developed into a request for proposal to industry partners

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and awarded to the overall best proposal that meets the government's selection criteria. A contract is established, and contractors begin developing the system in conjunction with government oversight to ensure cost, schedule and performance metrics established within the contract are being met. Systems and subsystems are then tested and evaluated by the government T&E team to ensure performance requirements are being satisfied prior to full-rate production and fielding. The T&E process continues until the government is satisfied with the system's level of performance and/or the user accepts limitations against requirements. Operational Test and Evaluation (OT&E) activities, typically take place near the end of the engineering maturation phase and are both schedule and cost drivers. Technical issues identified during OT&E can be catastrophic during development, especially for autonomous functionality that is linked to human safety.

As in the case of SREHD's operational test event, in which operators were evaluated on how successful they could utilize all SREHD's capabilities to navigate lanes with hidden explosive devices. This test was conducted at the end of the DT&E phase due to the need to utilizing mature systems and software together. Thousands of hours were spent on hardware and software changes to ensure the system could meet the user requirements, but very little time was spent with the system in actual soldiers' hands. Per (James & Chang, 2017) the test was ultimately a failure because the consensus from the user representatives was that the system found to be non-operationally effective in comparison to the already fielded hand-held systems which were quicker and more, more versatile an in conjunction with the operator's awareness, more efficient at identifying threats.

In contrast, the autonomous systems industry has overcome these issues by establishing a continuous process of experimentation, testing and evaluation. Since there are no gaps in the development team structure, "real-world" data is continuously utilized to identify system problems and assist with better decision making. Statistics and human factor analysis are used throughout the system's life cycle to recognize system limitations early on and assist program managers with adjusting resources to better fit the needs of its customers. Commercial companies like autonomous electric vehicle manufacturer, Tesla and drone manufacturer DJI, both utilize a process of continuous real-world data collection

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throughout the entire life cycle of their autonomous systems. The continuous data collection enables quicker iterations of products to market and retroactively provide them with upgrades that increase the performance of their autonomous functionality. Continuous experimentation and data collection throughout development reduces the risk of operational test failures.

B. AVAILABILITY OF TEST RESOURCES THAT CAN ACCOMMODATE AUTONOMOUS SYSTEMS

In the DOD *Autonomy Report*, (2012) the Secretary of Defense, stated that "DOD's testing infrastructure will not be able to support future testing of new technologies such as hypersonic and autonomous systems without increased funding." This was also acknowledged by the DOT&E who rebutted major sections of DBB's report but affirmed that the current infrastructure of the DOT&E was not fully postured for the future and requested a follow-on study to assess the state-of-the-art technology to close the capability gap. Additionally, infrastructure was also reported to be an issue by the STAT T&E Center of Excellence which stated, "Many of the necessary processes, systems, test infrastructure and other capabilities simply do not exist, and may not have even been conceived at this point" (Parson & Ahner, 2016). The DOD needs to invest in test facilities and test evaluators that can accommodate an autonomous system in order to be successful in the future.

Based on the data collected for this JAP, all four case studies used to examine DOD's T&E methodology for autonomous systems utilized traditional man-in-the-loop type facilities and equipment as a means of qualification. In none of the four case studies were test facilities and/or equipment developed alongside the development of the autonomous capability to ensure that a better more efficient method of testing was available. Logically, autonomous systems are still an insignificant percentage of capability within the military and, with limited budgets, DOD has not prioritized funds for specialized facilities and equipment to test autonomous systems. However, until program managers, alongside the test and evaluation community, identify gaps in the T&E methodology of AS, programs will continue to be hampered by inefficient, expensive and unadaptable T&E methodology.

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As an example, the SREHD T&E methodology required pre-existing lanes created for testing hand-held detectors. The AMAS's test facility is the Army's primary test venue for qualifying medium/heavy military vehicles; Gray Eagle is tested in airspace used to qualify the military's fleet of fighter jets; and Project Perdix is tested over China Lake, a naval weapon test site. Based on our research, currently none of these facilities use adaptive instrumentation needed to evaluate the system's ability to learn and adapt to its environment. Inadequate instrumentation becomes a critical issue when trying to identify the root cause of a failure and leaves test operators and data collectors vulnerable to "false positives" or test failures that are due to systems trying to adapt to environmental changes.

Alternatively, industries like the autonomous driving industry work together to advance test facilities for autonomous vehicles with the vision of modernizing vehicle proving ground facilities for the future. The University of Michigan and industry partners have invested $20 million in the Mcity test facility specifically to evaluate autonomous vehicles through a broad range of urban and suburban environments.

The Mcity proving ground can simulate several types of road surface conditions and structures while remotely monitoring a vehicle and passenger conditions. Mcity is also one of the only vehicles proving ground facilities to provide infrastructure capable of dedicated short-range communication, which is the future of autonomous vehicle communication enabling advanced coordination and cooperation that will reduce congestion and improve traffic flow in the future. The test facilities provide the autonomous vehicle industry a test bed to compare its simulated "virtual" performance with actual roadside data that can be evaluated in real time to help engineers identify changes and deficiencies quickly and turn around corrective alternatives.

Theoretically, if the AMAS IPT could duplicate the type of test facility that industry is using to qualify autonomous vehicles, DOD would have the capability of replicating multiple terrain types, environments, and threats at a single test facility versus having to fund and transport equipment, test hardware, and people to multiple test sites. The time and cost involved with transporting and maintaining multiple types of military vehicles to test and evaluate the AMAS system could be used more efficiently to expedite development of the overall test program.

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Another significant limitation facing DOD's T&E community is the lack of expertise working with autonomous systems. A report issued by the Scientific Test & Analysis Techniques Center of Excellence, "Test and Evaluation of Autonomous Systems," identified that DOD's current T&E workforce lack personnel who can apply new methodologies for the future autonomous system testing.

Leading autonomous systems technology firms imbed their T&E teams within their design teams to shrink development times and increase system reliability. Companies such as Autonomous Solutions Inc. (ASI), the current market leader in autonomous farming technology, utilize a single facility to both design and validate their autonomous systems. Test engineers work in tandem with the designers, programmers, and mechanical engineers to expedite the validation process of subsystems in simulated "operational environments" to verify functionality early in the development process. (Nielsen, 2016) The synergy created by having onsite test facilities available early in the development process assists with the system education process and allows evaluators to understand the full range of capabilities of autonomous systems.

Based on the four provided examples, the T&E methodologies for the government autonomous programs are typically repurposed man-in-the-loop test methods and facilities that are utilized to verify and validate functionality. Most of these tests take place on MRTFB with personnel who do not specialize with autonomous technology and were not part of the technology demonstration phase of the program. In addition, these tests are typically large and exhaustive efforts to ensure the maximum amount of conditions are evaluated for stakeholders to determine a capabilities readiness.

Conversely, industry has identified the profit to be made by the growing "smart" commercial sector and have heavily invested in specialized personnel and facilities to rapidly provide autonomous products into the marketplace. Newer products are based off designs of older products and do not require an extensive amount of testing, only incremental validation of new functionality. Overall, industry embraces partnerships with agencies who specialize in the T&E of autonomous capabilities, which can rapidly iterate on test results and provide the latest technology to assist with the verification and

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validation. The differences between the two methodologies drastically impairs the DOD's ability to design, test and field autonomous capabilities.

The DOD, as a non-profit agent, must provide test resources for several thousand programs of record across the country, whereas emergent startup companies can profit off the autonomous systems boom and create niche T&E facilities. Autonomous programs of record are still in the infancy phase and DOD does not have the resources to convert the current T&E facilities to specialized autonomous systems test facilities. Program offices developing new autonomous systems, in conjunction with their prime contractors, will leverage private test facilities and personnel to level the playing field. PMO's will utilize the changes made to Army Regulation 73-1 (AR 73-1), which requires ATEC to minimize redundant testing and utilize both contractor data and test facilities to accelerate development and get capability into the warfighter's hands. In the future, as the need for more autonomous capabilities grow, the DOD will have to assess if there is still a need for government owned, government operated test facilities specifically for autonomous systems.

1. DOD's Minimal Utilization of M&S during T&E of New Systems

Based on the research for the four programs within this JAP, M&S data was only utilized as a tool to prototype and analyze maturing technology. This JAP was unable to identify any M&S being used as a T&E methodology alternative to real-world, physical hardware testing. In most test cases we identified within this JAP, the four systems used M&S to corroborate existing data and verify performance metrics prior to physically testing hardware. A primary reason the DOD doesn't use M&S more liberally throughout system development is because the T&E community lacks a robust M&S test capability that can stress validated models within an integrated virtual environment (J. Brabbs, S. Lohrer, P. Kwashnak, P. Bounker, M. Brudnak, 2019).

During the development of the AMAS system, M&S was utilized to simulate the AMAS architecture within a virtual testbed. Engineers were able to evaluate what the AMAS system was capable of prior to physically running the system on a vehicle. Unfortunately, because of how the AMAS system uses several sensors to capture and relay

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information to the vehicle, the T&E community was unable to use the information to pre-plan test scenarios or capture any valid performance metrics. Vehicles were still required to be equipped with the AMAS system for testers to complete their analysis of the capability (D. Pirozzo, J.P. Hecker, A. Dickinson, T. Schulteis, J. Ratowski, and B. Theisen, 2019).

Gray Eagle was similarly developed with the same methodology. Government test and evaluators only utilized a virtual model of the Gray Eagle after the capability was complete and real-world data could be acquired to verify performance. Currently, the only government utilization of virtual simulation is to train Gray Eagle operators, but virtual testing could have been utilized to mitigate reliability issues that plagued the system early in development.

Project Perdix hasn't undergone formal developmental testing but there is no indication that DOD test and evaluators are utilizing virtual simulation software to evaluate performance. Only test data that was obtainable was taken from real world testing, evaluated for the purpose of increasing the size of the drone swarm, and evaluating new test environments. Simulation and modeling could be utilized during initial test events to mitigate user interface issues and determine ideal conditions for future test events.

Finally, during the development of the SREHD capability, the government did not utilize SREHD M&S data to validate changes made to the system. Every single design change required additional tests that resulted in additional time and cost against the acquisition program baseline. The government IPT did not request SREHD software models be kept up to date with changes made later in development and was unable to utilize virtual simulation to validate/verify critical reliability engineering change proposals (ECPs) efficiently. The only means of verification was to physically test and evaluate system performance by running the system over test lanes at Yuma Proving Grounds and AP Hill test facilities. If the government development team had contractually obligated the SREHD contractor to maintain virtual models of the SREHD system, months of test and evaluation could have been reduced without requiring a 12-month period of performance (PoP) extension and a substantial cost overrun.

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Alternatively, the federally funded National Aeronautics and Space Administration, (NASA) does utilize simulation and modeling at the beginning of the development process to test and validate concepts prior to design completion. Once models have been validated, NASA engineers can run virtual software simulations of entire complex systems within new environments to identify errors and increase reliability. Additionally, since testing takes place within a virtual environment, parts, materials and subsystems can be altered quickly, reducing the overall cost of late development changes.

Programs like SREHD, utilized M&S early in development, as a means for engineering teams to plan budgets, resources and judge the complexity of technical requirements. Once initial prototypes were completed, resources were focused on getting hardware and software mature enough to meet requirements but without regard of maintaining those changes to the virtual simulation. Developing complex software structures such as NASA's binary decision diagrams (BDDs) to simulate autonomous functionality before and throughout the development of autonomous systems, is a proven method of reducing both the cost and time required to physically validate autonomous functionality in complex systems.

2. DOD's Inefficient Operational Testing Of Autonomous System Methodology

Based on the information being presented, it is more likely that industry will be more capable of reducing the amount of resources required during T&E to bring autonomous systems to the market. The primary reason for our hypothesis is that the commercial sector for autonomous products is smaller, more niche and capable of focusing on data derived from experimentation during development testing which can be used to seize the scale of relations and reduce the need for redundant and inefficient testing. This enables industry to focus future tests on only the most critical components of an autonomous capability. The autonomous automotive industry already utilizes test facilities that incorporate the "Hue Peng" methodology of testing the I.Q. of autonomous vehicles rather than its ability to make identical decisions given different types of situations. This methodology not only increases the level of awareness of the autonomous capability but also reduces the amount of testing required to validate complex systems (Peng & Zhao,

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2017). The Hue Peng methodology is in direct conflict with DOD's T&E methodology that requires testers to verify and validate all system parameters. This methodology adapted to the Gray Eagle's autonomous liftoff and landing capability could have reduced the time needed to qualify this unmanned system.

The DOD uses information gained during the OT&E period to assess a system's operational effectiveness and operational suitability during a realistic simulated combat scenario. The *Role of Autonomy in DOD Systems* by the Defense Science Board (2012 summed up the issue of testing autonomous systems best in their report, "Testing all System of System requirements of all the systems is impossible." With the inception of autonomous systems on the battlefield, DOD needs to dynamically change its T&E methodology for operational testing to a more efficient and effective means of verifying and validating operational requirements that will assist in accelerate development and fielding.

Operational test events planned for the end of the EMD phase need to evolve into operational experimentation initiated in the technical demonstration phase The DOD has acknowledged the issues of the standard FAR based acquisition process and provided new guidance called, middle tier acquisition (MTA) authority issued by Congress in the FY16 National Defense Authorized Act (NDAA) Section 804. The authorization establishes an interim adaptive acquisition process that enables the PMO the opportunity to accelerate capability development and field prototype hardware within 5 years. MTA provides the PMO the authority to experiment with mature technologies in an operational environment from the beginning of the acquisition and enter into production within 6 months (Office of the (Under Secretary of Defense for Acquisition and Sustainment [USDAS], 2020).

Each PMO needs utilize tools and authorities like MTA to incorporate an operational experimentation strategy that gets autonomous systems in the hand of the actual warfighter as soon as feasibly possible. The benefits of early feedback by an actual user representative in a relevant environment will assist in both, shaping future test events while accelerating development. Typically, autonomy is incorporated into military systems to provide functionality that reduces burdens for safety critical tasks, such as maintaining head height of a sensor on a mine detection system or constantly monitoring

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communication systems for the purpose of safely navigating the skies. The T&E of autonomous systems require the evaluation of these system's behavior in both defined and undefined environments. System autonomy is derived from machine learning algorithms which inherently behave in varies ways to the same inputs overtime, since their knowledge increases over multiple operations over time. Fundamentally this means "that one successful test does not guarantee that the system will pass the same test on the next run" (Art & Philip & Helle, 2016). Non-deterministic behavior is a key challenge facing the DOD T&E community, requiring investment into advanced test simulation techniques, that significantly reduce the amount of test scenarios needed, in favor of fewer, more effective test. In the case of SREHD, early experimentation would have assisted the PMO in directing more development with the user interface and mitigated negative user feedback late in the development cycle.

The DOD's issues with aging test facilities, constrained resources for T&E and strict adherence to processes designed around testing "manned" systems is a self-imposed problem and unique to DOD's acquisition process. The commercial sector for autonomous systems created new and adaptive T&E methodologies specific to the needs of its products. As in the case for the automotive industry utilizing the "Hue Peng" methodology, which reduces the time spent, testing vehicles on the road to specifically what is required to verify the autonomous systems decision-making process.

Alternatively, the autonomous systems farming industry partners with their customer base specifically to obtain better T&E data during the development process. The DOD equivalent to this example would be for a system like the AMAS capability to be operationally tested during development by a deployed military transportation division. Unfortunately, the program stagnated and never progressed past the technology demonstration phase and has since transitioned into the Expedient Leader Follower (ExLF) program (DEFPOST 2018). Real-world developmental testing alongside laboratory test and evaluation is a critical step in advancing the T&E methodology for autonomous programs or record.

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V. CONCLUSIONS

A. ADAPTING INDUSTRY'S T&E METHODOLOGY

The purpose of this JAP was to collect information on DOD's current T&E methodology of autonomous systems through the analysis of case studies on four current programs of record (Gray Eagle, SREHD, and AMAS & Project Perdix) and identify corresponding industry T&E trends that could be used to successfully enhance DOD's T&E methodology for the future. Drawing comparisons between the defense acquisition process and private industry development process can be dangerous. The DOD is a non-profit organization that is responsible for ensuring the protection of U.S. citizens and national interests around the world and by proxy, that its military is outfitted with the most effective weaponry.

Private industry on the other hand is more concerned with developing products around commercial interests, maximizing profit and ensuring products meet the minimum safety standard required by government regulation. Pass/fail decisions are less relevant for commercial viability. This JAP acknowledges that not all best practices and commercial trends can be transitioned from industry to DOD's T&E methodology but based off of the analysis of the four systems within the JAP, we can conclude that the current DOD T&E model has significant weaknesses and recommend several industry T&E best practices that could be adopted by the DOD T&E community to advance methodology for military autonomous systems development.

B. ADVANCING DOD'S T&E METHODOLOGY FOR AUTONOMOUS SYSTEMS

As we framed our ideas for the JAP, we started out by seeking answers to two specific questions.

(1) Primary:

- What unique challenges are presented by autonomous systems to the Department of Defense's test and evaluation communities?

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Based on the research covered within this JAP, the DOD T&E community face several unique challenges that industry does not have to overcome. The challenges the DOD face in the T&E process for autonomous systems is like the development of other highly complex government acquisition PORs. The critical obstacle is to determine how the T&E community assesses the non-deterministic behavior of autonomous systems. We determined that answer to this question is exacerbated by the four specific challenge areas within the DOD T&E acquisition process for AS.

- DOD's fragmented T&E process that diminishes chances of fielding autonomous capabilities
- DOD's lack of test facilities that can accommodate an autonomous capability concurrently alongside the development process
- DOD's minimal use of M&S during T&E of new systems
- DOD's inefficient Operational Testing of autonomous systems methodology

This JAP concludes that the hurdles facing the DOD T&E community are due to current infrastructure, equipment and technical personnel that were created around the T&E of man-in-the-loop type systems. The military's autonomous capabilities of tomorrow require facilities that are capable of testing autonomous subsystems and systems in sync with development, as well as the trained personnel required to evaluate AI and machine learning over the life cycle of the system. The DOD T&E community need access to developmental data earlier in the life cycle of major development programs in order to efficiently evaluate the growth and maturity of autonomous systems. Additionally, DOD's T&E methodology has not sufficiently embraced M&S from the beginning of the life cycle, prohibiting virtually simulated testing of autonomous functionality early on, that would reduce the amount of time and resources needed to qualify systems. Finally, the DOD T&E methodology for operational testing requires a paradigm shift to be more effective and efficient at evaluating autonomous systems in relevant, realistic environments. Industry already embraces early real-world testing of autonomous systems for the purpose of

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evaluating the suitability and effectiveness of potential designs. The DOD should initiate methods of parallel verification and validation of operational experimentation, that would enable expeditionary forces to evaluate the effectiveness and suitability of autonomous systems prior to and throughout the EMD phase.

(2) • Secondary:

- Does DOD have the correct resources to conduct tests and evaluations of autonomous systems?

The DOD T&E community face unique challenges based on regulatory and statutory guidelines in the Federal Acquisition Regulation process, which prohibit adaptive and reflexive strategies required to keep pace with the constantly changing technologies of tomorrow. The DOD is also constrained by not having specialized personnel and processes in place that maximize the unique capabilities of autonomy. Examples like Mcity in Michigan developing specific test facilities and technologies to evaluate vehicles with autonomous capabilities or agencies like the FAA and USDOT developing policy's for the advancement of T&E research are evidence that the T&E community supporting the autonomous systems industry has rapidly developed new and better technologies. Even though most POR are developed in conjunction with defense contractors, most of the verification and validation of requirements still take place at DOD run facilities, limiting access to the latest innovative T&E methods and techniques. Some of these issues can be addressed, through the use of the adaptive acquisition framework, providing PMO's the authority to determine and tailor the most efficient method of acquiring, maturing and fielding a capability, delivering a better solution faster to the warfighter (USDAS 2020). Through the use of MTA, the PMO has the ability to leverage new technologies, contractor test data and government experimentation data for the purpose of maturing and fielding a capability that would otherwise take several years based on the typical major capability acquisition pathway.

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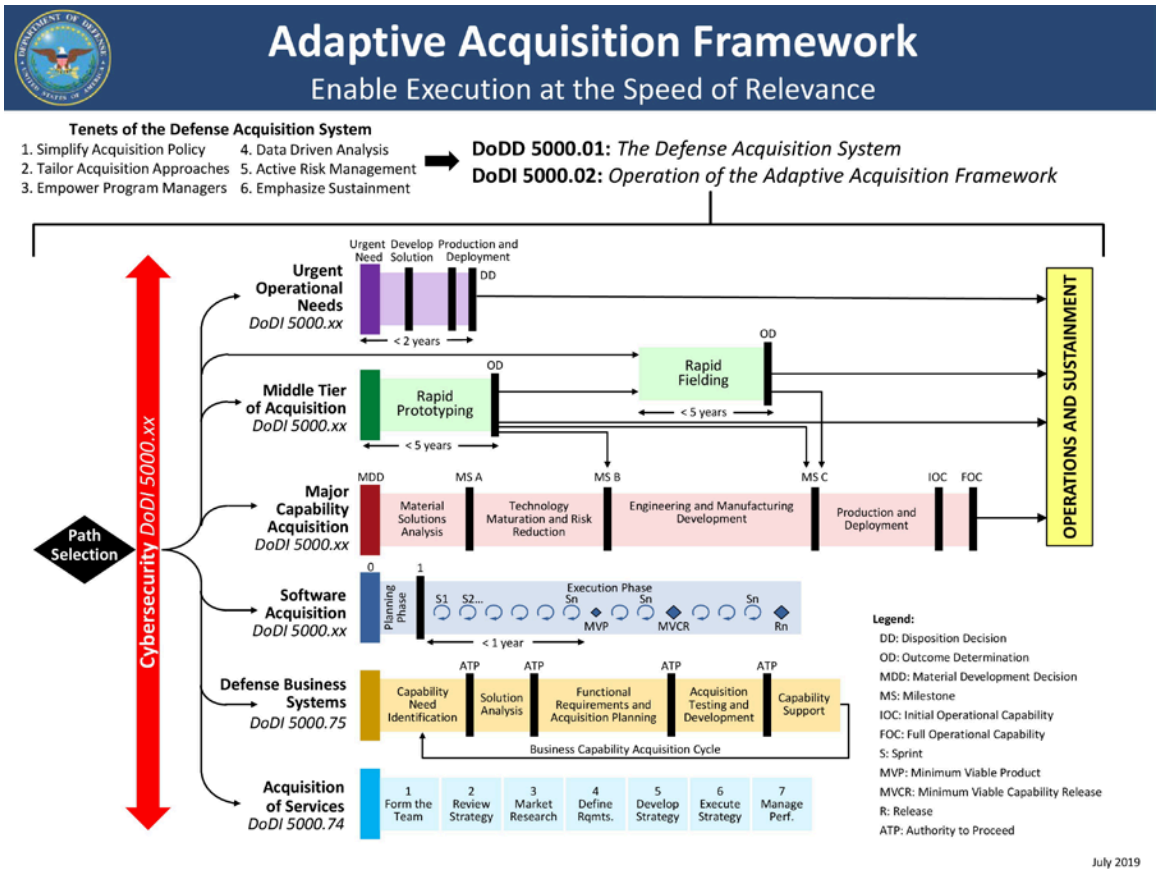


Figure 12. DoDI 5000.02 Adaptive Acquisition Framework. Source: Office Under Secretary of Defense for Acquisition and Sustainment [USDAD] AAF (2020).

C. FINAL THOUGHTS

Through the exploration of the DOD T&E methodology for autonomous systems, this JAP was able to identify several keyways in which DOD can advance its T&E process to be more in line with industry trends.

- DOD autonomous systems PORs should consider the addition of clauses in contracts that require contractors to create, maintain and utilize virtual models for the specific purpose of efficiently simulating test of autonomous functionality. These clauses can be used to increase the level

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of confidence of virtual models that can expedite development test and evaluation.

- DOD needs to increase funding and education in support of advancing the autonomous test capabilities at APG and YPG and test facilities. The education of the T&E community and restoration of DOD test facilities are critical to providing the warfighter the cutting edge in capability. To include MRTFBs retaining the capability to replicate multiple terrain types, environments, and threats at a single test facility versus having to fund and transport equipment, test hardware, and people to multiple test sites.

- DOD should consider incentiving PORs to develop T&E strategies that include parallel verification and validation of operational effectiveness and suitability during the EMD phase. Continuous operational evaluation of autonomous subsystems would provide contractors valuable data on the effects of machine learning outside of the laboratory environment, provide decision makers valuable information on how better to manage funding needed for corrective action strategies, and give users information on how to tailor requirements to only what is critical for operational effectiveness. With the use of expeditionary forces providing globally deployed soldiers' innovative solutions to address urgent needs operational, T&E development process should be included to provide as much information as soon as possible on operational effectiveness and suitability**.**

- DOD must establish a more consistent process for experimentation, T&E and updating already fielded autonomous capabilities. To note, defense programs like Gray Eagle, have a process in place to incrementally add enhancements but the ability to improve upon autonomy post initial fielding is only reserved for the larger MDAP initiatives. Advances in technology have enabled the tech industry to sell products in the marketplace with a limited feature set initially and continue to increase

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> that products' capabilities over time. If DOD were to adopt a similar methodology of fielding autonomous systems with limited capability and over time increasing functionality to bring enhanced autonomy retroactively, then DOD autonomous systems would require less test and evaluation, at a reduced cost and less schedule delays.

Ironically, it is now industry leading the way in the technology fields of artificial intelligence, machine learning, and virtual simulated testing that originally were government defense research initiatives. Fortunately, during the time it took to evolve our JAP, the DOD has initiated policies and postures that are intended to totally change the dynamic of how the military brings advancements and capability to the field. Army Future Command is the Army's primary command stood up in 2019, for the purpose of soliciting industry's best and brightest to rapidly evolve technology and demonstrate capability quickly for the warfighter. The Army has recognized that only through embracing rapid innovation of industry will we be able to keep ahead of our near-pear threats. It is our hope that the DOD will keep pushing ahead and use the information contained within this JAP to continue creating new policies and regulations that will facilitate the T&E of autonomous systems within DOD systems.

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TECHNICAL REPORT FCDD-AMT-20-12

SYNERGISTIC UNMANNED MANNED INTELLIGENT TEAMING (SUMIT) SIMULATION EVALUATIONS COGNITIVE WORK ANALYSIS (CWA)

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

With the ever-increasing complexity of military operations and adversary abilities, merely possessing advanced autonomous capabilities is not sufficient for battlespace superiority. Human-Autonomy Interfaces (HAIs) must be designed to ensure effective collaboration and coordination between human operators and the autonomous systems available to them. This report details the methods and results of a Cognitive Work Analysis (CWA) that informed the development of an integrated suite of autonomous tools that enables an Air Mission Commander (AMC), teaming with autonomous capabilities, for example, play calling, route planning, and asset allocation, to effectively command and control a team of multiple unmanned and manned aerial systems to complete an air assault mission. This report will highlight the practical applications that the CWA results provided for generating designs for the HAIs. In addition, feedback from Army Aviation Subject Matter Experts (SMEs) during the simulation interview is discussed since these results not only informed system development and design but illuminated critical details to ensure that the most ecologically valid and operationally relevant tasks and events were selected for the program's empirical evaluations.

15. SUBJECT TERMS

Cognitive Work Analysis (CWA), Human-Autonomy Interface (HAI), Human-Autonomy Teaming, Manned-Unmanned Teaming (MUM-T)

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EXECUTIVE SUMMARY

Advanced autonomous systems are being developed to enable a single operator to have the ability to effectively and simultaneously manage, command, and control a team of multiple Manned-Unmanned (MUM) vehicles. Critical to the teaming of human operators with autonomous systems is the Human-Autonomy Interface (HAI), which should be designed to ensure effective collaboration and coordination between the human operator and the autonomous systems available to them.

The first step in our HAI design process was to gain a deeper understanding of the complex work that an Air Mission Commander (AMC) performs during air assault operations. A Cognitive Work Analysis (CWA) was therefore conducted to uncover the behavior-shaping constraints of an AMC, including a set of semi-structured interviews with Army Aviation Subject Matter Experts (SMEs). Results of the CWA will be discussed, as well as examples of how the results informed the design of the HAI, the variables and constraints the suite of autonomous systems reasoned about, and the selection of events, tasks, and details later used for empirical evaluations of the human-autonomy team during simulated air assault mission.

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I. INTRODUCTION

New and recently developed autonomous systems, decision-aiding technologies, and Human-Autonomy Interfaces (HAIs) have the potential to assist an Air Mission Commander (AMC) tasked with conducting Manned-Unmanned Teaming (MUM-T) operations from the cockpit of a Vertical Takeoff and Landing (VTOL) aircraft. However, many of these technologies have failed to appreciate the critical role that human-to-autonomy communication and coordination play in successful human-autonomy teaming, instead they focus on optimizing separate human and autonomous components and leaving the design of interfaces and team processes as an afterthought [1]. However, team performance is more than the sum of the abilities of the individuals that compose the team [2, 3], and simply pairing the best human with the best autonomous system will not necessarily result in the best performance.

Effective collaboration is essential to the success of human-autonomy teams, especially in the context of sociotechnical systems where multiple agents, both human and autonomous, must work together to solve complex problems [1]. Reference 4 identified three stages for enabling successful collaboration:

- Understand—develop an accurate representation of the domain and ensure that the autonomous system can reason about relevant domain aspects
- Generate—design interfaces that enable a rich coupling between the human operator and the autonomous systems
- Validate—evaluate the human-autonomy team in a realistic test environment

This report details the methods and results of the initial Cognitive Work Analysis (CWA) designed to inform each stage for the development of Tasking and Execution of Collaborative Unmanned and Manned Systems with Autonomy (TECUMSA), a system designed to achieve the goals of the Synergistic Unmanned Manned Intelligent Teaming (SUMIT) program. Also covered in this report are examples to highlight the practical application of the CWA results, including designs that were generated for TECUMSA's HAI as well as critical aspects of an air assault mission that were integrated into the logic of the autonomous systems, for example, air route optimization parameters. Finally, this research will detail the results of the collaboration with Army Aviation Subject Matter Experts (SMEs) to ensure that the most ecologically valid and operationally relevant tasks and events were selected for the SUMIT program evaluation of the human-autonomy team.

II. UNDERSTANDING ARMY AIR ASSAULTS

In an air assault, mission helicopters transport ground-based military forces and supplies in order to gain a military advantage. Mission objectives include penetration and security of strategic terrain and engagement and neutralization of enemy forces. During an air assault mission, the AMC is the overall mission leader with delegated authority over decision making and providing oversight and directives to up to 16 or more aircraft in a hostile, dynamic, and largely unpredictable environment. While adding Unmanned Aerial Vehicles (UAVs) to the AMC's resources has the potential to benefit mission performance, it could also increase the AMC's already high workload. Thus, autonomous technologies that assist the AMC in

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managing UAVs, such as Cooperative Control Algorithms (CCAs) that plan optimal routes, Intelligent Agents (IAs) that recommend optimal courses of action, and autonomic frameworks that monitor ongoing events, are critical for MUM-T missions.

IAs are being developed that can recommend a plan to satisfy an operator request, for example, provide overhead surveillance, while taking into account relevant situational variables, such as fuel use and time enroute [5]. Reference 6 illustrated how these IAs reason, as shown in Figure 1, using a scenario in which an operator manages three UAVs (FN-11, FN-12, and FN-13) and two Unmanned Ground Vehicles (UGVs) (TR-21 and TR-22). In this example, all of the unmanned vehicles are equipped with Electro-Optical (EO) sensors, two unmanned vehicles (FN-12 and TR-21) also have an Infrared (IR) sensor, and the UGVs have better sensor resolution than the UAVs. The operator's task in Figure 1 is to image Point Charlie on a cloudy day, thus making IR sensors more capable than EO sensors. In this scenario, the IA reasons about the time it takes each unmanned vehicle to get to Point Charlie as well as their respective capabilities.

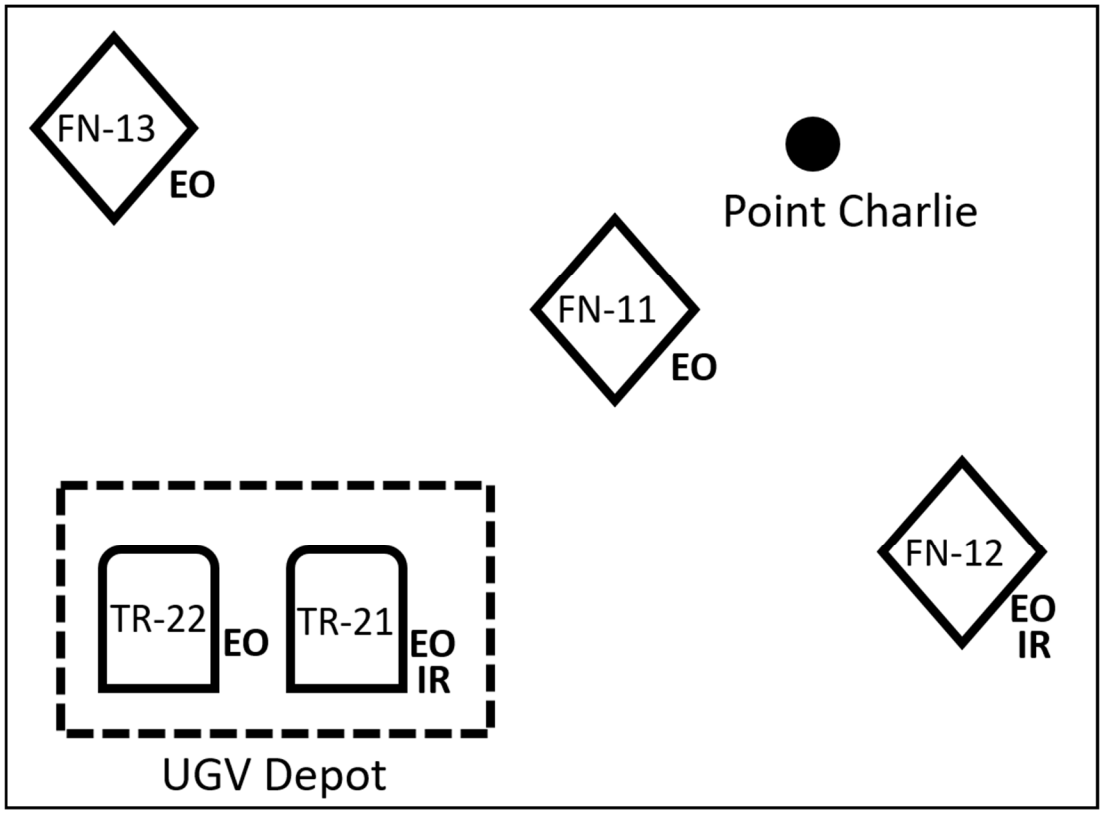


Figure 1. IA Reasoning Example Scenario [6]

The IA's reasoning is based on Pareto efficiency, whereby a plan is eliminated if another plan is better on all relevant dimensions [6]. Figure 2 illustrates the Pareto efficiency of each unmanned vehicle for this task, with Pareto optimal vehicle choices (FN-11, FN-12, and TR-21) on the dashed line. For example, FN-11 can get to Point Charlie the quickest so it is a better choice than FN-13, which has the same sensor capabilities but is farther away. Similarly, TR-21 is more optimal than TR-22 because even though both unmanned vehicles can reach Point

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Charlie in the same amount of time, TR-21 has better sensor capabilities, that is, an IR sensor. This leaves three Pareto optimal vehicles for the operator to choose from:

- FN-11—fastest speed and worst capability
- TR-21—slowest speed and best capability
- FN-12—average speed and average capability

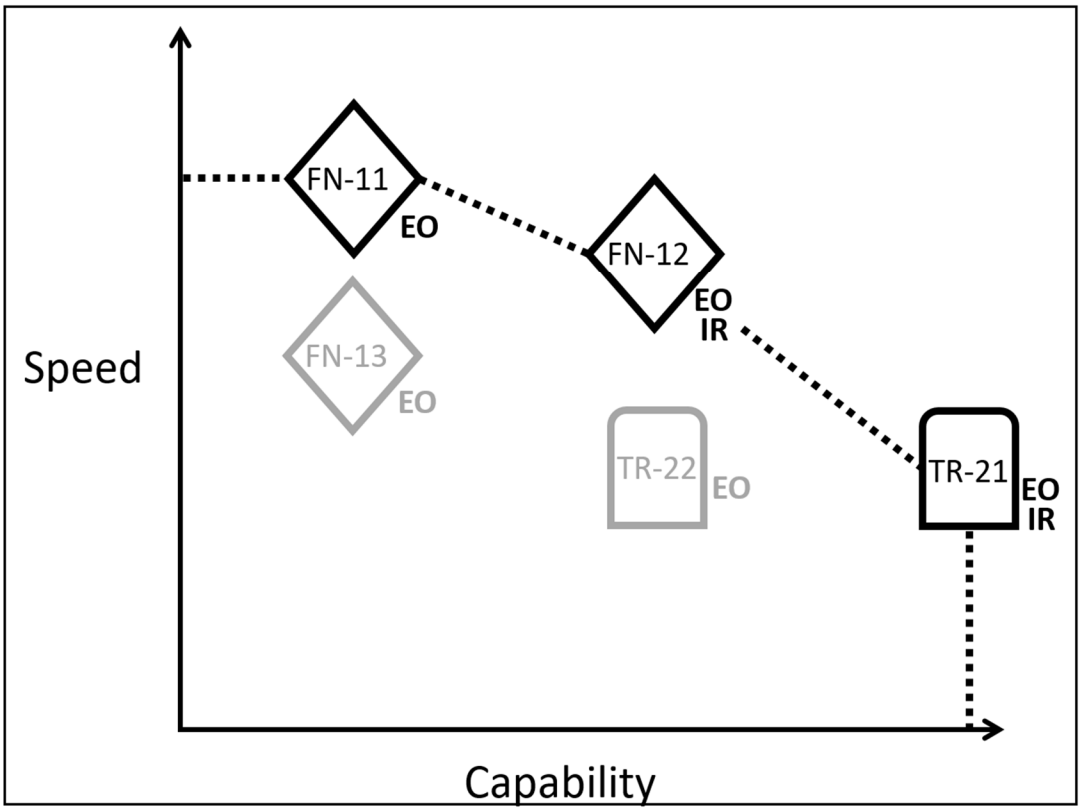


Figure 2. Pareto Optimal Vehicles Located on Dashed Line With Grayed Out, Sub-Pareto Optimal Vehicles [6]

The key to this process lies in the IA's Cognitive Domain Ontology (CDO), which is a representation of domain knowledge used to categorize situations, develop hypothesis, and plan and recommend courses of action [7]. With a CDO that accurately represents the constraints of the mission, which is in this case speed and sensor capability, the IA can rank and compare plans to determine which unmanned vehicle is the best to use. Thus, research to develop an IA that can support an AMC during an air assault mission must begin with an understanding of the work domain.

Researchers and developers can gain this understanding using a CWA, which is a set of methods used to understand how situational dynamics impact performance [8, 9]. For this effort, data were sourced from Army doctrine on procedures, tactics, and regulations, along with extensive interviews using several different methods, as described in Section V.A, with experienced AMCs.

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III. GENERATING USER INTERFACES

Although understanding the mission domain is necessary for autonomous systems to improve mission performance, it is not sufficient. Interfaces are needed that not only reflect the constraints and relationships of the complex work environment but also enable a rich coupling between the human operator and the autonomous technologies in order to bridge [10] gulf of evaluation and gulf of execution. The size of the gulf of evaluation depends on how well the human-autonomy team can observe, perceive, and understand the state of the world in terms of their intentions, for example, to see the best move on the chess board, while the size of the gulf of execution depends on the effectiveness of the actions or controllability the human-autonomy team has to achieve its goals [6]. However, if there is a poor coupling between the humans and autonomous technologies, for example, incompatible intentions, insufficient understanding of competency boundaries, then another gulf, known as coordination gulf, is introduced that creates additional uncertainties for each component, as shown in Figure 3.

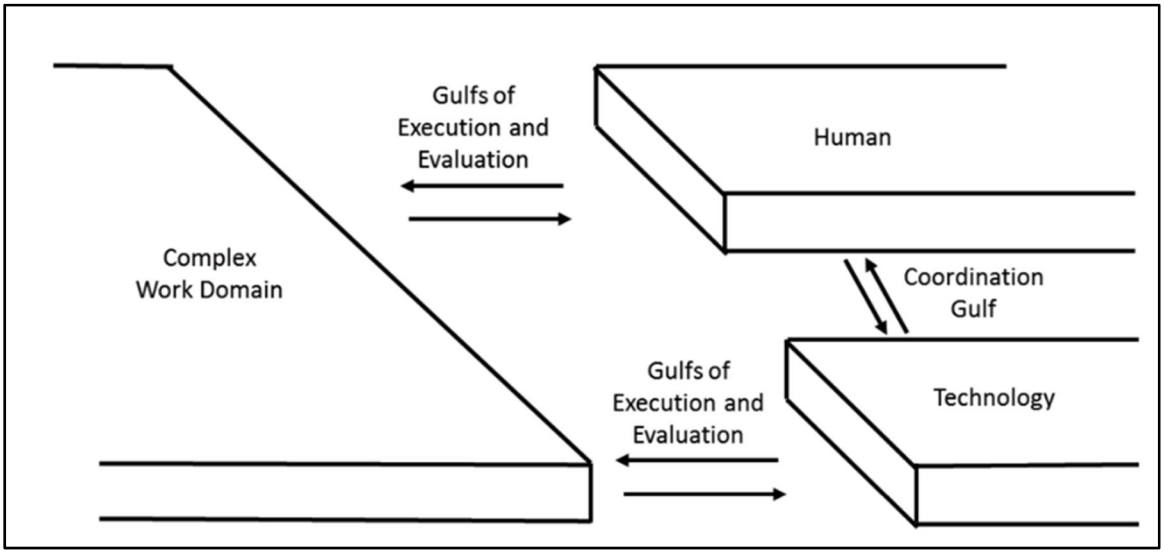


Figure 3. Gulfs of Evaluation, Execution, and Coordination [1]

In essence, a HAI must make the constraints of the work domain salient to the human-autonomy team in a manner that is consistent with the human operator's reasoning capabilities [11]. In Reference 12, Skill-Rule-Knowledge (SRK) framework has been proposed as a method for understanding alternative ways to represent constraints, signals, signs, and symbols, which in turn distinguish three levels of human performance, including skill-, rule-, and knowledge-based [1].

In the context of unmanned vehicle operations, an example of skill-based behavior is an unmanned vehicle operator manually controlling a sensor to keep a moving target in view. The location of the target in time and space provides the operator with the signal, and the goal is to continuously adjust the sensor any time the target deviates from the center of the screen.

In rule-based behavior, an operator has a set of predetermined solutions that are triggered by specific conditions, that is, signs. Figure 4 illustrates rule-based behavior for determining the best search pattern to use in the presence of a specific combination of signs for an unmanned

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vehicle operator to find a target. For example, if an operator is searching in a nonmountainous region for a target that is likely to still be near the last known location but the target's direction of travel is unknown, a sector search is the best option. These rule-based solutions often help an operator quickly identify a good enough solution [13].

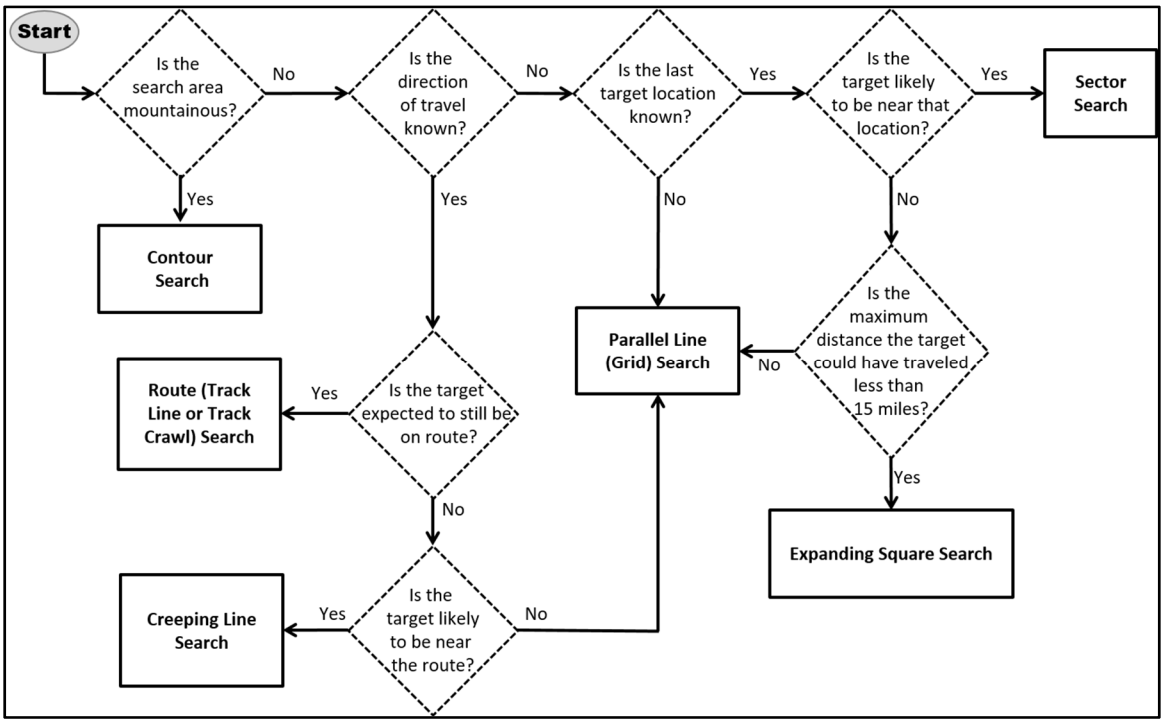


Figure 4. Optimal Search Pattern Decision Tree [13]

Knowledge-based behaviors occur when an operator encounters a novel unexpected situation for which no procedure exists [12]. In these instances, an operator may evaluate and critique skill- and rule-based tactics in order to learn from mistakes, take advantage of opportunities, and avoid threats that arise due to changing situation contingencies. For example, an operator may modify a rule-based strategy to find a target based on their knowledge of insurgent activity in the area or the limitations of the only unmanned vehicle that they have available [13].

Reference 14 developed an HAI that was designed to support rule- and knowledge-based behaviors for operators tasked with managing multiple unmanned vehicles in support of base defense missions. To support rule-based behaviors, interfaces were developed that allowed operators to quickly call high-level plays, which are adaptable plans of action using one or more unmanned vehicle, in response to different mission events. For example, in response to a report of an unidentified watercraft at Point Alpha, an operator can quickly call an Air Inspect play. In response, the IA recommends an unmanned vehicle that can get eyes on the unidentified watercraft in the least amount of time, plans a route for that unmanned vehicle, and monitors the unmanned vehicle's progress as it travels to Point Alpha.

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By default, the IA will recommend an unmanned vehicle that can reach the desired location in the least amount of time. However, the Play Workbook window allows the operator to provide the IA with information that will help it develop a better plan and change priority variables quickly to see how it impacts the IA's recommendations. For example, the operator can select the size of the target that they are searching for, which impacts the altitude a UAV would search at and/or the zoom level of the sensor. Additionally, environmental conditions that impact the effectiveness of unmanned vehicles, for example, if it is cloudy, an IR sensor might be better than an EO sensor. Since the Play Workbook provides parameters to optimize the plan, the operator can communicate to the IA what needs to be optimized, such as time to objective, fuel use, detectability, presence, crowd control, and/or tracking. With this interface, the operator can quickly tell the autonomy to find the target while keeping a low profile, optimize on time, and consider that it is cloudy.

The HAI also supports knowledge-based behavior by allowing the operator to explore the search space. For example, the Plan Comparison tool allows an operator to quickly determine the best plan based on a specific parameter as well as quickly view the overall quality of each plan based on weightings assigned to each parameter. For example, Plan 1 will consume the least amount of fuel, Plan 2 contains the best assets for deterring possible insurgent activity, and Plan 3 has the best crowd control and tracking capabilities.

In order to successfully bridge the gulfs of execution and evaluation, the user interface must support all three modes of interaction—skill-, rule-, and knowledge-based. Within the aforementioned HAI, extended play-based control was implemented to support a variety of human-autonomy teaming requirements [15]:

- Capturing the operator's intent
- Enabling plays that define the actions of one or more unmanned vehicles to be called or edited
- Allocating unmanned vehicles to tasks
- Routing unmanned vehicles
- Providing visibility into the autonomy's reasoning
- Monitoring play progress [15]

This HAI illustrates the importance of an interface design that supports skill-, rule-, and knowledge-based behaviors so that the human-autonomy team is able to perform not only in familiar events, but able to cope and adapt to unfamiliar and unanticipated events as well.

IV. VALIDATING HUMAN-AUTONOMY TEAMING

The goal of this research is to design HAIs that enable effective collaboration between human operators and autonomous tools to support AMC performance during air assault missions. To achieve this goal, any evaluation must support multiple performance measures in an experimental setting that, to the extent possible, captures and represents the constraints of the natural work domain. Reference 16 calls this type of experimental setting a synthetic task

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environment. The key is not the physical fidelity of the simulator but how well the research question maps to the properties of the real-world mission environment.

The Future Open Rotorcraft Cockpit Environment (FORCE) simulator, which is a Government-owned and operated simulation environment, contains all the features necessary for a synthetic task environment. An initial set of vignettes was developed by the United States (U.S.) Army Combat Capabilities Development Command (DEVCOM) Aviation & Missile Center (AvMC) Aviation Development Directorate (ADD) to evaluate the impact of TECUMSA on MUM-T missions. A simulation interview technique was used to identify the critical features of each vignette as well as map TECUMSA capabilities to each vignette's mission events.

V. METHODS, ASSUMPTIONS, AND PROCEDURES

A. Methods

Section V.A describes the various Cognitive Task Analysis (CTA) methods implemented during the semi-structured interviews for eliciting knowledge in regard to the general air assault work domain as well as specific AMC tasks.

1. Daily Walkthrough Method

In this portion of the interview, participants were asked to provide an initial, high-level description of their daily job duties as an AMC. The purpose of this segment was to put the participants into a reflective frame of mind and identify potential lines of questioning as the interview continued. The daily walkthroughs provided information about the general sequence of events that occurs upon receiving the operations order and the various considerations that go into air assault mission planning.

2. Task Diagram Method

The goal of the Task Diagram method is to elicit how a particular job is actually performed, not how doctrine prescribes it to be done [17]. In this case, the Task Diagram method was used to elicit the major components of the AMC's job during air assault missions. The interviewers placed a large piece of paper in front of the participants and asked if they could explain the 3-6 major aspects of their jobs as AMC. They were told to draw 3 to 6 circles, and each one would represent a major component of their job. Each component would be labeled, and bullets would be generated in each circle to describe that aspect of the job. Arrows would indicate if the major components were dependent on each other or occur in chronological order.

3. Wagon Wheel Method

The Wagon Wheel method [18] was used to understand the communication channels that exist between an AMC and their surrounding team during an air assault mission. For this exercise, participants were presented with the diagram in Figure 5 and asked to identify each individual the AMC communicates with during mission execution, including the direction of communication flow, which is indicated by the arrows; the information communicated; and the method by which the communication occurs, for example, radio, chat, and so forth. Communication channels that exist for an AMC can vary depending on mission type and

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available mission support; therefore, participants were initially told to consider including the communication channels that were generally present across a variety of missions and circumstances.

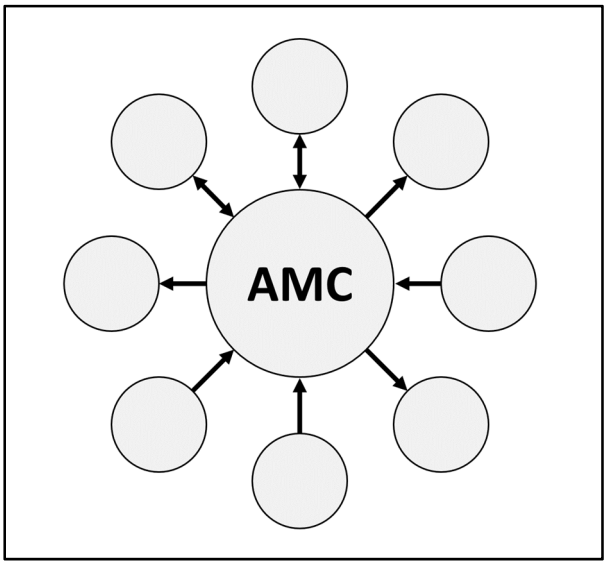


Figure 5. Wagon Wheel Template [18]

For each communication node the participant were asked the following questions [18]:

- What type of information is passed?
- From where did you receive the information you are transmitting?
- From where did they receive the information that was transmitted to you?
- Did you modify the information in any way? Was the information passed in its original form or was it altered, filtered, prioritized, and so forth in any way?
- What decisions does this information affect?
- Could this information be passed in another format, for example, digitally instead of voice?
- How do you know they received the information?
- How do you know when to provide them with this information?
- Would you consider this piece of information to be critical to the team's success?
- What's the impact to the team if this communication line is broken?

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4. TECUMSA Demonstration Method

For this portion of the interview, participants were given a brief demonstration of the TECUMSA HAI, including the play calling interfaces, plan comparison tool, and vehicle dashboard as well as TECUMSA's autonomous capabilities, including the route planner and IA. Participants were then asked to provide feedback on what they liked, disliked, and found confusing about the HAI as well as what modifications needed to be made to adapt the HAI for air assault missions.

5. Simulation Interview Method

A simulation interview was used to derive the contextualized judgements and decision making processes that experienced AMCs make across a variety of mission configurations and environmental circumstances [19]. For this effort, the simulation interview focused on how each participant would use their ownship and UAVs to accomplish different vignette tasks, for example, reconnaissance, surveillance, overwatch, and so forth. Using a paper and pencil method, SMEs were provided with a map of a battlespace with various terrain characteristics, including mountain ridges, Restricted Operating Zones (ROZs), known enemy locations, dense population areas, Named Areas of Interest (NAIs), a Landing Zone (LZ), and an objective location. Participants were encouraged to brainstorm events, tasks, constraints, and obstacles to include in future scenarios and asked to provide feedback on the fidelity of the vignettes as well as explanations for the courses of action that they considered and the respective optimality for mission success, crew survival, and so forth. Finally, participants were asked to map existing TECUMSA plays to the vignette mission events as well as determine the number of new plays that needed to be developed.

B. Participants

Three veteran Army helicopter pilots with a combination of over 55 years of experience in Army Aviation and extensive combat service as AMCs, as shown in Table 1, were interviewed. All three participants were male with an average age of 46.5 years. Combat deployments included Iraq, Afghanistan, Pakistan, South Korea, and Kosovo.

Table 1. Total Participant Experience

Aircraft	Noncombat Hours	Combat Hours
CH-47D/F Chinook	3500	3000
UH-60A/L (Sikorsky S-70)	1420	700
Bell 206	300	
OH-58A/C Kiowa	220	
AS350 AStar	200	
UH-1H Iroquois	110	
MH-47E Chinook	100	

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C. Assumptions

The methods of eliciting information from participants will ultimately determine the quality of the information that is gathered. To ensure both breadth and depth of the information received from participants, a broad set of knowledge elicitation methods were utilized to provide sufficient insight into the air assault work domain and the tasks of an AMC. In addition, participants answered all interview questions and knowledge elicitation prompts honestly and had a sincere interest in providing beneficial results.

D. Procedure

Participants were given an overview of the goals of the project, including the design of an intelligent human-autonomy team that can optimally manage multiple Manned-Unmanned (MUM) aerial systems in air assault mission environments, as well as a briefing on the capabilities of TECUMSA's autonomous systems. Basic demographic data, including rank and years of service, were then collected. Participants were also asked about their deployment history, specifically focusing on their experience as an AMC. After collecting this demographic data, interviewers conducted semi-structured interviews using the aforementioned methods described in Section V.A.

VI. RESULTS

A. Understanding Role of AMC During Air Assault Mission

During an air assault mission, the AMC is the leader and final authority of all air assets during the mission. Reference 20 states that "The AMC is the aviation unit commander. He/she receives and executes the Air Assault Task Force Commander's AATFCs guidance and directives, and controls all aviation elements. The AMC ensures continuity of command for all supporting aviation units and employs attack helicopters and artillery along the air route, fighting the battle from Pickup Zone (PZ) to LZ while keeping the AATFC informed." Participants identified three major phases of an air assault that the AMC plays an instrumental role in:

- Planning
- Briefing
- Execution

The final phase of an air assault mission would technically be the debriefing; however, participants suggested that there is not always time available to complete this phase. Figure 6 illustrates these three different phases and includes the primary activities of the AMC during each, according to SME feedback. Using the Task Diagram method, the major phases of the air assault and associated tasks of an AMC during each were identified.

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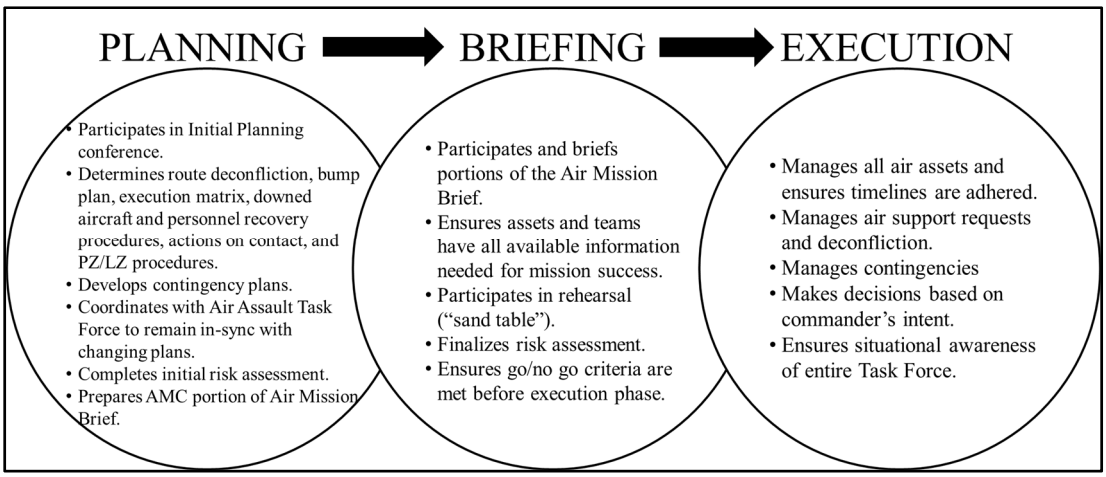


Figure 6. Task Diagram Method

1. Planning

Air assaults are not spontaneously executed. While a mission can be hastily planned for, it will not be unplanned for. The nature of air assaults is not very forgiving. They take place in hostile, unpredictable, and ever-changing environments where the slightest error can carry with it an unforgiving and often irreversible consequence. It is therefore critical that the objective is considered with respect to the desired end state of the battlespace. Therefore, extremely detailed and precise reverse planning that works backwards from the ground tactical plan, or the last stage of mission execution, is completed before the aircraft takeoff to ensure mission success, as shown in Figure 7. Figure 7 shows that air assault planning starts with the desired end state of the Ground Tactical plan and then works backwards, rather than planning in the chronological order that the air assault will actually be executed in. This is known as reverse-order planning. Contingency plans are also developed in the event that if something does not go according to plan, there is a prepared secondary course of action to take.

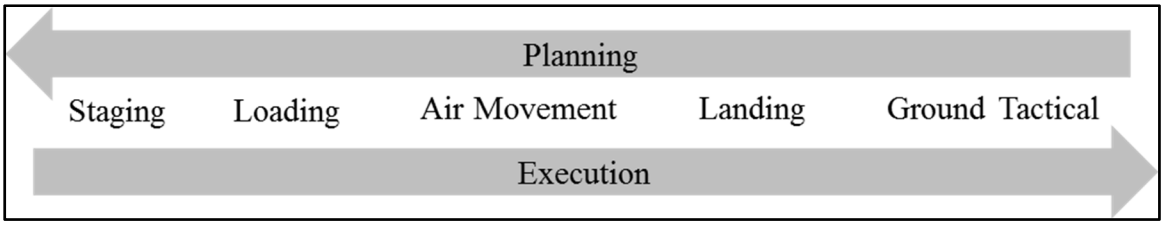


Figure 7. Stages of Air Assault

While the AMC does not lead every step of the planning process, they are considered one of the most knowledgeable personnel and leaned heavily upon for their expertise throughout the planning process. The primary tasks of an AMC during the planning phase include the following:

- Participating in Initial Planning Conference (ICP)—the ICP is an initial meeting between the Air Assault Task Force (AATF) and supporting aviation unit, for example, AMC, liaison officer, and flight leads, where they can address environmental factors, such as climate, weather, terrain,

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and altitude, which may impact the performance capabilities of the aircraft. The ICP is held as early as possible in the air assault planning process to ensure the crew is adequately prepared to successfully accomplish the upcoming mission.

- Determining route deconfliction, bump plan, execution matrix, downed aircraft and personnel recovery procedures, actions on contact, and PZ and LZ procedures
- Developing contingency plans
- Coordinating with AATF to remain in sync with changing plans
- Completing initial risk assessment
- Preparing AMC portion of Air Mission Brief

2. Briefing

The briefing phase is a critical step to ensure everyone involved in the air assault is on the same page. During this phase, planning should be finalized and only minor changes to the plan should occur. The AMC's role during briefing is to verify that every detail of the mission is accounted for and that the sequence of events will maximize the chance of success while minimizing the risk of losing personnel and/or equipment. The AMC's briefing activities include the following:

- Participating and briefing portions of the Air Mission Brief
- Ensuring assets and team members have the necessary information for mission success
- Participating in mission rehearsal (sand table exercise)
- Finalizing the risk assessment
- Ensuring go/no go criteria are met before the execution phase

3. Execution

During the execution phase, the AMC plays the most prominent role, with duties including:

1. Maintaining situation awareness over the entire battlespace, including aircraft states, mission flow, enemy status, and the Ground Commander's intent
2. Coordination with subordinates and superiors regarding updates and changes to the mission execution status
3. Making executive decisions under extreme time constraints and disseminating these action commands to the fleet of aircraft under their command, for example, whether to engage a newly materialized enemy, whether to recover a downed aircraft

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Primary tasks of an AMC during the execution phase include:

- Managing all air assets and ensures timelines are adhered
- Managing air support requests and deconfliction
- Managing contingencies
- Making decisions based on commander's intent
- Ensuring situational awareness of entire Task Force

At each of these three stages, the crux of almost every decision centers around Mission, Enemy, Terrain and Weather, Troops and Support Available, Time Available, and Civil (METT-TC) factors. Table 2 provides a high-level deconstruction of typical AMC considerations within each METT-TC factor. Note that this is not an exhaustive list.

Table 2. METT-TC Factors

Factor	Typical Considerations
Mission	• Answers to Who, What, When, Where, and Why • Commanders Intent • Desired End State • Concept of Operations • Scheme of Maneuver • Tasks to Subordinate Units
Enemy	• Composition, for example, number of personnel, vehicles, and weapons • Disposition, for example, organization, strengths, vulnerabilities, and tactical mobility • Equipment, for example, armored vehicles, and anti-aircraft artillery • Location • Capacity, strengths and weaknesses • Mission and Purpose • Possible and Probable Courses of Action • Recent Activities and Patterns of Life
Terrain	• Artificial and Natural Obstacles • Avenues of Approach • Advantageous Terrain Features, for example, cover, concealment, and reduced intervisibility • Disadvantages of Terrain Features, for example, affords enemy cover and concealment
Weather	• Wind • Temperature • Visibility • Cloud Cover • Precipitation • Humidity

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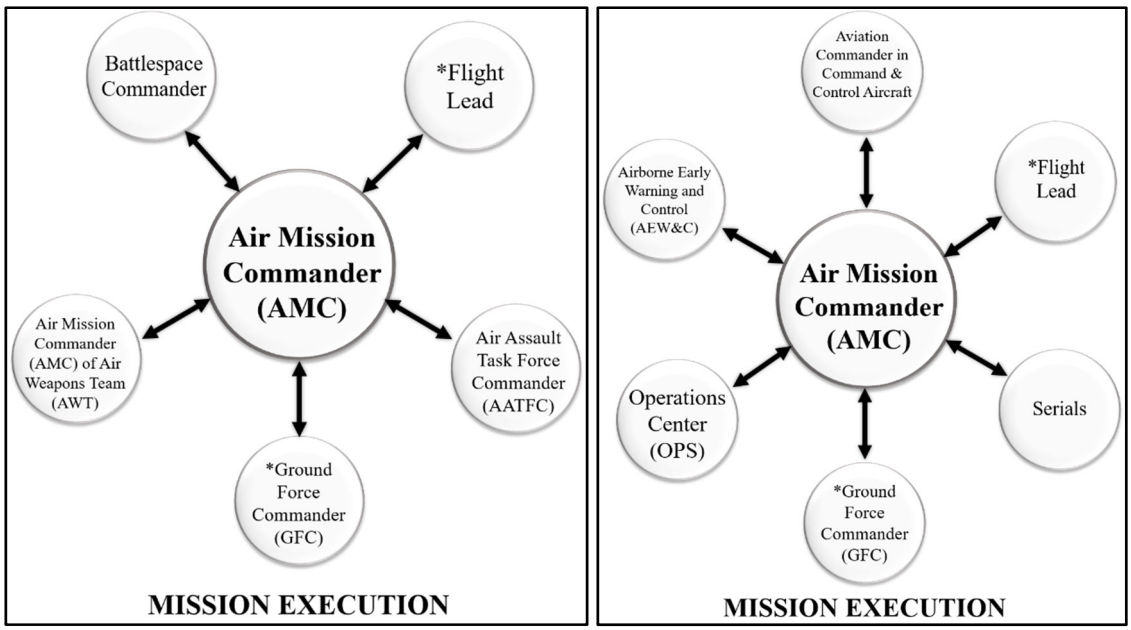
Table 2. METT-TC Factors (Concluded)

Factor	Typical Considerations
Troops and Support	• Number, type, capabilities, and condition of available friendly troops and support. These include supplies, services, and support available. • Crew Availability, for example, crew members require superior's approval to work in excess of 12 consecutive hours and crew strengths guide personnel selection • Aircraft Status, for example, in maintenance • Support Systems, for example, MEDEVAC aircraft available for standby • Combat Resources, for example, finite weapons and fuel onboard
Time	• Planning and Preparation of combat orders, that is, deliberate, constrained, and hasty • Inspection and Rehearsals • Timeline for Movement, for example, PZs, Start Phases, Air Control Points, Release Points, and LZs • Movement: Strict Time Constraints During Air Movement, for example, aircraft are only allowed to be +/- 30 seconds off of the flight plan during air movement
Civil Considerations	• Cultures and Activities • Civil Institutions • Infrastructures and Organizations • Populated Areas

4. AMC Communication

Coordination and communication, particularly before and during mission execution, ensures that command and control is maintained and mission objectives are successfully accomplished. The wagon wheel interview methodology was employed as a tool for taking a brief audit of the main communication channels that exist for the AMC during the air assault execution. Although it is common for the acting AMC of the mission to also be the pilot-in-command of their aircraft, this particular aspect of communication within the aircraft between the pilot-in-command and their aircrew, for example, a copilot or flight medic, was not discussed in detail during the wagon wheel exercise and is therefore not included in the results. Figure 8 contains two completed wagon wheel diagrams that were filled out independently by interviewees. Figure 8 also includes asterisks that indicate a position included in both SME 1 and 2 diagrams.

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a. SME 1 *b. SME 2*

Figure 8. Wagon Wheel Diagram Filled Out Independently

Noting the similarities and differences between the two diagrams provided a concrete artifact from which to resolve discrepancies during a joint session with participants. Having participants explain and justify the inclusion of each personnel in their diagram helped fully capture how air assault teams communicate. This discussion resulted in the agreed-upon revised wagon wheel shown in Figure 9. The updated wagon wheel diagram includes Contingency Assets (CAs) that are not universally available across every air assault mission but are considered essential elements to include in the diagram. If available, any of the CA support can be requested by the AMC, at which point the AATFC can then temporarily assign the requested CA to support the AMC, thus creating an additional branch of communication with the AMC. Note that the AMC will probably not be the only one communicating with the newly assigned CA. Flight leads, AATFC, Unmanned Aerial Systems (UASs) and Air Weapons Team (AWT), and Ground Force Commanders (GFC) can and likely will all be coordinating directly with the newly assigned CA as well. To facilitate the process of rebuilding a united wagon wheel diagram, participants focused on specific details of SUMIT's Simulation Evaluation Plan training vignettes. For example, the node in Figure 9 labeled UAS and AWT was largely included based on the parameters of the vignette. Although this communication channel, that is, node, is not necessarily uncommon, it is less universal across missions.

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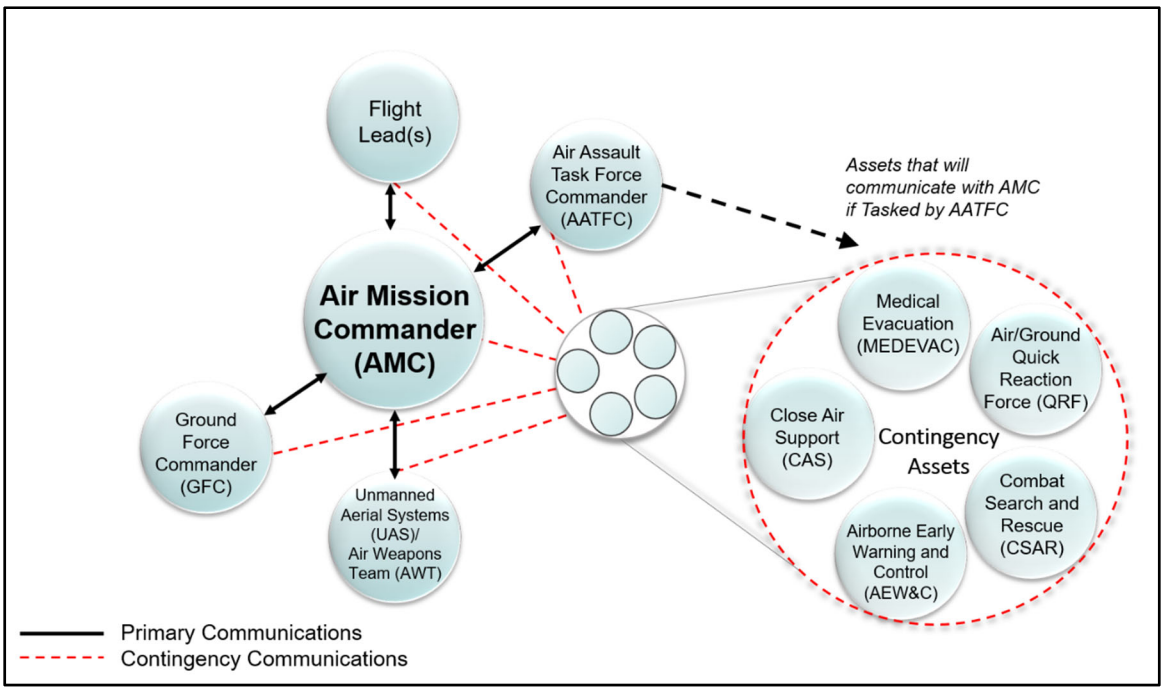


Figure 9. Updated Wagon Wheel Diagram

Table 3 provides more details regarding each communication node listed in Figure 9, including a description of that individual's roles and duties, what information that individual sends to and receives from the AMC, and the method of communication, for example, radio and chat via the tactical internet.

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Table 3. AMC Communication Channels

Position	Roles and Duties	Communications From AMC	Communications to AMC	Communication Method
AATFC	• Overall commander of the AATF • Ensures continuity of command throughout the operation • Overall responsibility for the air assault operation	• Mission event milestones, for example, Ex-check • Additional support unit requests • Updates and mission changes	• Additional tasking or mission changes • Updates regarding the AMC's requested contingency assets, for example, approval of request and estimated time of arrival for asset	• Radio • Chat
GFC	• Commands largest ground maneuver force inserted during air assault • Usually one of the AATFC's subordinate maneuver commanders • Maintains communication with AATFC throughout operation	• AMC monitors GFCs execution checklist transmission to the AATFC • Mission event milestones - only source of situation awareness for the GFCs	• Requests additional support, for example, surveillance and fire support	• Radio • Chat
Flight Lead(s)	• Navigation • Enroute communication, for example, keeps AATFC updated on flight status • Obstacle and threat avoidance • Monitors energy state of all aircraft	• Mission changes or deviations, for example, route changes • Request for updates and aircraft status	• Flight status, for example, obstacles and threats	• Radio • Chat
UAS and AWT	• Reconnaissance of the route, LZ, and NAIs • Fires and overwatch for ground forces	• Tasking requests, for example, video feed of LZ	• Video feeds • Laser designation data • Target identification data	• Radio to UAS operators • Chat

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Table 3. AMC Communication Channels (Continued)

Position	Roles and Duties	Communications From AMC	Communications to AMC	Communication Method
MEDEVAC	• Called in to evacuate any wounded service member • Would also communicate directly with the owning unit of the injured service member	• Situation awareness information, for example, threats in or around the point of injury, safest ingress, and egress routes • Status updates, for example, location of friendly and enemy forces	• Estimated time of arrival • Request for safest ingress and egress routes • Status of friendly forces • Patient status	• Radio • Chat
Air and Ground QRF	• On standby to assist in any emergency situation that may arise, for example, down aircraft, troops in contact, vehicle accident or any other troop isolating event	• Change to activation status • Guidance and situation reports pertinent to both air and ground forces • Airspace deconfliction information, for air QRF	• Estimated time of arrival to the incident site • Onboard assets, for example, equipment, personnel • Request for incident site updates, for example, threats and friendly forces in the area	• Radio • Chat
CSAR	• Typically used specifically for rescues and extractions deep in enemy territory • Equipped with special equipment and weapons that MEDEVAC aircrews do not have	• Situation awareness information, for example, threats in or around the incident site, safest ingress and egress routes • Status updates, for example, location of friendly and enemy forces • Airspace Deconfliction	• LZ and PZ updates, for example, obstacles, threats, friendly forces status • Best ingress and egress routes • Status of the source of the call out, for example downed aircraft, isolated personnel	• Radio • Chat

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Table 3. AMC Communication Channels (Concluded)

Position	Roles and Duties	Communications From AMC	Communications to AMC	Communication Method
AEW&C	• Provides airborne radar services and threat detection to give early warning of incoming aircraft or missiles • Assist AMC with airspace deconfliction	• Request for assistance with airspace deconfliction	• Incoming threats, for example, aircraft and surface-to-air missiles	• Radio • Chat
CAS	• Provide ground troops with additional fire support and enemy suppression	• Request for BDA • Request amount of ordinance on board • Request time available on station	• Time to target and response time • BDA reports • Any new threat updates • Weapons status for follow on missions	• Radio

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B. Participant Feedback on TECUMSA Demonstration

Participants were asked to provide feedback on the original user interface during a brief demonstration of TECUMSA. Participants received introductions to features including the play calling interface and vehicle dashboards as well as TECUMSA's autonomous capabilities including the route planner and IA. In-depth discussions were largely focused on the details in the Simulation Evaluation Plan, prompting context relevant insights into how to better tailor the HAI to assist an AMC during an air assault mission.

1. Map

Participants provided inputs regarding TECUMSA's map display. For example, when asked whether a satellite or topographic map was preferable, participants explained that different information can be gleaned from each. Roads, heavily traveled paths, and possible obstruction and characteristics of the LZ cannot be seen in topographic maps; however, terrain elevation is vague in satellite imagery. Allowing TECUMSA users to switch between or even overlay the two map types would cover the largest range of user needs. Participants also mentioned that it would be beneficial to incorporate Military Grid Reference System (MGRS) into TECUMSA's map display.

2. Icons

Due to the range of aircraft and capabilities in the simulation vignettes, it became apparent that certain distinguishing characteristics should be emphasized in the aircraft icons so entities in the map, vehicle dashboard, and so forth can be easily recognizable. Distinctions and information that participants agreed were valuable to include in the icon design included the following:

- manned versus unmanned
- missile quantity on-board
- current Level of Interoperability (LOI)
- fixed or rotorcraft airframe
- whether the aircraft is ownship, friendly aircraft with LOI, or friendly aircraft but without LOI

While all of these characteristics have the potential to be represented in the icon design, there is a point of diminishing returns where the mass of information will merely serve to clutter the icon and display and confuse the user. Figure 10 shows the original TECUMSA icon representing unmanned fixed-wing aircraft.

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Figure 10. Original TECUMSA Icon Representing Unmanned Fixed-Wing Aircraft

3. Vehicle Status Panel

One participant mentioned the benefit of a weapons summary page to keep track of the quantity and type of armament onboard each of the UAVs available to the operator. Since missiles were not part of the payload previously utilized in the TECUMSA system, the need to represent the quantity and type of missiles onboard each UAV became an HAI requirement. However, with the limited armament considered in the initial evaluation of TECUMSA since only Hellfire missiles are available, the solution concept involved revamping the Vehicle Status Panel into a Vehicle Summary Panel that provides a high-level snapshot of each aircraft's payload information. The Vehicle Status Panel design is discussed further in Section VI.D.3.

4. Vehicle Dashboard

The TECUMSA system includes vehicle dashboards that provide vehicle state information for each vehicle, such as speed, altitude and elevation, payloads, fuel level, sensor status as well as the current sensor feed. One notable suggestion from participants was to have an indicator of the time remaining until bingo fuel, that is, when the UAV needs to return to base to refuel. The participants explained that having this information would be helpful for task management decisions since a blue force overwatch task would be best served by an aircraft that could remain overhead for the entire duration of the overwatch. Participants also suggested that weapon information, such as type and quantity, be added to the vehicle dashboard, again due to the influence this information would have on aircraft assignments and mission planning.

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5. Airspace Deconfliction

One of the techniques used to elicit participant HAI ideas and feedback was to provide concrete constraints and mission details to reason about during a demonstration of the TECUMSA interface. Based on SUMIT's Simulation Evaluation Plan vignettes, participants were provided a scenario where four UAV's were concurrently in the air and under the AMC's command and control. These were specifically two Gray Eagle (GE) MQ-1Cs, one Shadow (SH) RQ-7, and one Fire Scout (FS) MQ-8. This specific scenario details prompted participants to draw a stack diagram similar to the one seen in Figure 11. This diagram is used as a clear and concise way for air assault crews to visually represent the altitudes of each aircraft flying in the mission and ensure adequate separation. Note at the highest altitude in Figure 11, there is a dashed line representing a lateral separation, which is required since both of the GEs begin the vignette at the same altitude above Mean Sea Level (MSL). This dashed line could represent a predetermined division of the battlespace where GE 1 covers one half of the battlespace and GE 2 covers the other half.

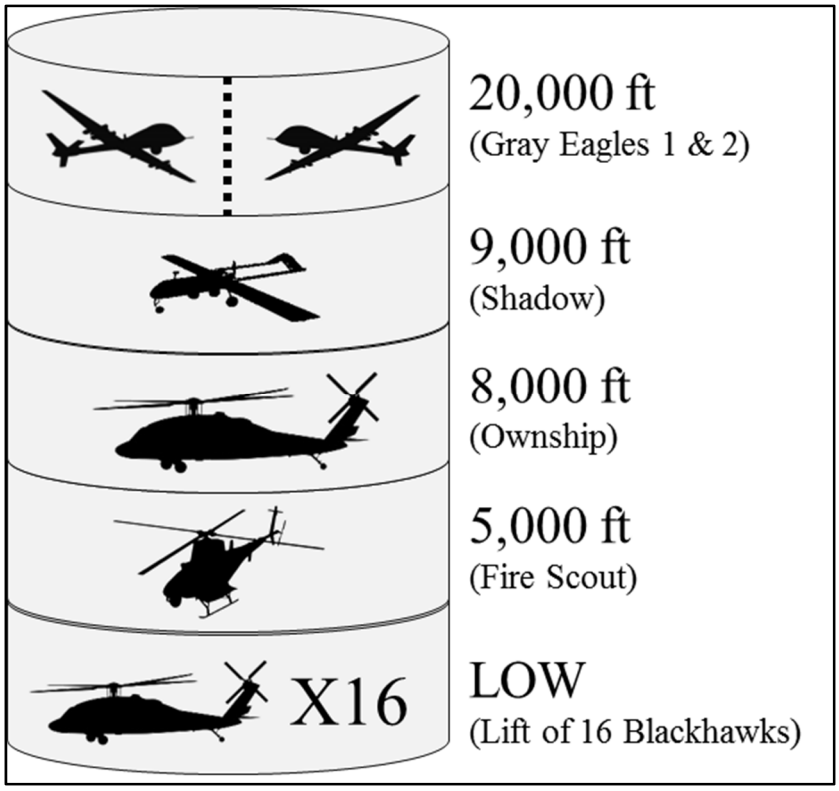


Figure 11. Altitude Deconfliction Stack Diagram in MSL

C. Participant Feedback During Simulation Interview

Developing an IA that can support an AMC during an air assault mission requires understanding the realm of possibility considered by the AMC during a wide range of tasks. The simulation interview technique was used to elicit the step-by-step decision making that a veteran AMC would make across a variety of different scenarios. Example questions included the following:

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- What would you do if an enemy was found behind this ridge?
- What route would you take if a ROZ was called along this section of your current lift route?
- How would this dense population area effect your decisions?

Think-out-loud procedures provided explicit data regarding veteran AMC's thought processes, reasons for action selection, combat strategies, situation assessments, and critical cues to look for. Participants identified how they would complete each of the Intelligence, Surveillance, and Reconnaissance (ISR) tasks listed in Table 4 while utilizing a fleet of up to two manned and four unmanned aircraft. The results of the simulation scenarios were used to guide future TECUMSA play development and optimization parameters for the IA to reason about, for example, an additional play for engagements that optimizes aircraft selection for combat power. For example, participants indicated that the ability to hover could be valuable for certain tasks or in certain environments since in mountainous terrains, a fixed-wing UAV that needs to loiter may have its sensor obstructed by the terrain at various times during the loiter. In contrast, a rotorcraft could avoid these obstructions by hovering in place.

Table 4. TECUMSA's IA Feedback

Vignette Event	Optimization Parameters(s)	Optimal Vehicle	Play	Priority (Order of Operation)
Conduct Renaissance at LZ Direwolf	1. Undetected 2. Sensor Capability	Ownship	Rout Inspect	2
Conduct Renaissance at Axis Mormont	1. Undetected 2. Sensor Capability	SH	Point Inspect	1
Renaissance NAIs	1. Sensor Capability	GE	Parallel Search	3
Overwatch Friendly Forces	1. Combat Power	FS	Air Overwatch	4
Locate Militia Vehicles and Engage if Positive ID	1. Combat Power 2. Laser Capabilities	Depends Where Found	Engage (1 Aircraft Designates and Engages)	*
Surveil Possible Militia Compounds	1. Undetected 2. Sensor Capability	Depends Where Found	Point Inspect	*

Table 4 summarizes participant feedback regarding TECUMSA's IA. Note that an asterisk in the priority column indicates a subtask that would be accomplished during the prioritized tasks.

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During the simulation interview session, participants were asked to provide feedback on the evaluation scenarios and asked if anything in the scenarios needed clarification. Sections VI.C.1 through 7 are a sample of the questions participants asked during the simulation interview, along with implications for the IA's logic and future scenario design.

1. What are the weather conditions along the route and at the LZ? Are there clouds?

After further probing, these questions revealed the importance of weather considerations for planning and executing an air assault. For example, the aircraft may need to land into the wind depending on how strong the winds are and how experienced the pilots are. If landing into the wind is too difficult or unfeasible, it may require deferment to the alternate LZ. Aircraft sensor capabilities are also affected by weather conditions. For example, in foggy or hazy conditions, an IR sensor might be required for reconnaissance of the ingress route, which may not be a capability of any available aircraft and could require a contingency asset to be requested or a task to be reassigned.

The implication is that the sensor type, for example, EO and IR, should remain an optimization parameter that the operator can select to narrow the search space for the IA to optimize vehicle assignment during play calling.

2. Is it day or night?

There are advantages and disadvantages to both. While day operations are easier to operate aircraft in, there is also an increased risk of enemy fire since the air assault is more visible in daylight. Night operations have the advantage of reducing enemy fire risks but also increases the risk of blue force operator errors and friendly air collisions. Other factors also contribute to whether day or night is preferable, such as the skill levels of the pilots, forecasted weather conditions, and the error tolerance of aircraft movability by the specific characteristics of the LZ.

The implications presented supports the preservation of the sensor type optimization parameter, for example, EO and IR. Furthermore, in the future, default settings for the IA could be set so that in night operations, UAV's are set to fly with higher lateral and vertical separation to avoid collisions that could be particularly beneficial in instances where the AMC chooses to manually fly a UAV.

3. What is the purpose of the dead cow in the LZ? Is it an obstacle?

Participants suggested that power lines or an antenna are more common obstacles. There are even cases when enemy forces have erected power lines in anticipation of an incoming air assault.

The implication is that there is an endless array of obstacles and threats that can be used to evoke a variety of responses from participants during system evaluations; therefore, it is prudent to build simulation scenarios that span both the common and atypical events to promote the development of an adaptable system.

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4. Is there an alternate LZ or just the one?

Participants pointed out that there would typically be an alternate LZ for the lift aircraft to land in so that if the risk of landing in the primary LZ was too high, they could defer to the alternate LZ. For example, if enemy forces appeared in or around the primary LZ, or a suspicious foreign object materialized soon before the lift was scheduled to land. While the alternate LZ will not always be used, part of contingency planning is to ensure that foreseeable risks are prepared for. As such, if the terrain affords it, a secondary LZ will be included in the landing contingency plan.

The implication is that in the future, TECUMSA's IA could be capable of alerting the AMC of newly detected entities found within the primary or alternate LZs within x minutes of the lift's arrival. In addition, customizable scheduling of play execution, for example, execute a Point Inspect of the primary LZ in 15 minutes, and task reminders, for example, a reminder to call a Point Inspect of the alternate LZ in 20 minutes, are in development. This would allow the AMC to offload some of the task and time management workload onto the TECUMSA system, which can be particularly valuable when nearing the arrival of an incoming lift.

5. When during the vignette should the AMC engage positively identified enemies?

Engaging enemy targets is done very strategically in air assaults. Participants interpreted the vignette details to mean that any positively identified enemies are to be engaged at any point during the 30-minute vignette. However, based on their experience, participants would avoid engagement in the LZ until the last possible minute before the lift arrives in order to preserve the element of surprise and avoid giving nearby threats time to prepare for the lift's arrival. One participant recalled a time where the LZ was cleared and enemies were kinetically engaged just 30 seconds prior to their aircraft arriving in the LZ area. A similar strategy to delay enemy engagement can be applied to enemies along the ingress route; however, target engagement can be unnecessary altogether since changing a route is typically easier than changing a LZ.

The implication is that similar to the actions the IA takes with ROZs, the IA could suggest a re-routed ingress path for the lift to take once hostiles are identified, thus minimizing risk of enemy fire.

6. What is considered PID?

Participants requested clarification of what constitutes Positive Identification (PID) of enemy forces. For example, is it an individual in a uniform, the presence of a weapon, or suspicious activity, such as multiple military-age figures moving in a tactical formation or digging by the roadside?

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The implication is that if Automatic Target Recognition (ATR) is integrated into TECUMSA, these types of cues and engagement rules will be important to train the system on.

7. What are the highest altitudes that can be flown by each aircraft to still provide the ATR with usable sensor data to spot a militia compound and an anti-aircraft artillery system? How large of a field of regard is available for each aircraft's sensor, that is, how much area can each aircraft reconnaissance?

This question revealed a strategy for surveying large areas with a limited number of aircraft. The participants suggested that they would plan the mission so that they could assign a high altitude UAV to be positioned central to multiple NAIs. If the sensor on the UAV could provide usable video feed at a high altitude, this strategy would allow the AMC to survey multiple NAIs at once, exemplifying an experienced mission planner's strategy to always optimize the number of tasks achieved and the amount of resources required.

The implication is that there are certainly more and less optimal aircraft allocation and tasking strategies; therefore, in the future the IA could consider variables, such as area of coverage in the logic for recommending vehicles to fulfill operator play calling.

D. Generating Human-Autonomy Interface to Support Air Mission Commander

Sections VI.D.1 through 7 describe solution concepts based on participant feedback on TECUMSA's HAI components, including updates to the vehicle dashboard, vehicle icons, Play Calling Tile, and Play Workbook, as well as an initial design for a possible airspace deconfliction tool. However, interface concepts described within Section VI.D may be adapted and revised as TECUMSA development progresses.

1. Map

Figures 12 and 13 are screenshots of a portion of the current TECUMSA map display that provides the operator with a pan-, tilt-, and zoom-able map that can be tilted to a 2 ½ dimensional view, which is rendered using Digital Terrain Elevation Data (DTED). Figure 12 includes a bird's eye view of the terrain in TECUMSA's map as well as three UAVs and their corresponding sensor footprints. The user is able to cursor over any spot on the map and get the latitude and longitude decimal coordinates as well as elevation at that location. All known aircraft are represented on the map at all times. Note that the UAV icons used in the map were designed as Two-Dimensional (2-D) images and that modifications may be needed to improve the discriminability from a tilted 2 ½ dimensional vantage point, as shown in Figure 13. Sensor footprints can be seen projecting out from GE2 and FS1 in Figure 13. Note that Figure 13 was taken at a different time than the image in Figure 12.

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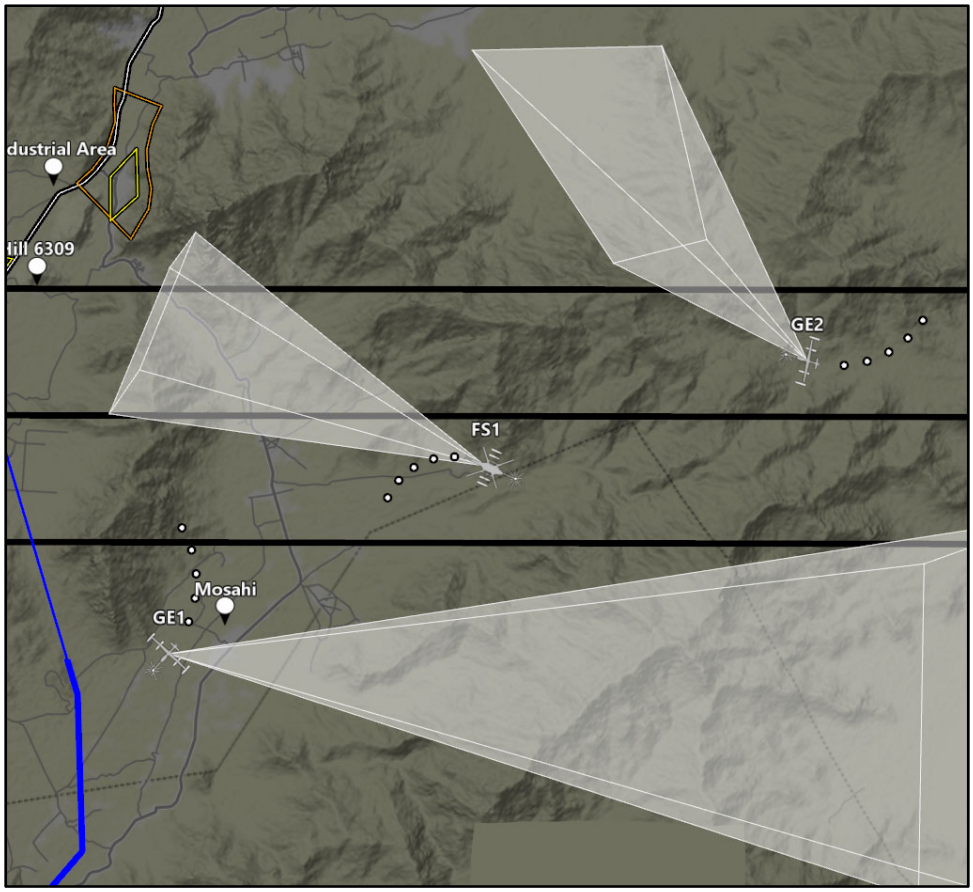


Figure 12. 2-D Vantage Point Terrain in TECUMSA's Map

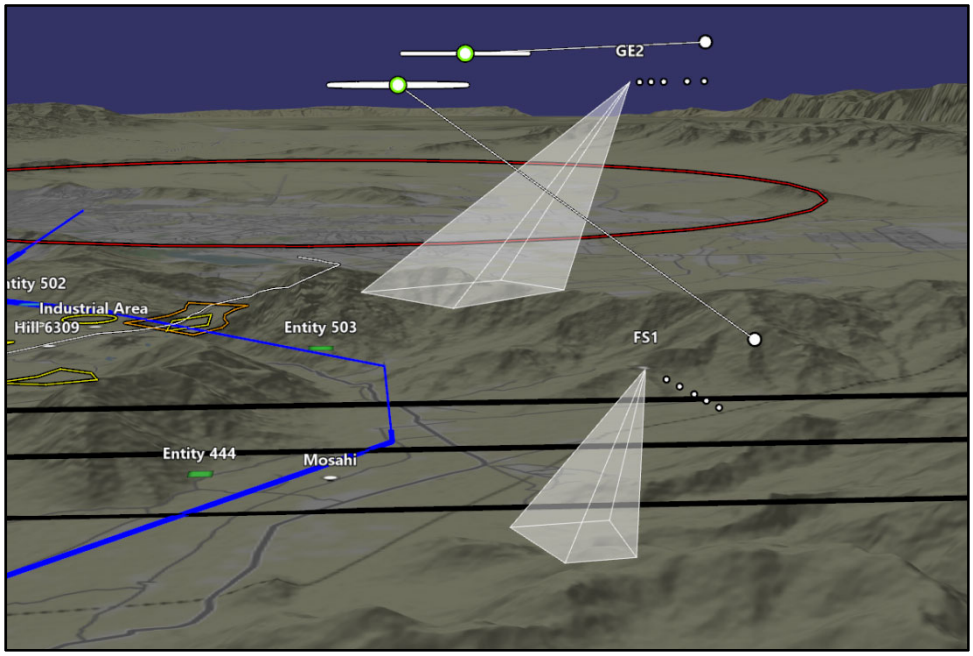


Figure 13. 2½ Dimensional Vantage Point of Terrain in TECUMSA's Map

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2. Icons

Figure 14 shows a sample set of icons for a Blackhawk Utility Helicopter (UH) 60 (ownship), GE MQ-1C, FS MQ-8, and SH RQ-7. As these icons are based on the actual aircraft, characteristics such as fixed-wing versus rotorcraft are inherently represented in the design. The narrow black cylindrical shapes attached to the sides of the aircraft icons represent Hellfire missiles. The SH RQ-7 is the only aircraft that does not carry missiles. Furthermore, the number of missiles attached to each vehicle icon updates as they are fired, creating direct perception of the aircraft's current payload, as seen in Figure 15.

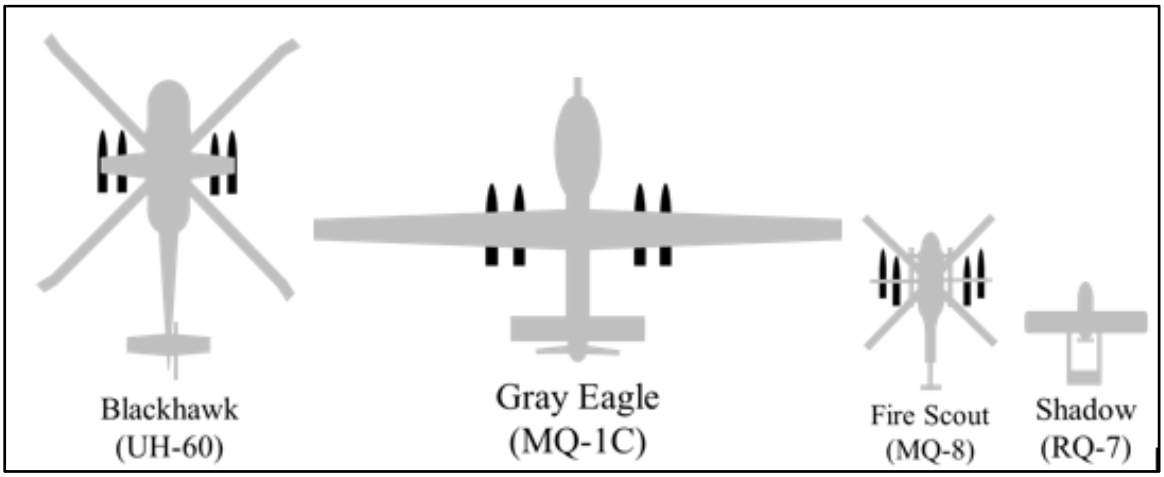


Figure 14. Aircraft Icon Design With Number of Missiles Seen in Black

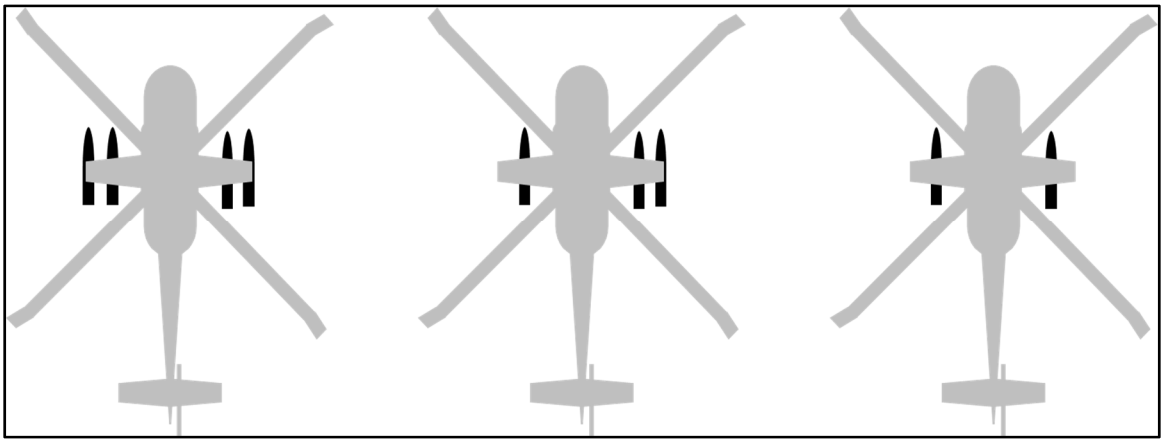


Figure 15. Icon Updating as Missiles are Fired

Figure 16 is an anticipated design that includes features indicating laser designation status, current LOI, aircraft error notification, and play assignment status. For example, after calling a point inspect at Point Charlie, the vehicle changes its course of action and the icon for the assigned aircraft changes from gray to orange. After revisiting this proposed design, it became clear that the LOI value that is depicted in the anticipated design would be illegible when the aircraft icon is scaled down to fit the TECUMSA map, as shown in Figure 12. In addition to being illegible, there is potentially more informational value when the LOI is communicated in terms of functionalities associated with that LOI as opposed to a mere

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numerical value. Sections VI.D.3 and 4 will cover the graphical representations, that is, icons, for the associated functionalities at a particular LOI.

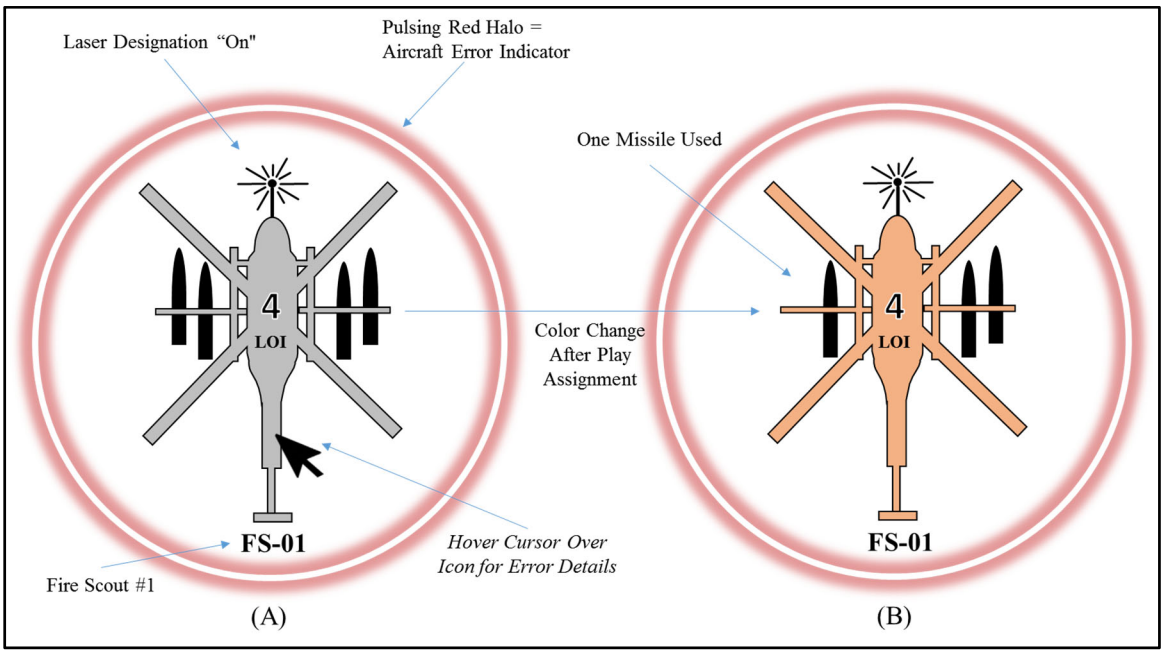


Figure 16. Conceptual Design for Aircraft Icon and Status Features

3. Vehicle Summary Panel

Based on participants' desire for more detailed weapon information, TECUMSA's Vehicle Summary Panel, as shown in Figure 17, was updated to provide a high-level snapshot of each available aircraft as well as the number of missiles onboard, laser designation status, and functionality associated with each aircraft's LOI. The row of icons in each aircraft in Figure 17 are designed to quickly communicate to the AMC what functionalities are available based on the current LOI. For example, the row of icons under the leftmost vehicle (GE-01) indicates that sensors, weapons, and aircraft are all controllable by the AMC. The white fill or background of an icon indicates that the operator has control over that feature, whereas a dark gray or transparent background indicates receipt and transmission of that features data. For example, the operator can view sensor feed but cannot steer it. From left to right in Figure 17, the first UAV (GE-01) has LOI 4, SH-01 has LOI 2, FS-01 has LOI 4, and GE-02 has LOI 3. A potential feature may be added to allow the AMC to have the vehicles sorted and ordered from left to right based on LOI, number of missiles onboard, recency of use, or some other variable. Note that there are pros and cons to having fixed versus dynamic positioning, which can be more thoroughly explored during TECUMSA's HAI testing. In addition, future development efforts may be dedicated to making the LOI icons actionable buttons. For example, clicking the mortar icon opens play calling options where weapons are required.

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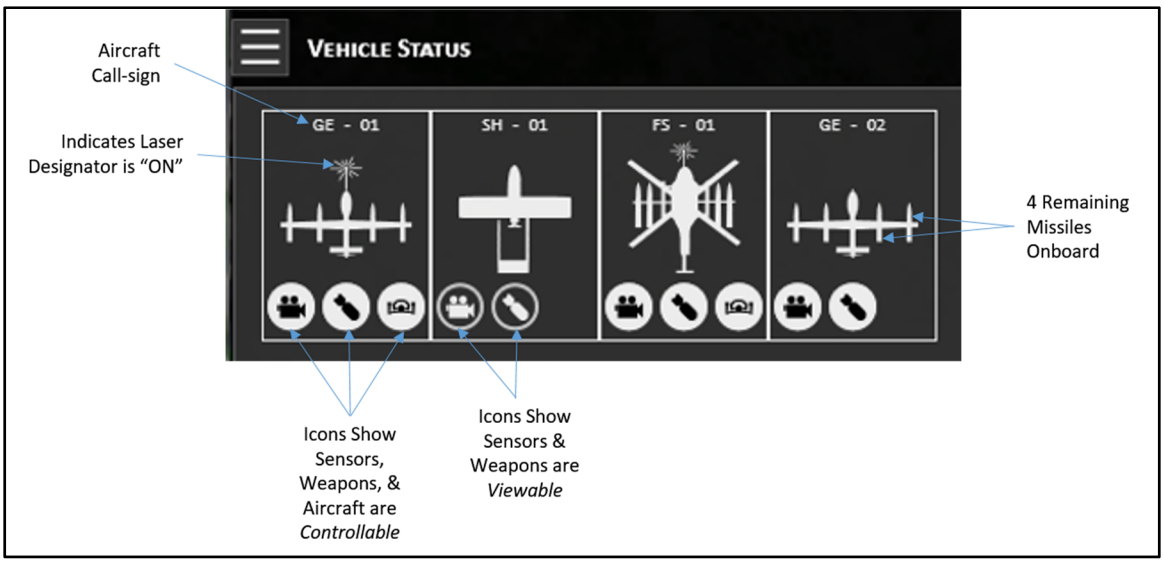


Figure 17. Vehicle Summary Panel Offers Details of Each Aircraft

4. Vehicle Dashboard

Revisions to the vehicle dashboard were made based on the SME's feedback. Figure 18 shows the modified vehicle dashboard display, which includes the following:

- Call sign of aircraft
- Laser Designator Status
- Numerical LOI value as well as icons representing features associated with that LOI
- Fuel Gauge - percentage of remaining fuel
- Low Fuel Icon
- Knots True Airspeed
- Altitude
- Available Sensors on the aircraft
- Remaining Hellfire Missiles onboard
- Station Time - a countdown clock indicating the remaining time before the aircraft reaches Bingo fuel and must return to base, which is a dynamic value since it depends how far away the aircraft is from base.

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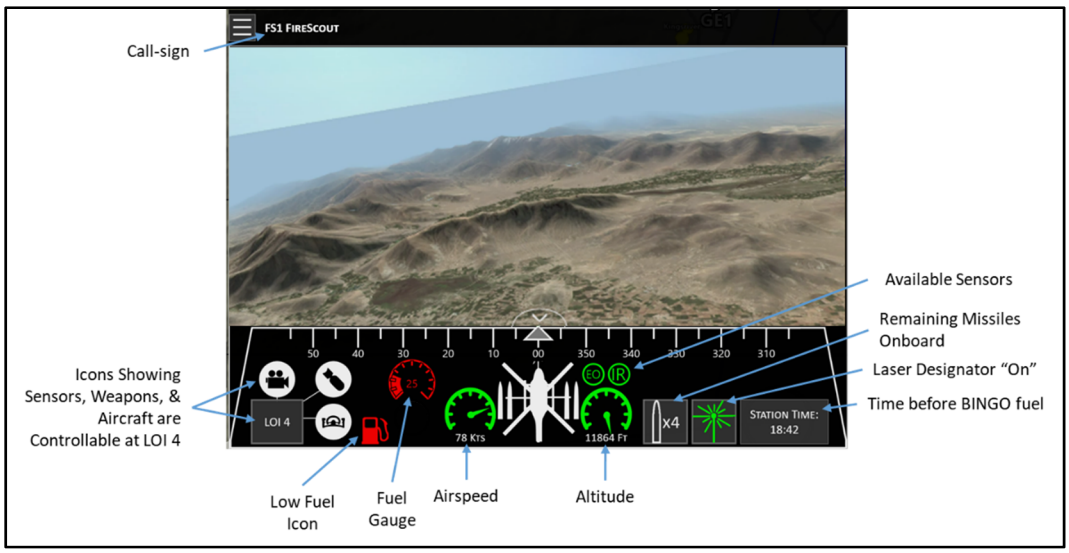


Figure 18. Vehicle Dashboard

Additionally, during a hostile entity engagement, the vehicle dashboard of the engaging aircraft provides a missile release confirmation to the operator, as shown in Figure 19. Providing this information in the sensor feed of the engaging aircraft allows the operator to maintain situation awareness over the unfolding battlespace, both minimizing the probability of casualties and preserving positive identification of the target. The availability of the Fire Now button is context sensitive and is only available once the engaging aircraft is within range of missile release, for example, less than or equal to 9 kilometers (km) slant range.



Figure 19. Vehicle Dashboard Confirming Missile Release During Target Engagement

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Once the Fire Now button is selected, a secondary safety popup appears so that the operator can either confirm or cancel the missile release. Although a subtle design detail, the decision to have an additional input from the operator to confirm weapons release was deemed essential. Popups that require operator input should be implemented cautiously as they can be jarring to a user and can pull attention away from potentially more important tasks occurring at the time. However, in this case, the cost of an additional operator input is greatly eclipsed by the consequence of an unintended and irreversible user input that has a high probability of resulting in a casualty event.

Additional changes may be made to the vehicle dashboard later in the development process to allow quick access to information regarding the diverse set of onboard weapons, for example, cursor hover-over text and/or expandable Weapons Information page. Future updates may also allow an operator to directly manipulate certain features in a vehicle's dashboard, such as the desired units, for example, switching altitude from meters to feet or fuel from liters to pounds. Other features may be added, such as a fuel bug marker on the fuel gauge that informs the operator of the Bingo fuel level, as shown in Figure 20, or another countdown timer that indicates how long an operator has control over a particular UAV. The countdown timer would be beneficial in situations where control of the asset is time limited. It may be helpful to think of there being operator station time with an aircraft as well as global station time and the latter being independent on who has control over the aircraft. Figure 20 shows the fuel bug updates throughout the flight from A to D that reflect the amount of fuel needed for the aircraft to return to home base.

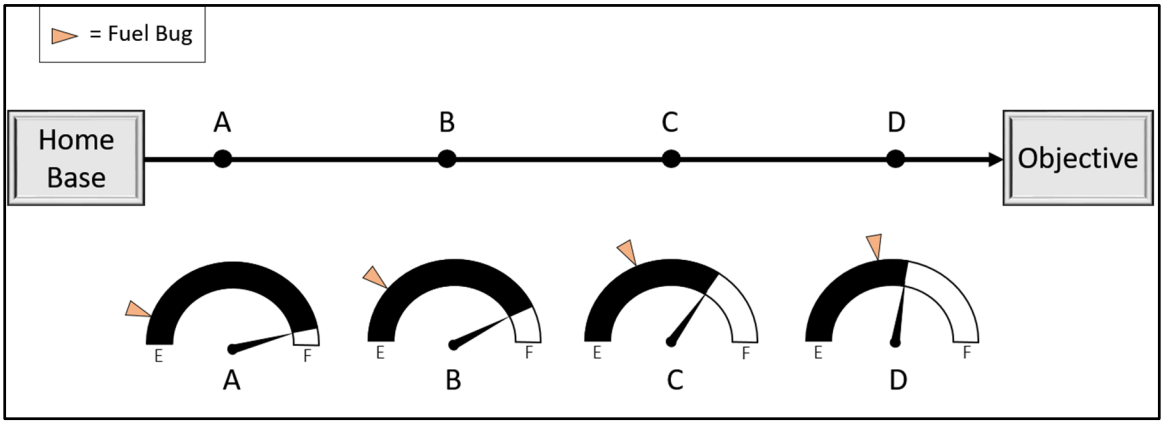


Figure 20. Dynamic Fuel Bug or Bingo Fuel Marker

5. Airspace Deconfliction

Figures 21 through 23 show three airspace deconfliction tools that are designed to provide an AMC direct perception of the occupied airspace and direct manipulation capabilities as a means to quickly manage and correct impending problems via drag-and-drop capabilities. Used in coordination, the tools are expected to prove instrumental for unmanned-manned teaming operations where a single operator is in charge of maintaining situation awareness over multiple aircraft in the same airspace.

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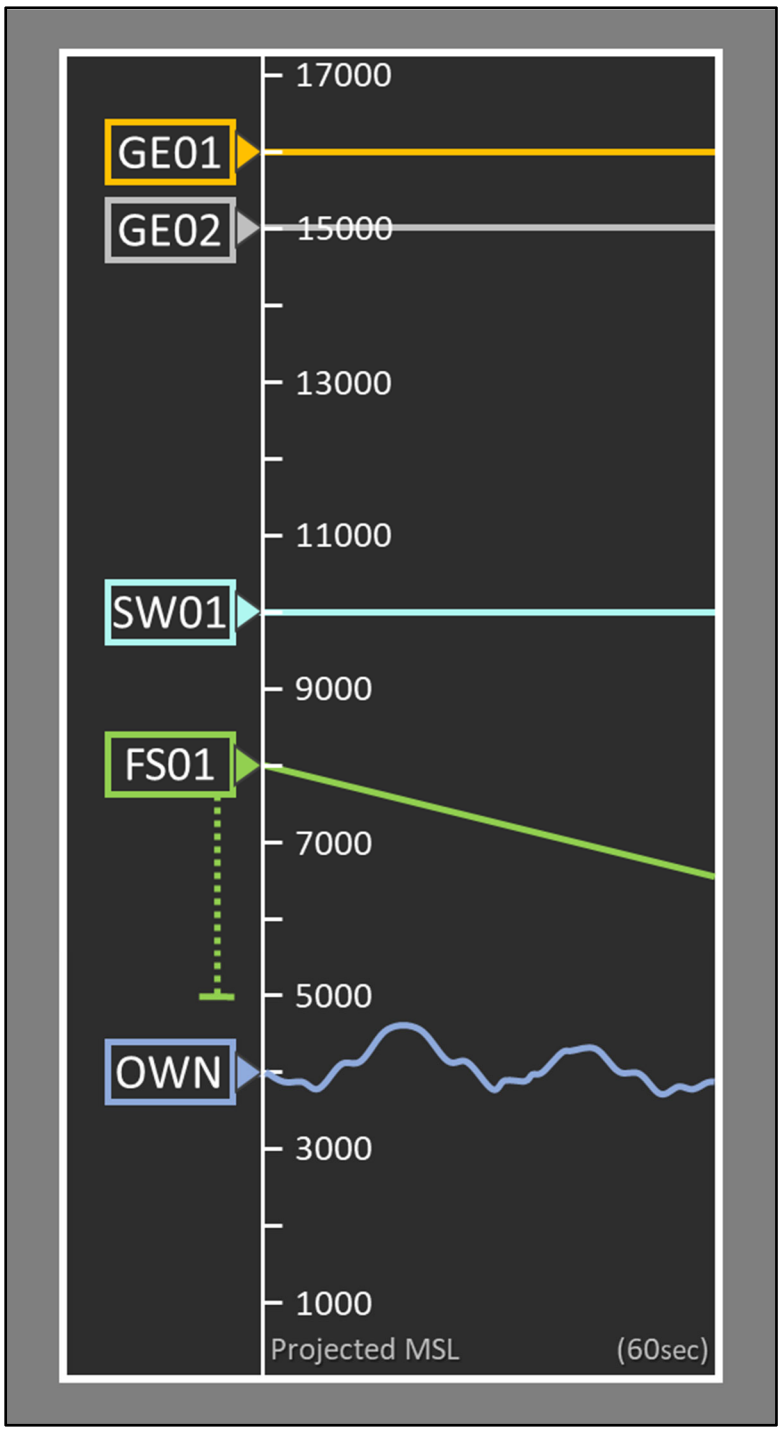


Figure 21. Fleet Altitude Management Tool

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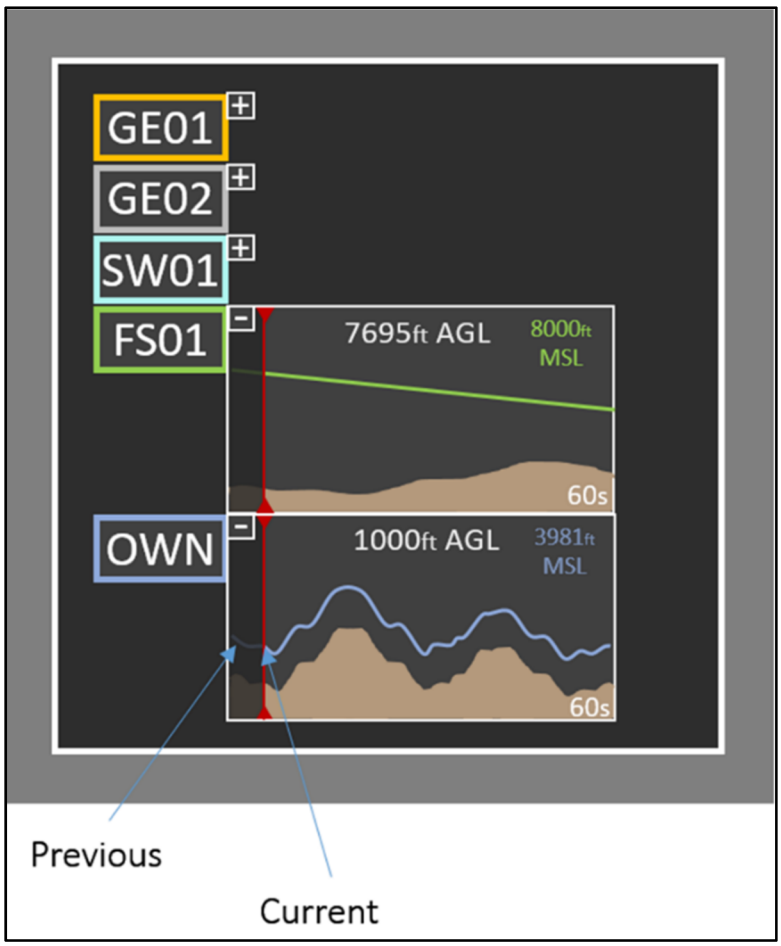


Figure 22. Individual Altitude Management Tool

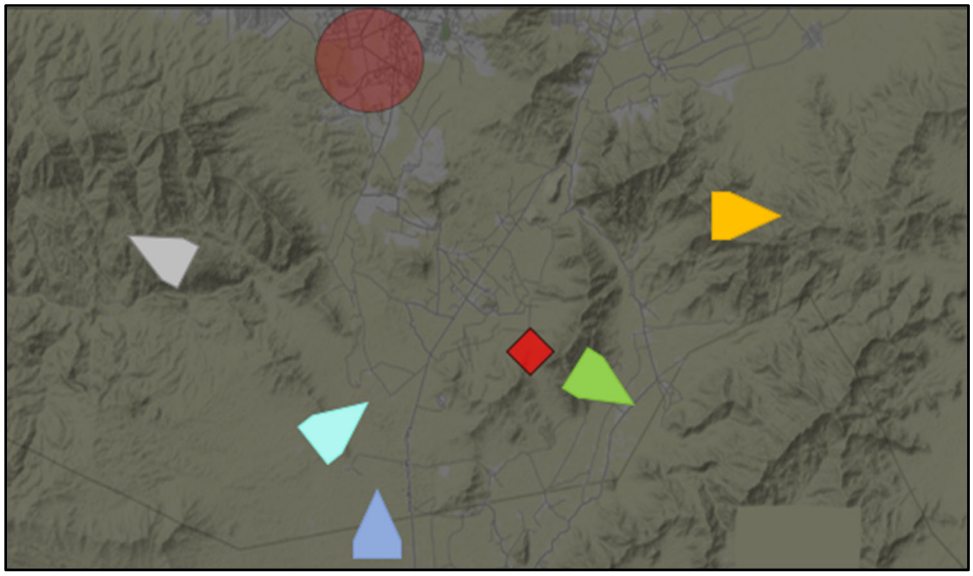


Figure 23. Abbreviated Map

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Figure 21 illustrates the Fleet Altitude Management tool, which includes the current altitudes in MSL of all known aircraft in the airspace, projected altitudes of these aircraft in the next 60 seconds, and commanded altitude if an aircraft is directed to ascend and descend. The scale range of the display dynamically adjusts to include the highest and lowest altitudes of the represented aircraft, and the projected altitude is designed to be operator-adjustable, for example, 60 and 120 seconds. The color of each aircraft is consistent with the color coding observed in all other displays, for example, Vehicle Summary Panel, aircraft icon in the map, and vehicle dashboard, as a way to manage situation awareness of aircraft that are actively executing plays.

A drag-and-drop feature is intended to allow the operator to quickly move an aircraft's call sign box to the desired altitude. Once set, the aircraft begins to descend and ascend to the newly commanded altitude. Figure 21 shows that the newly commanded altitude for FS-01 is set to 5,000 feet (ft), and after 60 seconds of descending, FS-01 is projected to be flying at just below 7,000 ft. This tool could also allow the operator to hover their cursor over a particular aircraft's call sign box to see additional flight information, such as the altitude Above Ground Level (AGL) and ascent and descent rate.

Using the Fleet Altitude Management tool, the operator can quickly determine if there are any current or near-term airspace conflicts between aircraft. In addition, context sensitive warnings can be tied in to warn the operator of possible problems. A sample of the warning conditions that the autonomous system could be programmed to look for include aircraft violating a minimum vertical separation of 500 meters, an impending collision between aircraft based on altitude and heading, an aircraft that is violating or going to violate a ROZ, and/or an aircraft that is in range of a known hostile.

Representing aircraft altitudes in MSL ensures a stable reference point, that is, the average MSL, allowing an operator to easily know where the aircraft are relative to one another. If the FS is at 8,000 ft MSL and the ownship is at 4,000 ft MSL, the operator immediately knows that there is 4,000 ft of vertical separation between them. However, only having altitudes in MSL can become problematic, particularly when aircraft are flying at lower altitudes in mountainous areas. The Individual Altitude Management tool was therefore designed to provide the operator with information regarding an aircraft's position relative to the terrain, emphasizing the AGL altitude, as shown in Figure 22.

Only the FS and ownship's displays are opened in Figure 22. SME's indicated that having the individual displays with terrain information might only be useful for certain aircraft at certain times, so a collapsible display for each aircraft provides the capability to reduce unnecessary clutter when it is not needed by the operator. There is also the MSL altitude indicated in the individual aircraft displays to make pertinent information available across both of the altitude management tools.

Although the Fleet and Individual Altitude Management tools provide a comprehensive view of the vertical airspace, there remained a concern of being able to quickly communicate the lateral separation between aircraft. A task saturated operator may want a quick representation of the battlespace without the need to pan and/or zoom the TECUMSA map. Figure 23 illustrates the idea for an abbreviated map display that offers the operator a small

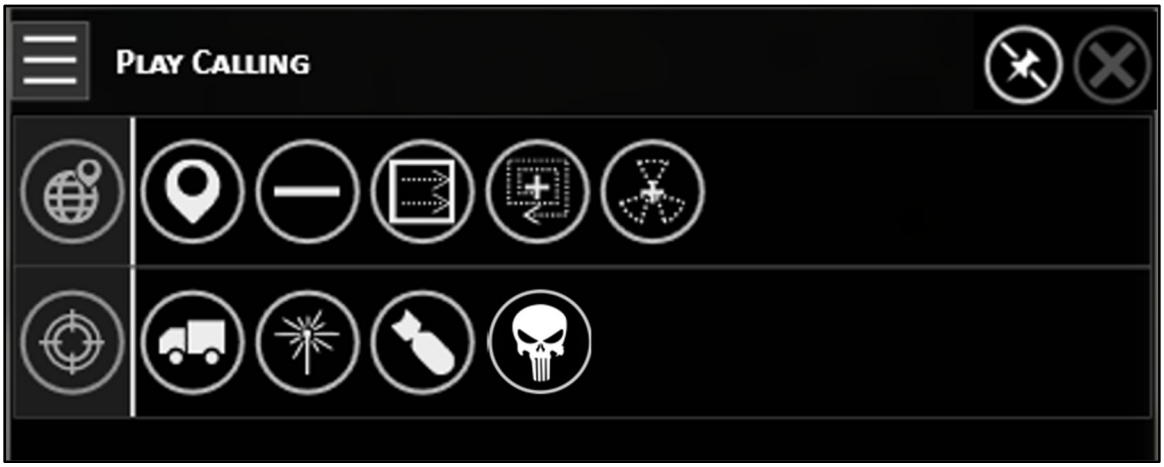
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decluttered version of the full TECUMSA map. This would provide the operator with an updating top-down snapshot of the critical elements for airspace management. The abbreviated map in Figure 23 shows the current location and heading of each known aircraft (irregular pentagons) as well as the location of a ROZ (red semi-transparent circle) and a known hostile entity (red diamond).

6. Plays

Participants provided feedback on the existing play calling interface, identifying existing plays that would be relevant to air assault missions and suggesting new plays that need to be developed. Based on this feedback, Figure 24 shows a revision of the play calling interface was developed that contains two rows of plays. The top row contains location-based plays, including the following from left to right:

- Point Inspect—UAV travels to a point and hovers and loiters with its sensor focused on the point.
- Route Inspect—UAV travels along a route with its sensor focused on the route.
- Parallel Search—UAV searches a specified area using a bidirectional raster scan search pattern.
- Expanding Square Search—UAV searches around a specified point using an expanding square search pattern.
- Sector Search—UAV searches around a specified point using a sector search pattern.



- *Figure 24. TECUMSA Play Calling Tile*

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The bottom row contains target-based plays and from left to right:

- Overwatch—UAV continuously updates its position to ensure its sensor is on a target. The route planner will adjust appropriately according to the type of target, for example, friendly, neutral, unknown, or hostile.
- Designate—UAV continuously updates its position to ensure that it is successfully lasing a target.
- Engage—UAV uses a weapon to engage a target.
- Remote Engage—A dual-UAV play where one UAV laser designates the target and a second UAV engages it.

In addition to these plays, a possible multi-vehicle play was identified which would task multiple UAVs to search multiple NAIs or Points of Interest (POIs)

7. Optimization Parameters

Based on SME feedback, the optimization parameters in the Play Workbook were modified to the parameters shown in Figure 25 in order to capture the parameters most vital for air assault missions. The optimization parameters include from left to right:

- Speed—time to reach the play location and target
- On Station Time—duration on task before needing to be refueled
- Low Observable—remain undetected
- Combat Power—maximal firepower
- Sensor Capability—range of sensor
- Laser Designation Capability—range of laser



Figure 25. TECUMSA Optimization Parameters

Figure 26 shows additional Play Workbook modifications to allow the AMC to specify the desired fixed-wing or rotorcraft airframe, required EO or IR sensors, and need for weaponry, whether or not missiles are required. Due to the nature of certain plays, some parameters could be automatically disabled. For example, the engage play would disable the no weapons required option since an engage play could not be executed without at least one missile.

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Figure 26. Airframe, Sensor, and Weapons Parameter

E. Validating Human-Autonomy Team

In order to validate TECUMSA's ability to support an AMC during air assault missions, TECUMSA will be tested in a realistic test environment using a variety of scenarios and tasks. AMC SMEs provided valuable inputs on SUMIT's Simulation Evaluation Plan, which was largely focused around increasing the ecological fidelity of the vignettes, as shown in Section VI.B. However, no matter how well the properties of the real world are mapped to the synthetic task environment, capturing all of the variables, constraints, events, and unpredictability that an AMC can experience during an air assault is a monetary and temporal investment that few can afford.

For that reason, TECUMSA has been designed to allow the user to finish the design or adapt to scenarios that TECUMSA may or may not have been planned for. TECUMSA is capable of allowing the operator the full spectrum of control, as shown in Figure 27, where the operator can:

- Manually pilot the UAVs
- Work collaboratively with the autonomy, where the user issues high-level commands and the autonomy carries out lower level tasks such as route planning
- Let the autonomous tools in TECUMSA automatically respond to events and re-routing requirements, for example, re-routing an aircraft to avoid a pop-up ROZ

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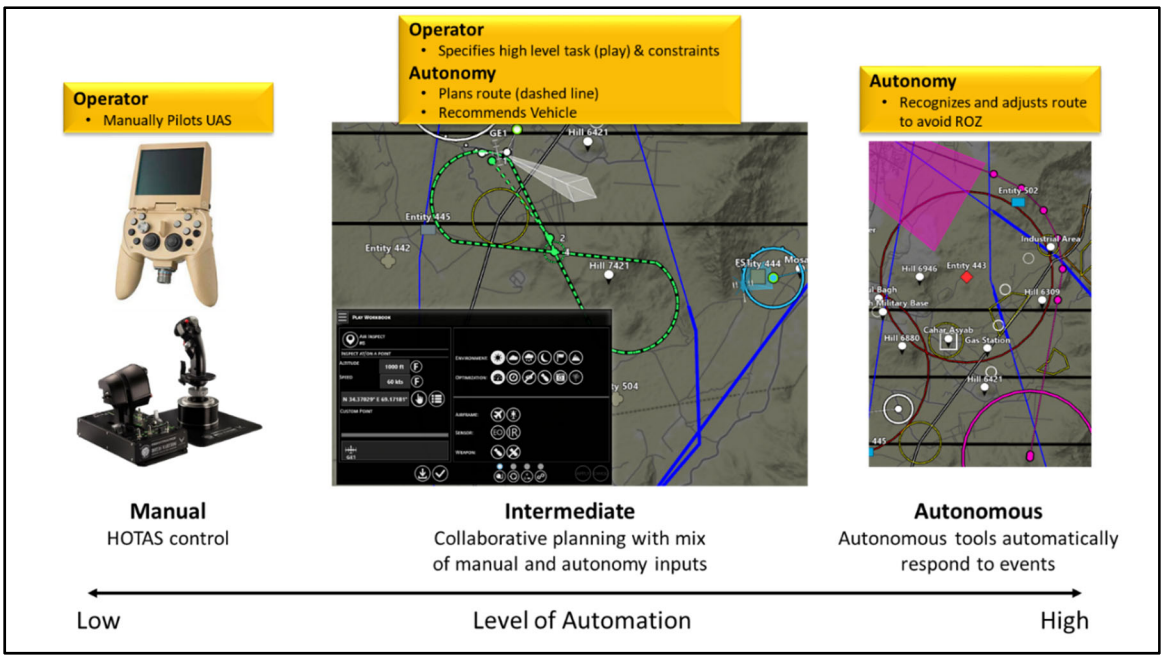


Figure 27. TECUMSA's Spectrum of Control Ranging From Fully Manual to Fully Autonomous Control

This spectrum of control is designed to enable the effective collaboration that is critical to the success of human-autonomy teams, especially in the context of complex sociotechnical systems.

VII. RESULTS AND DISCUSSION

The importance of collaboration between a human-autonomy team was central to the goal of this research. Therefore, this research followed the process of understand, generate, and validate framework employed by Reference 4 in order to develop an HAI that supports an AMC controlling multiple unmanned aircraft in the context of an air assault mission. The CWA revealed the complexity of the domain possibilities along with the boundaries on action. CWA methods using information from Army doctrine and SME interviews provided an understanding of the processes and procedures in an air assault, uncovered the general composition of an air assault team, and identified the specific tasks and duties of an AMC. The CWA began with defining the sequence of events in air assaults, that is, planning, briefing, execution, and the associated tasks of an AMC during each, for example, develop contingency plans, finalize risk assessments, and ensuring timeline adherence. Subsequently, the wagon wheel exercise was used to uncover the communication and coordination that occurs between an AMC and their surrounding team members during mission execution.

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In order to generate an HAI that supports AMC performance across a range of air assault missions, TECUMSA's current autonomous capabilities were demonstrated to expert AMCs. They provided feedback on TECUMSA's HAI components, including the play calling interface, Play Workbook, and vehicle dashboard. This feedback was used to tailor existing HAI components to support air assault missions, for example, adding laser designation capability and combat power to the Play Calling Workbook optimization parameters, as well as adding new HAI components, for example, airspace deconfliction tools.

An additional goal of this research effort was to provide feedback to SUMIT's evaluation team on their proposed simulation evaluation plan. Participants generated an extensive list of questions, clarifications, and comments in response to a simulation interview in which they were guided through each simulation plan vignette. This feedback not only helped strengthen the fidelity of the simulation evaluation plan, but it deepened the team's understanding of the complex work domain and provided valuable inputs for the autonomous system development, for example, preserve sensor's last commanded stare-point even once an engage play is ended to allow for Battle Damage Assessment (BDA).

Reference 1 compares a human-autonomy team to a pair of scissors, with one blade representing the human and the other blade representing the autonomy. Regardless of the sharpness of the blades, that is, the respective abilities of the human and autonomy, the scissors' effectiveness is dependent upon the hinge or interface between them. With respect to the current research, the CWA not only helped to sharpen the blade but also polished the hinge, which is indicative of refinements to TECUMSA's autonomy capabilities and HAI.

VIII. CONCLUSION

While this initial CWA was greatly informative, it will not suffice to end analysis at this point. Air assaults are very complex work domains with many prioritization hierarchies, decision makers, scenarios, resources, and so forth. There are still a range of topics that have yet to be thoroughly investigated, including documents used in flight, for example, air movement table, route cards, Excheck, and kneeboard packets, and the range of technology and software being utilized inside of an air assault aircraft, for example, Blue Force Tracker. These additional topics will be addressed with AMC SMEs in follow-up discussions. Additionally, a spiral development method will be used in which AMC SMEs are brought in throughout the development process to test and evaluate TECUMSA as new features are added. Including SMEs throughout the design process will ensure that TECUMSA will be able to effectively support AMCs during current and future air assault MUM-T missions.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

&	and
#	number
2-D	Two-Dimensional
AATF	Air Assault Task Force
AATFC	Air Assault Task Force Commander
ACTA	Applied Cognitive Task Analysis
ADD	Aviation Development Directorate
AEW&C	Airborne Early Warning and Control
AGL	Above Ground Level
AMC	Air Mission Commander
ATR	Automatic Target Recognition
AvMC	Aviation & Missile Center
AWT	Air Weapons Team
BDA	Battle Damage Assessment
CA	Contingency Asset
CAS	Close Air Support
CCA	Cooperative Control Algorithm
CDO	Cognitive Domain Ontology
CSAR	Combat Search and Rescue
CTA	Cognitive Task Analysis
CWA	Cognitive Work Analysis
DEVCOM	Combat Capabilities Development Command
DTED	Digital Terrain Elevation Data
EO	Electro-Optical

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (CONTINUED)

FORCE	Future Open Rotorcraft Cockpit Environment
FS	Fire Scout
ft	foot
GE	Gray Eagle
GFC	Ground Force Commander
HAI	Human-Autonomy Interface
HOTAS	Hands-On Throttle and Stick
IA	Intelligent Agent
ICP	Initial Planning Conference
ID	Identification
IR	Infrared
ISR	Intelligence, Surveillance, and Reconnaissance
km	kilometer
LOI	Level of Interoperability
LZ	Landing Zone
MEDEVAC	Medical Evacuation
METT-TC	Mission, Enemy, Terrain and Weather, Troops and Support Available, Time Available, and Civil
MGRS	Military Grid Reference System
MSL	Mean Sea Level
MUM	Manned-Unmanned
MUM-T	Manned-Unmanned Teaming
NAI	Named Areas of Interest
PID	Positive Identification
POI	Point of Interest

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (CONCLUDED)

PZ	Pickup Zone
OPS	Operations Center
QRF	Quick Reaction Force
ROZ	Restricted Operations Zone
s, sec	second
SH	Shadow
SME	Subject Matter Expert
SRK	Skill, Rule, Knowledge
SUMIT	Synergistic Unmanned-Manned Intelligent Teaming
TECUMSA	Tasking and Execution of Collaborative Unmanned and Manned Systems with Autonomy
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
UH	Utility Helicopter
U.S.	United States
UV	Unmanned Vehicle
VTOL	Vertical Takeoff and Landing

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Rethinking Special Operations Armed Overwatch

A Monograph

by

Maj Matthew J. Sabatino
US Air Force



School of Advanced Military Studies
US Army Command and General Staff College
Fort Leavenworth, KS

2021

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14. ABSTRACT
The 2017 ambush of four US special operations soldiers in Niger prompted United States Special Operations Command (USSOCOM) to undertake an "armed overwatch" program to provide a dedicated aircraft to support special operations forces (SOF) across austere environments. Despite Department of Defense (DoD) support, Congress prohibited funding a new aircraft in the 2021 National Defense Authorization Act (NDAA) and mandated more analysis regarding armed overwatch roles and responsibilities, doctrinal changes, and relevance to the future threat environment. Armed overwatch is not a doctrinally defined term. USSOCOM has suggested four existing doctrinal characteristics represent its cumulative character: close air support (CAS), armed intelligence surveillance and reconnaissance (ISR), precision strike, and strike coordination and reconnaissance (SCAR). Instead of clarity, however, the fusion of these doctrinal missions creates friction. This is paradoxical for a glaring reason; the essence of armed overwatch, protecting ground troops from the air, is not a new military phenomenon. Historically, the concept of armed overwatch has deep roots in US military aviation, especially among congressionally mandated special operations activities such as special reconnaissance (SR), direct action, and counterinsurgency (COIN). Mindful of the past, armed overwatch must determine whether to acknowledge challenges of the future threat environment. An era of great power competition viewed through the lens of grey zone warfare provides an analytical approach for armed overwatch below the threshold of large-scale combat operations. Alternatively, the rapid emergence of technological trends characterizes an evolution in warfare that armed overwatch must consider both doctrinally and materially to remain relevant in non-contested environments. The term armed overwatch is presently used interchangeably in various contexts: a program, an aircraft, and a mission. Because of a lack of shared understanding, armed overwatch suffers from a lack of identity and narrative, especially amidst the current and future international security environment. This monograph seeks to apply the lenses of doctrine, history, and the future operating environment to make sense of and "rethink" armed overwatch.

15. SUBJECT TERMS
Armed Overwatch, SOF, Tongo Tongo, NDAA, requirement, identity, narrative, doctrine, special operations activities, history, great power competition, future threat environment

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Abstract

Rethinking Special Operations Armed Overwatch, by Maj Matthew J. Sabatino, US Air Force, 68 pages.

The 2017 ambush of four US special operations soldiers in Niger prompted United States Special Operations Command (USSOCOM) to undertake an “armed overwatch” program to provide a dedicated aircraft to support special operations forces (SOF) across austere environments. Despite Department of Defense (DoD) support, Congress prohibited funding a new aircraft in the 2021 National Defense Authorization Act (NDAA) and mandated more analysis regarding armed overwatch roles and responsibilities, doctrinal changes, and relevance to the future threat environment.

Armed overwatch is not a doctrinally defined term. USSOCOM has suggested four existing doctrinal characteristics represent its cumulative character: close air support (CAS), armed intelligence surveillance and reconnaissance (ISR), precision strike, and strike coordination and reconnaissance (SCAR). Instead of clarity, however, the fusion of these doctrinal missions creates friction. This is paradoxical for a glaring reason; the essence of armed overwatch, protecting ground troops from the air, is not a new military phenomenon. Historically, the concept of armed overwatch has deep roots in US military aviation, especially among congressionally mandated special operations activities such as special reconnaissance (SR), direct action, and counterinsurgency (COIN). Mindful of the past, armed overwatch must determine whether to acknowledge challenges of the future threat environment. An era of great power competition viewed through the lens of grey zone warfare provides an analytical approach for armed overwatch below the threshold of large-scale combat operations. Alternatively, the rapid emergence of technological trends characterizes an evolution in warfare that armed overwatch must consider both doctrinally and materially to remain relevant in non-contested environments.

The term armed overwatch is presently used interchangeably in various contexts: a program, an aircraft, and a mission. Because of a lack of shared understanding, armed overwatch suffers from a lack of identity and narrative, especially amidst the current and future international security environment. This monograph seeks to apply the lenses of doctrine, history, and the future operating environment to make sense of and “rethink” armed overwatch.

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Abbreviations

A2/AD	Anti Access/Area Denial
AFRICOM	United States Africa Command
AFSOC	Air Force Special Operations Command
AI	Artificial Intelligence
C2	Command and Control
CAS	Close Air Support
COIN	Counterinsurgency
CT	Counterterrorism
CVEO	Countering Violent Extremist Organizations
DoD	Department of Defense
DOTmLPF-P	Doctrine, Organization, Training, materiel, Leadership and Education, Personnel, Facilities, and Policy
F2T2EA	Find, Fix, Track, Target, Engage and Assess
FAC(A)	Airborne Forward Air Controller
GCAS	Ground Alert Close Air Support
ISR	Intelligence, Surveillance, and Reconnaissance
IW	Irregular Warfare
JADC2	Joint All-Domain Command and Control
JFIRE	Joint Application of Firepower
JP	Joint Publication
LAA	Light Attack Aircraft
NATO	North Atlantic Treaty Alliance
NDAA	National Defense Authorization Act
NDS	National Defense Strategy
NSS	National Security Strategy
SCAR	Strike Coordination and Reconnaissance

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SF	Special Forces
SOF	Special Operations Forces
SR	Special Reconnaissance
sUAS	Small Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
USSOCOM	United States Special Operations Command
XCAS	Airborne Alert Close Air Support

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Introduction and Armed Overwatch Fundamentals

> Airplanes engaged in reconnaissance missions will be prepared to attack hostile ground forces, in order that emergency combat support may be rendered [to] friendly ground units without delay.
>
> —United States Marine Corps, *Small Wars Manual, 1940*

Background

On October 4, 2017, armed Islamic State militants ambushed a United States Special Forces (SF) team near Tongo Tongo, Niger.[1] Four American SF and five allied Nigerien troops died during the attack.[2] The incident represented the most significant combat loss of American lives in Africa since the Battle of Mogadishu in 1993.[3] Subsequent concern over US special operations military activities in Africa led to formal congressional and United States Africa Command (AFRICOM) investigations.

The roles of airborne intelligence, surveillance, and reconnaissance (ISR), command and control (C2), and close air support (CAS) were significant factors in the review of the Tongo Tongo incident. First, an airborne ISR asset that initially supported the SF team during their mission was re-tasked to support another military objective before the team returned to their base.[4] After friendly troops encountered enemy fire, it took ninety-one minutes for a US aircraft to arrive overhead.[5] Second, the area of operations in Africa is geographically large and diverse (Appendix A), and it is impossible to dedicate aircraft to every mission or priority concurrently.

---

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[2] Ibid.

[3] Ibid.

[4] Col Robert Manning, Robert S. Karem, Gen Thomas D. Waldhauser, and Maj Gen Roger L. Cloutier Jr., "DoD Press Briefing on the Results of the Investigation into the October 4, 2017, Ambush in Niger," (Transcript, May 10, 2018), 12, accessed September 14, 2020, https://www.defense.gov/Newsroom/Transcripts/Transcript/Article/1518332/department-of-defense-press-briefing-on-the-results-of-the-investigation-into-t/.

[5] Ibid., 13.

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The AFRICOM investigation found that ISR "was hindered by limited operational planning and procedures, and a lack of coordination and synchronization with US forces and partner nations."[6] The SF team did not receive dedicated airborne ISR throughout the entirety of the mission.[7] Conceivably, uninterrupted ISR coverage, especially from the same platform, would have alerted friendly forces to the advance of potentially hostile forces during critical stages of the mission. Finally, the inability to provide immediate CAS from a US military aircraft was significant. The only available CAS, two allied French fighter jets, were not airborne when the enemy first attacked the SF team.[8] Once the jets arrived overhead to assist, they could not establish contact with the SF team, identify their exact location, or distinguish enemy personnel.[9] Outside of providing a show of force, they were combat ineffective for their intended purpose of providing CAS.

These findings point to a resounding conclusion: an airborne platform capable of providing a distinctive arrangement of dedicated ISR, discrete CAS, and C2 would likely have alerted the SF team to hostile forces and prevented the event's tragic outcome. Today, the Tongo Tongo incident represents a watershed event within United States Special Operations Command (USSOCOM). The outcome serves as a seminal foundation for the acquisition effort of an entirely new USSOCOM aviation program called "armed overwatch."

[6] US Africa Command, "Army Regulation 15-6 Investigation Findings: 4 October 2017 Enemy Contact Event in Tongo Tongo, Niger" (Memorandum for Commander, October 14, 2017), 130, accessed October 26, 2020, https://www.aclu.org/sites/default/files/field_document/34-8._exhibit_2.7_3.25.20.pdf, document is now declassified.

[7] US Africa Command, "Army Regulation 15-6 Investigation Findings: October 4, 2017, Enemy Contact Event in Tongo Tongo, Niger" (Memorandum for Commander, October 14, 2017), 3-4, accessed October 26, 2020, https://www.aclu.org/sites/default/files/field_document/34-5._exhibit_2.4_3.25.20.pdf.

[8] Ibid., 142.

[9] Ibid., 79.

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The armed overwatch program received formal support from stakeholders within USSOCOM.[10] Moreover, numerous opinion articles were published in the wake of the Tongo Tongo incident and argued that a special operations armed overwatch aircraft for USSOCOM is valid and justified.[11] However, congressional concerns about the requirement's validity have jeopardized funding and the program's future. In both houses of Congress, US lawmakers raised questions in committee meetings regarding armed overwatch's overall value, rapid acquisition timeline, operation, sustainment costs, and potential negative impacts.[12] In particular, the Senate Armed Services Committee stipulated "an analysis to define the special operations-peculiar requirements for armed overwatch aircraft and determine whether the acquisition of a new special operations-peculiar platform is the most effective means of fulfilling such requirements."[13] Ultimately, a final bipartisan congressional committee expressly mandated more analysis regarding armed overwatch roles and responsibilities, doctrinal impacts, threats from the future operating environment, and potential materiel solutions.[14] The final passage of the National Defense Authorization Act (NDAA) in January 2021 restricted any funding until armed overwatch could be reviewed, validated, and certified.[15]

[10] USSOCOM, *U.S. Special Operations Validation of Special Operations Rapid Requirements Document for Special Operations Forces Armed Overwatch* (Document received by author via email September 2, 2020), 1.

[11] Lt Gen John Mulholland, Lt Gen Tom Trask, Maj Gen Mark Clark, and Rear Adm Brian Hendrickson, "The Growing Need for a Modern Aircraft Platform for Special Forces," *The Hill (blog)*, July 2, 2020, accessed July 10, 2020, https://thehill.com/blogs/congress-blog/politics/505757-the-growing-need-for-a-modern-aircraft-platform-for-special.

[12] Rachel S. Cohen, "Congress Questions Need for New Armed Overwatch Planes for SOCOM," *Air Force Magazine*, July 1, 2020., accessed July 12, 2020, https://www.airforcemag.com/congress-questions-need-for-new-armed-overwatch-planes-for-socom/.

[13] Select Committee on Armed Services, Senate, National Defense Authorization Act for Fiscal Year 2021, 116th Cong., 2nd sess., January 2020, S. Rep. 116-236, sect. 176, 19.

[14] Select Committee on Armed Services, House, National Defense Authorization Act for Fiscal Year 2021, 116th Cong., 2nd sess., December 2020, HR Rep. 116-617, sect. 163, 1535-1536.

[15] US Congress, William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021, 116th Cong., 2nd sess., January 2021, Public Law 116-283, sect. 163, 64.

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Purpose

This monograph analyzes armed overwatch by examining its identity as charged by the 2021 NDAA. The questions below provide a structure for underwriting this primary research task:

1. What is armed overwatch, and what are its doctrinal roles and characteristics?
2. What does a dual framework of special operations unique missions and historical applications of armed overwatch suggest regarding its validity?
3. What is armed overwatch's role and responsibility in future threat environments amid an era of great power competition, and does this indicate a need to rethink alternatives?

Scope

Organizational theorist Karl Weick defines "sensemaking" as the process of "turning circumstances into a situation that is comprehended explicitly in words that serve as a springboard into action."[16] Tongo Tongo's circumstances give meaning to armed overwatch and help give the requirement an identity and a shared narrative. However, as Congress has indicated in the NDAA, more analysis is needed to answer the question of "what is the story of armed overwatch?"

Making sense of armed overwatch requires an understanding of clear roles, responsibilities, and characteristics. The first section of this monograph will examine armed overwatch through doctrine to determine its identity. The term armed overwatch is presently used interchangeably as a program, mission, and potential future aircraft. Armed overwatch's lack of exact meaning prevents common understanding and obstructs identity and narrative development crucial to gaining Congressional approval and funding. Doctrine is a helpful framework to

[16] Karl E. Weick and Kathleen M. Sutcliffe, "Organizing and the Process of Sensemaking," *Organization Science* 16, no. 4 (August 2005): 409.

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develop a clear and shared understanding of armed overwatch and is valuable in determining a succinct identity and forming a crisp narrative.

Second, special operations activities as defined by US Title 10 law, coupled with historical case studies, provide another lens to analyze armed overwatch. Special reconnaissance (SR), direct action, and counter insurgency (COIN) represent three special operations activities that prove armed overwatch is valid because it is a historical aerial mission. Surprising examples from the American Civil War, early 20th century Marine Corps' expeditions, and Korean and Vietnam Wars illustrate a critical point: armed overwatch is not a new idea or unique to special operations but rather an enduring military phenomenon.

Finally, the character of warfare has changed substantially in recent years due to the shifting geopolitical environment. Armed overwatch must have a clearly defined role in the present era of great power competition. Despite the strategic focus and anticipation of potential major combat operations with Russia or China, conflict below the threshold of large-scale combat in non-permissive environments is likely to persist as a national security threat. A Cold War-era theory of warfare illustrates validity for a "low-end" armed overwatch requirement within a paradigm of peer or near-peer competition. Alternatively, in an entirely different scenario, armed overwatch must be mindful of the future threat environment, especially the semi or non-permissive one. To that end, a manned, fixed-wing armed overwatch platform tied to airfields and dependent on centralized logistics might be doctrinally and materially incompatible with a contested future battlespace.

USSOCOM is unique compared to the military services. It has prescribed express authority by Title 10 US law to pursue the "development and acquisition of special operations-peculiar" equipment and does so through either rapid or deliberate processes.[17] This monograph

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does not seek to analyze armed overwatch procurement through the lens of the acquisition process. Nor does it "cherry-pick" past or current publications that aim to confirm or deny armed overwatch's validity. Finally, it does not seek to analyze the acquisition program from a financial perspective. The goal, instead, is to separate the "signal" of armed overwatch from the "noise" via an exploration of doctrine, historical revelations, and the future threat environment to discover prescriptive insights and "rethink" the identity of armed overwatch.

Doctrinal Foundations

> AO [armed overwatch] is a non-doctrinal, new term to describe the conduct of Close-Air Support (CAS), Armed Intelligence, Surveillance, and Reconnaissance, Strike Coordination & Reconnaissance, and Precision Strike in direct support of small, geographically isolated SOF units.
>
> —Vice Admiral Tim Szymanski, Deputy Commander, USSOCOM

Armed Overwatch

Doctrine offers fundamental principles for how our military employs its forces through coordinated action toward a common objective.[18] While directive in nature, it is not prescriptive yet provides a logical starting point for military capabilities and troops in warfare. Doctrine can help focus our awareness on what is essential because it is rooted in past lessons. Chairman of the Joint Chiefs of Staff Instruction 5705.01G, *Standardization of Military and Associated Terminology*, mandates military terminology standardization to improve communication and mutual understanding within the Department of Defense (DoD) federal agencies.[19]

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[17] A Joint Resolution Making Continuing Appropriations for The Fiscal Year 1987, and for Other Purposes, Public Law 99-500, title X, §1783-124, *Statutes at Large* (1986): 124, Unified combatant command for special operations forces, codified at *US Code* 10 (2018), §167(k).

[18] US Joint Staff, Joint Publication (JP) 1, *Doctrine for the Armed Forces of the United States* (Washington, DC: Government Publishing Office, 2017), 27.

[19] US Joint Staff, Chairman of the Joint Chiefs of Staff Instruction 5705.01G, *Standardization of Military and Associated Terminology* (Washington, DC: Government Publishing Office, 2020), 1.

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According to the *DoD Dictionary of Military and Associated Terms*, armed overwatch is not a formally recognized doctrinal term.[20] Occasional armed overwatch references appear across joint and service-wide doctrine publications, but their usage is inconsistent and does not suggest an overall integrated idea.

An acquisition effort for a novel and potentially costly aircraft program without a joint doctrinal foundation requires a greater degree of explanation because it lacks shared understanding. A lack of doctrinal standardization leaves enormous room for interpretation across the joint force, notwithstanding limitations, integration, tactics, techniques, and procedures. USSOCOM acknowledges armed overwatch's mission void and submits that it is the unique combination of the missions of CAS, armed ISR, precision strike, and strike coordination and reconnaissance (SCAR).[21] However, instead of providing clarity, an analysis of these subordinate characteristics generates further misunderstanding through the friction caused by their forced composition. Rather than the emergence of synchronized, "X-centered" doctrine, the result is haphazard stitching together of like doctrines, the equivalent of "Franken-doctrine."

Current US military doctrine provides a minimal reference to armed overwatch. A 2008 military journal article written by current Air Force Deputy Chief of Staff for Strategy, Integration, and Requirements, Lieutenant General Clinton "Q" Hinote, defines armed overwatch as "not CAS, but not ISR either."[22] Joint Publication (JP) 3-05, *Special Operations*, revised and updated in September 2020, makes zero references to the term.[23] The multi-service manual for

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[20] US Joint Staff, *DoD Dictionary of Military and Associated Terms* (Washington, DC: Government Publishing Office, 2020).

[21] USSOCOM, *U.S. Special Operations Validation of Special Operations Rapid Requirements Document for Special Operations Forces Armed Overwatch*, 1.

[22] Lt Col Clint "Q" Hinote, "Military Operations in Urban Terrain: Armed Overwatch: Key to Successful COIN Operations in Urban Terrain," *Air Land Sea Bulletin* no. 2008-1 (January 2008): 9-11.

[23] US Joint Staff, JP 3-05, *Special Operations* (Washington, DC: Government Publishing Office, 2020).

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the joint application of firepower, more commonly known as JFIRE, contains no armed overwatch definition.[24]

Because the term armed overwatch lacks definition, we must assign it meaning. Doctrinal gaps and voids offer virtually no foundation for understanding its character and nature and do little to determine its roles and responsibilities of a mission or suggest the program's validity and pursuit of a new aircraft. Therefore, one way of better understanding armed overwatch's identity is through an indirect analysis of its four proposed doctrinal mission characteristics.

Close Air Support

One common criticism of armed overwatch is that it is merely the mission of CAS by another name. The DoD Dictionary defines CAS as "Air action by aircraft against hostile targets that are in close proximity to friendly forces and that require detailed integration of each air mission with the fire and movement of those forces."[25] Likewise, joint doctrine defines CAS as the employment of "speed, range, maneuverability to attack targets that other supporting arms might not be able to engage due to limitations such as target type, range, terrain, or ground scheme of maneuver."[26] These definitions affirm the essence of what a special operations armed overwatch aircraft accomplish: air support to troops on the ground.

Current CAS doctrine does not differentiate between CAS and armed overwatch. JP 3-09.3, *Close Air Support*, references armed overwatch one time in the context of target marking.[27] Similarly, JP 3-30, *Joint Air Operations*, mentions armed overwatch one time regarding tasking

[24] Air Land Sea Application Center, JFIRE, *Multi-Service Tactics, Techniques, And Procedures for Joint Application of Firepower* (Langley AFB, VA: Government Publishing Office, 2019).

[25] US Joint Staff, *Department of Defense Dictionary of Military and Associated Terms*, 35.

[26] US Joint Staff, JP 3-09.3, *Close Air Support* (Washington, DC: Government Publishing Office, 2019), xii.

[27] Ibid., III-96.

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of unmanned aerial systems.[28] Creating even more confusion, Air Force Doctrine Annex 3-03, *Counterland Operations*, defines armed overwatch as a "non-doctrinal" mission category within COIN to provide ground commanders full-motion video, situational awareness, and immediate CAS when necessary.[29] Annex 3-03 further elaborates that if a CAS situation does develop, then the armed overwatch mission should be considered CAS and "not a new or independent counter land mission area distinct from CAS."[30] This is the sense of many subject matter experts. According to Dr. David Neuenswander, Director of Army and Air Force Doctrine Integration (and former A-10 pilot): "If I am armed and in a position to support ground troops, this is close air support."[31] The relationship between CAS and armed overwatch and whether they are distinct is a critical question. The Air Force's A-10 Thunderbolt II, better known as the "Warthog," and the historical challenge of C2 of military aircraft provide a framework for analyzing this question more in-depth.

The A-10 was explicitly designed for CAS. In 2018, the A-10 fleet size was deemed inadequate to support the National Defense Strategy's (NDS) requirements.[32] The Department of the Air Force projected 249 A-10 in service in 2021 across the active-duty Air Force, Air National Guard, and Air Force Reserve.[33] However, the A-10 is plagued by the dilemma of age. Even with modern upgrades, the A-10 is nearly fifty years old, and in that span, the total fleet size has slowly eroded. Due in part to this challenge, the Air Force's OA-X Light Attack Aircraft

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[28] US Joint Staff, JP 3-30, *Joint Air Operations* (Washington, DC: Government Publishing Office, 2019), 85.

[29] US Department of the Air Force, Air Force Doctrine Annex 3-35, *Counterland Operations* (Maxwell AFB, AL: Government Publishing Office, 2020), 12.

[30] US Air Force, Annex 3-35, *Counterland Operations*, 12.

[31] Dr David M. Neuenswander "El Cid", e-mail message to author, February 4, 2021.

[32] Jeremiah Gertler, *Air Force OA-X Light Attack Aircraft Program* (Washington, DC: Congressional Research Service, November 2019), 1, accessed February 9, 2021, https://crsreports.congress.gov/product/pdf/IF/IF10954.

[33] US Department of the Air Force, *Department of the Air Force FY 2021 Budget Overview* (Washington, DC: Government Publishing Office, 2020), 42.

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(LAA) initiative was intended to remedy this readiness imbalance by acquiring a new two-seat turboprop airplane designed for CAS operations in COIN operating environments. Since then, the LAA program has stagnated due to fiscal constraints, manpower limitations, and a national strategy shift toward great power competition. LAA and armed overwatch are mutually exclusive, and both programs will likely not be simultaneously funded. Today, the Air Force's LAA indecision is one reason that has given Congress pause for USSOCOM's separate but similar program. The 2021 NDAA explicitly prohibited the purchase of armed overwatch aircraft until the "Chief of Staff of the Air Force certifies the Air Force does not have the skill or capacity to provide CAS and armed overwatch at present."[34] This delay is necessary for the Air Force to analyze the OA-X program's state and explain to Congress why its current CAS aircraft inventory (A-10, AC-130, MQ-9, F-16, B-1, B-52, and F-15E) cannot meet the present USSOCOM CAS demands.

This illustrates a fundamental and historical C2 problem with CAS. The Air Force tenet of "centralized control, decentralized execution" is predicated on the philosophy that resource-scarce aircraft offer potentially operational and strategic effects.[35] In North Africa during World War II, Army Air Force fighter aircraft were placed directly into Army Corps echelons, and theater-level effectiveness was sacrificed for local effectiveness. Before long, it was realized that tactical airpower characteristics such as speed, flexibility, and range were more effective when centrally controlled at higher echelons.[36] The Air Force C2 model for airpower, allocated under a

[34] Select Committee on Armed Services, House, National Defense Authorization Act for Fiscal Year 2021, 116th Cong., 2nd sess., 2020, HR Rep. 116-617, sect. 163, 1539.

[35] US Department of the Air Force, Air Force Doctrine Volume 1, *Basic Doctrine* (Maxwell AFB, AL: Government Publishing Office, 2015), 67.

[36] Robert R. Leonhard, *Fighting by Minutes: Time and the Art of War* (self-pub., CreateSpace, 2017), 165.

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single Airmen's authority based on the highest priorities rather than parceled out to subordinate echelons, continues to this day.[37]

JP 3-09.3 states CAS is planned and executed to support tactical ground units at a time and place where friendly forces are close to enemy forces.[38] Additionally, Air Force CAS doctrine considers both preplanned and immediate requests for CAS to allow greater flexibility in planning and Air Tasking Order execution.[39] Air Force doctrine also accounts for "on-call CAS," which "involves putting the aircraft on ground-based or airborne alert during a preplanned time period when the need for CAS is likely, but not guaranteed."[40] The Air Tasking Order can organize CAS as either GCAS (ground alert) or XCAS (airborne alert).[41] Two additional doctrinal methods subdivide On-Call CAS even further. 'Push-CAS' and 'Pull CAS' allow for even greater flexibility to accomplish planned and un-forecasted needs for CAS.[42] These types of requests, missions, and methods advance a shared CAS understanding through doctrine. However, this CAS doctrinal terminology does not comprehensively account for the entirety of an armed overwatch requirement.

An important finding from the AFRICOM Tongo Tongo investigation found that aircraft response time was hindered by "limited operational planning and procedures, and a lack of coordination and synchronization with US forces and partner nations."[43] This finding signals the heart of USSOCOM's request for CAS from an armed overwatch platform: the ability to assign perpetually dedicated CAS independent of centralized C2. XCAS, as a centrally controlled

[37] US Air Force, Volume 1, *Basic Doctrine*, 67.

[38] US Joint Staff, JP 3-09.3, *Close Air Support*, xi.

[39] US Department of the Air Force, Air Force Doctrine Annex 3-03, *Counterland Operations* (Maxwell, AFB, AL: Government Publishing Office, 2020), 51.

[40] US Air Force, Annex 3-03, *Counterland Operations*, 52.

[41] Ibid.

[42] Ibid, 52-53.

[43] US Africa Command, "Army Regulation 15-6 Investigation Findings," 130.

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function, cannot assure complete and comprehensive CAS coverage for special operations forces (SOF). Furthermore, XCAS and GCAS cannot guarantee direct support for SOF missions. Therefore, armed overwatch requires a distinctive type of dedicated CAS that is not wholly defined or articulated by the present Air Force CAS C2 doctrine and missions (Appendix C). In particular, the Air Force's CAS integration model is theoretically too centralized and not flexible enough to support SF teams like those operated in Niger. Geographically isolated SOF requires organic and dedicated CAS that provides direct support due to the unique geographical demand of operating in austere environments.

Present CAS doctrine is relatively incompatible with one of the chief requirements of armed overwatch: "direct support of small, geographically isolated SOF units."[44] If one imagines Air Force CAS doctrine and the various requests, missions, and methods as a Venn diagram, then armed overwatch is analogous to the center of this diagram in which present CAS doctrine converges, but no cumulative or independent criteria exist (see Appendix C and Appendix D). Alternatively, resourcing limitations will always persist due to the unique operational environments of SOF. The unique CAS requirement of tactical SOF echelons in the austere environments among unique SOF resourcing requirements illustrates two essential ideas. First, armed overwatch needs to be understood as a mission before a program. Second, a requirement for this type of mission can be filled by CAS capable aircraft but is limited by current CAS inventory, such as the A-10.

Armed Intelligence Surveillance and Reconnaissance

Armed Intelligence, Surveillance, and Reconnaissance also lacks a common joint doctrinal definition. JP 2-01, *Joint and National Intelligence Support to Military Operations*, defines ISR as:

[44] USSOCOM, *U.S. Special Operations Validation of Special Operations Rapid Requirements Document for Special Operations Forces Armed Overwatch*, 1.

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> 1. An integrated operations and intelligence activity that synchronizes and integrates the planning and operation of sensors, assets, and processing, exploitation, and dissemination systems in direct support of current and future operations. 2. The organizations or assets conducting such activities.[45]

CAS and ISR's relationship is critical to understanding armed overwatch because they represent its two primary missions. Joint doctrine addresses the overlap of the two to a limited degree. JP 3-09.3 lists ISR as a consideration in troop support but not a primary role for CAS.[46] Likewise, CAS and strike platforms are doctrinally defined as "non-traditional" ISR assets that can provide ISR through capabilities such as ground-moving-target indicator tracker or full-motion video sensor data."[47] These sensors, however, are generally "limited in the field of view resolution, or scope of operations when compared to traditional [ISR] sources."[48] In their conduct of ISR, however, they "should only be considered on "an as-needed basis."[49] The doctrinal missions of CAS and ISR do not fully account for one another. Each mission can have varying degrees of the other capability, but a mission representing a fusion of the two doctrines does not presently exist. One could reason the fusion of CAS and ISR creates a void in which CAS and ISR do not account for the other's full doctrinal mission potential proves the legitimacy of an armed overwatch mission. The multi-mission MQ-9 *Reaper* unmanned aerial vehicle (UAV) is an example that illustrates this doctrinal overlap between ISR and CAS in a practical application.

The MQ-9 is an armed, multi-mission asset with an intelligence collection mission that can also perform limited CAS.[50] The special operations variants primarily conduct ISR in direct support of current and future SOF operations. To be sure, the MQ-9 does not match the CAS

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[45] US Joint Staff, JP 2-01, *Joint and National Intelligence Support to Military Operations* (Washington, DC: Government Publishing Office, 2017), GL-10.

[46] US Joint Staff, JP 3-09.3, *Close Air Support*, III-15.

[47] Ibid., III-16.

[48] Ibid.

[49] Ibid.

[50] Air Combat Command Public Affairs Office, "MQ-9 Reaper," Air Force Fact Sheet, September 23, 2015, accessed February 9, 2021, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104470/mq-9-reaper/.

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capabilities of the A-10. It lacks armament because it is primarily an ISR mission with robust electro-optical sensors, advanced radio-communications suites, data-link capabilities, and the ability to transmit and deliver secure voice communications full-motion video. A multi-mission platform that combines CAS characteristics with the advanced suite of ISR sensors is a blend of functions that armed overwatch requires overhead the battlefield, and the present doctrine fails to account for entirely.

The A-10 lacks the multiple advanced ISR capabilities that a multi-mission MQ-9 can employ, while the MQ-9 lacks the considerable weapons complement of ordnance, forward-firing cannon, and CAS the A-10 delivers. Army assets, such as the MQ-1C *Gray Eagle*, the RQ-7B *Shadow*, and AH-64 *Apache*, provide varying degrees of organic ISR and CAS to support a ground force commander's objective.[51] However, even in these direct support roles, aircraft, by being a limited resource, face similar C2 challenges at the division and corps echelons as that of the centralized Air Force construct.

C2 issues that operationally limit CAS for USSOCOM under an Air Force system also affect ISR. USSOCOM has a military department's distinctive role, such as the Army or Air Force, and a geographic combatant command, assigned with "unique functions, responsibilities, and authorities" prescribed by US law.[52] ISR is a significant military demand for all combatant commands and exacerbated by the limited number of airborne ISR platforms and missions allocated to accomplish their intelligence-gathering demands. The cumulative requirement for global ISR demand exceeds capability by a wide margin and is a common geographic combatant

[51] US Department of the Army, FM 3-04, *Army Aviation* (Washington, DC: Government Publishing Office, 2017).

[52] US Department of Defense, DoD Directive 5100.01, *Functions of the Department of Defense and Its Major Components*, Change 1 (Washington, DC: Government Publishing Office, 2020), 3.

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command challenge. A 2020 congressional committee noted the DoD could only meet 20 percent of worldwide ISR requirements.[53]

Presently, the Air Force utilizes most of its ISR platforms to prosecute national-level objectives and meet mission requirements.[54] These objectives usually are strategically oriented and generally do not prioritize special operations tactical mission requirements or goals. Air Force doctrine states, "timely detailed and global integrated ISR support is vital to special operations."[55] However, it is illogical to assume dedicated ISR allocated under the global ISR management planning process would receive prioritization, allocation, and decentralization under the purview of SOF, as joint doctrine suggests.[56]

A doctrinal gap exists between ISR and CAS that is not accounted for by current joint doctrine. This void justifies a new mission that more fully blends the doctrinal characteristics of both ISR and CAS. The full potential of both missions is not accounted for by doctrine nor a current multi-mission aircraft. This exclusion highlights the need for a new armed overwatch doctrinal mission and, ultimately, the program.

Precision Strike

In a now common theme, precision strike also has no DoD or joint publication definition. However, it is defined in Air Force Annex 3-05, *Special Operations*:

> Precision strike provides the joint force commander and the SOF operator with specialized capabilities to find, fix, track, target, engage, and assess (F2T2EA) targets. F2T2EA can use a single weapon system or a combination of systems to complete the kill chain. Precision strike missions include close air support, air interdiction, and armed reconnaissance. Attributes associated with precision strike include persistence, robust

[53] Select Committee on Armed Services, House, National Defense Authorization Act for Fiscal Year 2021, 116th Cong., 2nd sess., 2020, HR Rep. 116-442, sect. 176, 270.

[54] US Department of the Air Force, Air Force Doctrine Annex 2-0, *Global Integrated ISR* (Maxwell AFB, AL: Government Publishing Office, 2015), 4.

[55] US Air Force, Annex 2-0, *Global Integrated ISR*, 28.

[56] US Joint Staff, JP 2-01, *Joint and National Intelligence Support to Military Operations*, B-1.

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communications, high situational awareness, precise target identification, lethality, and survivability, as required.[57]

US military UAVs' usage to conduct counterterrorism (CT) operations and hunt high-value targets utilizing precision strikes as part of the F2T2EA process had become widely synonymous with the Global War on Terror. Despite the well-publicized effects of precision strike across mainstream media, however, the term remains remarkably ill-defined. The absence within current US doctrine is even starker. The precision strike concept dates to the mid-1980s when Soviet military authors first characterized it as "a new family of highly accurate, precision-guided deliver systems for non-nuclear munitions."[58] Despite nearly forty years of theory, amidst the employment of drone strikes in US CT operations in Iraq and Afghanistan, an approved joint doctrinal definition for precision strike remains remarkably non-existent.

Former Air Force pilot and author Barry Watt provides a rich study of the evolution of precision strike and makes an essential observation of why the diffusion of precision strike doctrine has been relatively slow. Watt suggests that precision strikes, or what he also refers to as "reconnaissance strike," have not achieved a greater diffusion among allies and adversaries due to complexity and other nations' adoption.[59]

Air Force doctrine defines precision strike as capabilities to conduct F2T2EA via missions that include "close air support, air interdiction, and armed reconnaissance."[60] However, the absence of a formal precision strike definition from joint doctrine is puzzling but does not suggest that armed overwatch is an illegitimate requirement. Though poorly defined in joint doctrine, precision strike has a tremendous identity and shared understanding through its

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[57] US Department of the Air Force, Air Force Doctrine Annex 3-05, *Special Operations (*Maxwell AFB, AL: Government Publishing Office, 2020), 17.

[58] Notra Trulock, III, "Emerging Technologies and Future War: A Soviet View," in *The Future Security Environment, Report of the Future Security Environment Working Group submitted to the Commission on Integrated Long-Term Strategy* (Washington, DC: Pentagon, 1988), 98.

[59] Barry D. Watts, *The Evolution of Precision Strike* (Washington, DC: Center for Strategic and Budgetary Assessments, 2013), 11.

[60] US Air Force, Annex 3-05, *Joint and National Intelligence Support to Military Operations*, 17.

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execution and application (not to mention its ubiquity across media like television shows). Absent clear joint doctrine, the Air Force doctrinal definition of a precision strike as a framework to understand precision strike suggests validity and legitimacy for armed overwatch. It is critical, though, that the precision strike doctrinal "knot" be untangled for the nature of armed overwatch to gain greater comprehensive meaning and clear understanding.

Strike Coordination and Reconnaissance (SCAR)

Ironically, the least familiar doctrinal characteristic of armed overwatch offers potentially the best doctrinal prescriptions for armed overwatch. The DoD dictionary defines SCAR as: "A mission flown for the purpose of detecting targets and coordinating or performing attack or reconnaissance on those targets."[61]

SCAR is codified in joint doctrine and governed by a multi-service publication sanctioned by the Army, Marine Corps, Navy, and Air Force.[62] The current SCAR doctrinal manual organizes SCAR by fundamentals, command and control, planning, execution, and incorporates examples of mission planning guides and even explains the relationship to joint doctrine.[63] Additionally, SCAR has numerous doctrinal examples within service-wide doctrine. Air Force Annex 3-03, *Counterland Operations*, establishes pertinent considerations for SCAR regarding C2, delineations from CAS, and authorities. Likewise, Marine Corps Training Pamphlet 3-20D, *Offensive Air Support*, lists similar essential planning considerations.[64] The level of doctrinal fidelity and resolution that SCAR provides is one possible way to codify and articulate armed overwatch. Also, it is noteworthy that there is no dedicated SCAR platform. Like

[61] US Joint Staff, *Department of Defense Dictionary of Military and Associated Terms*, 204.

[62] Air Land Sea Application Center, SCAR, *Multi-Service Tactics, Techniques, And Procedures for Strike Coordination and Reconnaissance* (Langley AFB, VA: Government Publishing Office, 2020).

[63] Ibid., vii.

[64] US Department of the Navy, Marine Corps Training Publication 3-20D, *Offensive Air Support* (Washington, DC: Government Publishing Office, 2018), 13.

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CAS, it is a mission that numerous aircraft can conduct, rather than a dedicated platform-centric concept.

Summary

The “Franken-doctrine” approach to creating a new doctrinal mission for armed overwatch from four separate doctrinal missions comes up short. An analysis of present doctrine shows that armed overwatch presently lacks identity because a clear and explicit doctrine of its subordinate characteristics does not exist. An attempt to doctrinally isolate armed overwatch and characterize it is confusing because the components that form its whole are either likewise not defined or too similar. Additionally, CAS and ISR do not account for the unique requirements of C2 requirements suggested by armed overwatch. Armed ISR and precision strike are themselves doctrinally ill-defined and, although they have relative levels of shared understanding via their significant application in the previous two decades. However, using them as foundational reasoning for an entirely new doctrinal mission misses the mark. As the least well-known mission, SCAR prescribes the best doctrinal foundation and an independent model for how armed overwatch could be codified within the doctrine.

A doctrinal analysis proves that a new type of armed overwatch mission is both justified and legitimate, lending validity to the program's ambitions. However, there is considerable ambiguity surrounding the meaning of armed overwatch through the lens of doctrine. Meaning cannot be assigned to armed overwatch until it is better defined and develops a better identity through doctrine. Likewise, the arrangement of its four characteristics within one another is opaque. Complete doctrinal clarity is not a precursor to the fielding or justification of a new requirement. However, for armed overwatch to mature from its present ambiguous state, it must be codified in joint doctrine as a mission. Within the framework of present joint doctrine, armed overwatch makes the most sense as a subordinate mission of CAS.

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Doctrine is just one way to form an identity and create a shared understanding. Fortunately, doctrine is relatively easy to create or modify to assign meaning. Historical examples and case studies provide another way to examine armed overwatch to inform its present identity.

Special Operations Core Activities and Historical Examples

> If the enemy is to be struck while he is most vulnerable, he must be attacked immediately by the air patrol, which discovers him.
>
> —United States Marine Corps, *Small Wars Manual,* 1940

USSOCOM's principal function is to prepare SOF to carry out assigned missions established by US law.[65] Title 10 US Code Section 167(k) lists (but does not define) nine special operations activities: direct action (DA), strategic reconnaissance, unconventional warfare, foreign internal defense, civil affairs, military information support operations, CT, humanitarian assistance, theater search and rescue and other activities that may be specified by the President or Secretary of Defense.[66] These missions, or "activities," are listed among DoD directives, joint doctrine and contain historical examples that provide a litmus test to evaluate the legitimacy of armed overwatch.

Unfortunately, these publications all exhibit minor variations of special operations activities. DoD Directive 5100.01, *Functions of the Departments of Defense and Its Major Components,* name twelve special operations activities to include security force assistance, counterproliferation of weapons of mass destruction, COIN, and information operations.[67] Notably, strategic reconnaissance is excluded and replaced by Special Reconnaissance. JP 3-05

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[65] *US Code* 10 (2018), §167(k).

[66] Ibid.

[67] US Department of Defense, DoD Directive 5100.01, *Functions of the Departments of Defense and Its Major Components,* Change 1 (Washington, DC: Government Publishing Office, 2020), 26-27.

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comprises the same special operations activities as the DoD directive but adds Hostage Rescue and Recovery.[68] USSOCOM Publication 1, *Special Operations Doctrine,* adds five new missions while removing one.[69] Finally, Air Force and Army doctrine list nearly identical missions with slight differences. Appendix B summarizes the similarities and differences between these publications.

The lack of standardization between the special operations activities across doctrine is concerning and affects armed overwatch. The dissimilarities affect the potential justification and validity of armed overwatch because it is unclear which comprehensive mission-set is authoritative. Lack of clarity, again, breeds a lack of shared understanding. The absence of a unified list of special operations missions creates confusion regarding scale and scope not only for USSOCOM but externally for service department special operations components, such as Air Force Special Operations Command (AFSOC) or United States Army Special Operations Command.

In the absence of doctrinal clarity, history is the most helpful framework to assign an identity to armed overwatch. The special operations activities of SR, CT, and COIN contain relevant examples of armed overwatch in the earliest military aviation applications. Three examples of armed overwatch shape its identity and give it narrative by proving its historical function and a legitimate and valid requirement.

Special Reconnaissance

The DoD dictionary of military terms defines SR as: "Reconnaissance and surveillance actions conducted as a special operation in hostile, denied, or diplomatically and/or politically sensitive environments to collect or verify information of strategic or operational significance,

[68] US Joint Staff, JP 3-05, *Special Operations,* 30.

[69] USSOCOM, USSOCOM Publication 1, *Doctrine For Special Operations,* (MacDill AFB, FL, 2011), 20-27.

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employing military capabilities not normally found in conventional forces."[70] JP 3-05 characterizes SR as a domain-agnostic mission and does not differentiate between airborne or ground domains. This is in error. There is a considerable application of airborne and illustrated through many historical examples. The neglected study of military balloons during the Civil War, the discouraging use of the first observation aircraft in the 1916 Mexican expedition, and the Marine Corps Nicaraguan expedition in the late 1920s provide early examples of SR that illustrate the perpetuity of armed overwatch as a historical function of SR.

Airborne SR visually observes or detects information about the enemy. This is just as true today as it was over two hundred years ago when military aviation was first introduced to the US during the American Civil War. Thaddeus S. C. Lowe, an early balloonist, manned a balloon multiple times in 1861 to support Union forces and become the first individual to direct artillery fire via a telegraph from a balloon.[71] The prospect of ballooning became so important during the Civil War that President Abraham Lincoln personally championed its use to General Winfield Scott, then commander in chief of the Union Army.[72] Although the military balloon never provided a decisive military advantage, Confederate rebels attempted to produce similar military balloons to compete with the Union. Most astounding, towards the end of the war, interest in heavier than air "air-machines" intended for observation and even bombing missions gained brief interest as well.[73] Aerial observation during the Civil War, literally the "first" application of US military aviation, was immediately identified as critical to warfighting. Union military balloons operated in sensitive areas apart from conventional forces to collect information concerning Confederate forces in much the same way that an MQ-9 would be tasked to collect ISR in the

[70] US Joint Staff, *Department of Defense Dictionary of Military and Associated Terms*, 200.

[71] Juliette A. Hennessy, *The United States Army Air Arm, April 1861 to April 1917* (Maxwell AFB, AL: USAF Historical Division, 1958), 5.

[72] Ibid.

[73] Hennessy, *The United States Army Air Arm, April 1861 to April 1917*, 11.

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Middle East today. The Civil War ended in 1865, suspending further aerial observation innovation, and it would be another fifty years before Congress would enact legislation to create the first official United States aviation section.

Two years after Congress officially commissioned US Army aviation, the 1st Aero Squadron mobilized in Columbus, New Mexico. In 1916, Eight Curtiss JN-3 "Jenny" biplanes supported the US Army expedition under General John J. "Blackjack" Pershing to capture Pancho Villa in Mexico.[74] The JN-3 was developed and associated as an aerial observer to support ground forces. These "Jenny" aircraft were tasked with observation, reconnaissance, scouting, and other duties supporting ground troops, and the pilots and planes would serve as General Pershing's "eyes" to prevent any surprise attack.[75] Although aviation support in the Mexican Punitive Expedition was far from a success, it brought about public awareness that convinced "Congress to authorize over thirteen million dollars for military aviation."[76] The Congress of 100 years ago recognized the supreme importance of the role of aerial reconnaissance and continued to fund it despite its failures and because of the promise it offered. They did so because they recognized the tactical and operational advantages it could provide. The mandate for SOF and armed overwatch today is no different. A special operations aircraft conducting SR in the airborne domain proves armed overwatch is a legitimate and entrenched historical function.

Another early example of specialized airborne reconnaissance and the advent of CAS is Nicaragua's Marine Corps' occupation. In 1927, rebel Augusto Sandino fought against the American-backed government. A small team of Marine aviators was dispatched to fly biplanes in both reconnaissance and combat roles in a semi-permissive environment to support ground

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[74] James S. Corum and Wray R. Johnson, *Airpower in Small Wars: Fighting Insurgents and Terrorists* (Lawrence, KS: University Press of Kansas, 2003), 11.

[75] Max Boot, *The Savage Wars of Peace: Small Wars and the Rise of American Power*, rev. ed. (New York: Basic Books, 2014), 194.

[76] Corum and Johnson, *Airpower in Small Wars: Fighting Insurgents and Terrorists*, 11.

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forces. The lessons learned from these aerial reconnaissance successes were captured in doctrine via the Marine Corps *Small Wars Manual*. The 1940 edition includes topics surprisingly relevant to armed overwatch, including: "general considerations, strategic reconnaissance, tactical (close) reconnaissance, infantry missions, and special combat missions."[77] Incredibly, this manual, dated eighty-years ago, states many appropriate prescriptions for armed overwatch today, such as: "it must be remembered that the primary mission of reconnaissance airplanes is not combat, but the procurement of information and the mere existence of offensive armament should not encourage their needless division to combat tasks."[78]

Reconnaissance is not just implied in the definition of SR; it is part of its name. JP 3-05 makes no distinction between ground-based or airborne SR, only mentioning that ISR is not confused with SR.[79] An *Air and Space Power Journal* essay acknowledges this inconsistency and submits that SR requires a formal distinction between air and ground domains.[80] It defines Aerial Special Reconnaissance, or ASR, as a separate and distinct function of SR conducted to fix the threat, visualize the terrain, and anticipate the enemy via functions that ground-based strategic reconnaissance cannot conduct.[81]

The separation of SR into air and ground domains lends additional justification to armed overwatch by giving it meaning through doctrine and a narrative. SOF are accustomed to operating in the deep battlefield as part of an Irregular Warfare (IW) campaign in small tactical echelons. Traditionally, they do not function in the same operational environments as

[77] US Marine Corps, *Small Wars Manual, United States Marine Corps 1940,* SWM 9-18.

[78] Ibid., 9-22.

[79] US Joint Staff, JP 3-05, *Special Operations*, II-5.

[80] Maj Nicholas T. G. Narbutovskih, "Minimum Force: Airborne Special Reconnaissance in War," *Air and Space Power Journal* 34, no. 3 (Fall 2020): 73-75, accessed February 10, 2021, https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-34_Issue-3/V-Narbutovskih.pdf.

[81] Narbutovskih, "Minimum Force: Airborne Special Reconnaissance in War," 77.

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conventional forces, and they employ SR and capabilities differently. The doctrinal definition of SR defines this capability, and early historical examples illustrate this concept.

Direct Action

The DoD dictionary defines direct action as: "Short duration strikes and other small-scale offensive actions conducted as a special operation in hostile, denied, or diplomatically sensitive environments and which employ specialized military capabilities to seize, destroy, capture, exploit, recover, or damage designated targets."[82] CAS is direct action from the air. The Korean War and the airborne Forward Air Controller (FAC(A)) exemplify direct action as a historical function of CAS and ultimately armed overwatch. Although informally executed during World War I and World War II through liaison and observation planes such as the L-5 Sentinel, the concept of FAC(A) gained significant traction during the Korean War due to ground controllers' inability to move far enough forward to control air strikes effectively.

As a result, the technique of "having a slower plane spot a target and call a jet in to attack" was developed and utilized to find enemy targets, control airstrikes, and enhance CAS due to a lack of artillery and direct army ground movement.[83] The propeller-driven T-6 trainer aircraft and their pilots, collectively known as "Mosquitos," made ideal "slow" FAC(A) aircraft. It was simple, durable, could average between five and six hours in the air per day, and its low stall speed enabled it to loiter and provide better observation of the ground.[84] The concept was operationally successful and received numerous accolades and military citations during and after the war. At the end of the Korean War, the Mosquito program was discontinued; however, no effort to formalize the doctrinal lessons learned occurred. At the time, many believed that future wars would utilize airborne controllers flying in high-performance and faster jet aircraft.

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[82] US Joint Staff, *Department of Defense Dictionary of Military and Associated Terms*, 64.

[83] Gary Lester, *Mosquitoes to Wolves: The Evolution of the Airborne Forward Air Controller* (Maxwell AFB, AL: Air University Press, 1997), 34.

[84] Ibid., 47.

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Mosquito operations enabled direct action via CAS from other airborne assets by flying toward the enemy front to search for enemy targets and provide reconnaissance for friendly ground troops. This methodology, not doctrinally defined at the time, has considerable similarities to the present-day application of SCAR, a characteristic of armed overwatch. Thus, the slow FAC(A) aircraft actions embodied modern-day armed overwatch characteristics like CAS and ISR and proved their validity through their historical use. Unfortunately, many of these lessons were forgotten and not incorporated into doctrine. However, the slow-FAC(A) concept and associated armed overwatch mission would be revisited a few years later in the South East Asia theater.

Counterinsurgency

JP 3-24, *Counterinsurgency,* prescribes relevant approaches and considerations to counter an insurgency and discusses aspects for conducting missions. DoD dictionary defines COIN as "comprehensive civilian and military efforts designed to simultaneously defeat and contain insurgency and address its root causes."[85]

JP 3-24 also details aviation contributions to COIN as "CAS, precision strikes, armed overwatch, ISR" as an alternative to conventional aviation that permits freedom of movement for counterinsurgents in haven and rugged terrain.[86] The explicit mention of armed overwatch in COIN doctrine is crucial because it indicates armed overwatch already exists and has meaning and identity within COIN. Furthermore, COIN doctrine lists direct action and SR as the top two special operations activity considerations for its conduct.[87] The explicit mention of CAS, precision strike, ISR, and armed overwatch is striking and suggests a doctrinal synchronization of

[85] US Joint Staff, *Department of Defense Dictionary of Military and Associated Terms*, xiii.

[86] US Joint Staff, JP 3-24, *Counterinsurgency* (Washington, DC: Government Publishing Office, 2018), VII-30.

[87] US Joint Staff, JP 3-24, *Counterinsurgency*, VII-30.

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armed overwatch together within COIN. The Vietnam War and the OV-10 "Bronco" provide another historical example of armed overwatch and its characteristics in practice.

The OV-10 was conceived by the Marine Corps and developed under a tri-service program and the Air Force and Navy as a twin-turboprop, multipurpose aircraft designed for COIN operations.[88] The OV-10 was extraordinarily versatile and configurable for observation, armed reconnaissance, gunfire spotting, limited ground attack, but most commonly used by the Air Force as a FAC-A.[89] The OV-10 was unique because it combined lessons from previous wars, including the success of CAS from low-performance aircraft during World War II and the maneuverability and observation of FAC(A) aircraft in Korea with new technology light level TV, to provide real-time video imagery. Additionally, it could be configured to carry rockets, missiles, and up to 3,000 pounds of ordnance.[90]

In 1968, six OV-10 were sent to Southeast Asia under the code name Combat Bronco as part of a task force to evaluate the use of a FAC-A.[91] The following year, as part of project Misty Bronco, a decision was made to experiment with the OV-10 in an armed FAC(A) role since its armament of forward-firing weapons and maximum ordnance load of 3,600 pounds made it ideal for providing "limited by highly responsive airstrike capability to support US Army forces requesting immediate close air support."[92] The results of the test were an overwhelming success. The armament of the OV-10 enhanced the FAC(A) with a "limited but highly responsive airstrike capability," and subsequently, all OV-10 FAC aircraft were armed to support "immediate strike

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[88] US Department of the Navy, NATOPS Flight Manual, *Navy Model, OV-10A Aircraft*, Change 1 (Washington, DC: Department of the Navy, 1980), 1-1.

[89] US Department of the Air Force, "OV-10 Bronco" Air Force Fact Sheet, November 2014, accessed February 10, 2021, https://www.hurlburt.af.mil/About-Us/Fact-Sheets/Fact-Sheets/article/204576/ov-10-bronco/.

[90] US Department of the Navy, NATOPS Flight Manual, *Navy Model, OV-10A Aircraft*, 1-1.

[91] Captain Joseph V. Potter, "OV-10 Operations in SEAsia" (Project CHECO Report, Air Force Headquarters Pacific Air Forces, 1969), 1, document is now declassified.

[92] Potter, *OV-10 Operations in SEAsia*, 12.

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response."[93] One FAC(A) pilot was asked in a 1969 interview to comment on future FAC(A) conflict compared to Southeast Asia. His response is illuminating: "I would say you would need an OV-10 type airplane, not necessarily the OV-10, but OV-10 characteristics: speed, range, ejection seat, and long-range visibility. Again, I think it should be a simple machine. Not the OV-10 exactly, but with the same characteristics."[94]

The success of the OV-10 and the resemblance of its characteristics with an armed overwatch mission extended beyond Vietnam. In 2012, DoD allocated $20 million toward the partial reactivation of the OV-10. In 2015, two planes deployed and saw combat missions to prosecute the Islamic State.[95] While the latest experiment mainly was a limited proof of concept, it illustrated a suitable alternative to the much more expensive to buy and maintain high-performance jets, which also frees other dedicated assets to train and prosecute peer or near-peer adversaries and targets.[96] Notably, the USSOCOM requirement for armed overwatch has prompted multiple defense contractors to team together to introduce a new variant of the OV-10 Bronco, the "Bronco II," to conduct "ISR, SCAR, CAS, FAC(A) and armed overwatch."[97] This prototype offers a promising next-generation materiel solution built on the successes of its predecessor in Vietnam.

Summary

From the military balloons of the Civil War through the Marine Corps expedition to Nicaragua to the slow FAC(A) in Korea and Vietnam, a persistent theme is clear: armed

[93] Ibid., 15.

[94] Maj Lawrence L. Reed, interview by Maj Donald J. Moore (transcript, U.S. Air Force Oral History Interview Program, Eglin Air Force Base, FL, October 25, 1969), 21-22.

[95] David Axe, "Why Is America Using These Antique Planes to Fight ISIS?," *The Daily Beast*, March 9, 2016, accessed February 10, 2021, https://www.thedailybeast.com/articles/2016/03/09/why-is-america-using-these-antique-planes-to-fight-isis.

[96] Axe, "Why Is America Using These Antique Planes to Fight ISIS?."

[97] Bronco II, "A Revolution in the Skies," Bronco II, Team Leidos, accessed February 10, 2021, https://www.bronco-usa.com/bronco-ii/p/1.

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overwatch characteristics were exhibited at various times in special operations unique settings in support of the special operation's unique activities. The justification of a new armed overwatch requirement to Congress nests within a historical mission has existed since Lincoln's presidency. Further, this galvanizes a vital point: the "means" that conduct armed overwatch (the aircraft) are a function of the mission.

Armed overwatch case studies from the Civil War, early and mid-twentieth century represent epochs that are not traditionally associated with SOF. However, the functions of ISR, CAS, and C2 from these periods prove that armed overwatch is equally suited for SOF today as it was in the past. ISR, CAS, and C2 may not have been doctrinal terms in the 1860s, but their character emerged, became realized, and their operational importance prized. A 150-year-old military balloon is wholly incapable of conducting armed overwatch over today's battlefield. Similarly, manned, fixed-wing aircraft employed in Korea, Vietnam, Iraq, and Afghanistan might be incompatible with the armed overwatch demands of future warfare. However, these case studies provide a fundamental and historical identity for armed overwatch as a mission.

A broad historical survey of armed overwatch in military aviation illustrates a rich tapestry of forgotten employment lessons, C2, and missions for an armed overwatch concept currently being re-imagined. The past offers numerous examples of concepts and aircraft to justify special operations armed overwatch and its characteristics that recall historical precedent and prove validity. In contrast to the past, however, a look into the future carries its own unique set of trends and challenges to analyze armed overwatch further.

Future Threat Environment

> Victory smiles upon those who anticipate the change in the character of war, not upon those who wait to adapt themselves after the changes occur.
>
> —Giulio Douhet, *The Command of the Air*

Making sense of armed overwatch's identity involves rethinking and anticipating its role and responsibility in the future. The 2021 NDAA specified armed overwatch must analyze "the

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future threat environment and impacts to concept survivability."[98] Armed overwatch's role in the future operating environment poses an important question, especially amidst warfare's changing character in an era of great power competition. US strategic guidance, a theory of grey zone warfare, a DOTmLPF-P doctrinal concept, and materiel solution alternatives provide a cumulative framework to make sense of armed overwatch's role and responsibility in the future threat environment.[99]

Roles and Responsibility

According to the 2017 National Security Strategy (NSS), US foreign policy has shifted its focus to compete with Russia and China.[100] For special operations, this change represented an abrupt departure from the paradigm of IW and countering violent extremist organizations (CVEO) since 9/11. Missions like CT, COIN, and foreign internal defense, where US forces-controlled tempo and timing across, especially in the air, were suddenly no longer the priority.[101]

The NDS's Irregular Warfare Annex acknowledged this transition and stated the new strategic priority of great power competition while noting that CVEO remains a persistent threat.[102] Most importantly, it established an inextricable link between unified action and IW that

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[98] Select Committee on Armed Services, House, National Defense Authorization Act for Fiscal Year 2021, 116th Cong., 2nd sess., 2020, HR Rep. 116-617, sect. 163, 1536.

[99] DOTmLPF-P stands for Doctrine, Organization, Training, materiel, Leadership and Education, Personnel, Facilities, and Policy. It is the US DoD's mechanism for introducing and implementing change recommendations within the U.S and is governed by CJCSI 5123.01H (31 Aug 2018) and the Manual For the Operational of the Joint Capabilities Integration and Development System dated August 31, 2018. The "little m" represents a materiel DOTmLPF-P consideration for everything necessary to equip DoD forces to operate effectively. The letter "m" in the acronym is usually lower case and spelled "materiel".

[100] White House, *National Security Strategy of the United States of America* (Washington, DC: Government Publishing Office, 2017), 2.

[101] John R. Hoehn and Nishawn S. Smagh, *Intelligence, Surveillance, and Reconnaissance Design for Great Power Competition* (Washington, DC: Congressional Research Service, June 2020), 17, accessed July 16, 2020, https://crsreports.congress.gov/product/pdf/R/R46389.

[102] US Department of Defense, *Summary of the IW Annex to the National Defense Strategy 2020* (Washington, DC: Government Publishing Office, 2020), 7, accessed October 3, 2020, https://media.defense.gov/2020/Oct/02/2002510472/-1/-1/0/Irregular-Warfare-Annex-to-the-National-Defense-Strategy-Summary.PDF.

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connects conventional forces and SOF:[103] This is paramount because it mandates the joint force must institutionalize IW.[104] It also demonstrates a basic logic for SOF and armed overwatch: IW and great power competition are not mutually exclusive but mutually supporting.[105] A Cold-War era theory of warfare from the 1950s provides a structure to understand this logic further and creates a foundation for armed overwatch roles and responsibilities amidst a national strategy of great power competition.

Thomas Finletter, a former Secretary of the Air Force and North Atlantic Treaty Organization (NATO) ambassador, originally described what is referred to as "grey zone" in 1954 as "countries outside of NATO or nearly so with Russia and China."[106] Since then, grey zone warfare has re-emerged as relevant in the contemporary international environment. A 2019 RAND Corporation report stated the United States should expect competition with Russia and China to be "played out primarily below the threshold of armed conflict . . . in the grey zone between peace and war."[107] Furthermore, the 2021 Interim NSS states: "We will maintain the proficiency of special operations forces to focus on crisis response and priority counterterrorism and unconventional warfare missions. Moreover, we will develop capabilities to compete better and deter grey zone actions."[108] Today, grey zone warfare suggests that although competition with Russia or China *might* occur at or above a threshold of armed conflict, it is far more likely to

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[103] US Department of Defense, *Summary of the IW Annex to the National Defense Strategy 2020*, 4

[104] Ibid., 5.

[105] Ibid.

[106] Thomas K. Finletter, *Power and Policy: US Foreign and Military Policy in the Hydrogen Age* (New York: Harcourt, Brace, 1954), 84-85.

[107] Lyle J. Morris, Michael J. Mazarr, Jeffrey W. Hornng, Stephanie Pezard, Anika Binnendijk, and Marta Keep, *Gaining Competitive Advantage in the Gray Zone* (Santa Monica, CA: RAND Corporation, 2019), 2, accessed July 16, 2020, https://www.rand.org/pubs/research_reports/RR2942.html.

[108] White House, *Interim National Security Strategy of the United States of America* (Washington, DC: Government Publishing Office, 2021), 14.

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exist on the conflict continuum below that of large-scale or major combat operations (Appendix E). According to a bi-partisan House Armed Services Committee report on the future of defense, Russia has used private military corporations in Ukraine, Venezuela, Syria, and Libya.[109] Thus, it is reasonable to conclude future indirect challenges from Russia and China proxy forces in the gray zone, especially in parts of the Middle East, Africa, and South America in which SOF have operated in the past in support of CVEO. This manifestation of grey zone warfare in practice, coupled with the 2021 interim NSS, is critical because it gives SOF a mandate to not depart significantly from its execution and support of special operations activities and creates a foundational role for armed overwatch in an era of great power competition.

Great power competition is not synonymous with large-scale or major combat operations. While they exist on a spectrum, by definition, competition, conflict, and confrontation are distinct. Also, great power competition does not equate to high-end major combat or large-scale combat operations. Therefore, the military conflict continuum requires "low-end" missions that are arguably more likely to occur in the grey zone than towards the higher end of the conflict continuum involving large-scale combat operations. Armed overwatch conceptually supports great power competition precisely because it is not a "high-end" mission conducted as part of large-scale combat operations but rather one that supports the rest of the military competition continuum. This logic provides clarity for armed overwatch in great power competition. However, it accounts for only one potential scenario in the future operating threat environment and does not address the dilemma of a contested or denied environment.

The requirement to gain access and then operate in contested domains with degraded systems is a significant military challenge. Senior DoD officials indicated that military conflict with Russia or China, whether it be direct or indirect, would severely challenge and strain the ISR

[109] House, Committee on Armed Service, *Future of Defense Task Force Report 2020* (Washington DC: Government Publishing Office, 2020), 25, accessed September 24, 2020, https://armedservices.house.gov/2020/9/future-of-defense-task-force-releases-final-report.

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enterprise in a highly contested environment.[110] Since 9/11, SOF aviation has enjoyed relative freedom of access into and within a permissive operating environment. Armed overwatch cannot assume that future conflicts will have unilateral permissive movement and maneuver in the air. While a requirement for armed overwatch amidst permissive environments may persist, this might not always be the case. Therefore, the permissive maneuver assumption comes at the expense and potential risk of future relevancy in a contested environment.

Across permissive environments such as Africa, armed overwatch underwrites a national strategy of great power competition by accounting for the military conflict continuum below the threshold of major combat operations.[111] Alternatively, the future threat environment is likely to be a "sophisticated, highly contested, A2/AD environment" that will be "won by the side with an information advantage, enabling the ability to outpace, outthink, and outmaneuver adversaries across multiple domains."[112] This question of the contested environment presents two very different future scenarios. Armed overwatch must determine its role in exclusive support of low-end missions in a permissive environment versus an alternative future. This includes potential escalation to a non-permissive or even denied environment amidst Access/Area Denial (A2/AD) threats.

Armed overwatch must overcome the contested environment's dilemma if it is meant to account for joint force integration. An emergent all-domain operations joint warfighting doctrine enhanced by future emerging technologies such as artificial intelligence (AI) and autonomous systems provides a doctrinal approach to nest within.

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[110] Mark Pomerleau, "What the New 16th Air Force Means for Information Warfare," *C4ISRNET*, October 13, 2019, accessed February 11, 2021, https://www.c4isrnet.com/dod/air-force/2019/10/14/what-the-new-16th-air-force-means-for-information-warfare/.

[111] Valerie Insinna, "Special ops still bullish on new armed overwatch plane," *Defense News*, February 16, 2021, accessed March 17, 2021, https://www.defensenews.com/air/2021/02/16/special-ops-still-bullish-on-new-armed-overwatch-plane/.

[112] Brig General Chance Saltzman, "MDC2 Overview" (Presentation, 2018 C2 Summit, Washington DC, July 18-20, 2018), accessed January 9, 2020, https://www.mitre.org/sites/default/files/ publications/Special-Presentation-Gen%20Chance-Saltzman%20MDC2%20Overview%20for%20MITRE-June2018.pdf.

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DOTmLPF-P: Doctrine

The 2018 National Military Strategy highlights the "diffusion, competition, and new threats" of technology as likely future security trends.[113] A2/AD, robotics, drone swarms, AI, lethal autonomous weapons, and hypersonic weapons are just a few examples of emergent US technologies in the so-called present "Era of Accelerated Human Progress."[114] Meanwhile, US strategic competitors have also invested in, adapted, and incorporate new technologies to exploit weaknesses and gain relative advantage or superiority across physical and non-physical domains. These emerging "high-end" technologies are relevant for armed overwatch because they point to an integrated technological approach for the joint force within the DoD's technology culture that armed overwatch cannot ignore and must exist within. It is essential for armed overwatch nest conceptually within this new all-domain joint warfighting concept if it is meant to be relevant amidst the contested environment.

A joint warfighting organizational concept for the US military provides overwatching guidance for how the joint force collectively fights. The idea of a joint warfighting concept is not novel and, coincidentally, has precedent in the air and ground domains. General Donn A. Starry, then commander of US Army Training and Doctrine Command, authored a 1981 essay to promote the concept of "extended battlefield," which led to the Air-Land battle doctrine between the Army and Air Force.[115] With the rise of great power competition against the backdrop of emerging technologies in the cyber and space domains, especially A2/AD, a new joint warfighting concept is now necessary. According to the Vice Chairman of the Joint Chiefs of

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[113] US Joint Staff, *Description of the National Military Strategy 2018* (Washington, DC: Government Publishing Office, 2018), 2.

[114] US Army Training and Doctrine Command, *The Operational Environment and the Changing Character of Warfare* (Fort Eustis, VA: Government Publishing Office, 2019), 19.

[115] General Donn A. Starry, "Extending the Battlefield," *Military Review* 61, no. 3 (March 1981): 31-50, accessed January 10, 2021, https://www.armyupress.army.mil/Portals/7/online-publications/documents/1981-mr-donn-starry-extending-the-battlefield.pdf.

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Staff", the new joint warfighting concept will utilize future all-domain capabilities to overcome the traditional battlefield lines and integrate “fires from all domains, including space and cyber.”[116] This means future capabilities, such as armed overwatch, will connect ISR sensors and fire capabilities in real-time via a more extensive integrated network and across contested or degraded environments.

Armed overwatch must integrate more fully in this doctrine and its future network-centric battlefield under a new future C2 model if it is meant to operate in a semi or non-permissive environment. Joint All-Domain Command and Control (JADC2) is a conceptual solution to operationally connect C2 “sensors-to-shooters” into a single organizational network that uses a typical data architecture. A JADC2 integrated armed overwatch platform could potentially share ISR sensor data in real-time with not just a ground-based SF unit but also long-range artillery, cyber, or space-based assets. To be sure, current manned and unmanned special operations aircraft, such as the MQ-9, already exhibit a partial degree of this capability at the tactical level in the competition space below the armed conflict threshold. The benefits of JADC2, however, primarily emerge at the operational level of war. The following example illustrates a practical example of potential armed overwatch integration with JADC2 at the operational level of war.

Project Convergence is the Army’s modernization strategy to enable multi-domain operations and integrate into JADC2 by creating simultaneous effects from all domains faster than the enemy.[117] In an integrated multi-domain “close fight” scenario, an MQ-1C “Grey Eagle” could integrate with a multipurpose helicopter within a JADC2 network to simultaneously

[116] Mark Gunzinger, “A Consensus-Driven Joint Concept for All-Domain Warfare Will Fall Short,” *Defense News*, September 18, 2020, accessed January 28, 2021, https://www.defensenews.com /opinion/commentary/2020/09/22/a-consensus-driven-joint-concept-for-all-domain-warfare-will-fall-short/.

[117] Tom Greenwood and Pat Savage, “In Search of a 21st-Century Joint Warfighting Concept,” *War on the Rocks*, September 12, 2019, accessed January 28, 2021, https://warontherocks.com/2019/09/in-search-of-a-21st-century-joint-warfighting-concept/.

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incorporate low-earth-orbit satellites to find a ground-based target, sense air targets, and communicate with a ground-based artillery system to destroy the objective.

The preceding scenario is not from the distant future; it occurred in September 2020. More astonishing, the entire sequence took twenty seconds.[118] It demonstrated the revolutionary potential of JADC2: autonomy. Semi-autonomous military operations with a "human in the loop" are not optimized for non-permissive threats in which the speed of the decision is critical. "Human-on-the-loop" operations, enabled through JADC2, could potentially leverage a degree of autonomy where rapid observation, orientation, decision, and action deliver much fast and synchronized effects.[119] JADC2 is the means to enable decentralized execution, rather than vice versa.[120] Mission command through decentralized execution is a hallmark of SOF, and armed overwatch within a JADC2 architecture in a future threat environment amid potential degradation supports that idea by enhancing the operational decision.[121]

The future threat environment requires an operational organization that leverages decision speed to create opportunities and presents multiple dilemmas for the enemy. Expanding decision space is a salient theme of all-domain operations and JADC2, and armed overwatch must nest within this operational logic if it is meant to be relevant in a contested environment. Armed overwatch within an all-domain warfighting concept connects SOF, through mission command, to enhance decision. Enhanced operational agility across multiple domains, enabled by armed overwatch, has the potential to create more opportunities and options for SOF commanders

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[118] Andrew Feickert, *The Army's Project Convergence* (Washington, DC: Congressional Research Service, October 2020), 1, accessed January 28, 2020, https://crsreports.congress.gov/product /pdf/IF/IF11654.

[119] Paul Scharre, *Army of None: Autonomous Weapons and the Future of War* (New York: W. W. Norton, 2018), 29.

[120] US Department of the Air Force, Air Force Doctrine Annex 3-99, *Department of the Air Force Role in Joint All-Domain Operations (JADO)* (Maxwell AFB, AL: Government Publishing Office, 2020), 12.

[121] US Air Force, Annex 3-99, *Department of the Air Force Role in Joint All-Domain Operations (JADO),* 12.

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and their teams against the enemy.

The above section made a case for the validity, necessity, and requirement of a legacy-based armed overwatch capability to support SOF amidst the fringes of great power in a permissive or contested environment. Meanwhile, the 20th-century paradigm of a low-end, manned, fixed-wing airplane supporting SOF troops in either environment might be altogether incompatible with future warfare trends and threats. These scenarios present two possible futures for the roles and responsibilities of armed overwatch. Senior military leaders and Congress must determine the final way forward. Alternatively, small, unmanned aircraft systems (sUAS) technology paired with AI autonomy and a recent military conflict in the Lower Caucasus might offer a hybrid of both armed overwatch future scenarios and account for both contested and permissive environments.

DOTmLPF-P: materiel

USSOCOM SOF Truth 1 states: "Humans are more important than hardware."[122] This maxim seems fundamentally at odds with the trend of emerging technology on and above the future battlefield and the operating concepts that aim to deepen battlefield dependence on networked technology under JADC2. For that reason, it must be addressed. In *Army of None*, author Paul Scharre provides a structure for analyzing the paradox of technological means and SOF ethos via different degrees of autonomy.

Scharre states in "human-in-the-loop" autonomy, a machine performs a task before querying a human before taking action.[123] "Human-on-the-loop" empowers a machine with the abilities of sensemaking, decision, and action, with a human supervisor capable of intervening, if

[122] USSOCOM, "SOF Truths," accessed January 30, 2021, https://www.socom.mil/about/SOF-truths.

[123] Scharre, *Army of None*, 29.

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necessary.[124] Finally, in "human-out-of-the-loop" operations, a machine is given complete autonomy independent of human action.[125] As robotics, machine learning, and AI continue to advance rapidly, armed overwatch must co-evolve within the present and future technological climate to accommodate these trends to be relevant in the future contested threat environment. For the present and foreseeable future, out-of-the-loop autonomy remains morally and ethically murky at best. However, in the case of armed overwatch, a materiel solution must strike a balance between the requirements of the present versus the anticipated trends of the future battlefield. sUAS offers a 21st-century alternative to the 20th-century aircraft paradigm of a manned, fixed-wing, legacy aircraft.

A key finding from a 2019 RAND study on distrusted air operations in a future battlespace was that the current force presentation model is incompatible with the future contested environment.[126] sUAS offer one way to mitigate this risk through an alternative to a manned aircraft. An sUAS armed overwatch capability is not bound by limitations such as austere forward arming and refueling points or airfields like a legacy fixed-wing aircraft.

sUAS provides cost-effective, persistent surveillance and reconnaissance capability for collection deep in enemy territory.[127] sUAS can also be transported organically with an SF team, such as the one that operated in Tongo Tongo with a low profile. This is precisely the location on the battlefield where special operations forces are likely to operate: in-depth. sUAS, unlike a legacy fixed-wing aircraft, does not have to fight its way past A2/AD into a non or semi-permissive environment like a legacy aircraft. Instead, its portability allows it to be transported,

[124] Ibid.

[125] Ibid.

[126] Miranda Priebe, Alan J. Vick, Jacob L. Heim, and Meagan L. Smith, *Operations in a Contested Environment: Implications for USAF Force Presentation* (Santa Monica, CA: RAND Corporation, 2019), viii, accessed February 24, 2021, https://www.rand.org/pubs/research_reports/RR2959.html.

[127] US Marine Corps Aviation, "2019 Marine Corps Aviation Plan," last modified November 2019, accessed February 11, 2021, https://www.aviation.marines.mil/portals/11/2019%20avplan.pdf.

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configured, and launched by an operator. sUAS can be quickly configured or launched to conduct ISR and a limited degree of CAS or precision strike to alert or protect ground forces.

sUAS is not without its limitations. To be sure, sUAS significantly lacks the full complement of capabilities and effects a larger aircraft could provide, such as offensive armament and loiter time. However, sUAS technology will only continue to develop and accelerate. An SF team equipped with sUAS has a limited range of ISR or CAS. Some sUAS require a significant amount of manpower. For example, an eleven personnel team operates the Army's "Scan Eagle" UAV.[128] Also, as drone technology advances, so does counter-drone technology. Electronic attacks and cyber capabilities are two of the most obvious ways to neutralize drones, rendering their ISR, communication, data, and weapons combat ineffective. Technology to "harden" drones to function against these threats will continue to advance to mitigate these threats, but it is folly to envision every vulnerability can be protected in every instance. The robotics revolution, led by cutting-edge defense organizations such as Defense Advanced Research Project Agency, offers continued promise through technology that enables "swarm tactics" and incorporates varying degrees of coordination and redundancy amongst many lightweight drones.[129]

As previously stated, SOF may not always operate in austere and isolated environments independently of conventional forces as they have in the previous two decades. Chairman of the Joint Chiefs of Staff, GEN Mark Milley, stated: "In the future, I can say with very high degrees of confidence, the American Army is probably going to be fighting in urban areas."[130] One future scenario offers a much different alternative to the operational environments of deserts in Africa or mountains in Afghanistan. A military conflict in the Southern Caucasus provides an unlikely

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[128] Jon Harper, "Special Operations Drones Face Obsolescence," *National Defense Magazine*, May 17, 2020, accessed February 11, 2021, https://www.nationaldefensemagazine.org/articles/2017/5/17/special-operations-officials-are-worried-that-their-drones-are-becoming-obsolete.

[129] Scharre, *Army of None*, 20-21.

[130] Paul McLeary, "Special Ops Command to Hold Flyoff of Tiny Drones," *Breaking Defense*, August 23, 2018, accessed January 30, 2021, https://breakingdefense.com/2018/08/special-ops-command-to-hold-flyoff-of-tiny-drones/.

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glimpse into one potential future scenario relevant for armed overwatch in which the "old" way of conventional warfare involving armored warfare and artillery was blended with the contemporary use of sUAS.

The use of sUAS in a modern military conflict, in which SOF and conventional forces operate in tandem, offers insights into the future of war that must be considered for an sUAS armed overwatch capability to operate in a non-permissive environment. The six-week conflict in the Southern Caucasus between Armenia and Azerbaijan in 2020 involved small, lightweight, and relatively inexpensive sUAS. Azerbaijan employed an arsenal of Israeli and Turkish drones to destroy "up to 100 Armenian tanks and armored vehicles, 100 artillery pieces, 150 vehicles, and 60 air defense assets."[131] Heavy losses were inflicted upon Armenian armored forces due to Azerbaijan sUAS drones purchased from Israel and Turkey.[132]

Furthermore, Azerbaijan forces employed the lightweight "Orbiter 1K" (Appendix F) as a "kamikaze drone" in which it flew like a cruise missile into a target and self-destructed.[133] In a first in warfare, the drone attack video was circulated almost immediately afterward across social media platforms. "Cheap airpower" drones indicate a future battlefield trend that incorporates airpower and armed overwatch elements that have applications for both conventional and special operations warfare. These applications allude to a potential future where SOF and conventional forces integrate across the future battlefield, an idea nested with IW guidance.

sUAS, such as the lightweight PC-1 multipurpose quadcopter, offers a materiel solution that provides an alternative worthy of analysis for an armed overwatch program. The PC-1 quadcopter (Appendix H), manufactured by Ukraine, is a vertical take-off and landing multi-role

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[131] Zeeshan Ahmad, "The Second Drone Age," *The Express Tribune*, February 15, 2021, accessed February 15, 2021, http://tribune.com.pk/story/2284243/the-second-drone-age.

[132] Seth J. Frantzman, "Israeli Drones in Azerbaijan Raise Questions on Use in the Battlefield," *The Jerusalem Post*, October 1, 2020, accessed January 30, 2021, https://www.jpost.com/middle-east/israeli-drones-in-azerbaijan-raise-questions-on-use-in-the-battlefied-644161.

[133] Frantzman, "Israeli Drones in Azerbaijan Raise Questions on Use in the Battlefield."

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helicopter that can carry a variety of payloads, can be configured for multiple ISR sensors, and can be equipped for a variety of missions such as "ISR, detection, and tracking of ground targets, and search and rescue."[134] It can be set-up in two minutes, can operate up to an altitude of about 3,000 ft. to transmit video and telemetry data up to five kilometers, and fits inside a backpack.[135] The downside of this technology comes with certain limitations and is not perfect. Radio and video communications are susceptible to interference such as jamming and are limited by range and line of sight. Although it can only stay airborne for up to thirty-eight minutes, that time is sure to improve as battery technology improves.

Summary

US national strategy indicates a new approach to the American way of war in an era of great power competition. For armed overwatch, the future threat environment poses challenges such as the contested operating environment. Simultaneously, a new joint warfighting concept driven by emerging technology aims to synergize military services and capabilities across all battlefield domains. Today's grey zone presents many of the same fundamental missions of the previous two decades, accompanied by technology's emergent challenges. In an era of great power competition, all-domain operations, and sUAS alternatives to warfare, armed overwatch cannot exist in a special operations silo and must account for these hybrid operations alongside conventional forces. Drones such as the PC-1 and others' applications in recent warfare suggest trends in the future operational environment such as AI that cannot be ignored. To be sure, the technology has not yet advanced to the point where it can fully meet the operational demands that can presently satisfy the required characteristics of armed overwatch. However, the technological gap is closing, and this will not always be the case. For this reason, armed overwatch must be conscious of the future threat environment and integrate emerging technology.

[134] Air Force Technology, "PC-1 Multipurpose Quadcopter," Projects, accessed February 15, 2021, https://www.airforce-technology.com/projects/pc-1-multipurpose-quadcopter/.

[135] Ibid.

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Findings, Recommendations, and Conclusion

The purpose of this monograph was to apply frameworks of doctrine, history, and the future operating environment to make sense of and "rethink" armed overwatch. Armed overwatch means something different to everyone (doctrine, concept, mission, aircraft, program, tactic) because it lacks shared understanding. Although doctrine cannot (and should not) prohibit the execution of a mission or acquire a new requirement, it is a tool to explain what is likely to work as the best way to accomplish a task.

Armed overwatch is presently a topical subject within both AFSOC, USSOCOM, and Congress. The findings and recommendations are offered as pragmatic recommendations for staff and leaders associated with the armed overwatch program.

Findings and Recommendations

Finding/Recommendation 1 – Armed overwatch is a mission and must be codified into doctrine. Doctrine can formally define the roles and responsibilities of armed overwatch and describe its nuances, especially between CAS and ISR. JP 3-05, *Special Operations* is an ideal doctrinal publication to explain armed overwatch and specify its unique nuances of CAS, C2, ISR, precision strike, and SCAR. Fully accepting armed overwatch as doctrinal is not the primary barrier to validating armed overwatch as a requirement. However, recognizing the voids and nuances between its doctrinal concepts further legitimizes a mission not fully accounted for by present ISR and CAS technology and capabilities.

Finding/Recommendation 2 – Armed overwatch makes the most sense as a subordinate doctrinal mission of CAS. CAS is most effective when equipped with a premier sensing ability. Integration of armed overwatch into a joint doctrine as an independent doctrinal mission is a challenging approach that requires joint-service support and endorsement. The fastest way to get

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armed overwatch codified into doctrine is via an annex or appendix to the JFIRE.[136] The Air Land Sea Application Center, located at Langley Air Force Base, is "a multi-service (Joint) organization which produces Multi-Service Tactics Techniques and Procedures.[137] Armed overwatch could also be incorporated much faster as a doctrinal "tactic" and explained as a multi-service tactic, technique, procedure.

Finding/Recommendation 3 – The requirement for armed overwatch is primarily a problem of resourcing. Without armed overwatch, SF teams like in Tongo Tongo are at the mercy of democratizing theater resources that could alert, enable, or protect them. CAS and ISR aircraft are limited resources that are centrally controlled, allocated, and apportioned. As such, they are unlikely to be provided in direct support for SF teams. This is evidenced by the absence of a dedicated US CAS asset at Tongo Tongo. Therefore, the identity and narrative for an armed overwatch requirement at its core is a requirement for a dedicated CAS/ISR hybrid capability for USSOCOM.

Finding/Recommendation 4 – Armed overwatch special operations activities. The special operations activities provide a framework within the mandate of US law to justify armed overwatch. As illustrated, armed overwatch supports SR, direct action, and COIN special operations missions. This list, not all-inclusive, justifies armed overwatch as charged by the 2021 NDAA because it demonstrates to Congress that it supports the very law they had previously passed. However, the lack of standardization of the special operations activities across doctrine is a notable concern outside the monograph's scope and warrants additional attention.

Finding/Recommendation 5 – Armed overwatch is unquestionably a historical function of US military aviation. Rather than illustrate examples of armed overwatch in the eras of

[136] Lt Col Nathan L. "Booster" Owens, telephone interview with author, February 16, 2021.

[137] Air Land Sea Application Center, "Air Land Sea Application Center Point/White Paper," December 2016, accessed February 10, 2021, https://www.alsa.mil/Portals/9/Documents /alsapoint.pdf?ver=2016-12-02-094123-783.

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USSOCOM and AFSOC, historical examples of armed overwatch that predate these institutions provide richer meaning and prove it is a historical and enduring mission. Indeed, the IW Annex to the current NDS states that "IW is an enduring mission and core competency. It is "a persistent and enduring operational reality employed by non-state actors and increasingly state actors with the United States."[138] Civil War ISR, early 20th century CAS, and Korean and Vietnam War SCAR suggest armed overwatch is a historically entrenched aviation mission, albeit by different names.

Finding/Recommendation 6 – Armed overwatch is a topical issue for Air Force Special Operations Command. According to the AFSOC guidance strategy from 2020, the fielding of a cost-effective multi-role armed overwatch platform is a strategic focus area.[139] One major challenge for AFSOC regarding armed overwatch is to reconcile armed overwatch within a great power competition strategy while also being clear-eyed about present operational demands.

In permissive environments, armed overwatch represents a crucial currency in underwriting great power competition, especially in the gray zone. However, a significant question of identity and roles and responsibilities persists, requiring senior leader and probable congressional discernment. One armed overwatch narrative envisions a future in which armed overwatch exclusively supports SOF across austere and permissive environments as a "low-end" mission. These gray zones represent seams in great power competition that asymmetrically benefit United States strategic interests. This armed overwatch future scenario foresees strategic support of great power competition along the geographical fringes against proxies and in support of missions like CT, COIN, and CVEO. Although China has emerged as the pacing threat for the DoD, the need to compete along the competition continuum below the armed conflict threshold

[138] US Department of Defense, *Summary of the IW Annex to the National Defense Strategy 2020,* 2.

[139] Air Force Special Operations Command, AFSOC Strategic Guidance, May 26, 2020, 9, accessed March 17, 2021, https://media.defense.gov/2020/May/26/2002305551/-1/-1/1/AFSOC%20STRATEGIC%20GUIDANCE.PDF.

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remains necessary and is unlikely to end soon. In this scenario, armed overwatch supports the special operations activities. It underwrites great power competition by fulfilling a persistent requirement across the military conflict continuum to support missions other than major war.

This first scenario assumes that armed overwatch will primarily operate in an austere environment that will always remain generally permissive or uncontested. Alternatively, a second future scenario and an essential question for armed overwatch remain its role, if any, in a contested environment. SOF are likely to play a significant role in Africa or similar environments should competition with China or Russia escalates horizontally or vertically. If great power competition does escalate, Russian and Chinese organic or proxy forces in low-end armed conflict across Africa, Middle East, Asia, and South America may rapidly intensify their involvement resulting in a contested environment and present A2/AD challenges that a low-end armed overwatch capability or asset may be unprepared to adapt within.

Finding/Recommendation 7 – Armed overwatch must consider future warfare characteristics and cannot ignore the challenge of contested environments. sUAS offers the ability to operate in contested airspace or a permissive environment. The use of small, lightweight drones in warfare as recent as the 2020 conflict between Armenia and Azerbaijan indicates a future warfare technological trend that suggests an alternative to present armed overwatch acquisition considerations.

Conclusion: Special Operations Armed Overwatch Re-thought

Armed overwatch has problems related to policy decisions, resourcing, and technology challenges that require senior military leaders and Congressional resolution. Additionally, current trends on and above the battlefield point toward a new age of warfare characterized by irregular adversaries relying on technology-driven capabilities. Without a nearly constant and locally capable armed overwatch capability, today's SOF cannot survive to build access in permissive, semi-permissive, or non-permissive operational footprints. This scenario jeopardizes the US's

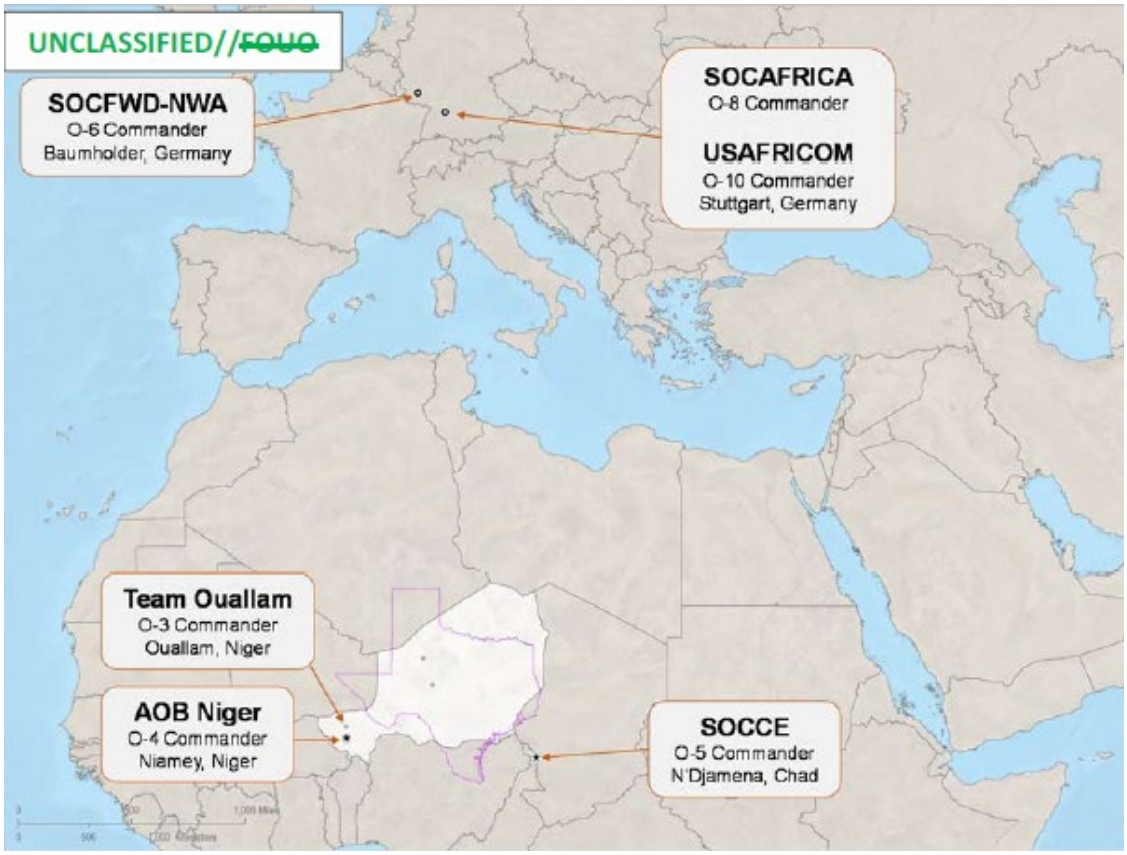
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ability to develop and deepen alliances with partners and gain or sustain access to environments necessary to compete in great power competition.

It is challenging to assign narrative in the absence of shared understanding. Doctrine, history, and the future threat environment lend legitimacy to armed overwatch by rethinking its identity and nuances. A scenario is one way to promote shared understanding and provide a straightforward narrative for armed overwatch. In one respect, this already exists. Tongo Tongo creates a baseline to understand armed overwatch as a mission in which an airborne capability provides dedicated effects of responsive CAS, ISR, precision strike, and SCAR. Likewise, past and present doctrine, the special operations activities, examples from military aviation, and the future threat environment provide prescriptive insights into armed overwatch to rethink its identity, sharpen its narrative and promote a shared understanding.

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Appendix A
Force Laydown and C2 Structure in Africa



US Africa Command, "Army Regulation (AR) 15-6 Investigation Findings: October 4, 2017, Enemy Contact Event in Tongo Tongo, Niger" (Memorandum for Commander, October 14, 2017), 2, accessed October 26, 2020, https://www.aclu.org/sites/default/files/field_document/34-5._exhibit_2.4_3.25.20.pdf. Document is now declassified.

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Appendix B
Doctrinal Comparison of the Special Operations Activities

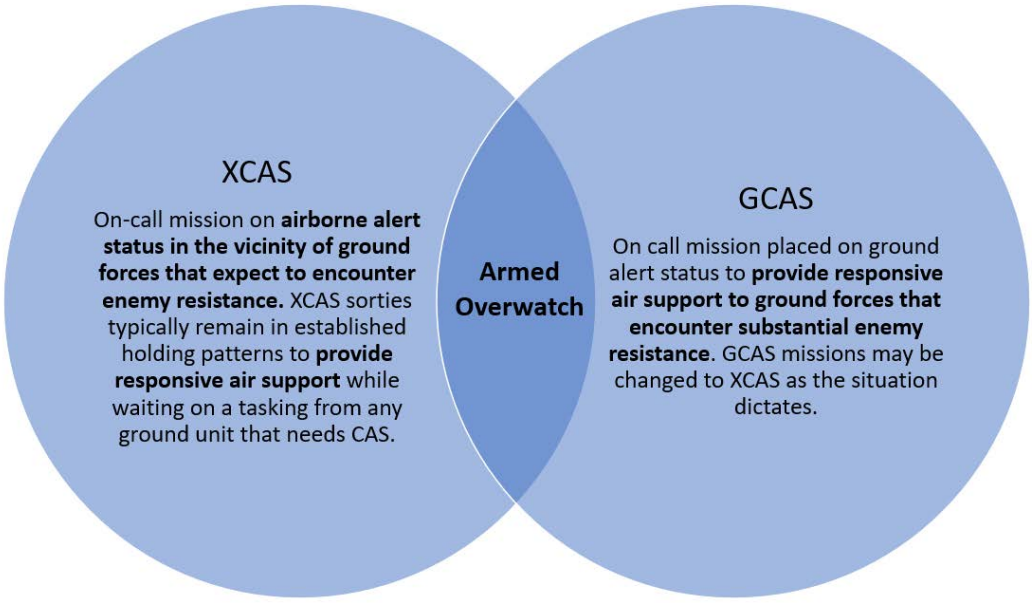
TITLE 10 USC §167(k) 10-Nov-20	DoDD 5100.01 - CH1 17-Sep-20	JP 3-05 16-Jul-14	USSOCOM Pub 1 5-Aug-11	ADP 3-05 31-Jul-19	AF 3-05 1-Feb-20
DA	DA	DA	DA	DA	DA
Strategic Reconaissance					
UW	UW	UW	UW	UW	UW
FID	FID	FID	FID	FID	FID
Civil Affairs	CAO	CAO	CAO	CAO	CAO
MISO	MISO	MISO	MISO	MISO	MISO
CT	CT	CT	CT	CT	Counterterrorism
Humanitarian Assistance				FHA	FHA
Theater Search and Rescue					
Such other activities as may be specified by the President or Secretary of Defense	Such other activities as may be specified by the President or Secretary of Defense				
	SFA	SFA	SFA	SFA	SFA
	CWMD	CWMD	CWMD	CWMD	CWMD
	COIN	COIN	COIN	COIN	COIN
	SR	SR	SR	SR	Special Reconaissance
	IO	IO			
			Stability Operations		
			Support to Major Operations and Campaigns		
		Hostage Rescue and Recovery	Hostage Rescue and Recovery	Hostage Rescue and Recovery	Hostage Rescue and Recovery
			Interdiction and Offensive Weapons of Mass Destruction Operations		
			Preparation of the Environment	Preparation of the Environment	
			SOF Combat Support and Combat Service Support		

LEGEND	
DA	Direct Action
UW	Unconventional Warfare
FID	Foreign Internal Defense
CAO	Civil Affairs (Operations)
MISO	Military Information Support Operations
CT	Counterterrorism
SFA	Security force Assistance
CWMD	Counterproliferation of Weapons of Mass Destruction
COIN	Counterinsurgency
SR	Special Reconaissance
IO	Information Operations

Title 10, *US Code* §167(k), November 2020; US Department of Defense, DoD Directive 5100.01, *Functions of the Department of Defense and Its Major Components*, Change 1 (Washington, DC: Government Publishing Office, 2020); US Department of Defense, Joint Staff, Joint Publication (JP) 3-05, *Special Operations* (Washington, DC: Government Publishing Office, 2020); US Department of the Army, Army Doctrine Publication (ADP) 3-05, *Army Special Operations* (Washington, DC: Government Publishing Office, 2019); US Department of the Air Force, Air Force Doctrine Annex 3-05, *Special Operations* (Maxwell AFB, AL: Government Publishing Office, 2020).

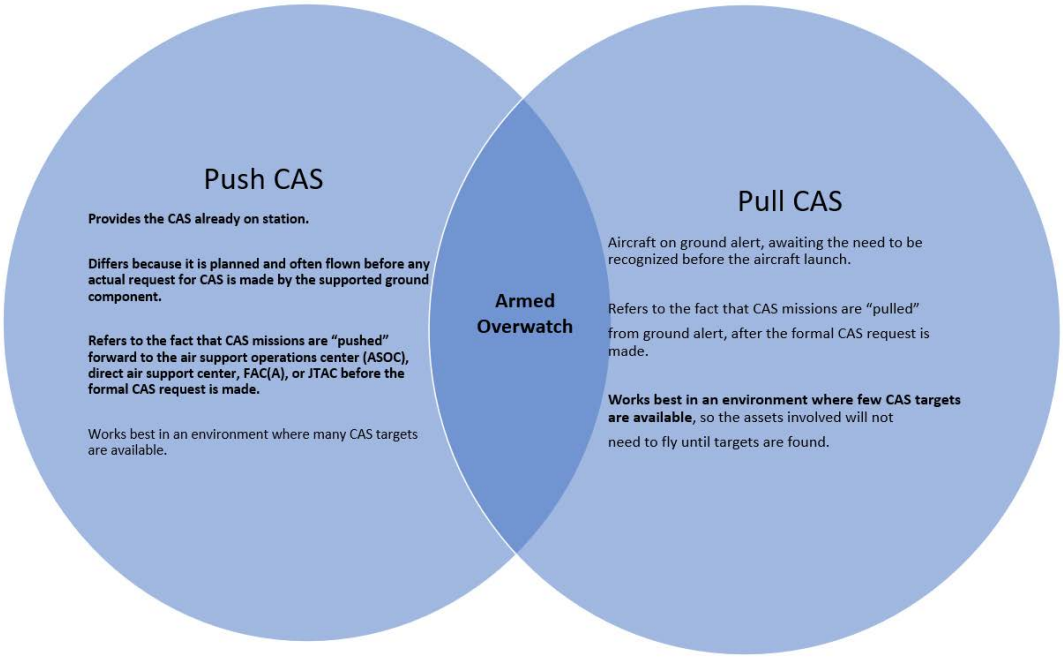
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Appendix C
Types of CAS Missions: XCAS vs. GCAS



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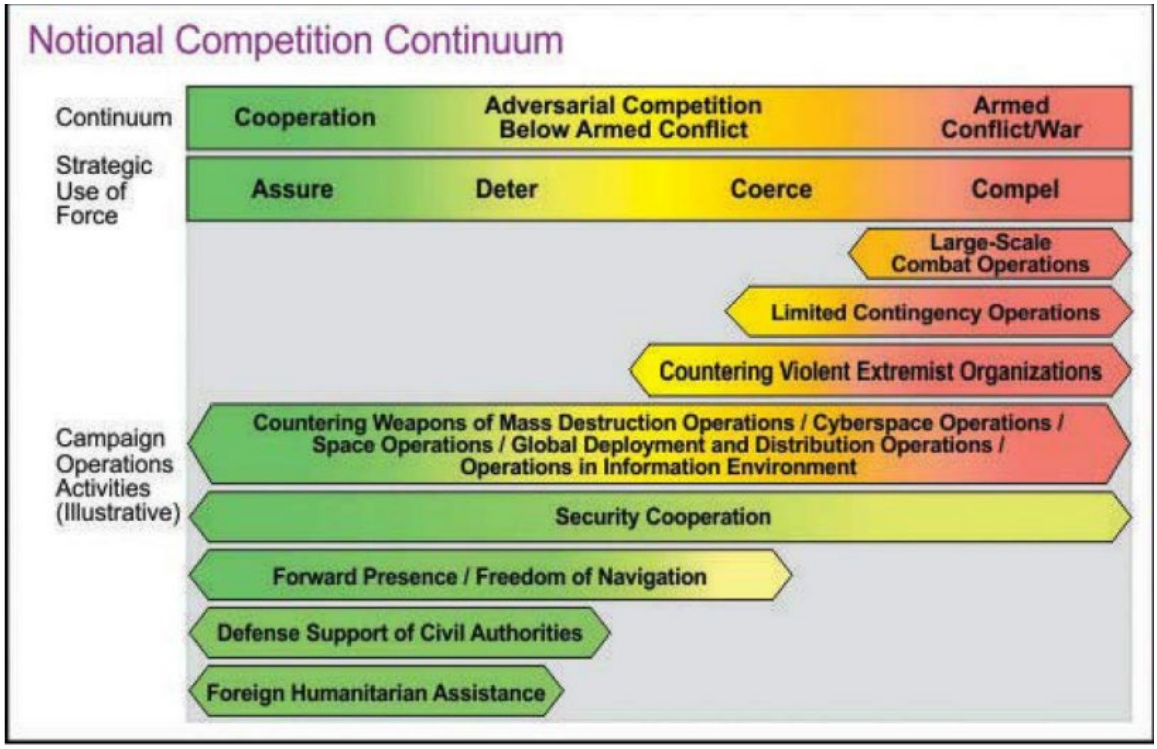
Appendix D
Types of CAS Methods: Push vs. Pull CAS



US Department of the Air Force, Air Force Doctrine Annex 3-03, *Counterland Operations* (Maxwell, AFB, AL: Government Publishing Office, 2020), 52-53.

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Appendix E
Notional Competition Continuum



US Department of Defense, Joint Staff, Joint Publication (JP) 1, *Joint Warfighting*, vol 1 (Washington, DC: Government Publishing Office, December 2019), 25. (DRAFT)

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Appendix F
Aeronautics Group Orbiter 1k



Aeronautics Group, “Orbiter 1K,” accessed February 15, 2021, https://aeronautics-sys.com/home-page/page-systems/page-systems-orbiter-1k-muas/.

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Appendix G
Soldier Unmanned Aircraft System (sUAS)



PEO Aviation, “Soldier Unmanned Aircraft System (SUAS),” US Army, September 24, 2020, accessed February 18, 2021, https://www.army.mil/article/239374 /soldier_unmanned_aircraft_system_suas.

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Appendix H
PC-1 Multipurpose Quadcopter



Airforce Technology, “PC-1 Multipurpose Quadcopter,” Projects, accessed February 15, 2021, https://www.airforce-technology.com/projects/pc-1-multipurpose-quadcopter/.

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14. ABSTRACT

Marine Special Operations Command (MARSOC) and its service conventional partner, the Marine Corps, have increased integration, interoperability, and interdependence (I-3) since 2006 when MARSOC was formed. To be better prepared for future threats and challenges in what has been called, "The Age of Everything," MARSOC will be required to build upon MARSOC-Conventional Forces (CF) I-3 and strengthen and build interagency I-3. In order to identify and combat future threats, MARSOC must continue to develop further I-3 between service, joint conventional forces, and its increasing interagency partners. MARSOC-CF I-3 begins with understanding the future threats. MARSOC-USMC I-3 and MARSOC-Interagency I-3 are the fundamental concepts of increase I-3 for MARSOC. To build and increase I-3 between MARSOC, the Marine Corps, and the interagency the future operating environment in which all three players will respond to must first be identified. Once the future operating environment is established, MARSOC can align with the Marine Corps and its interagency partners by better integrating, becoming more interoperable, and interdependent.

15. SUBJECT TERMS

MARSOC, Integration, Interoperability, Interdependence, Interagency

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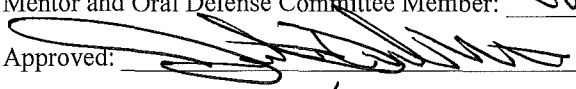
Prevailing in the "Age of Everything": Marine Special Operations Command and Improved Integration, Interoperability, and Interdependence

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF MILITARY STUDIES

Maj Nathan L. Golike (USMC)

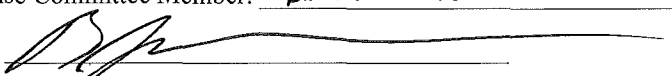
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Executive Summary

Title: Prevailing in the "Age of Everything": Marine Special Operations Command and Improved Integration, Interoperability, and Interdependence

Author: Major Nathan L. Golike, United States Marine Corps

Thesis: Marine Special Operations Command (MARSOC) and its service conventional partner, the Marine Corps, have increased integration, interoperability, and interdependence (I-3) since 2006 when MARSOC was formed. To be better prepared for future threats and challenges in what has been called, "The Age of Everything," MARSOC will be required to build upon MARSOC-Conventional Forces (CF) I-3 and strengthen and build interagency I-3. In order to identify and combat future threats, MARSOC must continue to develop further I-3 between service, joint conventional forces, and its increasing interagency partners. MARSOC-CF I-3 begins with understanding the future threats. MARSOC-USMC I-3 and MARSOC-Interagency I-3 are the fundamental concepts of increase I-3 for MARSOC.

Discussion: To build and increase I-3 between MARSOC, the Marine Corps, and the interagency the future operating environment in which all three players will respond to must first be identified. Once the future operating environment is established, MARSOC can align with the Marine Corps and its interagency partners by better integrating, becoming more interoperable, and interdependent. MARSOC shares many core tasks with the Marine Corps and has numerous solutions for future I-3. These MARSOC and Marine Corps solutions are represented in: Marine Corps air capabilities (Marine Air integrated with SOF for tailored response operations, utilizing already established fixed and rotary wing assets to conduct SOF training and operations), Marine Air Ground Task Force (MAGTF) and SOF capabilities (MAGTF-SOF Capabilities, Marine Corps assistance to SOF core tasks, MAGTF-SOF digital systems interoperability and operations/intelligence fusion), MARSOC-Marine Corps I-3 in Common Operating Areas (Liaison elements between SOF and USMC, sharing geographic alignment responsibilities), I-3 through Intelligence (Enhanced concept of intelligence, filling the Electronic Warfare (EW) capabilities gap, networking for rapid/precise fires, and USMC and MARSOC theater intelligence, surveillance, and reconnaissance (ISR)) and lastly through training (Urban operations and complex terrain, and expeditionary logistics). MARSOC and its interagency partners can seek to expand I-3 through expanding the global SOF network, increasing liaisons, and through MARSOC's further and expanded commitment to Irregular Warfare.

Conclusion: In order to combat future threats, MARSOC will have to increase its I-3 with CFs and its interagency partners. By examining the future threats and operating environments there are multiple I-3 solutions and themes that assist the Marine Corps, MARSOC and the interagency to better combat future threats. MARSOC will be required to further develop service relationships with the Marine Corps in overlapping area within training, equipping and operationally. Additionally, MARSOC must further develop established interagency

partnerships. The I-3 solutions represent a model to identify, coordinate and implement better I-3 between MARSOC, CFs and the interagency.

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Prevailing in the "Age of Everything": Marine Special Operations Command and Improved Integration, Interoperability, and Interdependence

Since the creation of Marine Special Operations Command (MARSOC) in 2006, integration, interoperability, and interdependence (I-3) between the Marine Corps and conventional forces (CF) has improved. To be better prepared for future threats and challenges in what has been called "The Age of Everything," MARSOC will be required to build upon MARSOC-CF I-3 and strengthen interagency I-3. This paper first examines future challenges for MARSOC and a way forward that supports multiple future operating concepts. It will then examine relationships with the greater Marine Corps focusing on manpower, training, and equipping. Finally, it will explore MARSOC-interagency relationship with the aim of enhancing whole of government I-3.

In addition, this paper develops a "concept" for I-3. For the purpose of increased understanding of I-3, the below definitions are critical to understanding the theme of this concept. Integration is the arrangement of military forces and their actions to create a force that operates by engaging as a whole.[1] Interdependence is the purposeful reliance on each other's capabilities to maximize the complementary and reinforcing effects of both.[2] Lastly, interoperability is the ability of both organization's systems, units, and forces to exchange information and services to operate in synergy in the execution of an assigned task.[3] In 2016, the Marine Corps created The *Marine Corps Operating Concept (MOC): How an Expeditionary*

[1] U.S. Joint Staff, *JP 1, Doctrine for the Armed Forces of the United States*, 25 March 2013, GL-8.
[2] *MCRP 3-30.4, Multi-Service Tactics, Techniques, and Procedures for Conventional Forces and Special Operations Forces Integration, Interoperability, and Interdependence*, 2014, P. 1.
[3] U.S. Joint Staff J7 Irregular Warfare Assessment and Integration Division, *Special Operations Forces – Conventional Forces: Integration, Interoperability, and Interdependence Final Report*, April 2015, Pg. 5.

Force Operates in the 21st Century to describe how the Marine Corps will conduct the range of military operations (ROMO) in accordance with its Title 10 responsibilities.

Part 1: MARSOC's Future Operating Environment, The Age of Everything

SOF provides critical capabilities to resolve future crises and support major operations. Success in the future environment will be determined by SOF's ability to navigate conflicts that fall outside traditional peace-or-war constructs. SOF's greatest value to the nation lies in its global perspective, coupled with the ability to act early with partners to provide a range of options for policy makers. Operating ahead of crisis allows SOF and partners to develop long-term and cost-effective options to prevent or mitigate conflict.[4] MARSOC will be required to develop a deeper understanding of the environment to see and act ahead of flashpoints of instability, inform the development of US options, and reduce operational and strategic blind spots.[5] In order to create critical tasks needed to be prepared for the future operating environment, MARSOC must establish a future operating concept that draws upon joint, service and SOF future operating environments. The degree to which MARSOC will contribute to the United States' (US) future defense will depend on its ability to recognize and adapt to the challenges of the future operating environment.[6] The joint operating environment (JOE) focuses on powerful states and non-state actors that establish their own sets of rules against the US and its interests (contested norms). The joint future operating environment also directs the joint force to address a second issue where weak states become increasingly incapable of maintaining domestic order or good governance (persistent disorder).[7]

[4] U.S. Special Operations Command. *Special Operations Forces Operating Concept.* Tampa, FL. (1 February 2016): Commander's Forward.
[5] Ibid., 2.
[6] U.S. Marine Corps Special Operations Command. *Marine Special Operations Forces (MARSOF) 2030 (Draft not approved).* Stone Bay, NC. (January 2018): 2.
[7] U.S. Joint Staff. *Joint Operating Environment (JOE) 2035: The Joint Force in a Contested and Disordered World*. Washington, DC. (14 July 2016): 4.

In addition, the Marine Corps' Future Operating Environment (FOE) focuses on the control of information and defending across all domains. Conflict will be fought by ideologically aligned coalitions and their proxies. Armed intervention will be only one tool in an increasingly information-centered battlespace. The US and its allies will play a key role in how to counter the proliferation of old and new weapons of mass destruction (WMD). Information and influence operations will shape the political and social battlespace.[8] The future operating environment will be characterized by an increasingly complex set of challenges in every part of the world. These challenges will range from the destabilizing influence of state aggression, to the expansion of radical networks across regions, to the growing threat of information warfare.[9] Threats will be increasingly transnational, trans-regional, and multi-domain. This era of extraordinary security challenges has been described as "the age of everything," an age where commanders must meet the high demand for all types of missions and threats.[10] Beyond the employment of improved technology, adversaries will continue to blend traditional and irregular techniques, capabilities, and resources to execute hybrid approaches in the gray zone[11], the space between peaceful competition and war.

To respond and prepare for future threats, MARSOC will continue its emphasis on a limited footprint and will find itself as a key constituent to any US response. The first US combat elements to respond to this future threat will be the US SOF and the MAGTF. MARSOC will have to grow in areas to be better equipped to respond to threats. Within all future operating concepts, the use of SOF as a tool will increase. In order to fully understand each problem that MARSOC is faced with and respond correctly without escalating tensions will entail accepting a

[8] U.S Marine Corps. Marine Corps Intelligence Activity: *Future Operating Environment 2015-2025*. Quantico, VA. (15 March 2015): 16.
[9] U.S. Special Operations Command. *SOCOM's Strategic Appreciation and USSOCOM 2035*. MacDill AFB, FL. 2017.
[10] Carter, Ashton B., "Maintaining the Edge in the Age of Everything." Speech. 2 November 2015; Bradley Peniston, Work: "The Age of Everything Is the Era of Grand Strategy," November 2015.
[11] U.S. Special Operations Command. *White Paper: The Gray Zone*. 09 September 2015.

certain level of political risk. The complexity of a particular situation will likely require a wide range of interagency and allied partners to understand and an even larger network of capabilities to address.[12] This will require MARSOC to establish better interagency partnership and a better relationship with the Marine Corps.

MARSOC and the Marine Corps mission sets will include assisting in security missions, protecting vulnerable US diplomatic facilities, supporting counterterrorism (CT), and protecting innocents.[13] Marine Special Operation Forces (MARSOF) will execute missions set against the context of regional competition or instability. The complexity of the operating environment will dramatically challenge the ability of leaders at all levels to understand it and come to meaningful solutions. MARSOC formations must be prepared to solve volatile, complex, multi-party, high-stakes problems that defy the application of traditional US strengths and solutions.[14] As conflict moves further into the information and cyber spaces, MARSOF will find itself leveraging theater, interagency, and national level tools to achieve desired outcomes.[15] Globally integrated operations will encourage collaboration across the Joint Force and with partners. These operations allow stakeholders to bring differing perspectives and capabilities to bear on complex challenges.[16]

Part 2: MARSOC-USMC I-3

Several Marine Corps capabilities intersect with special operations (SO) mission sets. By comparing a services' general-purpose forces (GPF) and its SOF component, the Marine Corps

[12] U.S. Marine Corps Special Operations Command. *Marine Special Operations Forces (MARSOF) 2030 (Draft not approved).* Stone Bay, NC. (January 2018): 6.
[13] U.S Marine Corps. Marine Corps Intelligence Activity: *Future Operating Environment 2015-2025*. Quantico, VA. (15 March 2015): 15.
[14] U.S. Marine Corps Special Operations Command. *Marine Special Operations Forces (MARSOF) 2030 (Draft not approved).* Stone Bay, NC. (January 2018):6.
[15] U.S. Marine Corps Special Operations Command. *Marine Special Operations Forces (MARSOF) 2030 (Draft not approved).* Stone Bay, NC. (January 2018): 7.
[16] U.S. Joint Chiefs of Staff. *Capstone Concept for Joint Operations: Joint Force 2020.* Washington, DC. (10 Sept 2012): 8.

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and US Army (USA) have the most overlap and ability for I3. All core tasks that MARSOC conducts are comprised of several functions that conventional Marine intelligence, logistics, aviation, infantry, communication, and reconnaissance units can support or conduct. This overlap is seen as many support personnel rotate between conventional and SOF units. SOF missions have resulted in a situation in which MARSOC and the "Big Marine Corps" retain significant overlap in mission competencies.[17] Both MARSOC and the Marine Corps gain from integrating capabilities that ultimately sharpen each other's skills. MARSOC can develop better I-3 in four areas: Marine Corps air capabilities, MAGTF capabilities, geographic common operating areas, intelligence collection, and training.

Marine Corps Air Capabilities within I-3: Marine Air Integrated with SOF for Tailored Crisis Response Operations, USMC HMLA (Marine Light Attack Helicopter Squadron) and MARSOC Relationship in the Conduct of SOF Training and Operations

Marine Air Integrated with SOF for Tailored Crisis Response Operations:

MARSOC and the Marine Corps can build on the relationships and capabilities that the Navy and Naval Special Warfare (NSW) already possess. U.S. Navy assault support helicopter platforms have already established effective relationships with NSW SOF elements. This relationship has established the very best tactics, techniques and procedures (TTP) for specific amphibious and maritime operations such as vessel visit, board, search and seizure (VBSS) operations. MARSOC has worked to better its VBSS TTPs through working with these same U.S. Navy helicopter units. The USMC would gain from working with both NSW and U.S. Navy helicopter units in VBSS operations. By dedicating an Marine light attack helicopter squadron

[17] Schroden, Jonathan, David Broyles, Vera Zakem, Jerry Meyerle, and Ryan Evans. *Improving SOF-GPF Integration for Crisis Response: An Action Plan for HQMC and SOCOM.* Center for Naval Analysis, Arlington, VA. (December 2015): 24.

(HLMA) to both the east and west coast MARSOC elements that train specifically to SOF TTPs, the Marine Corps will gain experience that remains in its own aviation community. The Marine Corps and MARSOC gain by working with each other on these types of mission profiles on a regular basis and get bilateral training on critical mission sets.

MARSOC and the USMC should also explore the use of Marine Corps aircraft to set up VBSS elements. The Marine Corps is not currently equipped to support "bottom up" or boat assault force (BAF) operations. The Marine Corps conducts limited bottom up VBSS operations and requires navy assistance. The Marine Corps is able to support "top down" or helicopter assault force (HAF) VBSS operations through organic MAGTF air support. MARSOC and the USMC should partner to create USMC aerial support element for VBSS operations. The aerial support element would consist of a Marine assault force (Marine Corps reconnaissance element or MARSOC), a rotary wing assault support element, a possible rotary wing escort element, and a fixed wing element to command and control the task force and provide initial sensor support on the target.

USMC HMLA (Marine Light Attack Helicopter Squadron) and MARSOC Relationship: MARSOC is not set to establish its own aviation element in the near future but, can establish relationships with Marine Corps aviation elements that accomplish similar results. In order to better develop a relationship between MARSOC and the Marine Corps, both elements should focus on strengthening each other's strongest capabilities. Assault support, ISR, close air support (CAS), Close Combat Attack (CCA) and an ability to provide overhead command and control, are critical to both MARSOC and the MAGTF, however, both elements do not greatly assist each other in training or during combat operations to the full extent. The Marine Corps and MARSOC would greatly benefit in forming a HAF element that works solely with SOF elements

and trains to specific special operation (SO) missions. This element would not solely be utilized by SOF elements. The HAF element should be comprised of Marine aviation assets both rotary and fixed wing. The concept has functioned inside of Operation Enduring Freedom (OEF) but has since been lost. The concept also worked between the navy and NSW through the Helicopter Sea Combat Squadrons (HSC). Although only a single HSC squadron still exists, HSC-85 is dedicated to special operations support as its primary role and can be tasked by USSOCOM. HSC-85 and NSW elements train and specialize in special operations missions as well as being deployed in support of each other. The concept has proved very successful with a pool of seasoned aviators with extensive SO experience who solely focused on SO, SOF support.

The Marine Corps and MARSOC do now have a relationship where a tasked Marine squadron provides direct support (DS) or specializes in SO mission to MARSOC. The concept has worked operationally during combat SO HAF missions but has not cemented any type of relationship. The Marine Corps was able to create a tailored assault support element that was comprised of Marine Corps CH-53s that were escorted by Marine Corps AH-1s. The assault support and escort element was scalable depending on the size of assaulters. The Marine Corps provided overall command and control through the fixed wing Harvest Hawk (KC-130J) and interoperability between conventional and SOF systems was established in extensive rehearsals. The Intelligence surveillance and reconnaissance (ISR) platforms, Command and Control (C2), Close Combat Attack (CCA), Close Air Support (CAS), and the assault support elements will all be comprised of Marine Corps air assets. Marine Corps aviation possesses the required assault support, escort, attack helicopter, fixed wing C2, sensors and payloads needed for world class HAF operations. The Marine Corps would gain from aligning a HAF squadron that provided DS to MARSOC and other SOF elements. This relationship would be mutually beneficial and

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strengthen each other's ability to integrate and increase special capabilities. A dedicated HMLA would be similar to the navy-NSW HSC model where a Marine squadron would specialize and maintain resident knowledge on SO missions and SOF tactics. The Marine Corps could dedicate two HMLAs (one to each coast) and concentrate its highly skilled aviators to these units for high risk mission and building inherent trust into a relationship between MARSOC and Marine Corps aviation planners and operators.

MAGTF-SOF I-3: MAGTF-SOF Capabilities, USMC Assists with SOF Core Tasks, MAGTF-SOF Digital Systems Interoperability and Operations/Intelligence Fusion

Integrating MAGTF-SOF Capabilities: The Marines Corps and US SOF are naturally aligned in terms of mission approach and execution. Both are forward-deployed in similar geographical areas, both are actively engaged in shaping operations and are able to respond immediately to crises with a tailored response, and perform operations in an enduring campaign. The MAGTF possesses powerful capabilities that complement SOF operations.[18] Marines and SOF can combine their unique mission orientations and approaches to be better postured to defeat the modern enemy operating around the globe. The effectiveness of this combined force of Marine and SOF interconnectedness must be strengthened, expanded, and formalized to better support geographic combatant command (GCC) requirements.[19]

Forward-deployed MAGTFs and MARSOF, operating within the same region, provide increased opportunity for interoperability between the Marine Corps and the special operations community.[20] A forward-deployed SOF, with an established footprint, communicates the

[18] U.S. Marine Corps. *United States Marine Corps and United States Special Operations Command Concept for Integration, Interdependence, and Interoperability.* Washington, DC. (28 July 2017): 7.
[19] U.S. Marine Corps. *United States Marine Corps and United States Special Operations Command Concept for Integration, Interdependence, and Interoperability.* Washington, DC.)28 July 2017): 2.
[20] U.S. Marine Corps. *Marine Corps Special Operations,* MCWP 3-05. Washington, DC. (1 June 2017): 8-2.

evolving situation to the MAGTF, which provides a sustained national response.[21] SOF access and relationships present significant advantages for the integrated Marine and SOF team. This access and relationships give Marine Corps forces the visibility on crisis response or plans the Theater Special Operations Command (TSOC) is working on in support of the GCC.[22] This allows the Corps to suggest ways that Marines could support such plans, ideally in an integrated manner.

SOF and CF often share the same operational areas for extended periods when they are mutually reliant on each other's capabilities. SOF-CF synchronization facilitates unity of effort and maximizes the capability of the joint force which allows the Joint Force Commander (JFC) to optimize the principles of joint operations in planning and execution.[23] MAGTFs also execute phase zero operations or respond to crises, often without the advantage of local area knowledge and preexisting relationships. USSOCOM's global presence and foreign partnerships developed with strong language and cultural expertise, are critical to working with the local populace and security forces and can assist the MAGTF.

USMC assists with SOF core tasks: The GCCs are increasing their demand for tailored forces to conduct Theater Security Cooperation (TSC) activities with a wider number of partner nations. Security Force Assistance (SFA), joint combined exercise training (JCET), and phase zero activities are important elements for both the Marine Corps and MARSOC's engagement strategy and the GCC's theater campaign planning. These activities ensure access prior to the start of contingencies and contribute directly to the reduction of ungoverned spaces from which

[21] Ibid., 8-4.
[22] U.S. Marine Corps. *United States Marine Corps and United States Special Operations Command Concept for Integration, Interdependence, and Interoperability.* Washington, DC. (28 July 2017): 8.
[23] U.S. Joint Staff. *Joint Publication 3-05 - Special Operations.* Washington, DC. 16 July 2014: III-23.

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future adversaries may originate.[24] The Marine Corps must develop additional opportunities for regional rotational training bases that improve interaction with partner militaries, increase regional knowledge and keep Marines forward deployed. The Marine Corps and MARSOC would benefit from partnering during these types of rotations by deploying to similar regions and working together while deployed. Security cooperation and Marine Corps train and assist units could reduce the redundancy by partnering with MARSOC regional security elements.

Prior to MARSOC, the Marine Corps conducted Foreign internal defense (FID) and SFA through the Foreign Military Training Unit (FMTU). The FMTU structure and personnel were used to create the Marine Raider Regiment staff and a third Marine battalion that was known as the Marine Special Operations Advisory Group (MSOAG). Since then the Marine Corps has not fully re-established a robust ability to conduct FID and SFA. Several units exist in the Marine Corps that conduct special operation type missions and train to SOF core capabilities. Following FMTU becoming part of MARSOC, the Marine Corps Training and Advisory Group (MCTAG) and Marine Corps Security Cooperation Education and Training Center (SCETC) filled the Marine Corps role in security cooperation (SC) programs around the globe. Both Marine units combined in 2011 to create the Marine Corps Security Cooperation Group (MCSCG). Globally, Marine Corps personnel deploy to conduct similar missions as their MARSOC counterparts. Both units include advisor skills, training and assessment expertise, and security assistance program management with the major difference being in training, equipment, funding, and authorities. The MCSCG mission is to execute and enable SC programs, training, planning, and activities in order to ensure unity of effort in support of our Corps and Regional Marine Component Command (MARFOR) objectives, and in coordination with operating forces and

[24] United States Marine Corps, Combat Development and Integration, *Expeditionary Force 21 – Forward and Ready: Now and in the Future*, March 2014, Pg. 9.

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MAGTFs. MARSOC and MCSCG would greatly benefit from assisting one other. The Marine Corps should increase MCSCG overall staff and missions. There are numerous SC missions that are designated as SOF missions that are unable to be filled due to the shortfall in US SOF. MCSCG could work with MARSOC to conduct supporting and geographically connected missions. This would allow for shared training, culture and regional expertise and increased involvement with CF and SOF during deployment area of operations.

MAGTF-SOF digital systems interoperability and operations/intelligence fusion: Interoperability is a lower state of SOF-GPF interaction than integration. CF and SOF often use different digital systems from radios to computer systems. Integration can be achieved in the absence of interoperable systems. MARSOC and the Marine Corps should seek interoperable systems or train to share information. Because MARSOC must work with both USSOCOM and Marine Corps units, it is important to understand each other's systems. MARSOC must lead the way on digital systems interoperability and seek like systems or work arounds. Interoperability of systems lowers the barriers to integration and reinforces the shifts in thinking, operations, and culture described above.[25]

MARSOC-USMC I-3 in Common Operating Areas: Liaison Elements Between SOF and USMC, Sharing Geographic Alignment Responsibilities

Strengthen Liaison Elements between SOF and USMC: Liaison between SOF commands and the Marine Corps has improved over the last ten years. For starters, the Marine Corps has been involved in using the special operations command and control element (SOCCE) as a critical point for SOF-CF coordination and synchronization of special operations activities

[25] Schroden, Jonathan, David Broyles, Vera Zakem, Jerry Meyerle, and Ryan Evans. *Improving SOF-GPF Integration for Crisis Response: An Action Plan for HQMC and SOCOM.* Center for Naval Analyses, Arlington, VA. (December 2015): 13.

with other joint operations. The SOCCE is normally employed when SOF conducts operations in support of a CF. It performs C2 or liaison functions according to mission requirements and as directed by the establishing SOF commander.[26] Since MARSOC was established, the SOF Liaison Element (SOFLE) has evolved to be more than a task organized rotational SOF element deployed within a specific nation or embedded within CF to conduct liaison activities to a permanent liaison within Marine Corps organizations. The SOFLE is tasked with coordination, assessing, and recommending training, equipping, and engaging opportunities with host nation (HN) forces or provide connectivity and synchronization of expeditionary forces.[27] Having a permanent SOFLE on Marine Expeditionary Units (MEU) was created by the USSOCOM Commander and the Commandant of the Marine Corps (CMC) to facilitate greater cooperation between SOF and Marine forces.[28] This greater cooperation was successful in the integration of Marines and SOF through the deployment of a SOFLE with Amphibious Readiness Groups (ARG)/MEUs.[29] The first ARG/MEU SOFLE conducted a workup and deployed with the 11 th MEU in July 2014 and continues to today with each east and west coast MEU. The SOFLE provides the critical links to the SOF network, the TSOC forward-deployed SOF elements, and interagency partners. Collaboration between SOF and Services will facilitate cross-organizational knowledge and communication for dynamic responses to rapidly evolving events.[30] To demonstrate the importance of the SOFLE, in 2017, the USSOCOM commander made the program an operational requirement. The SOFLE program has been a wide success for the Marine Corps as well. Theater Special Operation Commands (TSOC) have increased their

[26] Ibid., III-18.
[27] Ibid., III-22.
[28] Insinna, Valerie. "Marine Corps Adds Special Operations Element to Expeditionary Units." *Defense Daily* (20 April 2015).
[29] Schroden, Jonathan, David Broyles, Vera Zakem, Jerry Meyerle, and Ryan Evans. *Improving SOF-GPF Integration for Crisis Response: An Action Plan for HQMC and SOCOM.* Center for Naval Analysis, Arlington, VA. (December 2015): 3.
[30] U.S. Marine Corps. *Marine Corps Special Operations,* MCWP 3-05. Washington, DC. (1 June 2017): 8-4.

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need for Marine MEU aviation, logistics and intelligence support. MARSOC has trained all SOFLEs since it was created. The Marine Corps has reciprocated this by placing a "Marine liaison element" (MARLE) in the TSOC.[31] This has allowed the Marine Corps to provide more responsive and tailored, MAGTF centered, crisis response options to the TSOC.

MARSOC can further integrate with the USMC by placing liaisons at various MAGTFs. SOF liaison elements at CF headquarters play a critical role in SOF-CF I-3.[32] The Marine Expeditionary Brigade (MEB) and the USMC's Special Purpose MAGTFs for crisis response (SPMAGTF-CRs)[33] would be ideal due to similar training and capabilities. Liaison elements could help mitigate the lack of trusted relationships, SOF misunderstandings and could help educate MAGTF leaders on how to utilize SOF as an additional option or capability.

Sharing Geographic Alignment Responsibilities: The Marine Corps and MARSOC have yet to align forces in support of each other's geographic expertise. The Marine Corps has cultural, language, intelligence and tactical expertise within each Marine Expeditionary Force (MEF) that could benefit from the current geographic alignment of MARSOC's construct. MARSOC remains tied in some way to a region through an established partner force either for a long period of time. A MEF and an Marine Raider Battalion (MRB) can begin habitual relationships that support each other through training and operationally. Due to MARSOC's enduring commitment to several partner forces and expertise in several regions of the world, increased integration of Marine Corps forces into these geographic areas would be mutually beneficial. Talks must begin between the MEF and MARSOC commanders and their staffs to

[31] Schroden, Jonathan, David Broyles, Vera Zakem, Jerry Meyerle, and Ryan Evans. *Improving SOF-GPF Integration for Crisis Response: An Action Plan for HQMC and SOCOM.* Center for Naval Analysis, Arlington, VA. (December 2015): 34.
[32] Wesbrock, Jason, Glenn Harned, and Preston Plous. "Special Operations Forces and Conventional Forces Integration, Interoperability, and Interdependence." *Prism 6*, no 3 (2015): 91.
[33] Schroden, Jonathan, David Broyles, Vera Zakem, Jerry Meyerle, and Ryan Evans. *Improving SOF-GPF Integration for Crisis Response: An Action Plan for HQMC and SOCOM.* Center for Naval Analysis, Arlington, VA. (December 2015): 3.

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begin coordination between MRBs and USMC general purpose force (GPF) battalions conducting these deployments. These relationships facilitate the involvement of MARSOC and MEF units (SPMAGTFs and MEUs) in each other's pre-deployment training and work-up cycles (MARSOF play in the MEU certification exercise (CERTEX) and USMC GPF observation of the MARSOC RAVEN exercises).[34]

I-3 through Intelligence: Enhanced Concept of Intelligence, Electronic Warfare (EW) Capabilities Gap, Networking for Rapid/Precise Fires, USMC and MARSOC Theater ISR

Enhanced Concept of Intelligence: Future forces will increasingly rely on sensors, networks, architectures, and tradecraft to establish and maintain situational awareness, influence the operating environment, and support decision-making at higher headquarters and on down to the point of action. The MAGTF must complement this with information harvested from commercial and social information sources. A deeper understanding of the environment developed from the collected observations, information, and experiences of Marines up and down the echelons of the force. MARSOC and Marine Corps elements must seek to capture the value of pushing networked intelligence down to tactical units.

Intelligence sharing between the Marine Corps and MARSOC is a requirement in order to maintain an edge on future threats. Marines and SOF have access to formidable operational, theater, and national intelligence capabilities. Both the MAGTF and SOF are equipped to generate tactical intelligence but require reach-back support for analytical depth and capacity. With its robust communications and ISR architecture, a MAGTF not only can generate a multi-

[34] Schroden, Jonathan, David Broyles, Vera Zakem, Jerry Meyerle, and Ryan Evans. *Improving SOF-GPF Integration for Crisis Response: An Action Plan for HQMC and SOCOM.* Center for Naval Analysis, Arlington, VA. (December 2015): 12.

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source, multi-discipline intelligence picture organically, but also possesses a robust reach-back capability through the Marine Corps' Intelligence, Surveillance, and Reconnaissance Enterprise (MCISRE) that provides ready access to a broad range of Service and Intelligence Community resources.[35] MCISRE and the Marine Corps can further develop a better relationship with USSOCOM through MARSOC. No agency or service has sufficient ISR capacity and would benefit by assisting each other.

Preparation of the environment and phase zero operations are integral to both SOF and CF. SOF conducts preparation of the environment prior to the arrival of follow-on force[36] and has significant organic all source intelligence collection assets as well as a robust reach back capability that extends into all intelligence agencies within the US. Special operations forces take actions to prepare the operational environment for potential operations by various means but in many cases overlap with Marine Corps intelligence collections. SOF focuses on preparation of the environment (PE) during the shaping phase of an operation, as well as developing and preparing for the entry of conventional forces. SOF also supports agencies that resolve conflicts using either lethal or nonlethal action. SOF are usually located within an area and assigned to conducting PE. CF also play a large role in supporting PE through supporting special operations advance force operations (AFO). CFs are also forward-deployed or stationed in areas to conduct PE either alone or along with SOF. AFO encompasses many PE activities, but are intended to prepare for near-term direct action. The MAGTF along with several specialized units within the Marine Corps could greatly assist or take the lead on PE activities. Special operations AFO may include, but are not limited to, close target reconnaissance; tagging, tracking, and locating (TTL);

[35] U.S. Marine Corps. *United States Marine Corps and United States Special Operations Command Concept for Integration, Interdependence, and Interoperability.* Washington, DC. (28 July 2017): 9.
[36] U.S. Joint Staff. *Joint Publication 3-05 - Special Operations.* Washington, DC. 16 July 2014: II-4.

reception, staging, onward movement, and integration of forces; infrastructure development; and terminal guidance.[37]

The Electronic Warfare (EW) Capabilities Gap: Manned and UAS payloads can be equipped to support MAGTF and SOF operations**.** The Marine Corps will incorporate an EW capability into current and future UAS platforms as EA-6B Prowlers are being phases out. The Marine Corps addresses EW requirements through an approach called MAGTF EW where an integrated, platform-agnostic, EW capabilities, can be placed on manned and unmanned assets. The Marine Corps' vision is on developing a system or using existing systems like the Intrepid Tiger II (ALQ-231) that can be placed on any manned or unmanned aviation platform in the Marine Corps. Electronic Warfare Service Architecture (EWSA) allows data exchange and hardware protocol intended to connect EW/SIGINT airborne nodes to ground operators, Cyberspace and Electronic Warfare Coordination Cells (CEWCCs), and other air EW nodes. MARSOC and MAGTF operations can use the EWSA and have "on-demand EW fires" in operational conditions under CEWCC control, and will unite Air EW, Ground EW, and SIGINT via an adaptive network with multiple waveforms.[38]

Networking for Rapid/Precise Fires: In future conflicts MARSOC and the Marine Corps will operate against adversaries with effective ISR and the ability to place long-ranged fires both with precision and for massed effects. In the current fight with Islamic State (IS) both SOF and CFs have fought against an enemy with these capabilities. SOF depend on unmanned aircraft (UA) with imagery, signal intelligence (SIGINT), and other intelligence collection capability to provide persistent, high-fidelity intelligence on an adversary that moves and

[37] U.S. Marine Corps. *Marine Corps Special Operations,* MCWP 3-05. Washington, DC. (1 June 2017): 2-3.
[38] Marine Corps Concepts and Programs, "Electronic Warfare," *Marine Corps Concepts and Programs*, accessed December 2017, https://marinecorpsconceptsandprograms.com/programs/aviation

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operates among civilians.[39] Marine Corps units will have to learn to train and operate these capabilities down to the lowest level as MSOTs have been doing since their existence. MARSOC and the Marine Corps must acquire means to interdict and destroy enemy UAS capabilities. This shortfall effects both SOF and conventional forces. The Marine Corps and MARSOC must partner to integrate testing teams that explore ways to defeat enemy UAS capabilities.

The find, fix, finish, exploit, analyze and disseminate (F3EAD) model that was developed over the past several years of conflict serves to fully integrate intelligence and SOF operations in a continuous ISR and targeting cycle.[40]Airborne ISR, specifically full motion video (FMV) and SIGINT, is essential to COIN and counter-network operations. Outside of SOF it is clear that services are behind in providing adequate resources to deployed forces. The Marine Corps would benefit in purchasing similar program of record small and tactical UAS platforms. Airborne ISR is most effective when it is massed, synchronized with operations, integrated with all-source intelligence, and employed under a unity of organization. Forward deployed SOF and CFs must have forward processing, exploitation, and dissemination (PED) integrated into the Tactical Operations Center (TOC). MARSOC does not currently possess a system can PED and is integrated into a TOC. MARSOC must continue to develop this capability within each Marine Special Operation Company (MSOC). Marine Corps infantry units must have this capability at the infantry battalion level with the capability to conduct operations out of each company. This will require significantly increasing the personnel trained in managing ISR, purchasing appropriate level unmanned aerial systems (UAS), and establishing fully integrated TOCs. Airborne ISR is the centerpiece of the F3EA because it is tightly synchronized with a finishing

[39] U.S. Joint Staff. *Joint Publication 3-05 - Special Operations.* Washington, DC. 16 July 2014: II-6.
[40] Joint Special Operations University. *Special Operations Intelligence: Guiding the Tip of the Spear, JSOU Report,* November 2015. JSOU Press: MacDill AFB, FL: 96.

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force.[41] Marine aviators that fill the role of forward air controllers (FAC) within MARSOC and the Marine Corps down to the MSOC and infantry battalions are ideal for managing small and tactical UAS programs. This includes the ordering, training and sustaining of the personnel and equipment. To further integrate UAS operations into MARSOC and Marine Corps operations, the FAC should be used as a vital part of the company or battalion operations section. MARSOC is set to expand its UAS personnel by integrating permanent Unmanned Aerial Vehicle (UAV) military occupation specialty (MOS) trained Marines. These MOS trained UAV operators can be pushed down to the MSOC level and further deliver UAS support to operations.

USMC and MARSOC theater ISR: MARSOC and the Marine Corps have been working on ways for conventional Marine Unmanned Aerial Vehicle Squadrons (VMU) to support SOF operations through their various UAS platforms. The concept yielded negative results over the last two years but serves as an excellent starting point. Although the initial idea seemed to be sound, the VMU squadrons were too large and burdensome to support SOF effectively. The large footprint, in addition to the unrealistic force protection requirements, poor sensors, and limited flight hours made integration difficult.

The difficulty in integrating the VMU to support MARSOC does not negate the need for MARSOC and the Marine Corps to have an organic capability that can provide full motion video (FMV) processing, exploitation, and dissemination collaboration (PED) capability that supports the MAGTF, MARSOC, and the joint force. MARSOC units did not gain from having the VMU support and were able to address the UAS problem with organic and purchased small UAS (SUAS) and tactical UAS (TUAS) managed internally to the MSOC. Outside of the VMU, ISR was supplemented with contracted ISR that required little to no footprint, had more advanced

[41] Flynn, Michael T, Rich Juergens, and Thomas L. Cantrell. "Employing ISR: SOF Best Practices" *Joint Force Quarterly*, 50, 3rd Quarter (2008): 61.

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payloads and could fly additional hours. Lastly, MARSOC gained from the sourced conventional and SOF specific theater ISR that was far superior to the VMU capabilities. The support relationship that existed between the VMU and MARSOC forward deployed units was an excellent start, however, inferior sensors and the reasons listed earlier have slowed progress. Since the Marine Corps' entry into Operation Iraqi Freedom (OIF), and Operation Enduring Freedom (OEF), and now Operation Inherent Resolve (OIR) the demand for dedicated unmanned aerial reconnaissance systems has grown exponentially. ISR collections through organic UAS has played a critical part in supporting the MAGTF's aerial reconnaissance requirement as well as other missions such as communications relay and Signals Intelligence (SIGINT) collections.[42] For starters, the Marine Corps or MARSOC must purchase its own theater level UAS unit. Currently, the Marine Corps only operates TUAS (RQ-7B Shadow), Small Tactical UAS (STUAS) (MQ-21A Blackjack), and various SUAS (RQ-11B Raven, RQ-20 Puma and Wasp IV). In 2013, United States Special Operations Command upgraded to the MQ-1C Grey Eagle and is operated under the Special Operations Aviation Regiment (SOAR). The added range, endurance, and available payloads provides a capability that directly supports the service. MARSOC does not possess the structure to support the MQ-1C but VMU squadrons are capable of supporting a more capable system than they currently field. The Marine Corps is far behind all other services on group 4/5 UAS. An upgraded VMU could provide an added fires and collection capability for the MAGTF and MARSOC.

In the interim, MARSOC and the Marine Corps have purchased a group 2 SUAS that will be utilized by both elements. Although the Stalker XE (SUAS) is not a group 4/5 UAS it is a very capable system and is a step in the right direction in I-3 and a more advanced and capable

[42] Marine Corps Concepts and Programs, "Unmanned Aerial Systems," *Marine Corps Concepts and Programs*, accessed December 2017, https://marinecorpsconceptsandprograms.com/programs/aviation

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UAS. The Stalker XE is already being field in both MARSOC and the Marine Corps. The system boasts longer endurance (playtime) than any current SUAS, low altitude silent operations, and it can be equipped with several multi-function, plug and play payloads. The most important feature is its ability to broadcast its signal beyond the tactical UAS operator and into a TOC to give decision makers better situational awareness, shorten the kill chain or develop targets and patterns of life all real time.

Training: Urban Operations and Complex Terrain, Expeditionary Logistics

Urban Operations and Complex Terrain: The Marine Corps is experimenting with new equipment, structing, and training that better prepares the Marine Corps to fight in the future operating environment within urban areas and complex terrain. The Marine Corps Warfighting Laboratory (MCWL) has spearheaded this effort with the Marine Corps Force 2025 (MCF 25) to ensure the MAGTF is postured to address the challenges of the future operating environment. Sea Dragon 2025 (SD 25) takes MCF 25 and creates an experiment roadmap to build an expeditionary force for the 21st century. SD 25 focused on the Marine Corps Force 2025 (MCF 2025) infantry battalion. Most of the equipment that was used to equip the infantry battalion is already been used by SOF. The Marine Corps would have benefited from integrating MARSOC into the training of this phase to give the Marine Corps a better understanding of what it takes to train, equip, and sustain these skills and advanced equipment. Lessons learned in MARSOC over the last ten years would have assisted in this effort.

The next phase of SD 25 will include dynamic concurrent experiment efforts focused on dense urban operations, 21st century fires, an adaptive threat force, and the continuation of the Marine Corps Experiment Operational Advisory Group (EXP OAG). All of these efforts must be integrated with MARSOC. Both elements are trying to solve the same problems by using

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emerging concepts and technologies. This next phase of SD 25 has already started focusing on the MAGTF hybrid logistics and will proceed with information environment operations, and EAB operations. MARSOC and the Marine Corps must employ this concept for I3 during the remainder of SD 25.

Expeditionary Logistics: As described above, MCF 25 is addressing the logistics challenges of operating within the future operating environment through hybrid logistics experimentations. The Marine Corps is working to adopt a "hybrid" approach to expeditionary logistics that leverages the rapid development of unmanned/autonomous logistics systems, additive manufacturing, and "smart" logistics information technologies to support a widely distributed force in an anti-access/ area denial (A2/AD) environment. Combat Logistics Battalions (CLB) 8 and 6 are serving as the USMC FY18 experiment forces and support live-force experiments. The focus will focus on tactical-to-strategic logistics in contested environments. This is another area where MARSOC and the Marine Corps must work together. Lastly, this portion of MCF 25, hybrid logistics also focuses on the medical support in these same environments.[43] The MAGTF and this increased medical support is another way the Marine Corps can provide added support to SOF forward-deployed units.

Part 3: MARSOC-Interagency I-3

MARSOC must be as comfortable working as a part of interagency or multinational efforts when serving inside of a Raider formation.[44] SOF, as part of the Joint, Interagency, Intergovernmental and Multinational (JIIM) network, must be increasingly flexible, agile, and capable of integrating operations across national and GCC seams to effectively neutralize threats

[43] Marine Corps Warfighting Laboratory, "Sea Dragon 2025 Assessment Conference." *Marine Corps Warfighting Laboratory*, accessed December 2017, http://www.mcwl.marines.mil
[44] U.S. Marine Corps Special Operations Command. *Marine Special Operations Forces (MARSOF) 2030 (Draft not approved).* Stone Bay, NC. (January 2018): 10.

to US interests.[45] Policy objectives are only achieved by the integration of JIIM partners' capabilities focused toward shared objectives and common goals. Understanding this, SOF will execute Integrated Campaigning as part of a larger JIIM team to achieve the Central Idea of this concept.[46]

To achieve greater collective JIIM agility and flexibility, MARSOC will formally embed and exchange liaison elements with an evolving list of partners to achieve an unprecedented degree of understanding and capability for integrated action. MARSOC will modify organizations to ensure that each liaison element is properly structured and manned by SOF personnel with the education and experience to be valuable, productive contributors to partner organizations while advancing and protecting US interests globally.[47] Interagency interaction facilitates our development of Regional SOF Coordination Centers (RSCCs). These multilateral coordination forums established in key locations around the world are to promote multinational collaboration, education and training opportunities with partner nation SOF. RSCCs shall facilitate long-term relationships and burden-sharing to achieve mutual security objectives.[48] In order to expand the global SOF network for MARSOC, there must be better efforts to increase interagency liaisons and establish a further commitment to Irregular Warfare (IW) and specifically Unconventional Warfare (UW).

Increase interagency liaisons: MARSOC personnel must increase interagency billets along with increasing interagency partners brought in to fill billets within MARSOC. The most common way to achieve this is through increasing interagency liaisons through Special Operations Support Teams (SOST). USSOCOM elements in the national capital region (NCR)

[45] U.S. Special Operations Command. *Special Operations Forces Operating Concept.* Tampa, FL. (1 February 2016): 2.
[46] Ibid., 3.
[47] Ibid., 7.
[48] U.S. Special Operations Command. *SOCOM 2020: Forging the Tip of the Spear.* MacDill AFB, FL. (2013): 6.

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facilitate interagency coordination between SOF and other interagency partners, and are a major element in the global SOF network that enables interagency coordination overseas. MARSOC must fill all current SOST billets and expand to additional agencies. Special operations support teams (SOSTs) are cornerstones of the USSOCOM. MARSOC Special Operations Officer (SOO) career path must allow for short rotations to fill SOST billets and encourage participation for O-4 and O-5s and sending quality officers to represent MARSOC. The key hurdle in filling critical interagency liaisons is still availability of MARSOC personnel.

The Interagency Partnership Program (IAPP) is the methodology for providing on-site facilitation of DoD planning with other USG departments and agencies for global operations against terrorist networks. The IAPP supports intergovernmental agency information sharing, improves security situational awareness, and builds a teamwork approach to unified security activities. SOSTs are USSOCOM representatives embedded with the NCR HQ of interagency partners to foster interagency coordination and collaboration. MARSOC would greatly gain from aligning the activities of SOF with USG functional lines of effort through additional liaisons. USSOCOM elements in the NCR are a major element in part of the global SOF network that strengthens the relationships of SOF with USG departments and agencies and other organizations.[49] Unconventional warfare requires significant interagency participation because the activity includes support to both the military and political aspects of internal opposition.[50]

MARSOC's further commitment to Irregular Warfare: If MARSOC is going to take a more active role in the support to UW it must advance its strategic partnership with the Central Intelligence Agency (CIA). MARSOC planners and operations officers must be better integrated

[49] U.S. Joint Staff. *Joint Publication 3-05 - Special Operations.* Washington, DC. 16 July 2014: III-22.
[50] U.S Department of Defense. *Irregular Warfare: Countering Irregular Threats Joint Operating Concept, Version 2.0.* Washington, DC. 17 May 2010: 24.

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within the CIA to enable collaborative planning and execution of IW and UW activities. The CIA's intelligence activities that are authorized under Title 50 and MARSOC's military activities authorized under both Title 10 and Title 50 provide mutually supporting, not mutually exclusive, authorities. This provides a unique construct from which CIA and MARSOC planners can collaborate and complement unconventional options for national security needs.[51]

The CIA and the Marine Corps have been successful in partnering in unconventional warfare operations through counterinsurgency operations in Vietnam in programs like the Provincial Reconnaissance Units (PRU). PRUs were under the operational control of the CIA relied on specialized military teams from special operations and conventional units to conduct their unconventional recruiting, training and operations. The CIA drew upon service special operation units and Marine expertise in training, language skills, cultural and political understanding, and access and placement to be effective. Likewise, MARSOC still maintains MSOTs and MSOCs with a depth of knowledge on unconventional warfare both in training and practice. The CIA and MARSOC should establish a partnership that enables the CIA to utilize MARSOC elements in support of their UW operations.

Commander, United States Special Operations Command has assigned Commander, Marine Forces Special Operations Command (COMMARFORSOC) the following SOF core activities: direct action (DA), special reconnaissance (SR), counterterrorism (CT), foreign internal defense (FID), security force assistance (SFA), counterinsurgency (COIN), support to CWMD, and support to UW.[52] MARSOC is too small to be an expert at all of its core assigned tasks or to be the proprietor of several tasks. Instead MARSOC should further establish its role in

[51] Joint Special Operations University. *Special Operations Intelligence: Guiding the Tip of the Spear, JSOU Report,* November 2015. JSOU Press: MacDill AFB, FL: 75.
[52] U.S. Marine Corps. *Marine Corps Special Operations,* MCWP 3-05. Washington, DC. (1 June 2017): 2-4.

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irregular warfare by specializing in certain aspects. Once considered largely the province of special operations forces (SOF), irregular threats are now understood to fall within the purview of the entire joint force. To prevent, deter, disrupt, and defeat irregular threats, the U.S. military will apply some blend of counterterrorism, unconventional warfare, foreign internal defense, counterinsurgency, and stability operations. MARSOC must first collaborate with other governmental agencies, multinational partners to understand the situation in depth, act in concert, and continually assess and adapt their approach in response to the dynamic and complex nature of the problem. Unconventional warfare must be the cornerstone of MARSOC's core tasks.

Unconventional warfare operations span from support to groups resisting government authority to the overthrow of the government. Department of Defense (DoD), Department of State (DoS), and other interagency partners evaluate diplomatic, environmental, and economic costs and benefits prior to recommending UW operations but SOF usually conducts UW operations because of its size and forces trained in UW. These UW operations present significant risks, but they can also help resolve international crises without overt, large-scale CF. Resistance movements and insurgencies commonly organize around interrelated elements of an underground, an auxiliary, and a guerrilla force.[53] By partnering with all US government agencies that plan for UW operations, MARSOC will be best suited to conduct and execute UW operations. UW activities are conducted in support of a resistance or insurgency in a denied area. The initial focus of UW activities in support of an opposition is typically conducted in areas or environments where the governing authority has the capacity to deny overt freedom of action to the opposition and is best suited for SOF. UW operations rely on synchronization of SOF and CF and unified action with one or more interagency and multinational partners.[54]

[53] U.S. Joint Staff. *Joint Publication 3-05 - Special Operations.* Washington, DC. 16 July 2014: II-8.
[54] Ibid., II-8.

Conclusion

In the "Age of Everything," MARSOC will be required to develop, strengthen and build increased integration, interoperability, and interdependence (I-3) between the Marine Corps (MARSOC-USMC I-3) and its interagency partners (MARSOC-interagency I-3).

The concept above outlines several key MARSOC-USMC I-3 concepts such as potential Marine air integrating with SOF for specific crisis response operations and the establishment of relationships to conduct SOF training and operations. Globally integrated operations will encourage collaboration across the Joint Force and with partners. These operations allow stakeholders to bring differing perspectives and capabilities to bear on complex challenges.[55] There is also an opportunity for increased I-3 in commonalities between MAGTF and MARSOC capabilities, intelligence collection and capabilities and both training and operationally.

MARSOC can also increase I-3 within the vast interagency organization and expanding the global SOF network. The complexity of a FOE requires a wide range of interagency and allied partners to understand and an even larger network of capabilities to address.[56] This will require MARSOC to establish better interagency partnership. This can be accomplished through increasing interagency liaisons both inside and outside of MARSOC. Lastly, MARSOC must establish a deeper commitment to Irregular Warfare (IW) and within further develop an enduring relationship with the interagency partners that conduct and assist in IW.

[55] U.S. Joint Chiefs of Staff. *Capstone Concept for Joint Operations: Joint Force 2020.* Washington, DC. (10 Sept 2012): 8.
[56] U.S. Marine Corps Special Operations Command. *Marine Special Operations Forces (MARSOF) 2030 (Draft not approved).* Stone Bay, NC. (January 2018): 6.

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United States Government Accountability Office

GAO

Report to Congressional Committees

March 2012

DEFENSE ACQUISITIONS

Assessments of Selected Weapon Programs



GAO-12-400SP

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March 2012

DEFENSE ACQUISITIONS

Assessments of Selected Weapon Programs

GAO Highlights

Accountability * Integrity * Reliability

Highlights of GAO-12-400SP, a report to congressional committees

Why GAO Did This Study

This is GAO's annual assessment of DOD weapon system acquisitions, an area that is on GAO's high-risk list. The report is in response to the mandate in the joint explanatory statement to the DOD Appropriations Act, 2009. It includes (1) observations on the cost performance of DOD's 2011 portfolio of 96 major defense acquisition programs; (2) an assessment of the knowledge attained by key junctures in the acquisition process for 37 major defense acquisition programs, which were selected because they were in development or early production; (3) observations on the implementation of acquisition reforms, particularly for 16 future major defense acquisition programs that are not yet in the portfolio, which represent the best opportunity to assess DOD's progress in this area. To conduct this review, GAO analyzed cost, schedule, and quantity data from DOD's Selected Acquisition Reports and collected data from program offices on technology, design, and manufacturing knowledge; the use of knowledge-based acquisition practices; and the implementation of DOD's acquisition policy and acquisition reforms. GAO also compiled individual assessments of 68 weapon programs. Selection factors include major defense acquisition programs in development or early production, future programs, and recently cancelled programs.

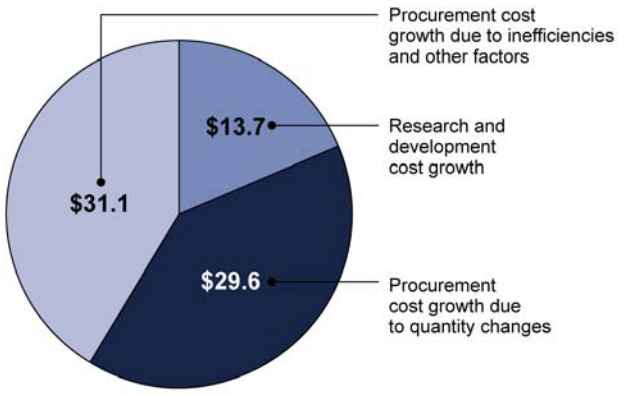
DOD agreed that cost growth has occurred, but did not fully agree with our metrics for measuring cost growth, stating that they did not adequately address when, why, and how it occurred. GAO believes the report directly addresses these distinctions.

View GAO-12-400SP. For more information, contact Michael J. Sullivan at (202) 512-4841 or sullivanm@gao.gov.

What GAO Found

The total estimated cost of the Department of Defense's (DOD) 2011 portfolio of 96 major defense acquisition programs stands at $1.58 trillion. In the past year, the total acquisition cost of these programs has grown by over $74.4 billion or 5 percent, of which about $31.1 billion can be attributed to factors such as inefficiencies in production, $29.6 billion to quantity changes, and $13.7 billion to research and development cost growth. DOD's portfolio is dominated by a small number of programs, with the Joint Strike Fighter accounting for the most cost growth in the last year, and the largest projected future funding needs. The majority of the programs in the portfolio have lost buying power in the last year as their program acquisition unit costs have increased. The number of programs in the portfolio has decreased from 98 to 96 in the past year and, looking forward, is projected to decrease again next fiscal year to its lowest level since 2004.

Cost Growth over the Past Year for DOD's 2011 Portfolio of Major Defense Acquisition Programs (Fiscal Year 2012 Dollars in Billions)



Source: GAO analysis of DOD data.

In the past 3 years, GAO has reported that newer programs are demonstrating higher levels of knowledge at key decision points. However, most of the 37 programs GAO assessed this year are still not fully adhering to a knowledge-based acquisition approach. Of the eight programs from this group that passed through one of three key decision points in the acquisition process in the past year, only one—Excalibur Increment Ib—implemented all of the applicable knowledge-based practices. As a result, most of these programs will carry technology, design, and production risks into subsequent phases of the acquisition process that could result in cost growth or schedule delays.

GAO also assessed the implementation of selected acquisition reforms and found that most of the 16 future programs we assessed have implemented key provisions of the Weapon Systems Acquisition Reform Act of 2009. Programs have also started to implement new DOD initiatives, such as developing affordability targets and conducting "should cost" analysis. Finally, as could be expected from the increased activity early in the acquisition cycle, the 16 future programs we assessed are planning to spend more funds in technology development than current major defense acquisition programs.

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Abbreviations

BMDS	Ballistic Missile Defense System
CAPE	Cost Assessment and Program Evaluation
DAMIR	Defense Acquisition Management Information Retrieval
DOD	Department of Defense
MDA	Missile Defense Agency
MDAP	major defense acquisition program
MRL	manufacturing readiness level
NA	not applicable
OMB	Office of Management and Budget
RDT&E	research, development, test, and evaluation
SAR	Selected Acquisition Report
TBD	to be determined
TRL	Technology Readiness Level

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Comptroller General
of the United States

United States Government Accountability Office
Washington, D.C. 20548

March 29, 2012

Congressional Committees

I am pleased to present GAO's annual assessment of selected weapon programs. This report provides a snapshot of how well the Department of Defense (DOD) is planning and executing its major defense acquisition programs—an item on GAO's high-risk list and an area that we have identified as having the potential for significant cost savings in our first two reports on *Opportunities to Reduce Potential Duplication in Government Programs, Save Tax Dollars, and Enhance Revenue*.[1] This year's report offers observations on the performance of DOD's $1.58 trillion portfolio of 96 major defense acquisition programs. These observations serve as measures of DOD's progress in managing weapon system cost growth and as indicators of potential challenges. This year's report also includes assessments of the risks on 68 individual weapon programs. These assessments can assist DOD and Congress in making decisions about the programs they approve and fund in a budget-constrained environment. When we issued our first annual assessment in 2003, it included 26 defense programs ranging from the Marine Corps' Advanced Amphibious Assault Vehicle to the Missile Defense Agency's Theater High Altitude Area Defense system. This edition still includes eight programs that appeared in the 2003 report, which is indicative of the lengthy development times and acquisition challenges that DOD has faced over the last 10 years.

Since we began issuing this report, Congress and DOD have made noteworthy improvements in the legal and policy frameworks that govern weapon system acquisitions by mandating and encouraging a more knowledge-based approach to the development and production of major systems. These changes have led to some improvement in the knowledge attained by programs at key points in the acquisition process, but more still needs to be done. Practice has lagged behind policy in certain areas and we have not yet seen improvements in outcomes that are commensurate with the improvements in law and policy. In our review this year, we found

[1]GAO, *High Risk Series: An Update*, GAO-11-278 (Washington, D.C.: Feb. 16, 2011); GAO, *Opportunities to Reduce Potential Duplication in Government Programs, Save Tax Dollars, and Enhance Revenue*, GAO-11-318SP (Washington, D.C.: Mar. 1, 2011); GAO, *Follow-up on 2011 Report: Status of Actions Taken to Reduce Duplication, Overlap, and Fragmentation, Save Tax Dollars, and Enhance Revenue*, GAO-12-453SP (Washington, D.C.: Feb. 28, 2012).

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that the cost to develop and produce DOD's current portfolio of major defense acquisition programs grew by over $74.4 billion, of which about $31.1 billion can be attributed to factors such as inefficiencies in production, $29.6 billion to quantity changes, and $13.7 billion to research and development cost growth. The implementation of knowledge-based acquisition practices that might prevent or mitigate the potential for cost growth has been uneven across the portfolio. For eight programs that passed through one of three key decision points in the acquisition process this year, only one implemented all of the applicable knowledge-based practices. As a result, most of these programs will carry technology, design, and production risks into subsequent phases of the acquisition process that could result in cost growth or schedule delays.

There have been some positive developments, especially with regard to DOD's future major defense acquisition programs, which are now approaching system development or will bypass system development for production. We found that most of these future programs are implementing acquisition reforms, such as competitive prototyping, early systems engineering reviews, and acquisition strategies ensuring competition or the option of competition, which have the potential to reduce risk and improve outcomes. Some of these activities require higher upfront investments in systems engineering and other areas to reduce longer term development risk, and it will be important for decision makers to sustain these investments when appropriate, even as DOD's budgetary resources shrink.



Gene L. Dodaro
Comptroller General of the United States

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Washington, D.C. 20548

March 29, 2012

Congressional Committees

This is GAO's annual assessment of selected Department of Defense (DOD) weapon system acquisitions, an area that is on GAO's high-risk list. The report is in response to the mandate in the joint explanatory statement to the DOD Appropriations Act, 2009, which requires us to perform an annual assessment.[1] This report provides a snapshot of how well DOD is planning and executing its weapon programs. Congress and DOD have long explored ways to improve the acquisition of major weapon systems, yet programs are still incurring billions of dollars in cost growth. Given the prospect of decreased defense spending, including the possibility of over $1 trillion in sequestration and other budget cuts over the next 10 years, finding ways to prevent or mitigate cost growth is crucial to our national security. In the past 3 years, we have reported improvements in the knowledge that programs attained about technologies, design, and manufacturing processes at key points during the acquisition process. DOD policy and legislation emphasize key knowledge-based acquisition practices; however, we have found that most programs continue to proceed with less knowledge than recommended, putting them at higher risk for cost growth and schedule delays.

This report includes (1) observations on the cost and schedule performance of DOD's 2011 portfolio of 96 major defense acquisition programs, (2) our assessment of the knowledge attained at key junctures in the acquisition process for 37 weapon programs in development or early production, and (3) observations on the extent to which DOD is

[1]See Explanatory Statement, 154 Cong. Rec. H 9427, 9526 (daily ed., Sept. 24, 2008), to the Department of Defense Appropriations Act Fiscal Year 2009, contained in Division C of the Consolidated Security, Disaster Assistance, and Continuing Appropriations Act, 2009, Pub. L. No. 110-329.

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implementing acquisition reforms, particularly for 16 future major defense acquisition programs.[2]

There are three sets of programs on which our observations are based in this report:

- We assessed all 96 major defense acquisition programs in DOD's 2011 portfolio for our analysis of cost and schedule performance. To develop our observations, we obtained cost, schedule, and quantity data from DOD's December 2010 Selected Acquisition Reports (SAR) and from the Defense Acquisition Management Information Retrieval Purview system. The Ballistic Missile Defense System (BMDS) is excluded from these observations because comparable cost and quantity data are not available.

- We assessed 37 major defense acquisition programs that were mostly between the start of development and the early stages of production for our analysis of knowledge attained at key junctures and the implementation of acquisition reforms. To develop our observations, we obtained information on the extent to which the programs follow knowledge-based practices for technology maturity, design stability, and production maturity using a data-collection instrument. We also submitted a survey to program offices to collect information on systems engineering reviews, design stability, manufacturing planning and execution, and the implementation of specific acquisition reforms. We received survey responses from all 37 programs.

- We assessed an additional 16 future major defense acquisition programs that we selected because they were preparing to enter system development or production. These programs represent the best opportunity to assess DOD's progress in implementing selected acquisition reforms. To develop our observations, we submitted a survey to program offices to collect information on the implementation

[2]Major defense acquisition programs are those identified by DOD that require eventual total research, development, test, and evaluation (RDT&E) expenditures, including all planned increments, of more than $365 million, or procurement expenditures, including all planned increments, of more than $2.19 billion, in fiscal year 2000 constant dollars. DOD has a list of programs designated as pre–major defense acquisition programs (pre-MDAP). These programs have not formally been designated as MDAPs; however, DOD plans for these programs to enter system development, or bypass development and begin production, at which point they will likely be designated as MDAPs. We refer to these programs as future major defense acquisition programs throughout this report.

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of these reforms and other data and received responses from all the programs.

In addition to our observations, we present individual assessments of 68 weapon programs. Selection factors include major defense acquisition programs in development or early production, future programs, and recently cancelled programs.

We conducted this performance audit from August 2011 to March 2012 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings based on our audit objectives. Appendix I contains detailed information on our scope and methodology.

Observations on the Cost Performance of DOD's 2011 Major Defense Acquisition Program Portfolio

The cost of DOD's 2011 portfolio of major defense acquisition programs continues to grow, and the delays in delivering capability to the warfighter have gotten longer. Our analysis of the 96 programs in DOD's 2011 portfolio of major defense acquisition programs allows us to make nine observations.

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Cost Performance Observations

1. The estimated cost of DOD's 2011 portfolio stands at about $1.58 trillion and has grown by over $74 billion or 5 percent in the past year.[a]
2. About $30 billion of this growth can be attributed to quantity changes within major defense acquisition programs; the other $45 billion is due to research and development cost growth and production inefficiencies.[b]
3. Many of the programs in the portfolio with the greatest growth in estimated research and development costs in the last year are already in production and either experienced growth because of lingering development issues or added funding for upgrades or modernization efforts.
4. The cost of the portfolio is driven by the 10 highest-cost programs, which account for 55 percent of its total cost.
5. The Joint Strike Fighter accounts for 21 percent of the total cost of the portfolio and 52 percent, or about $39 billion, of the cost growth in the past year.
6. Ninety-one percent of the funding needed to complete the programs in the portfolio is for procurement, with most of that for a few large programs.
7. Over 60 percent of programs have lost buying power in the last year—as measured by an increase in program acquisition unit cost—depriving DOD of funding that could have been used for additional quantities or other priorities.
8. About 40 percent of the programs have experienced cost increases in the past year that exceed cost growth targets discussed by DOD, the Office of Management and Budget (OMB), and GAO; and over 50 percent exceeded the targets for growth in the past 5 years and since the first full estimate.
9. Looking forward, the number of programs in DOD's 2012 portfolio is projected to be the smallest since 2004 as more programs continue to leave the portfolio than enter it—a positive sign that DOD is adjusting its number of programs to meet resources.

[a]All dollar figures are in fiscal year 2012 constant dollars, unless otherwise noted.

[b]Discussion of growth in the 2011 portfolio does not include BMDS as DOD does not consider adjustments to this system to represent cost growth because the program has been allowed to add 2 years of new funding with each biennial budget. See GAO, *Missile Defense: Actions Needed to Improve Transparency and Accountability*, GAO-11-372 (Washington, D.C.: Mar. 24, 2011) for an assessment of the Missile Defense Agency's (MDA) cost, schedule, testing, and performance progress in developing BMDS.

Additional details about each observation follow.

- **The total cost of DOD's 2011 portfolio of major defense acquisition programs has grown by over $74 billion, or 5 percent, in the last year.** The over $74.4 billion in cost growth over the past year consists of a rise in development costs of $13.7 billion, or 4 percent, and an increase in procurement costs of $60.6 billion, or 5 percent. When

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measured from their first full estimates, which have been put in place over a number of years, the growth in total acquisition cost for these programs is $447 billion, or 40 percent. In addition, programs continue to deliver capabilities later than anticipated, with the average delay increasing by 1 month in the past year, and averaging 23 months when measured against a program's first full estimate. Table 1 shows the increases in programs' estimated cost and schedule over the last year, and appendix II presents our analysis of cost growth and delays over the past 5 years and against first full estimates.

Table 1: Changes in DOD's 2011 Portfolio of 96 Major Defense Acquisition Programs over the Past Year

Fiscal year 2012 dollars in billions

	Estimated portfolio cost in 2010	Estimated portfolio cost in 2011	Estimated portfolio growth since 2010[a]	Percentage growth since 2010
Total estimated research and development cost	$310	$324	$14	4%
Total estimated procurement cost	1,160	1,221	61	5
Total estimated acquisition cost[b]	1,503	1,578	74	5
Average delay in delivering initial capabilities	—	—	1 month	2

Source: GAO analysis of DOD data.

Note: Figures may not add due to rounding.

[a]The portfolio cost columns do not include the reported cost or cost growth of BMDS. DOD does not consider changes in BMDS costs to represent cost growth because the program has been allowed to add 2 years of new funding with each biennial budget.

[b]In addition to research and development and procurement costs, total acquisition cost includes acquisition-related operation and maintenance and system-specific military construction costs. Details on program costs used for this analysis are provided in app. III.

- **Quantity changes account for almost $30 billion of the nearly $61 billion in procurement cost growth over the last year.** Of the $60.6 billion in procurement cost growth realized in the past year, $29.6 billion

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is attributable to adjustments in quantities on 36 programs.[3] Twenty-two programs experienced procurement cost increases due to added quantities. The Littoral Combat Ship reported its total planned procurement for the first time in 2010 and accounts for most of this increase.[4] Fourteen programs experienced procurement cost decreases due to reductions in quantities. The Expeditionary Fighting Vehicle and Medium Extended Air Defense System, which had their production quantities reduced significantly after they were cancelled, account for most of the decrease. The remaining $31.1 billion in procurement cost growth cannot be attributed to quantity changes and is indicative of production problems and inefficiencies or flawed initial cost estimates. For example, the cost to procure the Joint Strike Fighter rose by almost $35 billion because of manufacturing inefficiencies, parts shortages, and quality issues; the number of aircraft procured did not change. Other programs, such as the Virginia-class submarine and the E-2D Advanced Hawkeye, were able to reduce their expected procurement costs without reducing quantities, by improving production processes or negotiating contracts with terms more favorable to the government. Table 2 shows how procurement costs changed across the DOD portfolio due to changes in planned procurement quantities as well as other factors.

[3]To calculate the portion of procurement cost growth attributable to quantity changes, we compared a program's quantities from the December 2009 SAR with its quantities from the December 2010 SAR. When quantities changed, we multiplied the change by the previous average procurement unit cost, using the December 2009 SAR estimate where available, to determine the expected cost growth or decrease due to these quantity changes. The Joint Tactical Radio System Handheld, Manpack, and Small Form Fit changed the mix as well as the quantity of radios procured but this change to radio type is not accounted for in our calculations. The Gray Eagle unmanned aircraft program changed how it calculates quantities for the 2010 SAR. We based our calculation on the change in procurement cost due to quantity for that program on the number of aircraft procured to account for this. See app. I for additional information on our scope and methodology.

[4]The Littoral Combat Ship program was initiated in May 2004 with an acquisition program baseline that included 2 procurement-funded ships. The program did not report its total planned procurement quantity of 53 ships until the December 2010 SAR.

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Table 2: Change in Procurement Cost Due to Quantity Changes and Other Factors

Fiscal year 2012 dollars in billions

	Number of programs	Actual cost change	Estimated cost change directly attributable to quantity changes	Estimated cost change not directly attributable to quantity changes
Programs with quantity increases	22	$53.6	$63.0	-$9.3
Programs with quantity decreases	14	-28.1	-33.4	5.2
Programs with no change in quantity	59	35.2	0	35.2
Total	**95[a]**	**$60.6**	**$29.6**	**$31.1**

Source: GAO analysis of DOD data.

Note: Figures may not add due to rounding.

[a]The analysis does not include BMDS.

- **Many of the programs with the highest amounts of research and development cost growth in the last year are in production and are utilizing concurrent development and production strategies or funding modernization or upgrade efforts.** Over the past year, the research and development cost associated with the 2011 portfolio has risen 4 percent, or roughly $14 billion, and programs in production account for the overwhelming majority of this growth. This runs counter to what one might expect, namely that programs in production are beyond the point of development cost increases. Table 3 lists examples of these programs and the reasons they cited for their research and development cost growth in the past year.

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Table 3: Examples of Programs with Significant Research and Development Cost Growth in the Past Year

Program	Growth in last year (dollars in millions)	Reason for growth	Start of production
Joint Strike Fighter	$3,922	Additional funding to reduce risk	2007
Space Based Infrared System High Program	785	Additional funding needed to meet requirements	2001
F-22 Raptor	780	Additional funding for modernization	2001
P-8A Poseidon	742	Additional funding for new increment of capability, correction of deficiencies, and updated estimates	2010
Virginia-class Submarine	727	Additional funding for enhancements, cost reduction initiatives, and testing	1997
Global Hawk	722	Additional funding for the inclusion of new capabilities and testing	2001
DDG 51 Destroyer	656	Additional funding for the inclusion of new capabilities	1985
Trident II Missile	624	Additional funding for modernization and replacement	1987
Apache Block IIIA Remanufacture	506	Additional funding for software development	2010

Source: GAO analysis of DOD data.

Several of these programs, including the Joint Strike Fighter, Space Based Infrared System High, and Apache Block IIIA Remanufacture, have concurrent development and production strategies, which increases manufacturing risk and can result in increased cost and schedule if problems are discovered late in design or production. Other programs, such as the F-22 Raptor, Virginia-class submarine, DDG 51 Destroyer, and Trident II Missile, have begun efforts to add capability to or modernize the system within the existing program. The P-8A Poseidon and Global Hawk have done both. According to DOD's primary acquisition policy—Department of Defense Instruction 5000.02—upgrades, improvements, and similar efforts that provide a significant increase in operational capability and meet the major defense acquisition program threshold should be managed as

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separate increments.[5] None of the efforts in these six programs were being managed as separate increments.

- **The cost of the portfolio is driven by the 10 highest-cost programs, which account for 55 percent of the total.** DOD's portfolio of major defense acquisition programs is unbalanced. As shown in table 4, the 10 highest-cost programs account for 55 percent, or roughly $868 billion, of the 2011 portfolio's $1.58 trillion total acquisition cost. These programs are also driving overall portfolio outcomes and account for over $53 billion, or about 72 percent, of the total cost growth for the portfolio in the past year. All 10 of these programs are currently in production and all but three—the Joint Strike Fighter, the CVN 78 Class, and the P-8A Poseidon—have attained initial operational capability.

Table 4: Ten Highest-Cost Acquisition Programs in 2011 Portfolio

Fiscal year 2012 dollars in billions

Program	Total acquisition cost	Percent of 2011 portfolio cost
Joint Strike Fighter	$327	21
DDG 51 Destroyer	102	6
Virginia-class Submarine	84	5
F-22 Raptor	79	5
F/A-18E/F Super Hornet	58	4
V-22 Osprey	57	4
Trident II Missile	53	3
Joint Mine Resistant Ambush Protected Vehicle	42	3
CVN 78 Class	34	2
P-8A Poseidon	33	2
Total	**$868**	**55**

Source: GAO analysis of DOD data.

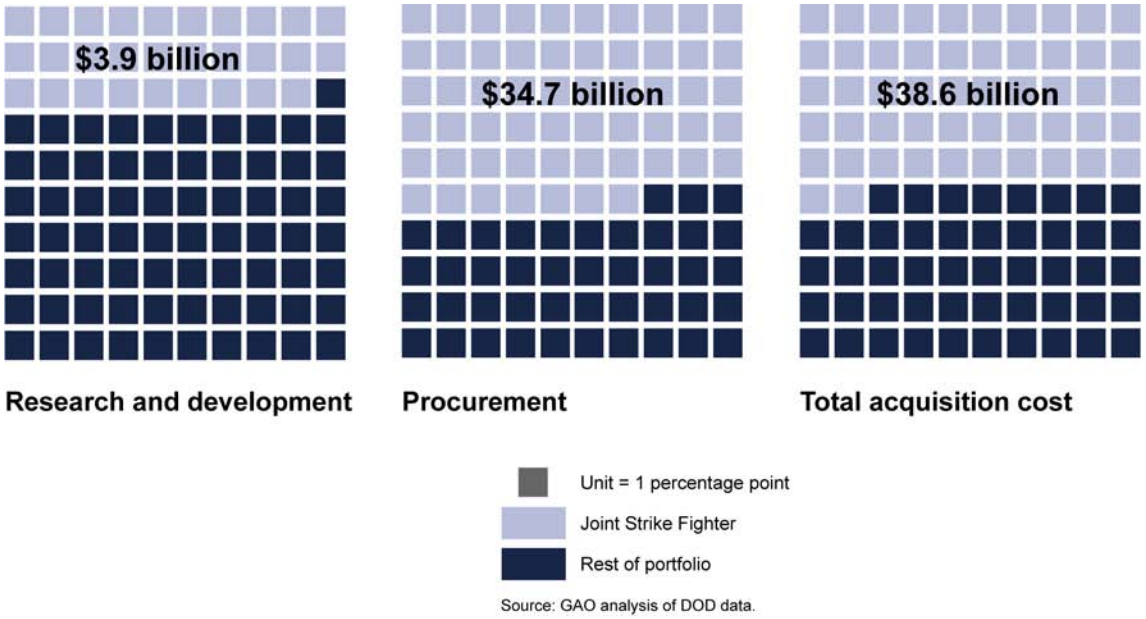
Note: Figures may not add due to rounding.

[5]Department of Defense Instruction 5000.02, *Operation of the Defense Acquisition System* enc. 2, para. 2.(c) (Dec. 8, 2008).

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- **The Joint Strike Fighter is driving much of DOD's poor portfolio performance and it will continue to drive outcomes for the foreseeable future.** Among the 96 programs in DOD's 2011 portfolio, the Joint Strike Fighter is the costliest, the poorest performer in terms of cost growth, and the program with the largest remaining funding needs. The Joint Strike Fighter accounts for 21 percent, or nearly $327 billion, of the planned total acquisition cost of the portfolio. It is also responsible for the most significant research and development, procurement, and total acquisition cost growth in the past year, as shown in figure 1. This growth took place without any change in procurement quantities by the program.

Figure 1: Joint Strike Fighter as a Portion of 2011 Portfolio Cost Growth



Source: GAO analysis of DOD data.

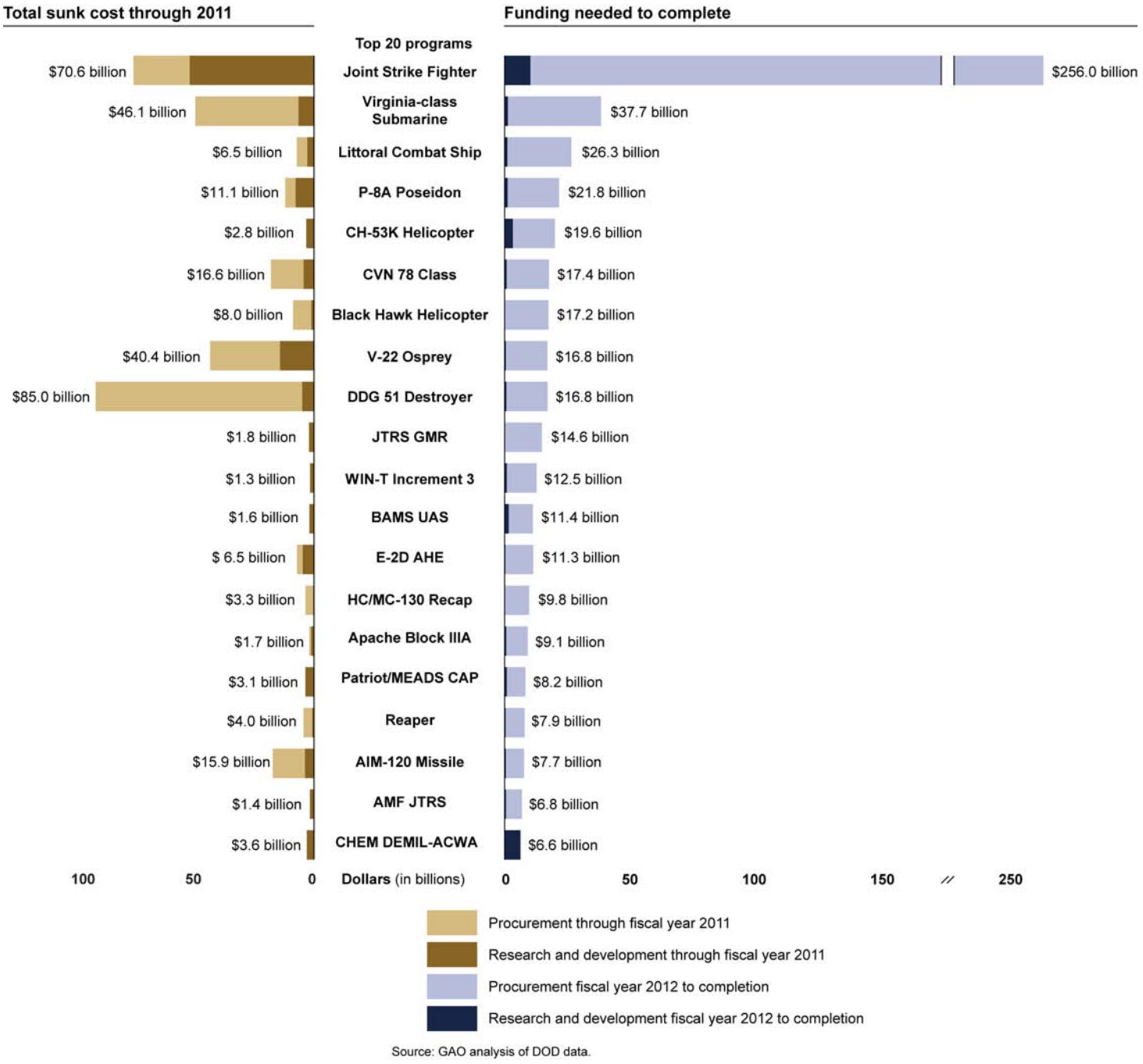
- **Most of the remaining funding for the 2011 portfolio is for procurement.** Over 91 percent of the almost $705 billion needed to complete the programs in the 2011 portfolio consists of procurement funding; therefore, any future funding cuts to these programs will likely result in quantity reductions. The Joint Strike Fighter program alone is expected to account for 38 percent—or almost $246 billion—of the future procurement funding needed. This amount is enough to fund the remaining procurement costs of the next 15 largest programs. Figure 2

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shows the funding spent and still needed for the 20 programs with the highest remaining funding needs.

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Figure 2: Twenty Costliest Acquisition Programs by Funding Needed to Complete



Source: GAO analysis of DOD data.

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Note: BMDS is excluded from this analysis. JTRS GMR is the Joint Tactical Radio System Ground Mobile Radios; this program was terminated during the course of our review. WIN-T Increment 3 is the third increment of the Warfighter Information Network-Tactical program. BAMS UAS is the Broad Area Maritime Surveillance Unmanned Aircraft System. E-2D AHE is the Advanced Hawkeye. HC/MC-130 Recap is the recapitalization program for the HC/MC-130 aircraft. Patriot/MEADS CAP is the Patriot/Medium Extended Air Defense System Combined Aggregate Program. AMF JTRS is the Airborne and Maritime/Fixed Station Joint Tactical Radio System. CHEM-DEMIL ACWA is Chemical Demilitarization-Assembled Chemical Weapons Alternatives.

- **Buying power, as measured by program acquisition unit cost, has decreased for over 60 percent of programs over the past year.** Of the 96 programs or components in DOD's portfolio that reported program acquisition unit cost data, 61 are planning to deliver capabilities at higher unit costs than estimated a year ago while 35 are planning to deliver capabilities at or below the same estimates.[6] Unit costs are sensitive to how many are being bought. If quantities are decreased, unit costs would be expected to go up and vice versa. However, only 11 of the 61 programs with unit-cost increases in the past year decreased quantities in the past year, indicating that unit-cost growth in the other 50 cases was due to actual research and development or procurement cost growth—not changes in quantities. We did not examine whether these programs delivered a higher or lower level of performance than initially planned.

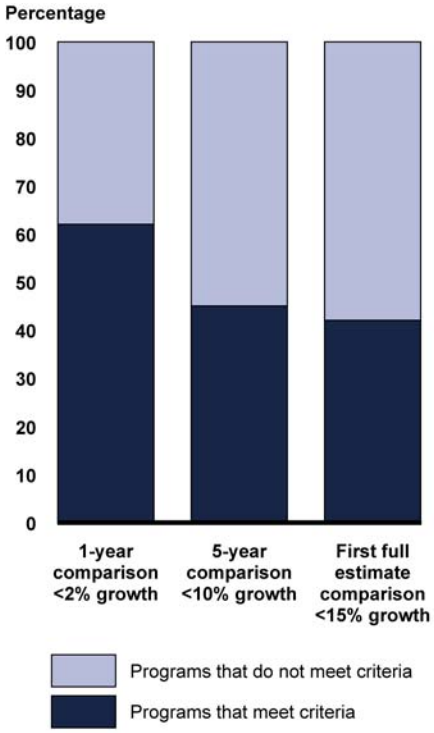
- **Less than half of the programs in the 2011 portfolio met cost-growth targets used to measure DOD's progress on addressing GAO's weapon system acquisition high-risk area.** In December 2008, DOD, OMB, and GAO discussed a set of cost growth metrics and goals to evaluate DOD's progress on improving program performance for purposes of our high-risk report. These metrics were designed to capture total cost-growth performance over 1-year and 5-year periods as well as from the original program estimate on a percentage basis as opposed to dollar amount to control for the disparity in the amount of funding between programs. As shown in figure 3, 40 percent of major defense acquisition programs did not meet the criteria for less than 2

[6]Program acquisition unit cost is the total cost for development, procurement, acquisition operation and maintenance, and system-specific military construction for the acquisition program divided by the number of items to be produced. DOD's 2011 portfolio includes 96 programs with SARs; however, DOD's SAR summary tables break down several of these programs into smaller elements. We did not include BMDS or the National Polar-orbiting Operational Environmental Satellite System because comparable cost and quantity data were not available, or the Expeditionary Fighting Vehicle and Patriot/Medium Extended Air Defense System Combined Aggregate Program Fire Unit, because these programs were cancelled.

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percent growth in total acquisition cost over the past year, and over half did not meet the less than 10 percent metric for growth over a 5-year period and the less than 15 percent metric from their first full estimate. When measured against the same criteria for growth using program acquisition unit cost or average procurement unit cost, the percent of programs that do not meet the criteria remain roughly the same.

Figure 3: Programs Meeting High-Risk Cost Metrics



Source: GAO analysis of DOD data.

Notes: The number of programs represents those in the 2011 portfolio—those with December 2010 SARs—which break down several programs into smaller elements for reporting purposes. One program, Airborne Signals Intelligence Payload (ASIP), was not included in the 5-year comparisons because data were not available to make that comparison. BMDS was not included in this analysis.

- **The number of programs in DOD's portfolio decreased in fiscal year 2011 and, looking forward, is expected to decrease again in the next fiscal year to its lowest level since 2004.** DOD's portfolio for 2011 contains 96 major defense acquisition programs, a net decrease of 2 since last year. Six programs left the portfolio and four programs

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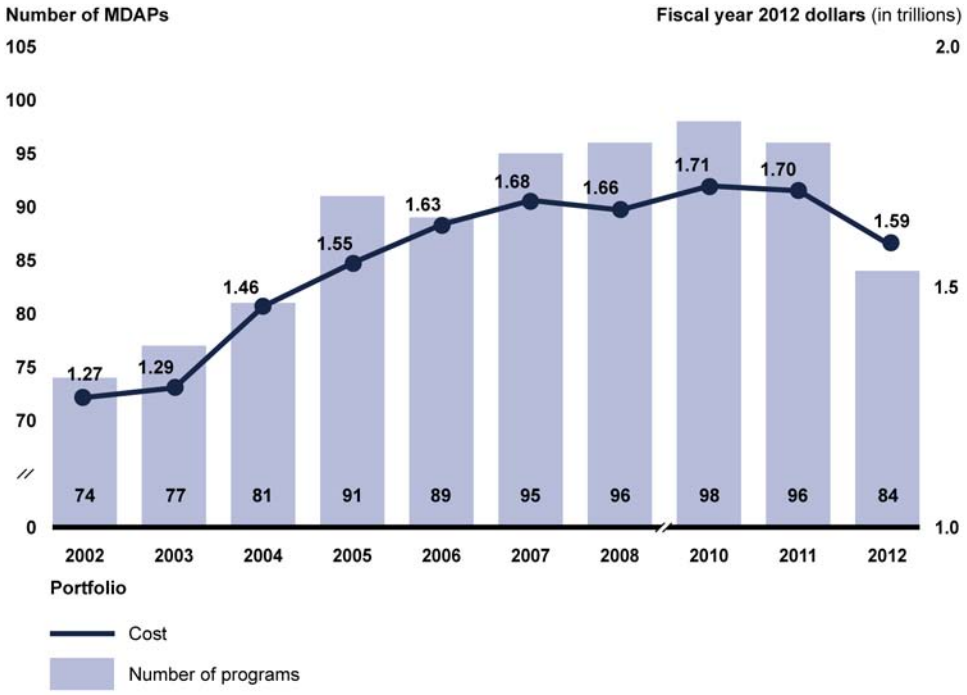
entered.[7] The six programs that left the portfolio cost an estimated $108 billion to develop and produce, and the four new entries are expected to cost $29 billion. Based on DOD data on programs that will enter and exit the portfolio in fiscal year 2011, we project that the number of programs and DOD's total planned investment in them will decrease again in the next fiscal year.[8] As shown in figure 4, the expected decrease would reduce the number of programs to its lowest level since 2004.

[7]The six programs that exited the portfolio were Bradley armored fighting vehicle upgrade, C-17A aircraft, CVN 68 aircraft carrier, EA-6B Improved Capability III aircraft, Minuteman III Propulsion Replacement Program, and the MQ-1B Predator unmanned aircraft. The four that entered were Apache Block IIIB New Build helicopter, HC/MC-130 Recapitalization program, KC-130J aircraft, and Small Diameter Bomb Increment II.

[8]The programs exiting the portfolio in 2012 will do so because of cancellation or delivery of 90 percent of end items. Programs include: Airborne Signals Intelligence Payload, Advanced Threat Infrared Countermeasure/Common Missile Warning System, B-2 Radar Modernization Program, C-5 Avionics Modernization Program, Expeditionary Fighting Vehicle, F-22 Raptor, Force XXI Battle Command Brigade and Below, Increment 1 Early-Infantry Brigade Combat Team, Joint Mine Resistant Ambush Protected vehicle, Large Aircraft Infrared Countermeasures, Longbow Apache, Space Based Space Surveillance Block 10, and the Lewis and Clark-class Dry Cargo/Ammunition ship (T-AKE). The one program that is currently scheduled to become a major defense acquisition program and begin annual selected acquisition reporting in fiscal year 2012 is the KC-46 Tanker Modernization Program.

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Figure 4: Number of Programs in DOD Portfolio over the Past 10 Years



Source: GAO analysis of DOD data.

Note: The 2009 portfolio is excluded because there were no annual SARs released for 2008. The 2012 portfolio is projected from DOD data.

It is not clear whether this reduction in the number of programs in the portfolio is the result of DOD's recognition of the increasing constraints on the defense budget and the beginning of a longer-term trend or whether it is a 1-year anomaly resulting from a number of large and capital-intense programs, such as F-22 and the Joint Mine Resistant Ambush Protected vehicle, leaving the portfolio. Regardless, if the cost growth of the programs remaining in the portfolio can be controlled, the end result would be a better balance between the number of programs and DOD's available resources.

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Observations from Our Assessment of Knowledge Attained by Programs That Have Not Yet Reached Full-Rate Production

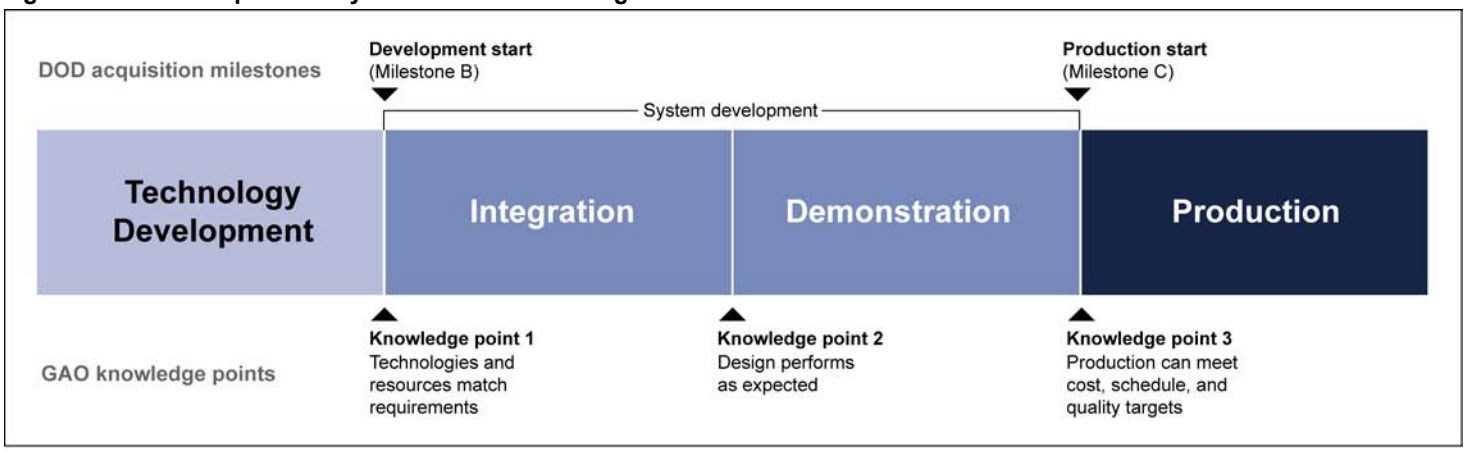
Positive acquisition outcomes require the use of a knowledge-based approach to product development that demonstrates high levels of knowledge before significant commitments are made. In essence, knowledge supplants risk over time. In our past work examining weapon acquisitions and best practices for product development, we have found that leading commercial firms and successful DOD programs pursue an acquisition approach that is anchored in knowledge, whereby high levels of product knowledge are demonstrated by critical points in the acquisition process.[9] On the basis of this work, we have identified three key knowledge points during the acquisition cycle—development start, critical design review, and production start—at which programs need to demonstrate critical levels of knowledge to proceed.[10] Figure 5 aligns the acquisition milestones described in DOD's primary acquisition policy with these knowledge points. In this report, we refer to DOD's engineering and manufacturing development phase as system development. Production start typically refers to a program's entry into low-rate initial production.

[9]GAO, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*, GAO/NSIAD-99-162 (Washington, D.C.: July 30, 1999); GAO, *Best Practices: Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes*, GAO-01-288 (Washington, D.C.: Mar. 8, 2001); GAO, *Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*, GAO-02-701 (Washington, D.C.: July 15, 2002); GAO, *Defense Acquisitions: A Knowledge-Based Funding Approach Could Improve Major Weapon System Program Outcomes*, GAO-08-619 (Washington, D.C.: July 2, 2008); GAO, *Best Practices: High Levels of Knowledge at Key Points Differentiate Commercial Shipbuilding from Navy Shipbuilding*, GAO-09-322 (Washington, D.C.: May 13, 2009); GAO, *Best Practices: DOD Can Achieve Better Outcomes by Standardizing the Way Manufacturing Risks Are Managed*, GAO-10-439 (Washington, D.C: Apr. 22, 2010).

[10]For shipbuilding programs, we have identified two key knowledge points during the acquisition cycle—detail design contract award and fabrication start.

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Figure 5: DOD's Acquisition Cycle and GAO Knowledge Points



Source: GAO.

The building of knowledge consists of information that should be gathered at these three critical points over the course of a program:

Knowledge point 1: Resources and requirements match. Achieving a high level of technology maturity by the start of system development is one of several important indicators of whether this match has been made. This means that the technologies needed to meet essential product requirements have been demonstrated to work in their intended environment. In addition, the developer should complete a series of systems engineering reviews culminating in a preliminary design of the product that shows the design is feasible. Constraining the development phase of a program to 5 to 6 years is also recommended because it aligns with DOD's budget planning process and increases funding predictability. For shipbuilding programs, critical technologies should be matured into actual system prototypes and successfully demonstrated in a realistic environment before a contract is awarded for detail design of a new ship.

Knowledge point 2: Product design is stable. This point occurs when a program determines that a product's design will meet customer requirements, as well as cost, schedule, and reliability targets. A best practice is to achieve design stability at the system-level critical design review, usually held midway through system development. Completion of at least 90 percent of engineering drawings at this point provides tangible evidence that the product's design is stable, and a prototype demonstration shows that the design is capable of meeting performance

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requirements. Shipbuilding programs should demonstrate design stability by completing 100 percent of the basic and functional drawings as well as the three-dimensional product model, when employed, by the start of construction for a new ship. Programs can also improve the stability of their design by conducting reliability growth testing and completing failure modes and effects analyses so fixes can be incorporated before production begins. At this point, programs should also begin preparing for production by identifying manufacturing risks, key product characteristics, and critical manufacturing processes.

Knowledge point 3: Manufacturing processes are mature. This point is achieved when it has been demonstrated that the developer can manufacture the product within cost, schedule, and quality targets. A best practice is to ensure that all critical manufacturing processes are in statistical control—that is, they are repeatable, sustainable, and capable of consistently producing parts within the product's quality tolerances and standards—at the start of production. Demonstrating critical processes on a pilot production line is an important initial step in this effort. In addition, production and postproduction costs are minimized when a fully integrated, capable prototype is demonstrated to show that the system will work as intended in a reliable manner before committing to production. We did not assess shipbuilding programs for this knowledge point due to differences in the production processes used to build ships.

A knowledge-based acquisition approach is a cumulative process in which certain knowledge is acquired by key decision points before proceeding. Demonstrating technology maturity is a prerequisite for moving forward into system development, during which the focus should be on design and integration. A stable and mature design is likewise a prerequisite for moving forward into production where the focus should be on efficient manufacturing. Additional details about key practices at each of the knowledge points can be found in appendix IV.

Overall, we assessed the knowledge attained by key junctures in the acquisition process for 37 individual weapon programs, which are mostly in development or early production.[11] In particular, we focused on the eight

[11]Not all programs provided information for every knowledge point or had reached all of the knowledge points—development start, design review, and production start. Because knowledge points and best practices differ for shipbuilding programs, we exclude the five shipbuilding programs in our assessment from some of our analysis.

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programs from this group that progressed through key acquisition points in 2011—one program began system development, four programs held critical design reviews, and three programs began production. Only one of these eight programs—Excalibur Increment Ib—implemented all of the applicable knowledge-based acquisition practices at these points; and overall, most of the 37 programs we assessed are not fully adhering to a knowledge-based approach, putting them at higher risk of cost growth and schedule delays. Our analysis of the eight programs that went through key acquisition points in 2011 allows us to make three observations.

Knowledge Point Observations

1. The one program that began system development in 2011 did so with all of its critical technologies nearing maturity, but without demonstrating them in a realistic environment.

2. Three of four programs that held critical design reviews in 2011 did so with stable designs, but only one tested an integrated prototype to demonstrate that the design was capable of meeting performance requirements.

3. One of the three programs that held a production decision in 2011 reported that its critical manufacturing processes were in control; one of the three programs demonstrated their production processes on a pilot production line; and two of the three programs tested production-representative prototypes to demonstrate reliable performance.

Additional detail about these observations follows.

- **The only program in our assessment that began development in 2011 did so with all of its critical technologies nearing maturity, but without demonstrating them in a realistic environment.** The KC-46 tanker began development with all its critical technologies at least nearing maturity—that is, demonstrated in a relevant environment—in accordance with DOD policy and statutory requirements.[12] Models of these technologies were demonstrated on other aircraft or in simulations. However, knowledge-based acquisition

[12]According to DOD policy, in order to be considered mature enough to use in product development, technology shall have been demonstrated in a relevant environment or, preferably, in an operational environment. Department of Defense Instruction 5000.02, *Operation of the Defense Acquisition System*, enc. 2, para. 5.d(4). In addition, a major defense acquisition program may not receive milestone B approval (development start) until the milestone decision authority certifies that the technology in the program has been demonstrated in a relevant environment. 10 U.S.C. § 2366b(a)(3)(D).

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practices recommend and DOD policy prefers that programs fully mature technologies and demonstrate them in a realistic or operational environment prior to entering system development, to gain additional knowledge about the technologies' form, fit, and function as well as the effect of the intended environment on those technologies.[13] Our analysis of the 37 programs in our assessment that provided technology data shows that 20 programs reported having all critical technologies at least nearing maturity prior to entering system development, with only 4 of those fully maturing their technologies. Of the five shipbuilding programs we assessed, only one had all its critical technologies fully mature before awarding its detailed design contract, the point at which technology maturity should be achieved.

Key acquisition practices also recommend, and statute requires, that programs hold systems engineering events, such as a preliminary design review, before development start to ensure that requirements are defined and feasible and that the proposed design can meet those requirements within cost, schedule, and other system constraints.[14] The KC-46 program received a waiver to enter development without conducting a preliminary design review, and plans to hold it in March 2012, about 13 months after development start. Overall, 29 of the 37 programs we assessed failed to hold preliminary design reviews prior to the start of development or the award of their detailed design contracts. Our analysis shows that these programs experienced, on average, more research and development cost growth and total acquisition cost growth than programs that held the review before these points.

Knowledge-based acquisition practices also recommend limiting the time a program or an increment of a program spends in development to

[13]Demonstration in a relevant environment is Technology Readiness Level (TRL) 6. Demonstration in a realistic environment is TRL 7. See app. V for a detailed description of TRLs.

[14]GAO, *Defense Acquisitions: Assessments of Selected Weapon Programs*, GAO-09-326SP (Mar. 30, 2009). A major defense acquisition program may not receive milestone B approval until the program has held a preliminary design review and the milestone decision authority has conducted a formal postpreliminary design review assessment and certified on the basis of such assessment that the program demonstrates a high likelihood of accomplishing its intended mission. 10 U.S.C. § 2366b(a)(2).

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5 or 6 years, and the KC-46 program plans to do so.[15] Constraining development time in this manner increases the predictability of funding needs as well as the likelihood of program success. Of the 32 programs whose development cycles we assessed, 21 currently plan to constrain their development time to 6 years or less. We did not assess shipbuilding programs against this metric as their development cycles do not align in a manner consistent with other programs. Figure 6 summarizes the KC-46 program's implementation of knowledge-based acquisition practices related to development start.

Figure 6: Implementation of Knowledge-Based Practices by a Program Beginning System Development in 2011

Knowledge-based practices at development start	KC-46
Demonstrate critical technologies in a relevant environment	●
Demonstrate critical technologies in a realistic environment	○
Complete preliminary design review	○
Constrain development phase to 6 years or less	●

● Practice implemented by program
○ Practice not implemented by program
——— Information not available
Practice not applicable

Source: GAO analysis of DOD data.

- **Three of four programs in our assessment that held a critical design review in 2011 demonstrated that their designs were stable, but only one showed that its design would perform as intended.** Knowing a product's design is stable before system demonstration reduces the risk of costly design changes occurring during manufacturing of production-representative prototypes—when investments in acquisition become more significant. For shipbuilding

[15]Additionally, DOD policy provides that a condition for exiting the technology development phase is that a system or increment can be developed for production within a short time frame, defined as normally less than 5 years for weapon systems. Department of Defense Instruction 5000.02, *Operation of the Defense Acquisition System*, enc. 2, para. 5.d(7).

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programs, starting fabrication of the lead ship with a stable design can minimize out-of-sequence work and rework, as Navy lead ships often become the platform upon which planned capabilities are eventually proven. Three of the four programs that completed a critical design review in 2011 stabilized their designs by releasing at least 90 percent of their total expected design drawings. Overall, 8 of the 37 programs we assessed released over 90 percent of their total expected design drawings before holding a critical design review or, for ships, demonstrated stable designs by completing 100 percent of their three-dimensional design models prior to the start of fabrication.

We have previously reported that early system prototypes are useful to demonstrate that the design will work as anticipated and can be built within cost and schedule. Only one of the four programs that held its critical design review in 2011—the Excalibur Increment Ib—demonstrated that its design was capable of meeting performance requirements by testing an integrated prototype before the design review. On average, the other three programs plan to test an integrated prototype 15 months after the critical design review, similar to the 13-month average we reported in last year's assessment. Overall, only 5 of the 32 programs we assessed for this purpose tested a system-level integrated prototype by the time of their critical design review. We did not assess shipbuilding programs against this metric as testing a system-level prototype in these programs may not be practical.

Reliability growth testing provides visibility over how reliability is improving and uncovers design problems so fixes can be incorporated before production begins. Three of the four programs that held a critical design review in 2011 established a reliability growth curve. Overall, 18 of the 37 programs we assessed had a reliability growth curve by the same point. Figure 7 shows how the four programs that held critical design reviews in 2011 performed against these and other knowledge-based practices.

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Figure 7: Implementation of Knowledge-Based Practices by Programs Holding Critical Design Reviews in 2011

Knowledge-based practices at critical design review	BAMS UAS	Excalibur Inc. Ib	Reaper	SDB II
Demonstrate critical technologies in a realistic environment	●	●	●	○
Release at least 90 percent of design drawings	○	●	●	●
Test a system-level integrated prototype	○	●	○	○
Use a reliability growth curve	●	●	○	●
Conduct producibility assessments to identify manufacturing risks for key technologies	○		●	●
Identify key product characteristics	●	●	○	●
Identify critical manufacturing processes			●	●
Complete failure modes and effects analysis	●		○	●

● Practice implemented by program
○ Practice not implemented by program
——— Information not available
Practice not applicable

Source: GAO analysis of DOD data.

Note: BAMS UAS is the Broad Area Maritime Surveillance Unmanned Aircraft System. SDB II is the Small Diameter Bomb Increment II.

- **One of the three programs that held a production decision in 2011 had its critical manufacturing processes in control; one of the three demonstrated production processes on a pilot production line; and two of the three tested production-representative prototypes.** Capturing critical manufacturing knowledge before entering production helps ensure that a weapon system will work as intended and can be manufactured efficiently to meet cost, schedule, and quality targets. For example, bringing processes under statistical control reduces variations in parts manufacturing, thus reducing the potential for defects, and is generally less costly than performing extensive inspection after a product is built. One of the three programs that held a production decision in 2011—Global Positioning System

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III—provided data that demonstrated its critical manufacturing processes were in control at production start.[16] Overall, 4 of the 32 programs in our production assessment provided data demonstrating their critical processes were in control. It is also DOD policy for manufacturing processes to be effectively demonstrated in a pilot-line environment before entering production.[17] One of the three programs that held a production decision in 2011—Joint Air-to-Surface Standoff Missile–Extended Range (JASSM-ER)—demonstrated its critical processes on a pilot production line. Overall, 26 of 32 programs reported that they have or planned to demonstrate their critical processes on a pilot line before production start.

Production and postproduction costs are also minimized when a fully integrated, capable prototype is demonstrated to show that the system will work as intended in a reliable manner. Since 2008, DOD policy has also required that a system be demonstrated in its intended environment using a production-representative article before entering production, which has led to an increase in the number and percentage of programs doing so.[18] Two of three programs that held production decisions in 2011 tested production-representative prototypes before committing to production. Overall, according to our analysis of survey results, one of the six programs that held their production decisions prior to 2009 tested production-representative prototypes prior to production start; and 15 of the 24 programs that have held or will hold production decisions after 2009 have tested or plan to test a production-representative prototype before those decisions. Figure 8 shows how the three programs that held production decisions in 2011 performed against relevant knowledge-based practices.

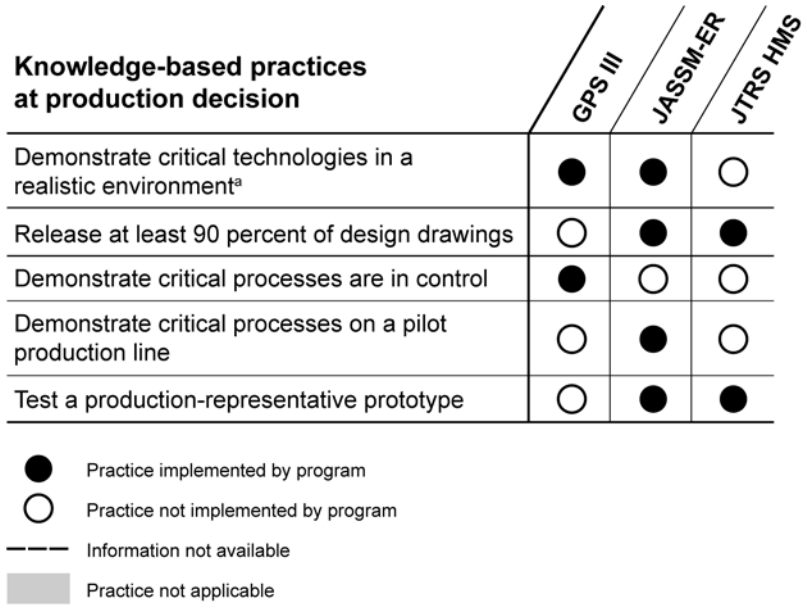
[16]In addition to using Process Capability Index data to determine whether critical processes are in control, we used data from manufacturing readiness level assessments of the process capability and control sub-thread to assess production process maturity. For more information on our methodology see app. I.

[17]Department of Defense Instruction 5000.02, *Operation of the Defense Acquisition System*, enc. 2, para. 6 (c)(6)(d).

[18]Department of Defense Instruction 5000.02, *Operation of the Defense Acquisition System*, enc. 2, para. 6 (c)(6)(d).

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Figure 8: Implementation of Knowledge-Based Practices by Programs Holding Production Decisions in 2011



Source: GAO analysis of DOD data.

Note: GPS III is the Global Positioning System III. JASSM-ER is the Joint Air-to-Surface Standoff Missile–Extended Range. JTRS HMS is the Joint Tactical Radio System Handheld, Manpack, and Small Form Fit.

[a]Critical technologies for the GPS III were demonstrated in a relevant environment which is considered mature for satellites.

Observations about DOD's Implementation of Acquisition Policy Reforms

In the past few years, a number of acquisition reform initiatives have been introduced both through legislation and through efforts undertaken by DOD; specifically the Weapon Systems Acquisition Reform Act of 2009, the reissuance of DOD Instruction 5000.02, and the Under Secretary of Defense for Acquisition, Technology and Logistics' "Better Buying Power" memorandum.[19] We assessed the implementation of four sections of the Weapon Systems Acquisition Reform Act of 2009, including requirements for major defense acquisition programs to: (1) conduct preliminary design

[19]Pub. L. No. 111-23. Department of Defense Instruction 5000.02, *Operation of the Defense Acquisition System* (Dec. 8, 2008); Office of the Under Secretary of Defense, Acquisition, Technology and Logistics Memorandum: "Better Buying Power: Guidance for Obtaining Greater Efficiency and Productivity in Defense Spending" (Sept. 14, 2010).

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reviews before development start; (2) demonstrate capabilities using competitive prototypes; (3) ensure that appropriate trade-offs among cost, schedule, and performance objectives are considered before development start; and (4) include measures to ensure competition or the option of competition throughout the programs' life cycle in their acquisition strategies. We also assessed a new requirement from the 2008 revision to DOD Instruction 5000.02 for a materiel development decision prior to a program's entry into the acquisition process and two initiatives from DOD's September 2010 better buying power memorandum focusing on affordability and "should cost" targets. Many of these reforms and others depend on increased investments of time and resources at the beginning of the acquisition process and encourage an awareness of cost performance throughout a program's life cycle. Increased funding of technology development can have beneficial effects for acquisition programs if the funds are spent on activities appropriate for that phase, such as prototype demonstrations and systems engineering analysis.

Our analysis of 16 future and 37 current major defense acquisition programs allows us to make three observations concerning DOD's progress in implementing these reforms.

Acquisition Reform Observations

1. Almost all of the future major defense acquisition programs we assessed have implemented or plan to implement acquisition reforms from the Weapon Systems Acquisition Reform Act of 2009; current programs have a mixed record in regards to implementing certification requirements from the act, such as considering appropriate trade-offs among cost, schedule, and performance objectives.
2. Some future programs have not implemented the new DOD policy requirement to hold a materiel development decision, and many future and current programs are still working to implement new initiatives, such as developing affordability targets and conducting "should cost" analysis.
3. The 16 future major defense acquisition programs we assessed are investing more funds before entering system development or production than current major defense acquisition programs, which should reduce their technical risk.

Additional information about these observations follows.

- **Almost all future programs have implemented, or plan to implement, most of the legislative reforms we examined. Current programs have waived several of the newest certification requirements.** The Weapon Systems Acquisition Reform Act of 2009

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introduced a requirement for a preliminary design review to be held for all major defense acquisition programs before the start of system development.[20] Eleven of the 16 future major defense acquisition programs in our assessment intend to conduct such a review in accordance with the act. Four of the remaining programs have not yet established a date for their preliminary design reviews; the fifth program is not required to hold a preliminary design review because it expects to enter the acquisition cycle at production start.

The Weapon Systems Acquisition Reform Act of 2009 also requires the acquisition strategy for major defense acquisition programs to provide for use of competitive prototypes before a program enters system development, which can provide a program with an opportunity to reduce technical risk, refine requirements, validate designs and cost estimates, and evaluate manufacturing processes. According to the results of our survey, 13 of the 16 future programs in our assessment intend to develop prototypes of the proposed weapon system or key subsystems before development start. Three programs do not intend to use prototyping and two of those programs intend to seek a waiver from the prototyping requirement, as provided by the act. The program that does not intend to seek the waiver—the Common Vertical Lift Support Platform—is proceeding directly to production and the competitive prototyping requirement is not applicable.

A requirement for major defense acquisition programs to have acquisition strategies that ensure competition or the option of competition throughout the acquisition life cycle was also included in the Weapon Systems Acquisition Reform Act of 2009.[21] Use of competition throughout a program's life cycle can help to reduce program costs. Measures to ensure competition or the option of competition may include developing competitive prototypes, using modular open architectures to enable competition for upgrades, and holding periodic system or program reviews to address long-term competitive effects of program decisions. Eleven of the 16 future programs in our assessment intend to use these measures or options after development start. Figure 9 summarizes the progress in implementing selected acquisition reforms for future programs.

[20]Pub. L. No. 111-23, § 205(a).

[21]Pub. L. No. 111-23, § 202.

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Figure 9: Progress in Implementing Selected Reforms in Future Major Defense Acquisition Programs

System	Hold preliminary design review	Competitive prototyping	Competitive acquisition strategy
Three Dimensional Expeditionary Long Range Radar	●	●	●
Air and Missile Defense Radar	●	●	●
B-2 Defensive Management System Modernization	TBD	●	○
B-2 Extremely High Frequency SATCOM Capability Increment 2	TBD	●	○
Combat Rescue Helicopter	TBD	○	●
Common Vertical Lift Support Platform			●
Enhanced Polar System	●	○	○
Ground Combat Vehicle	TBD	●	●
Global Positioning System OCX Ground Control Segment	●	●	○
Joint Air-to-Ground Missile	●	●	○
Joint Light Tactical Vehicle	●	●	●
Littoral Combat Ship Mission Modules	●	●	●
Nett Warrior	●	●	●
Ohio-class Replacement	●	●	●
Space Fence	●	●	●
Ship to Shore Connector	●	●	●

● Practice implemented by program
○ Practice not implemented by program
TBD To be determined
Practice not applicable or information not available

Source: GAO analysis of survey data.

The Weapon Systems Acquisition Reform Act of 2009 also required, as part of a mandatory program certification prior to development start, an analysis that appropriate trade-offs among cost, schedule, and performance objectives have been made to ensure the program is affordable.[22] The mandatory certification also requires that, before development start, a major defense acquisition program hold a

[22]Pub. L. No. 111-23, § 201(f).

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preliminary design review, have technology demonstrated in a relevant environment, have completed cost and schedule estimates with concurrence of the Director of Cost Assessment and Program Evaluation (CAPE), have funding available to execute the development and production of the program, perform an analysis to consider other alternatives, and have program requirements approved by the Joint Requirements Oversight Council. A waiver may be granted for any one or more provisions of this certification if it is determined that without the waiver the department would be unable to meet critical national security objectives. As shown in table 5, all three programs that received this certification in the past year—the KC-46 tanker, Littoral Combat Ship Seaframe, and DDG 1000 Destroyer—were granted waivers for multiple certification provisions.

Table 5: Certification Waivers Granted for Programs in 2011

Program	Waiver granted
KC-46 tanker	Trade-offs considered Full funding availability Preliminary design review held
Littoral Combat Ship Seaframe	Trade-offs considered Cost and schedule estimates with CAPE concurrence Full funding availability
DDG 1000 Destroyer	Trade-offs considered Full funding availability

Source: GAO analysis of DOD data.

Note: The DDG 1000 Destroyer program was required to be recertified following a Nunn-McCurdy unit-cost breach of the critical threshold. A breach of the critical cost growth threshold occurs when the program's acquisition unit cost or the procurement unit cost increases by at least 25 percent over the current baseline estimate or at least 50 percent over the original baseline estimate. 10 U.S.C. § 2433.

- **Some future programs have not implemented a DOD policy requirement to hold a materiel development decision, and a majority of future and current programs are still working to implement initiatives on developing affordability and "should cost" targets.** In 2008, DOD revised its primary acquisition policy to require a materiel development decision review as the formal entry point into the acquisition process. This review determines the acquisition phase where a program will enter the acquisition management system, and approves the parameters for analyzing the alternatives that might be able to address a defined capability need. Six of the 16 future programs we assessed have held or intend to hold this

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review.[23] Of the 10 future programs that did not hold a materiel development decision review, three—Three Dimensional Expeditionary Long Range Radar, Air and Missile Defense Radar, and Space Fence—began their respective technology development phases after DOD's policy instruction was revised in 2008.[24]

In September 2010, the Under Secretary of Defense for Acquisition, Technology and Logistics issued a memorandum intended to promote greater efficiency and productivity in defense spending. The memorandum emphasizes the need to treat affordability, defined as conducting a program at a cost constrained by the resources that DOD can allocate, as a key requirement akin to speed or power, and mandates establishing an affordability target at program start. According to our analysis of survey responses, 4 of the 16 future and 19 of the 37 current major defense acquisition programs we assessed have established affordability targets. For example, the Navy's planned Ohio-class submarine replacement program established an affordability target at the start of technology development. To assist in meeting this target, the Navy is working to identify areas where costs can be controlled by using existing technologies and aligning the program's production with the Virginia-class submarine. By incorporating these measures, the Navy expects to reduce the estimated cost of each submarine from $5.6 billion to $4.9 billion.

The Under Secretary's initiatives also emphasize the importance of driving cost improvements during contract negotiation and program execution. In accordance with direction provided in the memorandum, each program must conduct a "should cost" analysis justifying each element of the program with the aim of reducing negotiated prices for contracts. According to our analysis of survey responses, 6 of the 16 future and 23 of the 37 current major defense acquisition programs we assessed indicate that they have completed this type of analysis. For

[23]These programs include: B-2 Defensive Management System Modernization, Common Vertical Lift Support Platform, Ground Combat Vehicle, Combat Rescue Helicopter, Ohio-class Replacement, and Ship to Shore Connector.

[24]The programs that do not plan to hold a materiel development decision include: Three Dimensional Expeditionary Long Range Radar, Air and Missile Defense Radar, B-2 Extremely High Frequency SATCOM Capability Increment 2, Enhanced Polar System, Global Positioning System III OCX Ground Control Segment, Joint Air-to-Ground Missile, Joint Light Tactical Vehicle, Littoral Combat Ship Mission Modules, Nett Warrior, and Space Fence.

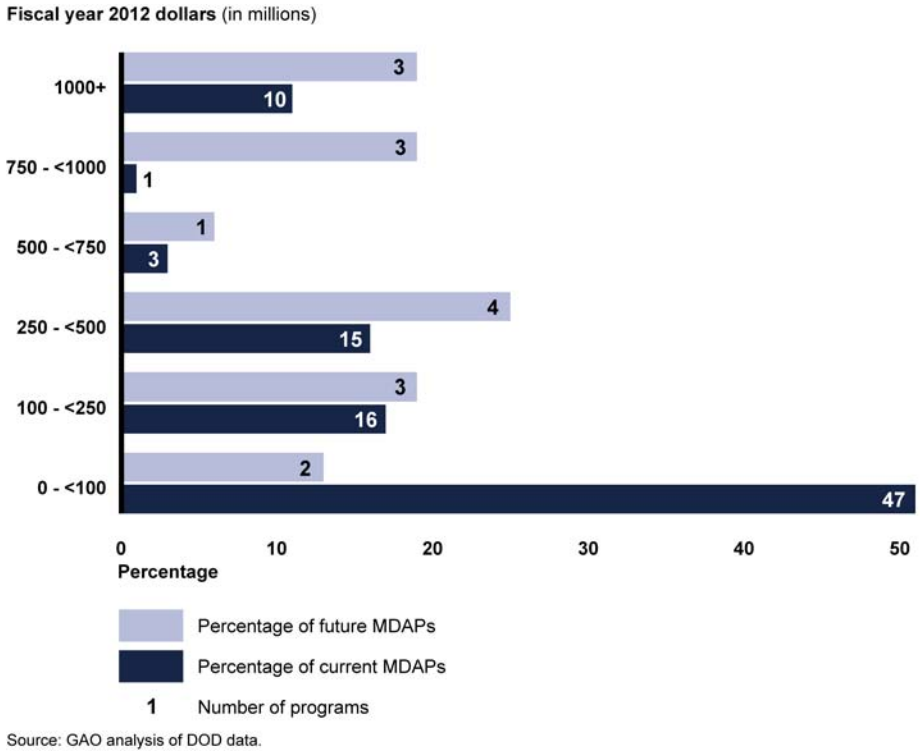
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example, the Navy's E-2D Advanced Hawkeye program completed a "should cost" analysis and used the knowledge gained to negotiate a 4.5 percent reduction in its third production contract.

- **The 16 future major defense acquisition programs we assessed intend to invest significantly more funds prior to entering system development or production than current programs.** Many of the recent acquisition reforms mandated by Congress or initiated by DOD increase knowledge prior to the start of system development. These activities help programs ensure that there is a match between requirements and resources before they begin, but they take money. As a result, DOD is beginning to allocate more funding earlier in a program's life cycle, according to our analysis of program spending plans. DOD spent over $450 million, on average, on 92 current major defense acquisition programs that reported cost data for the period prior to entering system development. For the 16 future programs in our analysis, DOD currently plans to spend an average of almost $700 million, or over $11 billion in total, before these programs begin system development or start production and bypass system development. See figure 10 for the amount of funding that future programs plan to spend and current programs spent.

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Figure 10: Funding for Future and Current Programs during Technology Development



Source: GAO analysis of DOD data.

For example, the Navy's Littoral Combat Ship Mission Modules and Ohio-class submarine replacement programs are projected to spend more than $1.2 billion and $2.4 billion respectively in technology development, and the Army's Ground Combat Vehicle expects to spend more than $1.9 billion in technology development. Increased funding of technology development can have beneficial effects for acquisition programs if the funds are spent on activities appropriate for that phase, such as prototype demonstrations and systems engineering analysis.

Assessments of Individual Programs

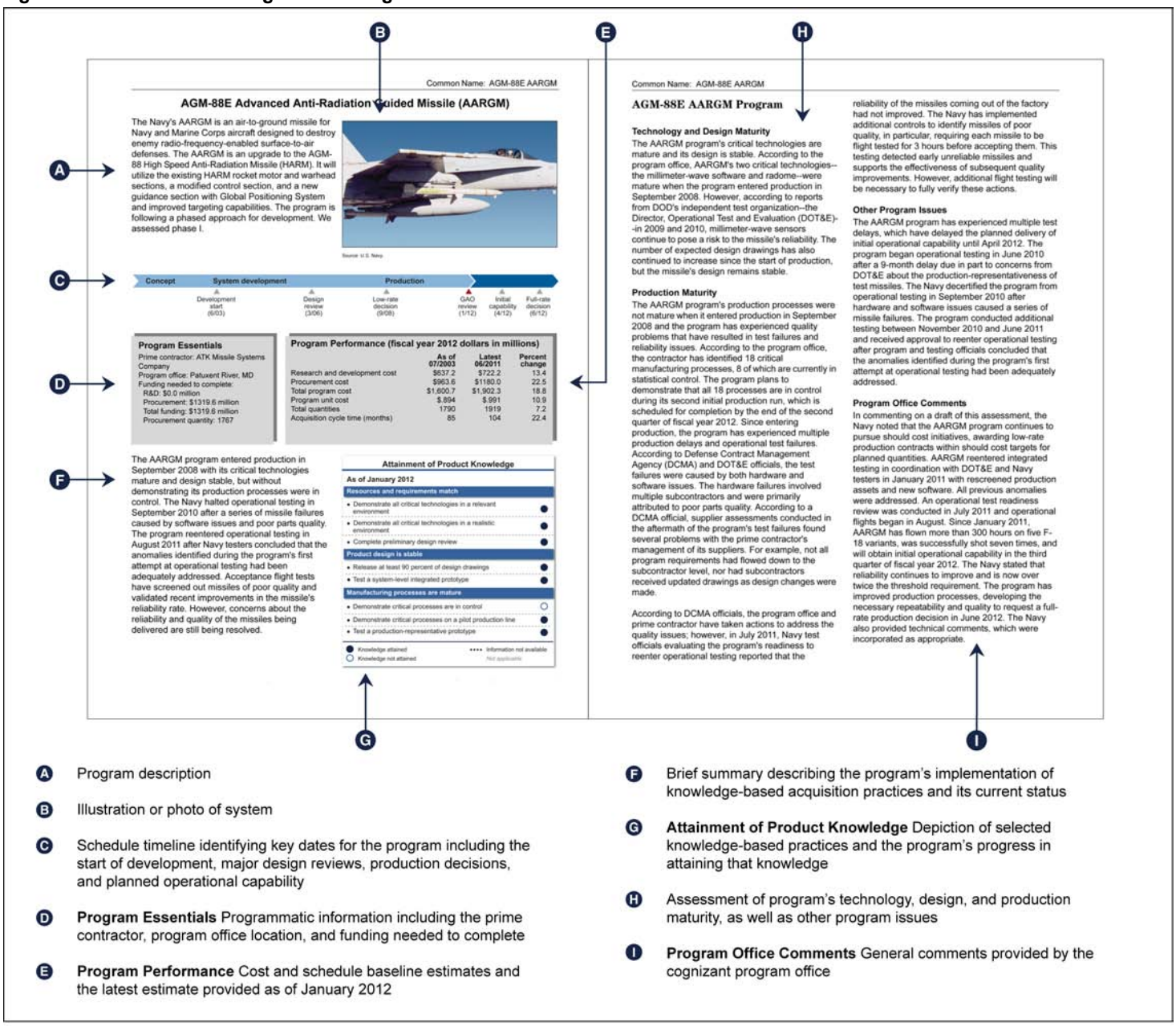
This section contains assessments of individual weapon programs. Each assessment presents data on the extent to which programs are following a knowledge-based acquisition approach to product development, and other program information. In total, we present information on 68 programs. For 48 programs, we produced two-page assessments discussing the

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technology, design, and manufacturing knowledge obtained, as well as other program issues. Each two-page assessment also contains a comparison of total acquisition cost from the first full estimate for the program to the current estimate. The first full estimate is generally the cost estimate established at development start; however, for a few programs that did not have such an estimate, we used the estimate at production start instead. For shipbuilding programs, we used their planning estimates if those estimates were available. For programs that began as non–major defense acquisition programs, we used the first full estimate available. Thirty-seven of these 48 two-page assessments are of major defense acquisition programs, most of which are in development or early production; 5 assessments are of elements of MDA's BMDS; and 6 assessments are of programs that were projected to become major defense acquisition programs during or soon after our review. See figure 11 for an illustration of the layout of each two-page assessment. In addition, we produced one-page assessments on the current status of 20 programs, which include 14 future major defense acquisition programs, 2 major defense acquisition programs that are well into production, 1 element of MDA's BMDS, and 3 major defense acquisition programs that were recently terminated.

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Figure 11: Illustration of Program Two-Page Assessment



- **A** Program description
- **B** Illustration or photo of system
- **C** Schedule timeline identifying key dates for the program including the start of development, major design reviews, production decisions, and planned operational capability
- **D** **Program Essentials** Programmatic information including the prime contractor, program office location, and funding needed to complete
- **E** **Program Performance** Cost and schedule baseline estimates and the latest estimate provided as of January 2012
- **F** Brief summary describing the program's implementation of knowledge-based acquisition practices and its current status
- **G** **Attainment of Product Knowledge** Depiction of selected knowledge-based practices and the program's progress in attaining that knowledge
- **H** Assessment of program's technology, design, and production maturity, as well as other program issues
- **I** **Program Office Comments** General comments provided by the cognizant program office

Source: GAO analysis.

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How to Read the Knowledge Scorecard for Each Program Assessed

For our two-page assessments, we depict the extent of knowledge gained in a program by the time of our review with a scorecard and narrative summary at the bottom of the first page of each assessment. As illustrated in figure 11 above, the scorecard displays eight key knowledge-based acquisition practices that should be implemented by certain points in the acquisition process. The more knowledge the program has attained by each of these key points, the more likely the weapon system will be delivered within its estimated cost and schedule. A knowledge deficit means the program is proceeding without sufficient knowledge about its technologies, design, or manufacturing processes, and faces unresolved risks that could lead to cost increases and schedule delays.

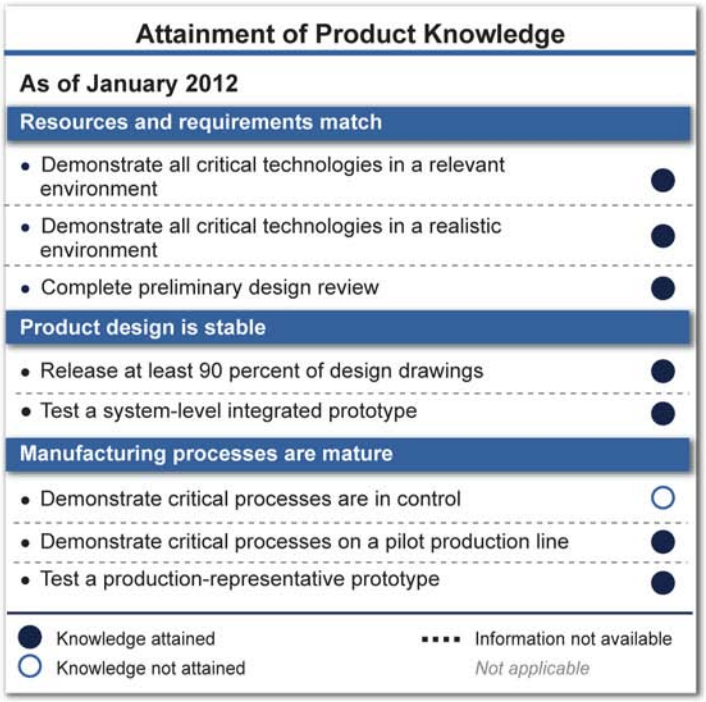
For each program, we identify a knowledge-based practice that has been implemented with a blue circle. We identify a knowledge-based practice that has not yet been implemented with an open circle. If the program did not provide us with enough information to make a determination, we show this with a dashed line. A knowledge-based practice that is not applicable to the program is grayed out. A knowledge-based practice may not be applicable to a particular program if either the point in the acquisition cycle when the practice should be implemented has not yet been reached, or if the particular practice is not relevant to the program. For programs that have not yet entered system development, we show a projection of knowledge attained for the first three practices. For programs that have entered system development but not yet held a critical design review, we assess actual knowledge attained for these three practices. For programs that have held a critical design review but not yet entered production, we assess knowledge attained for the first five practices. For programs that have entered production, we assess knowledge attained for all eight practices.

We make adjustments to both the key points in the acquisition cycle and the applicable knowledge-based practices for shipbuilding programs. For shipbuilding programs that have not yet awarded a detailed design contract, we show a projection of knowledge attained for the first three practices. For shipbuilding programs that have awarded this contract but not yet started construction, we would assess actual knowledge attained for these three practices. For shipbuilding programs that have started construction, we assess the knowledge attained for the first four practices. We do not assess the remaining four practices for shipbuilding programs. See figure 12 for examples of the knowledge scorecards we use to assess these different types of programs.

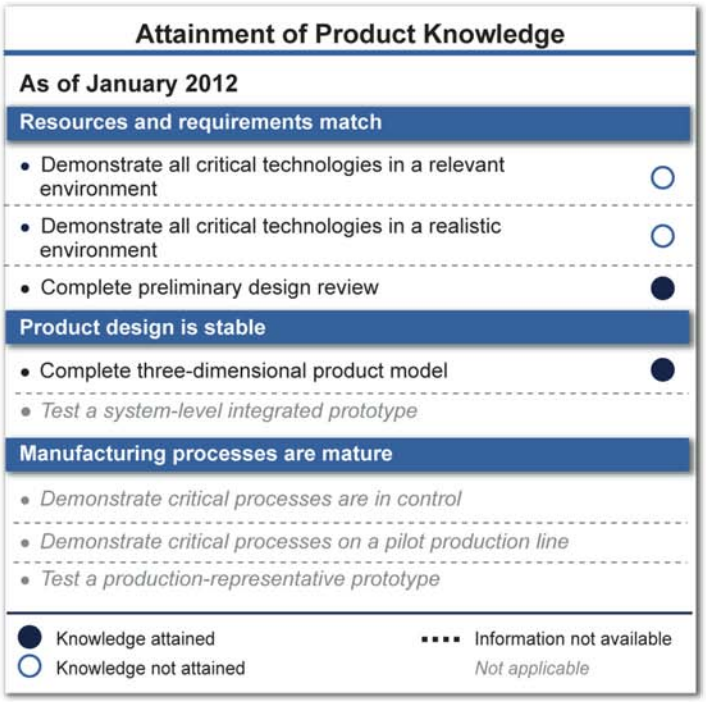
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Figure 12: Examples of Knowledge Scorecards

Program in production



Shipbuilding program



Source: GAO.

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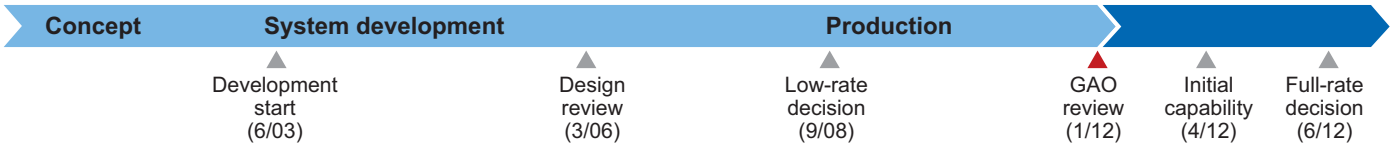
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AGM-88E Advanced Anti-Radiation Guided Missile (AARGM)

The Navy's AARGM is an air-to-ground missile for Navy and Marine Corps aircraft designed to destroy enemy radio-frequency-enabled surface-to-air defenses. The AARGM is an upgrade to the AGM-88 High Speed Anti-Radiation Missile (HARM). It will utilize the existing HARM rocket motor and warhead sections, a modified control section, and a new guidance section with Global Positioning System and improved targeting capabilities. The program is following a phased approach for development. We assessed phase I.



Source: U.S. Navy.



Program Essentials

Prime contractor: ATK Missile Systems Company
Program office: Patuxent River, MD
Funding needed to complete:
- R&D: $0.0 million
- Procurement: $1,319.6 million
- Total funding: $1,319.6 million
- Procurement quantity: 1,767

Program Performance (fiscal year 2012 dollars in millions)

	As of 07/2003	Latest 06/2011	Percent change
Research and development cost	$637.2	$722.2	13.4
Procurement cost	$963.6	$1,180.0	22.5
Total program cost	$1,600.7	$1,902.3	18.8
Program unit cost	$.894	$.991	10.9
Total quantities	1,790	1,919	7.2
Acquisition cycle time (months)	85	104	22.4

The AARGM program entered production in September 2008 with its critical technologies mature and design stable, but without demonstrating its production processes were in control. The Navy halted operational testing in September 2010 after a series of missile failures caused by software issues and poor parts quality. The program reentered operational testing in August 2011 after Navy testers concluded that the anomalies identified during the program's first attempt at operational testing had been adequately addressed. Acceptance flight tests have screened out missiles of poor quality and validated recent improvements in the missile's reliability rate. However, concerns about the reliability and quality of the missiles being delivered are still being resolved.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match	
• Demonstrate all critical technologies in a relevant environment	●
• Demonstrate all critical technologies in a realistic environment	●
• Complete preliminary design review	●
Product design is stable	
• Release at least 90 percent of design drawings	●
• Test a system-level integrated prototype	●
Manufacturing processes are mature	
• Demonstrate critical processes are in control	○
• Demonstrate critical processes on a pilot production line	●
• Test a production-representative prototype	●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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AGM-88E AARGM Program

Technology and Design Maturity

The AARGM program's critical technologies are mature and its design is stable. According to the program office, AARGM's two critical technologies—the millimeter-wave software and radome—were mature when the program entered production in September 2008. However, according to reports from DOD's independent test organization—the Director, Operational Test and Evaluation (DOT&E)—in 2009 and 2010, millimeter-wave sensors continue to pose a risk to the missile's reliability. The number of expected design drawings has also continued to increase since the start of production, but the missile's design remains stable.

Production Maturity

The AARGM program's production processes were not mature when it entered production in September 2008 and the program has experienced quality problems that have resulted in test failures and reliability issues. According to the program office, the contractor has identified 18 critical manufacturing processes, 8 of which are currently in statistical control. The program plans to demonstrate that all 18 processes are in control during its second initial production run, which is scheduled for completion by the end of the fourth quarter of fiscal year 2012. Since entering production, the program has experienced multiple production delays and operational test failures. According to Defense Contract Management Agency (DCMA) and DOT&E officials, the test failures were caused by both hardware and software issues. The hardware failures involved multiple subcontractors and were primarily attributed to poor parts quality. According to a DCMA official, supplier assessments conducted in the aftermath of the program's test failures found several problems with the prime contractor's management of its suppliers. For example, not all program requirements had flowed down to the subcontractor level, nor had subcontractors received updated drawings as design changes were made.

According to DCMA officials, the program office and prime contractor have taken actions to address the quality issues; however, in July 2011, Navy test officials evaluating the program's readiness to reenter operational testing reported that the reliability of the missiles coming out of the factory had not improved. The Navy has implemented additional controls to identify missiles of poor quality, in particular, requiring each missile to be flight tested for 3 hours before accepting them. This testing detected early unreliable missiles and supports the effectiveness of subsequent quality improvements. However, additional flight testing will be necessary to fully verify these actions.

Other Program Issues

The AARGM program has experienced multiple test delays, which have delayed the planned delivery of initial operational capability until April 2012. The program began operational testing in June 2010 after a 9-month delay due in part to concerns from DOT&E about the production-representativeness of test missiles. The Navy decertified the program from operational testing in September 2010 after hardware and software issues caused a series of missile failures. The program conducted additional testing between November 2010 and June 2011 and received approval to reenter operational testing in August 2011 after program and testing officials concluded that the anomalies identified during the program's first attempt at operational testing had been adequately addressed.

Program Office Comments

In commenting on a draft of this assessment, the Navy noted that the AARGM program continues to pursue should cost initiatives, awarding low-rate production contracts within should cost targets for planned quantities. AARGM reentered integrated testing in coordination with DOT&E and Navy testers in January 2011 with rescreened production assets and new software. All previous anomalies were addressed. An operational test readiness review was conducted in July 2011 and operational flights began in August. Since January 2011, AARGM has flown more than 300 hours on five F-18 variants, was successfully shot seven times, and will obtain initial operational capability in the third quarter of fiscal year 2012. The Navy stated that reliability continues to improve and is now over twice the threshold requirement. The program has improved production processes, developing the necessary repeatability and quality to request a full-rate production decision in June 2012. The Navy also provided technical comments, which were incorporated as appropriate.

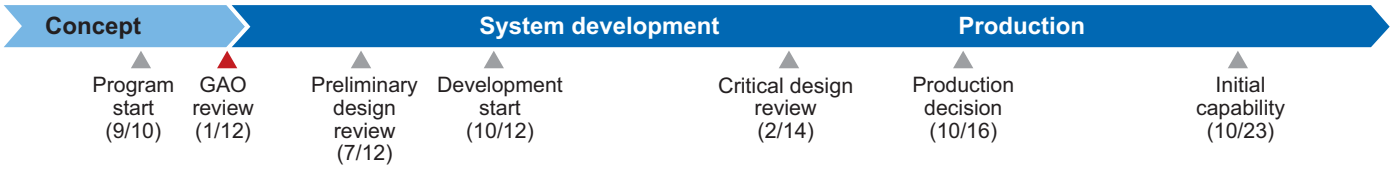
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Air and Missile Defense Radar (AMDR)

The Navy's Air and Missile Defense Radar (AMDR) will be a next-generation radar system designed to provide ballistic missile defense, air defense, and surface warfare capabilities. AMDR will consist of an S-band radar for ballistic missile defense and air defense, X-band radar for horizon search, and a radar suite controller that controls and integrates the two radars. AMDR will initially support DDG 51 Flight III. The Navy expects AMDR to provide the foundation for a scalable radar architecture that can be used to defeat advanced threats.



Source: U.S. Navy.



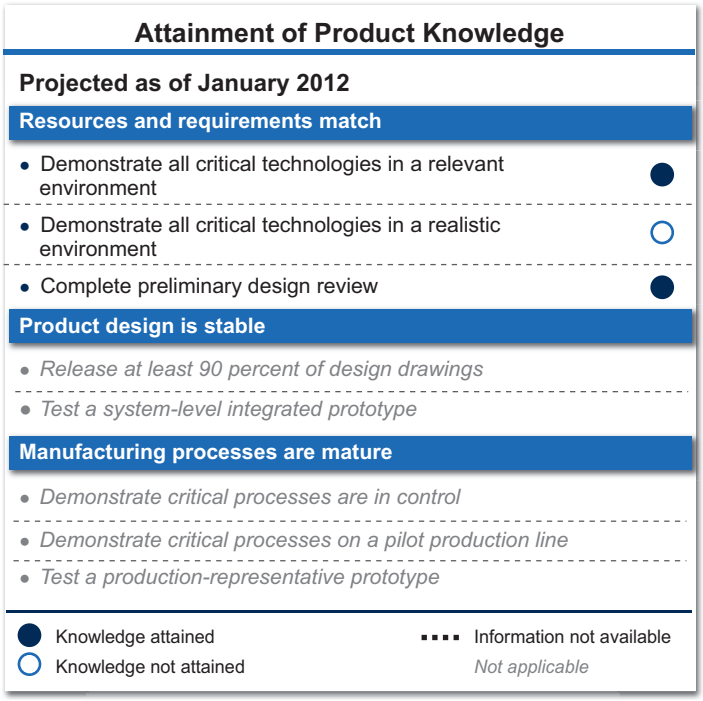
Program Essentials

Prime contractor: Lockheed Martin, Northrop Grumman, Raytheon
Program office: Washington, DC
Funding needed to complete:
R&D: $1,584.7 million
Procurement: $13,597.2 million
Total funding: $15,181.9 million
Procurement quantity: 24

Program Performance (fiscal year 2012 dollars in millions)

	As of	Latest 09/2011	Percent change
Research and development cost	NA	$2,211.8	NA
Procurement cost	NA	$13,597.3	NA
Total program cost	NA	$15,837.3	NA
Program unit cost	NA	$659.887	NA
Total quantities	NA	24	NA
Acquisition cycle time (months)	NA	149	NA

AMDR plans to enter system development in October 2012 with some of the recommended knowledge about its technology and requirements. According to the Navy, AMDR's six critical technologies are expected to be demonstrated in a relevant environment before the start of system development. The program also plans to conduct a preliminary design review to refine its requirements. In September 2010, the Navy selected three contractors to build and test prototypes to demonstrate AMDR's critical technologies. Program officials stated that digital beamforming technology, which is necessary for simultaneous air and ballistic missile defense, will likely take the longest to mature. The Navy and shipbuilders have determined that a 14-foot active radar is the largest that can be accommodated by the existing DDG 51. AMDR is also being developed to be scaled up in size.



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AMDR Program

Technology Maturity

According to the Navy, all six critical technologies for the AMDR program are expected to be nearing maturity and demonstrated in a relevant environment before a decision is made to enter system development. They are currently immature. Program officials stated that digital beamforming technology—necessary for AMDR's simultaneous air and ballistic missile defense mission—has been identified as the most significant challenge and will likely take the longest time to mature. Digital beamforming enables the radar to generate and process multiple beams simultaneously, which results in more radar resources being available to support simultaneous air and missile defense. Program officials stated that this technology has been used before, but it has never been demonstrated in a radar as large as AMDR.

The AMDR's transmit-receive modules—the individual radiating elements key to transmitting and receiving electromagnetic signals—also pose a challenge. According to the program office, similar radar programs have experienced significant problems developing transmit-receive modules, resulting in cost and schedule growth. To achieve the increased performance levels required for AMDR, the contractor will likely use gallium nitride semiconductor technology instead of the legacy gallium arsenide technology. The new technology has the potential to provide higher power and efficiency with a smaller footprint. According to the Navy, this would reduce the power and cooling demands placed on the ship by the radar. However, gallium nitride has never been used in a radar as large as the AMDR, and long-term reliability and performance of this newer material is unknown. If these transmit-receive units cannot provide the required power, the program would either need to use the legacy technology and increase the power and cooling resources available for the AMDR, or accept reduced power and performance for the AMDR S-band radar.

Other Program Issues

The AMDR program entered technology development in September 2010 and the Navy awarded fixed-price incentive fee contracts to Northrop Grumman, Lockheed Martin, and Raytheon for S-band radar and radar-suite controller technology development. The contractors will build and test prototypes to demonstrate all critical technologies during a 2-year technology development period. The X-band portion of AMDR will be based on existing technology that is already mature. Additional software development will be required to integrate the two radars.

The Navy plans to install AMDR on Flight III DDG 51s starting in 2019. The Navy has yet to determine the size of AMDR for Flight III. According to draft AMDR documents, a 14-foot radar is needed to meet requirements, but an over-20-foot radar is needed to fully meet the Navy's desired integrated air and missile defense capabilities. However, the shipyards and the Navy have determined that a 14-foot active radar is the largest that can be accommodated within the confines of the existing DDG 51 deckhouse, even though AMDR is being built with the capability to be scaled up in size to meet future threats.

Program Office Comments

The program office concurred with this assessment and provided technical comments, which were incorporated where appropriate.

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Apache Block IIIA (AB3A)

The Army's Apache Block IIIA (AB3A) program is upgrading AH-64D Longbow helicopters to improve performance, situational awareness, lethality, survivability, and interoperability, and to prevent friendly fire incidents. It consists of three sets of upgrades. For the first set of upgrades, AH-64Ds are sent to the factory for hardware changes. The second and third sets of upgrades are primarily software-related and can be installed in the field, reducing the time an aircraft is out of service and increasing training time for soldiers.



Source: U.S. Army.



Program Essentials

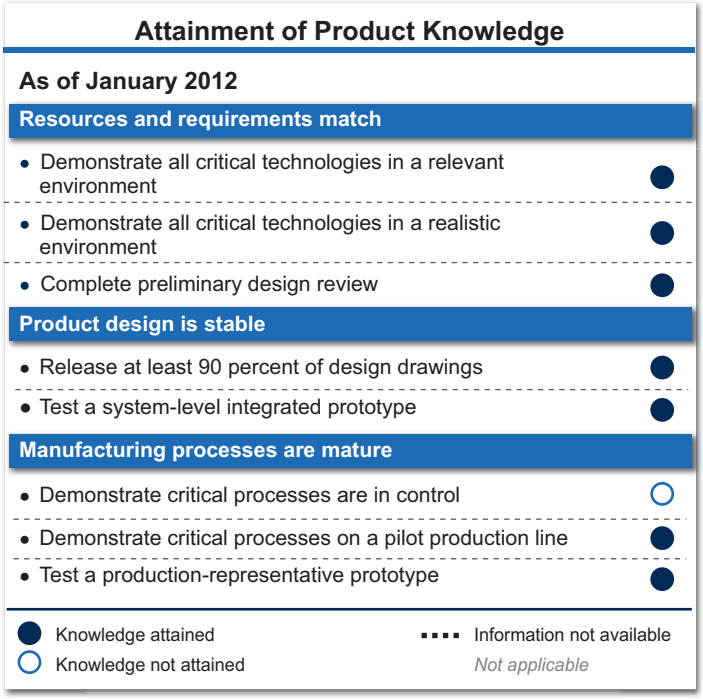
Prime contractor: Boeing
Program office: Huntsville, AL
Funding needed to complete:
R&D: $706.8 million
Procurement: $8,363.7 million
Total funding: $9,070.6 million
Procurement quantity: 610

Program Performance (fiscal year 2012 dollars in millions)

	As of 08/2006	Latest 12/2010	Percent change
Research and development cost	$1,155.6	$1,640.3	41.9
Procurement cost	$6,086.9	$9,096.8	49.4
Total program cost	$7,242.5	$10,737.0	48.3
Program unit cost	$12.031	$16.803	39.7
Total quantities	602	639	6.1
Acquisition cycle time (months)	79	82	3.8

The latest cost and quantities do not include the 57 new-build helicopters that are being acquired under the AB3B major defense acquisition program.

The AB3A program began production in October 2010 with mature critical technologies, a stable design, and manufacturing processes that had been demonstrated, but were not in control. The program is required to demonstrate its processes are in control prior to entering full-rate production. The program has begun installing the first of three sets of upgrades on AH-64Ds, and according to the program office, upgraded aircraft are on schedule to begin operational testing in March 2012. The design reviews for the second and third set of upgrades are planned for 2013 and 2015, respectively. These upgrades will be installed in the 2015 to 2017 time frame. In 2010, AB3 was restructured into two programs—AB3A for remanufactured aircraft and AB3B for new-build aircraft. New-build aircraft will be identical to the remanufactured ones and begin delivery in 2014.



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AB3A Remanufacture Program

Technology and Design Maturity

The AB3A program's one critical technology is mature and the design for the first set of upgrades is stable. The program has begun installing the first set of upgrades on AH-64D aircraft and the first upgraded aircraft entered service in October 2011. The development effort for the second and third set of upgrades, which are primarily software-related, is on track to begin in early 2012. According to the program office, these upgrades focus on reducing pilot and maintainer workload; expanding interoperability, survivability, and manned-unmanned teaming capabilities with other aircraft; improving targeting and navigation; and establishing the architecture for the integration of future technologies. According to the program office, the software development effort was preliminarily estimated at approximately 370,000 lines of code and this estimate was used to support the program's updated cost estimate for its production decision. Design reviews for these sets of upgrades are scheduled for 2013 and 2015, respectively, with follow-on operational testing planned for fiscal years 2014 and 2015.

Production Maturity

The AB3A program began production in October 2010 with manufacturing processes that had been demonstrated on a pilot production line, but were not in control. Prior to the production decision, the program concluded that its manufacturing readiness was at the level recommended by DOD guidance for the start of low-rate production. However, the program's manufacturing readiness level did not indicate that its production processes were in statistical control. The program is currently in the process of reassessing its manufacturing readiness. Before its planned July 2012 full-rate production decision, the program must successfully complete initial operational test and evaluation and meet other DOD criteria, which include demonstrating its processes are stable, in control, and meet acceptable process capability levels. AB3A has completed the first of three operational test readiness reviews and plans to hold the second and third reviews shortly before initial operational test and evaluation is planned to begin in March 2012. According to program officials, the AB3A is also on track to meet DOD criteria related to its performance, reliability, supportability, and manufacturing capability.

Other Program Issues

In 2010, following a Nunn-McCurdy unit-cost breach of the critical threshold, AB3 was restructured into two major defense acquisition programs—AB3A for remanufactured aircraft and AB3B for new-build aircraft. The original AB3 program involved taking legacy aircraft and remanufacturing them with upgraded capabilities. However, decreases in the numbers of legacy aircraft available for remanufacture, combined with increasing wartime demands, resulted in the addition of 57 new-build aircraft. The programs were separated to provide visibility into the cost, schedule, and performance of each segment. Structurally and technologically, the remanufactures and new-builds will be identical and the programs will share a common contract. New-build aircraft will cost significantly more than the remanufactured aircraft because of the need to procure all new parts. According to program officials, the production line for AH-64Ds did not have to be restarted for the AB3B program because it has been kept active for wartime replacements. The program expects to deliver the first new-build aircraft in fiscal year 2014. Foreign military sales have the potential to reduce the unit cost of the AB3A and AB3B. In 2012, the program will begin delivering foreign military sale aircraft to Taiwan, and several other countries are prospective buyers as well.

Program Office Comments

In commenting on a draft of this assessment, the Army provided technical comments, which were incorporated as appropriate.

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Army Integrated Air and Missile Defense (Army IAMD)

The Army's Integrated Air and Missile Defense (IAMD) program is being developed to network sensors, weapons, and a common battle command system across an integrated fire control network to support the engagement of air and missile threats. The IAMD Battle Command System (IBCS) will provide a capability to control and manage IAMD sensors and weapons, such as the Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System and Patriot, through an interface module that supplies battle-management data and enables networked operations.



Source: Northrop Grumman.



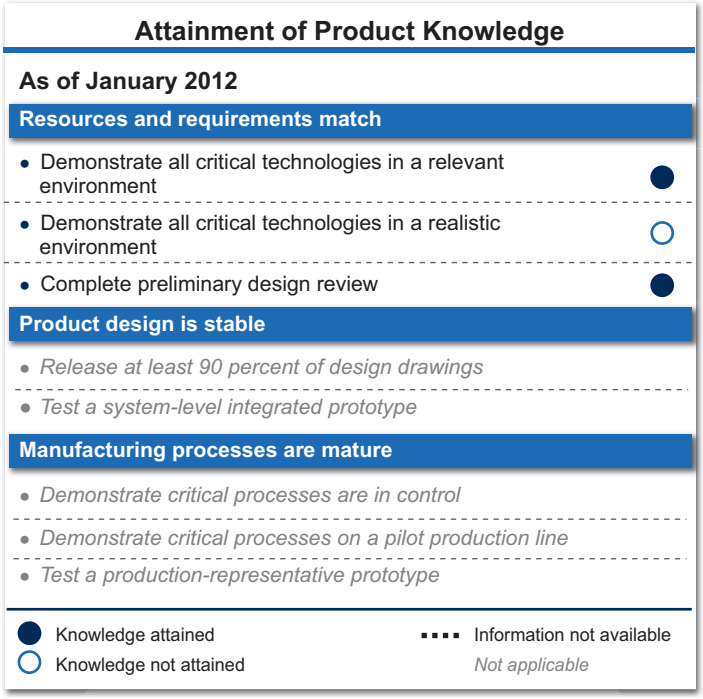
Program Essentials

Prime contractor: Northrop Grumman Space & Mission Systems Corp.
Program office: Huntsville, AL
Funding needed to complete:
R&D: $1,370.5 million
Procurement: $3,509.0 million
Total funding: $4,879.5 million
Procurement quantity: 285

Program Performance (fiscal year 2012 dollars in millions)

	As of 12/2009	Latest 08/2011	Percent change
Research and development cost	$1,595.2	$2,019.8	26.6
Procurement cost	$3,433.4	$3,509.0	2.2
Total program cost	$5,028.6	$5,528.8	9.9
Program unit cost	$16.988	$18.678	9.9
Total quantities	296	296	0.0
Acquisition cycle time (months)	80	81	1.3

IAMD's mission has not changed, but changes to its plans for integrating other systems have significantly increased the size of its software effort, delayed its design review by 8 months, and increased its development costs by over $400 million. These changes include adding Patriot launcher and radar functionality directly onto the integrated fire control network and increasing IBCS quantities. WIN-T integration is also a significant risk. The program is projecting that its design will be stable at its planned April 2012 design review, but it does not plan to demonstrate the design can perform as expected until August 2013. Additional cost increases may occur because the Army may increase the number of IBCS units it plans to buy. According to officials, DOD is expected to direct a new independent cost estimate and an updated program baseline.



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IAMD Program

Technology Maturity

The IAMD program entered system development in December 2009 with its four critical technologies—integrated battle command, integrated defense design, integrated fire control network, and distributed track management—nearing maturity, according to an Army technology readiness assessment based on a notional design. The Army updated the technology readiness assessment in March 2011 based on the winning contractor's design and reached the same conclusion about the technologies' maturity. The Office of the Assistant Secretary of Defense for Research and Engineering concurred with the assessment, but noted that integration with the Warfighter Information Network–Tactical (WIN-T) is a significant risk. It also noted that the assessment was based on modeling and simulations of the WIN-T and assumptions about performance. As a result, it recommended realistic, full-scale testing with WIN-T prior to a production decision. Program officials estimate that IAMD technologies will not be fully mature until its planned production decision in 2015.

Design Maturity

The IAMD program plans to release over 90 percent of its total expected drawings by its design review, but it does not plan to demonstrate that the design can perform as expected until August 2013—over a year later. As a result, the risk of design changes will remain. The IAMD design review has been delayed by 8 months to April 2012, in part because the program has made significant changes to the way it intends to integrate its planned engagement capabilities. These changes include adding Patriot launcher and radar functionality directly onto the IAMD integrated fire control network. The Medium Extended Air Defense System and Surface-Launched Advanced Medium-Range Air-to-Air Missile are no longer planned to be integrated with the system because those programs have been sharply curtailed or cancelled.

Other Program Issues

IAMD's development costs have risen by over $400 million or about 27 percent since development start and may increase further. According to program officials, the increases are primarily attributable to the decision to incorporate Patriot launcher and sensor functionality into the integrated fire control network and add a command and control module. According to program officials, increasing the number of IBCS units will provide for a common command and control at all echelons. Program officials now estimate the size of the software development at over 6.6 million lines of code—a 37 percent increase over the estimate at development start. In addition, about 63 percent will be newly developed code or auto-generated code. The cost of the added software has not yet been finalized, but program officials estimate that it will add 6 months to the software development effort. Other anticipated changes to the IAMD system, including an increase to the number of IBCS units, could increase costs further. According to program officials, DOD is expected to direct a new independent cost estimate for the program and an updated program baseline.

Program Office Comments

In commenting on a draft of this assessment, the program office noted that increases to the program include funds provided to add the Patriot sensor and launcher directly onto the integrated fire control network and IBCS units to provide full IAMD functionality at all echelons. The program is on schedule to conduct the design review in April 2012. Program delay is partially due to a reduction of $45 million shortly following the system development decision and the fiscal year 2011 continuing resolution. The Army IAMD program at development start was based on a generic design due to the competitive prototyping efforts of the contractors, and the originally estimated software lines of code were not specific to either contractor's approach. Since contract award, the contractor refined the estimates and software size should be stable going forward. To state that the software lines of code have grown 37 percent since development start is not wholly accurate since much of the increase is attributable to auto-generated code which requires less effort to complete. The program also provided technical comments, which were incorporated as appropriate.

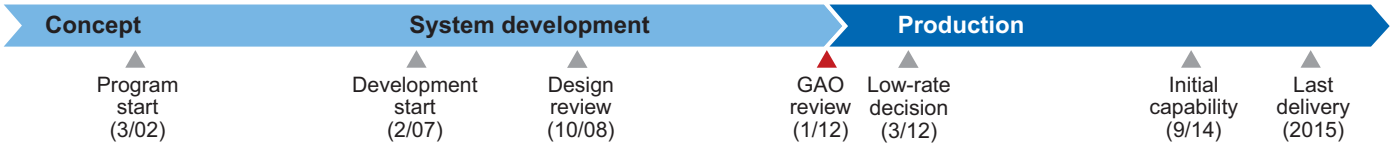
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B-2 Extremely High Frequency SATCOM Capability, Increment 1

The Air Force's B-2 EHF SATCOM Increment 1 program will upgrade the aircraft's flight-management computer processors, increase data-storage capacity, and establish a high-speed network that will serve as the foundation for future B-2 upgrades, such as those being developed by the B-2 EHF SATCOM Increment 2 and the Defensive Management System Modernization programs. The development and successful integration of new disk-drive units and integrated-processing units is a primary objective for Increment 1.



Source: U.S. Air Force.



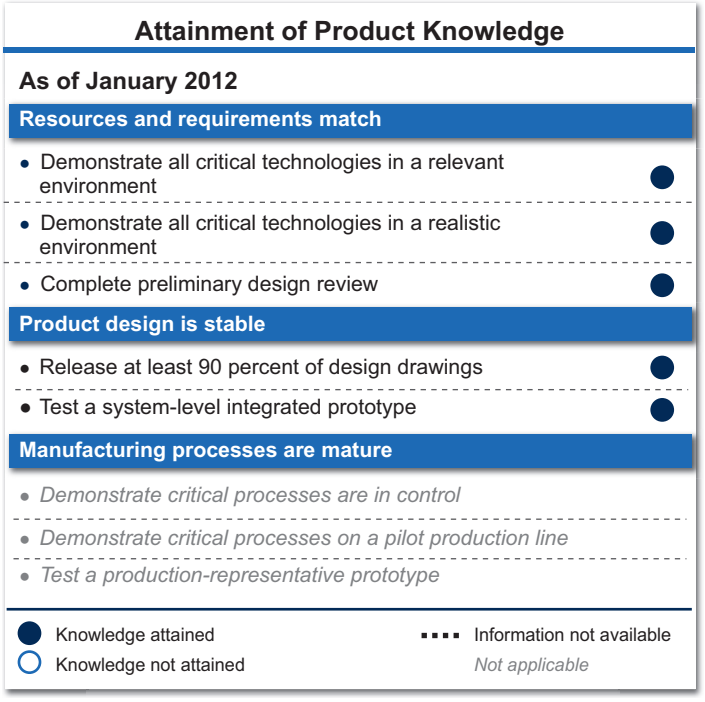
Program Essentials

Prime contractor: Northrop Grumman
Program office: Wright-Patterson AFB, OH
Funding needed to complete:
R&D: $62.6 million
Procurement: $127.4 million
Total funding: $190.1 million
Procurement quantity: 16

Program Performance (fiscal year 2012 dollars in millions)

	As of 05/2007	Latest 08/2011	Percent change
Research and development cost	$586.4	$497.7	-15.1
Procurement cost	$123.5	$127.4	3.1
Total program cost	$710.0	$625.2	-11.9
Program unit cost	$33.808	$31.258	-7.5
Total quantities	21	20	-4.8
Acquisition cycle time (months)	85	91	7.1

The B-2 EHF SATCOM Increment 1 program is expected to enter production in March 2012 with mature critical technologies and a stable design, but without fully demonstrating its production processes. A September 2011 operational assessment report indicated that Increment 1 is on track to meet system requirements; however, some software-related deficiencies must be resolved prior to initial operational test and evaluation in 2012. The program completed a production readiness review in May 2011, and expects to demonstrate sufficient manufacturing readiness prior to production. However, the program does not intend to demonstrate its critical manufacturing process is in control before starting production. According to the program office, it has demonstrated the capability to produce key components in a production-representative environment and established reliability through lab testing.



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B-2 EHF SATCOM Increment 1 Program

Technology and Design Maturity

All six B-2 EHF SATCOM Increment 1 critical technologies are mature and its design is stable. In February 2007, the program entered system development with all of its critical technologies nearing maturity. Since that time, these technologies have been matured and flight-qualified. The program office has reported that its design has been stable since its October 2008 critical design review. All expected drawings were releasable at that time and there has been no increase in the number of drawings since then. A September 2011 operational assessment report by the Air Force Test and Evaluation Center found that Increment 1 is on track to meet its effectiveness, suitability, and mission capability requirements; however, there are some software-driven shortfalls that need to be addressed prior to initial operational test and evaluation in 2012. In particular, the assessment report cited software deficiencies related to the system's communications capabilities and aircrew workload as critical issues requiring attention.

Production Maturity

The B-2 EHF SATCOM Increment 1 program is expected to enter production in March 2012 without fully demonstrating its production processes. The program completed a production readiness review in May 2011 and has identified one critical manufacturing process. According to the program office, by the start of production, manufacturing readiness will be at a level consistent with what is recommended in DOD manufacturing readiness level guidance. However, the program does not expect to demonstrate that its critical manufacturing process is in control—meaning that it meets our standards for production defect rates—before its production decision. In addition, the program will not be demonstrating manufacturing processes on a pilot line, but has employed alternative measures to demonstrate production maturity. For example, the program has demonstrated the capability to produce targeted components—disk-drive units, integrated-processing units, and a fiber harness—in a production-representative environment. According to program officials, they have also established that the integrated-processing and disk-drive units have high levels of reliability using data from lab testing.

Other Program Issues

The B-2 EHF SATCOM Increment 1 has been largely able to overcome early delays in its test program. The program completed software certification in April 2010, flight testing began in September 2010, and the completion of initial operational test and evaluation is expected by late fiscal year 2012. The health of the test aircraft has continued to be a challenge for meeting the test schedule. Nevertheless, the program's planned software release to flight test in late fiscal year 2011 was completed and an operational assessment found the system to be on track to achieve its planned mission capability.

According to the program office, the B-2 EHF Increment 1 production decision was postponed from October 2011 to March 2012 to allow the negotiated contract price and the program's production cost estimate to be reconciled. The program has received Air Force approval to speed up production by pursuing a firm fixed-price two-lot buy instead of the previously planned three-lot buy, which should reduce production costs and provide for an earlier full operational capability.

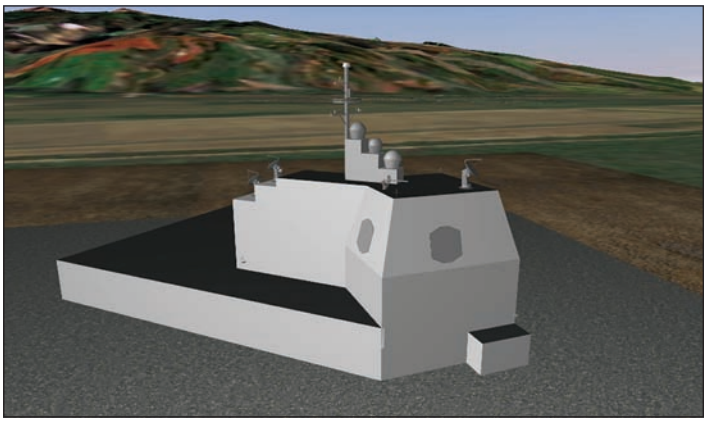
Program Office Comments

In commenting on a draft of this assessment, the B-2 EHF Increment 1 program office stated that in addition to the program reaching a sufficient manufacturing readiness level prior to the start of low-rate initial production, the program plans to conduct an additional manufacturing readiness assessment during the initial phase of production in summer 2012 to demonstrate achievement of further maturity prior to the full-rate production decision planned for December 2012.

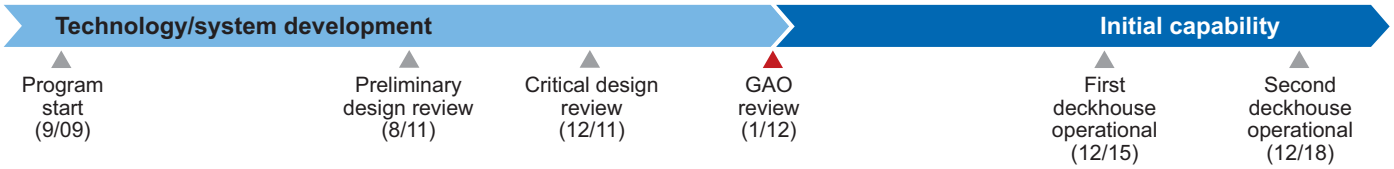
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BMDS: Aegis Ashore

MDA's Aegis Ashore is a planned land-based variant of the ship-based Aegis Ballistic Missile Defense system. It will track and intercept ballistic missiles using a vertical launching system, variants of the Standard Missile-3 (SM-3), and enclosures called deckhouses that contain a SPY-1 radar and command and control system. We assessed Aegis Ashore with SM-3 Block IB. DOD plans to first deploy this configuration in a host nation in the 2015 time frame as part of the European Phased Adaptive Approach Phase II.



Source: Missile Defense Agency.



Program Essentials

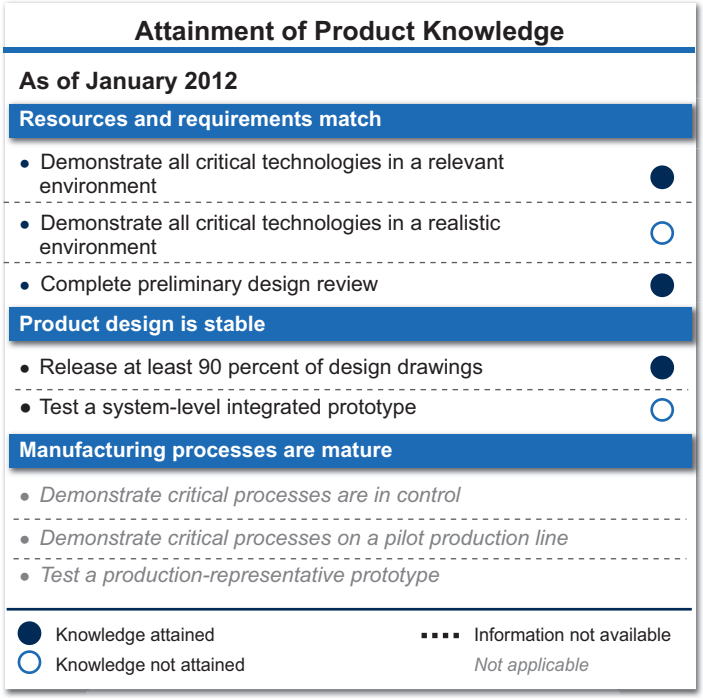
Prime contractor: Multiple
Program office: Dahlgren, VA
Funding needed to complete:
R&D: TBD
Procurement: TBD
Total funding: TBD
Procurement quantity: TBD

Program Performance (fiscal year 2012 dollars in millions)

	As of 04/2010	Latest 03/2011	Percent change
Research and development cost	$835.1	$1,418.6	69.9
Procurement cost	NA	NA	NA
Total program cost	$835.1	$1,418.6	69.9
Program unit cost	$417.565	$472.864	13.2
Total quantities	2	3	50.0
Acquisition cycle time (months)	NA	NA	NA

Estimates in table above do not include missile costs.

Aegis Ashore is following a concurrent acquisition approach by entering system development prior to holding a preliminary design review and purchasing operational components prior to completing testing—both of which increase the risk of cost growth and schedule delays. The program office has now assessed its five critical technologies as mature or nearing maturity. However, several of these technologies may be less mature than reported. The system's design was stable by February 2012, but the risk of design changes will remain until it demonstrates the design can perform as expected by flight testing, which will not occur until 2014. Program management stated that the development is low risk because the technologies are already used by Aegis BMD ships and the program's ground and flight test schedule will confirm the capability by the time it is deployed.



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BMDS: Aegis Ashore Program

Technology Maturity

According to the Aegis Ashore program office, all five of its critical technologies are mature or nearing maturity. The program has assessed the SPY-1 radar, command and control system, SM-3 Block IB interceptor, and vertical launching system as mature and the multimission signal processor as nearing maturity. However, the maturity of some of these technologies may be overstated. The SPY-1 radar requires modifications for its use on land and other changes may be necessary due to host nation radar frequency issues. Program management officials stated at least some of these changes are software modifications, but the frequency issues may require other changes. The launch system must also be modified for use both on land and at a greater distance from the deckhouse. In addition, the maturity of SM-3 Block IB may be overstated because some of its component technologies have not been flight tested or have experienced failures in testing. The multimission signal processor also faces development challenges, and the Defense Contract Management Agency has identified its schedule as high risk. We have previously reported that a significant percentage of its software still needs to be integrated.

Design Maturity

The deckhouse design was 100 percent complete in February 2012, prior to the planned award of the deckhouse fabrication contract in the third quarter of fiscal year 2012. However, the program does not plan to demonstrate the design can perform as expected by flight testing until 2014, although there will be ground testing to demonstrate Aegis Ashore component integration prior to the flight test. As a result, the risk of design changes will remain until developmental testing is complete.

Other Program Issues

The Aegis Ashore program is following an acquisition approach that increases the risk of cost growth and schedule delays. The program began system development 14 months before completing its preliminary design review. We have previously reported that this review should be held prior to starting development to ensure that requirements are defined, feasible, and achievable within cost, schedule, and other system constraints. The program also contains concurrency between development and production, which increases the risk of late and costly design changes and retrofits. For example, the program is simultaneously acquiring the developmental test deckhouse and the operational deckhouse and is constructing the operational deckhouse first. In addition, the first developmental flight test of Aegis Ashore is scheduled for the second quarter of fiscal year 2014, at which point two deckhouses will have been constructed and other components will already be in production. Program management officials stated its concurrent schedule is low risk given its use of technology already used by Aegis BMD and modifications can be made to the deckhouse before it is installed in Romania. In addition, it stated that the current strategy has cost benefits and construction and testing efficiency advantages.

The program has experienced cost growth because of additional requirement costs. In 2011, the unit cost of Aegis Ashore grew, which the program attributed to costs for the reconstitutable deckhouse design that were not included in its baseline and the addition of hardware for a third site in Poland.

Program Office Comments

In commenting on a draft of this assessment, MDA provided technical comments, which were incorporated as appropriate.

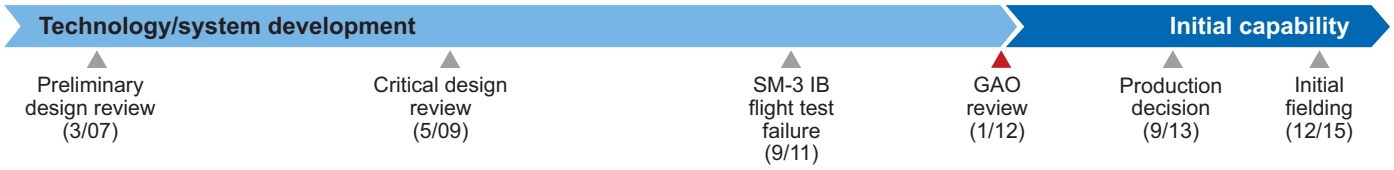
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BMDS: Aegis Ballistic Missile Defense Standard Missile-3 Block IB

MDA's Aegis Ballistic Missile Defense is a sea- and land-based system being developed to defend against ballistic missiles of all ranges. It includes a radar, battle management and command and control systems, and Standard Missile-3 (SM-3) missiles. We reviewed the SM-3 Block IB (SM-3 IB), which will feature an improved target seeker, an advanced signal processor, and an improved divert/attitude control system for adjusting its course. It is planned to be fielded in the 2015 time frame as part of European Phased Adaptive Approach Phase II.



Source: Missile Defense Agency.



Program Essentials

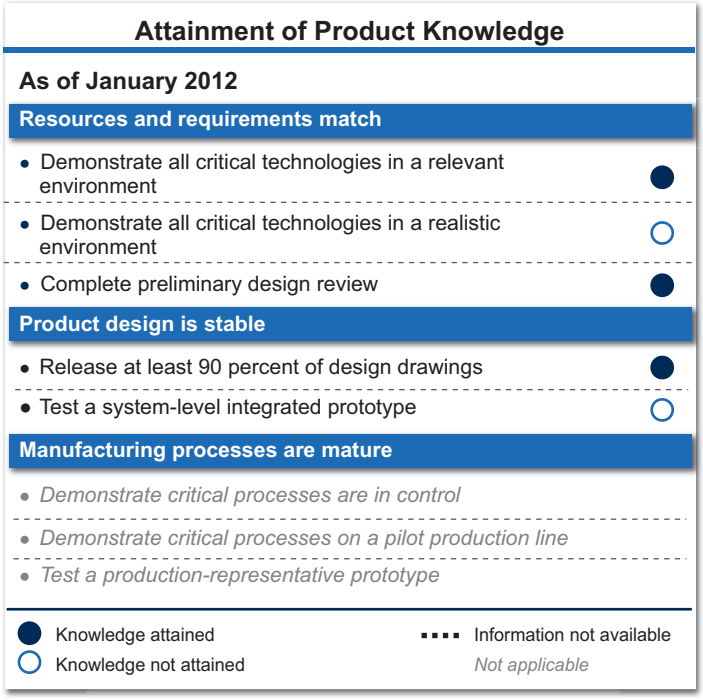
Prime contractor: Raytheon
Program office: Dahlgren, VA
Funding FY12 to FY16:
R&D: $250.7 million
Procurement: $3,330.1 million
Total funding: $3,580.8 million
Procurement quantity: TBD

Program Performance (fiscal year 2012 dollars in millions)

	As of	Latest 05/2011	Percent change
Research and development cost	NA	$676.6	NA
Procurement cost	NA	$3,330.1	NA
Total program cost	NA	$4,006.7	NA
Program unit cost	NA	NA	NA
Total quantities	NA	370	NA
Acquisition cycle time (months)	NA	NA	NA

Costs are from program inception through fiscal year 2016.

The SM-3 IB will be at continued risk of cost growth, schedule delays, and performance shortfalls unless it demonstrates that the missile's critical technologies and design perform as expected before committing to further production. In 2011, the SM-3 IB failed during its first developmental flight test. At the time of the failure, MDA had contracted for 25 SM-3 IB interceptors, 18 of which were dedicated to flight testing. As a result of the flight test failure, MDA halted acceptance of SM-3 IB deliveries, convened a failure review board, and delayed key program decisions. In addition, two critical technologies—the throttleable divert attitude control system and third-stage rocket motor—still may not be mature. The attitude control system has not completed developmental testing or been successfully flight tested and the third-stage rocket motor may need to be redesigned.



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BMDS: SM-3 Block IB Program

Aegis BMD Element - Block 2004

According to the program, all five of its critical technologies—the third-stage rocket motor, throttleable divert attitude control system, reflective optics, two-color warhead seeker, and kinetic warhead advanced signal processor—are mature. However, the attitude control system has not completed qualification testing or been demonstrated in a realistic flight environment. In addition, the third-stage rocket motor, which was previously considered the most mature technology, may need to be redesigned to address issues discovered in flight testing. In its first developmental flight test in September 2011, the SM-3 IB experienced a failure involving one of its critical technologies and did not intercept the target. A failure review board is investigating the cause. The program plans to redo the failed test and conduct two additional intercept flight tests in 2012. Program officials expect that all SM-3 IB technologies will be flight-qualified and demonstrated through testing by the program's planned fiscal year 2013 production decision.

Design Maturity

The SM-3 IB's design has been relatively stable since its critical design review in May 2009, although design changes may be necessary to address issues discovered in testing. In addition, the program has not demonstrated that the missile's design can perform as intended through developmental testing. As a result, it remains at risk for further design changes, cost growth, and schedule delays.

Production Maturity

MDA has delayed the official start of operational missile production from February 2010 to the fourth quarter of fiscal year 2013. According to officials, MDA will not make this production decision until it completes initial developmental testing with production-representative missiles and shipboard systems.

The program has already contracted for 25 missiles, 18 of which will be used for developmental testing. The seven additional missiles could require costly rework and retrofits if the program decides to use them as operational assets as planned. According to MDA, additional missiles will also be used to prove manufacturing processes and for other purposes. MDA is also planning to purchase 46 additional missiles in fiscal year 2012. Any additional missiles ordered in fiscal year 2012 before the completion of flight tests needed to validate the missile's performance would be at higher risk of cost growth and schedule delays.

The flight-test failure investigation and possible redesigns are delaying both developmental and operational missile production. The program's acceptance of developmental missile deliveries and the production of certain missile components are on hold pending the results of the investigations. Program officials estimate that the failure investigations, design modifications, and additional testing will increase costs and they have not yet determined how many missiles may need to be refurbished.

Other Program Issues

MDA originally planned to stop production of the SM-3 IA in 2010 and begin production of the SM-3 IB. However, SM-3 IB developmental issues have required MDA to twice delay the purchase of SM-3 IB missiles, purchase additional SM-3 IA missiles to avoid production gaps and keep SM-3 suppliers active, and reduce the planned initial purchase quantity of SM-3 IBs. The program's acceptance of SM-3 IA deliveries and the production of a missile component have been halted since April 2011, when an SM-3 IA missile experienced an anomaly during a flight test. The anomaly may have occurred in a component that is common to the SM-3 IA and SM-3 IB.

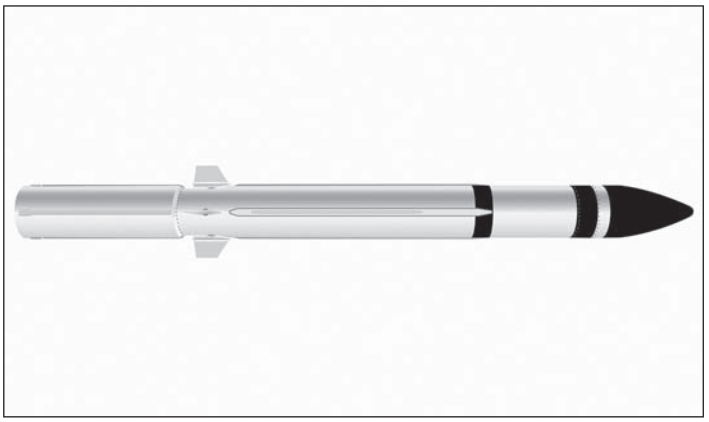
Program Office Comments

In commenting on a draft of this assessment, MDA provided technical comments, which were incorporated as appropriate.

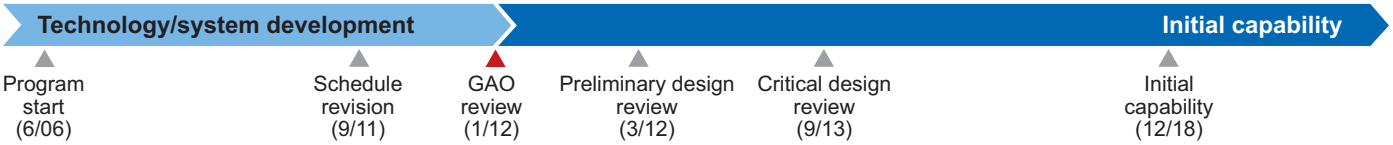
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BMDS: Aegis Ballistic Missile Defense Standard Missile-3 Block IIA

MDA's Aegis Ballistic Missile Defense (BMD) is a sea- and land-based system being developed to defend against missiles of all ranges. It includes a radar, command and control systems, and Standard Missile-3 (SM-3) missiles. We reviewed the SM-3 Block IIA, a cooperative development with Japan, which will have increased velocity and range, a more sensitive seeker, and a more advanced warhead than other SM-3 variants. It is to be fielded with Aegis Weapons System 5.1 in the 2018 time frame as part of the European Phased Adaptive Approach.



Source: Missile Defense Agency.



Program Essentials

Prime contractor: Lockheed Martin, Raytheon
Program office: Dahlgren, VA
Funding needed to complete:
R&D: TBD
Procurement: TBD
Total funding: TBD
Procurement quantity: TBD

Program Performance (fiscal year 2012 dollars in millions)

	As of 04/2010	Latest 05/2011	Percent change
Research and development cost	$2,062.7	$2,521.8	22.3
Procurement cost	NA	NA	NA
Total program cost	$2,062.7	$2,521.8	22.3
Program unit cost	NA	NA	NA
Total quantities	NA	NA	NA
Acquisition cycle time (months)	NA	NA	NA

The cost includes funding for Aegis Weapon System upgrades that will be fielded with the missile.

The SM-3 Block IIA program faces significant technology development challenges. Six of the program's eight critical technologies are immature and require additional development and testing before they can be demonstrated in a system prototype. In addition, four key components failed to complete their subsystem preliminary design reviews in fiscal year 2011, prompting a rebalancing of requirements, the substitution of some components, and an overhaul of the development schedule. Some of the program's critical technologies will need to be modified to address issues found during these reviews. The revised program schedule adjusted system-level design reviews and added more time for development. This will increase program costs, but it also has the potential to reduce acquisition risk and future cost growth and schedule delays.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment ○
- Demonstrate all critical technologies in a realistic environment ○
- Complete preliminary design review ○

Product design is stable

- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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BMDS: SM-3 Block IIA Program

Technology Maturity

The SM-3 Block IIA program faces significant technology development challenges. The majority of the SM-3 Block IIA components are new technology compared to the SM-3 Block IB. The program must develop a new propulsion system with a much greater thrust, a new divert and attitude control system, a more capable seeker, and use new solid fuel, all of which pose significant technological challenges. The development of similar components has been a challenge for previous SM-3 interceptors.

The SM-3 Block IIA program has identified eight critical technologies—six of which are immature and require additional development and testing before they can be demonstrated in a system prototype. The program held subsystem preliminary design reviews during fiscal year 2011, which demonstrated that some critical technologies required redesign or other adjustments. The program has plans in place to rebalance SM-3 Block IIA requirements or replace certain technology components. For example, the program has moved away from a component that has caused problems for the SM-3 Block IB. The program completed new reviews for the four technologies that failed to complete the initial reviews by early fiscal year 2012. In addition, two critical technologies—the second- and third-stage rocket motors—have experienced problems during testing. The program was investigating the causes of those problems and the potential effects at the end of fiscal year 2011. According to the program, all critical technologies will be nearing maturity by its planned September 2013 critical design review.

Other Program Issues

The SM-3 Block IIA program has extended its development schedule by more than a year, which likely will increase program costs, but lower the risk of further cost growth and schedule delays in the future. The program adjusted its system-level preliminary and critical design reviews after several key components failed their preliminary design reviews. The adjustment may reduce acquisition risk and the potential for future cost growth by providing the program more time to reconcile gaps between requirements and resources; demonstrate technical knowledge; and ensure that requirements are defined, feasible, and achievable before committing to product development. The new schedule also lowers risk in other ways, such as building in more recovery time between program reviews and flight tests. Under the revised schedule, flight tests will be delayed from 2015 to late 2016. The SM-3 Block IIA is still planned to be deployed with Aegis Weapons System 5.1 as part of the European Phased Adaptive Approach Phase III in the 2018 time frame.

Program Office Comments

In commenting on a draft of this assessment, Aegis BMD program management officials noted the SM-3 Block IIA program held 60 component-level preliminary design reviews in fiscal year 2011, of which 4 did not receive a pass during the first evaluation. This result drove a schedule adjustment of 1 year. The officials further noted the program used this additional time to implement a more robust engineering process. Actions the program took resulted in the completion of the four component-level reviews and support the completion of the system-level preliminary design review in March 2012. The rebalancing of the component-level requirements that occurred has not affected system-level requirements. Finally, the officials note that the program is on schedule to achieve its European Phased Adaptive Approach objectives. MDA also provided technical comments, which were incorporated as appropriate.

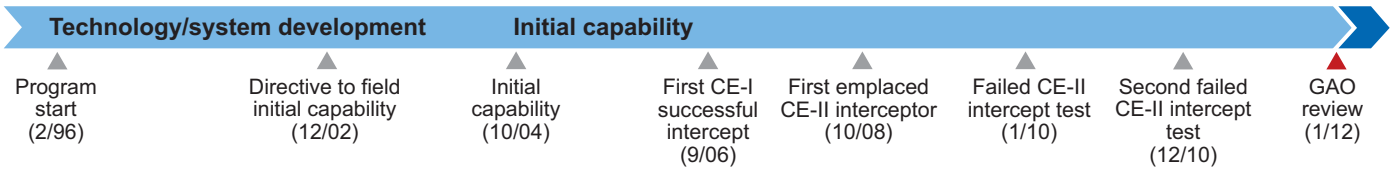
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BMDS: Ground-Based Midcourse Defense (GMD)

MDA's GMD is being fielded to defend against limited long-range ballistic missile attacks during their midcourse phase. GMD consists of an interceptor with a 3-stage booster and kill vehicle and a fire control system, which formulates battle plans and directs components that are integrated with BMDS radars. We assessed the maturity of all GMD critical technologies and the design of the Capability Enhancement II (CE-II) configuration of the Exoatmospheric Kill Vehicle (EKV), which began emplacements in fiscal year 2009.



Source: Missile Defense Agency.



Program Essentials

Prime contractor: Boeing
Program office: Redstone Arsenal, AL
Funding FY12 to FY16:
- R&D: $4,716.6 million
- Procurement: $0.0 million
- Total funding: $4,758.8 million
- Procurement quantity: 0

Program Performance (fiscal year 2012 dollars in millions)

	As of	Latest 08/2011	Percent change
Research and development cost	NA	$38,919.8	NA
Procurement cost	NA	$0.0	NA
Total program cost	NA	$39,161.8	NA
Program unit cost	NA	NA	NA
Total quantities	NA	NA	NA
Acquisition cycle time (months)	NA	NA	NA

Costs are from program inception through fiscal year 2016.

MDA has used a highly concurrent development, production, and fielding strategy for CE-II interceptors, which carried significant risks, some of which were realized after its latest flight test failure. Twelve CE-II EKVs have been manufactured and delivered, but both attempts to verify its capability in flight have failed—the first because of a quality issue and the second because of a failure in the guidance system. The guidance system failure has resulted in design changes, and the risk of further changes on the program will remain until flight testing is complete. The program plans to verify the guidance system fixes through a nonintercept flight test in fiscal year 2012 and has halted the final integration of the remaining CE-II EKVs until it does so. The cost of the CE-II test failures, including costs of failure review, testing, redesigns, and retrofits, could exceed $1.2 billion.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match	
• Demonstrate all critical technologies in a relevant environment	●
• Demonstrate all critical technologies in a realistic environment	○
• Complete preliminary design review	●
Product design is stable	
• Release at least 90 percent of design drawings	●
• Test a system-level integrated prototype	●
Manufacturing processes are mature	
• Demonstrate critical processes are in control	▪▪▪▪
• Demonstrate critical processes on a pilot production line	▪▪▪▪
• Test a production-representative prototype	○

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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BMDS: GMD Program

Technology Maturity

All nine technologies in the GMD operational configuration are mature, but two technologies in the enhanced CE-II interceptor—an upgraded infrared seeker and onboard discrimination—are only nearing maturity. Although the program has manufactured and delivered over 12 CE-II EKVs, its capability has yet to be demonstrated because it failed in its two intercept flight test attempts.

Design and Production Maturity

The GMD program has released all of its expected design drawings to manufacturing and has manufactured and delivered 12 interceptors, but the program remains at risk for design changes until it completes its flight test program, currently scheduled for 2021. For example, the December 2010 CE-II EKV intercept test failure resulted in design changes to resolve problems with the guidance system. These design changes are currently undergoing testing. Additionally, the interceptor design could still change because two of its technologies are not fully mature and have not had their capability verified through flight testing. We did not assess the maturity of production processes for the GMD interceptors. According to the program, the low number of planned quantities does not provide sufficient data to demonstrate its manufacturing processes are in statistical control.

Other Program Issues

MDA has used a highly concurrent development, production, and fielding strategy for CE-II interceptors, which carried significant risks, some of which were realized after its latest flight test failure. That failure has disrupted production, increased costs, and delayed fielding. GMD conducted an intercept flight test to assess the capability of the CE-II EKV in January 2010; however, it did not intercept the target because of a quality-control issue in the EKV. GMD reconducted this test in December 2010 and, although the booster and EKV launched successfully, the EKV failed to achieve an intercept because of a failure in the guidance system. After the test failure, the Director, MDA, halted the planned delivery of CE-II EKVs. In addition, the program deferred other planned fiscal year 2011 work in order to fund the activities necessary to conduct the failure investigation, as well as the resulting redesign efforts. The program plans to verify the fixes it is developing through a nonintercept flight test in fiscal year 2012. The flight test failures have cost MDA hundreds of millions of dollars thus far, and the eventual cost to demonstrate the CE-II through flight testing is likely to be around $1 billion. In addition to the costs of the actual flight tests, the Defense Contract Management Agency reported that mitigating the hardware problems that contributed to the failures will be very expensive and time consuming.

Consequently, the program will have to undertake another major retrofit program for the CE-II EKVs that have already been manufactured. According to GMD program officials, the total cost for this retrofit effort has not been determined, but they expect the effort to cost about $18 million per fielded interceptor resulting in an additional cost of $180 million.

Program Office Comments

In commenting on a draft of this assessment, MDA provided technical comments, which were incorporated as appropriate.

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BMDS: Terminal High Altitude Area Defense (THAAD)

MDA's THAAD is being developed as a rapidly-deployable, ground-based missile defense system with the capability to defend against short- and medium-range ballistic missiles during their late midcourse and terminal phases. A THAAD battery includes interceptors, launchers, an X-band radar, a fire control and communications system, and other support equipment. MDA is scheduled to deliver the first two of nine planned THAAD batteries to the Army in fiscal year 2012 for initial operational use.



Source: Missile Defense Agency.

Technology/system development | **Initial capability**

Program start (1/92)	Transition to MDA (10/01)	Contract award for batteries 1 & 2 (12/06)	Contract award for battery 3 interceptors (3/11)	First operational flight test (10/11)	GAO review (1/12)	Conditional materiel release to Army (2012)

Program Essentials

Prime contractor: Lockheed Martin
Program office: Huntsville, AL
Funding FY12 to FY16:
R&D: $1,451.9 million
Procurement: $4,049.2 million
Total funding: $5,839.0 million
Procurement quantity: NA

Program Performance (fiscal year 2012 dollars in millions)

	As of	Latest 08/2011	Percent change
Research and development cost	NA	$16,146.2	NA
Procurement cost	NA	$5,458.9	NA
Total program cost	NA	$21,942.9	NA
Program unit cost	NA	NA	NA
Total quantities	NA	NA	NA
Acquisition cycle time (months)	NA	NA	NA

Costs are from program inception through fiscal year 2016.

THAAD's major components are mature and its design is currently stable. The number of design drawings has increased by about 30 percent since production began in 2006, due in part to design changes on a critical safety system. Production issues, driven mostly by design changes, have delayed interceptor deliveries by 18 months and have cost the program nearly $40 million. In fiscal year 2011, the program mitigated some of these issues and was able to meet or exceed its production goals for the first several months of fiscal year 2012. The program still must demonstrate that it can steadily produce at this rate over time. THAAD also conducted its first operational flight test in October 2011—a significant event for the program.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ●

Manufacturing processes are mature

- Demonstrate critical processes are in control — ▪▪▪▪
- Demonstrate critical processes on a pilot production line — ▪▪▪▪
- Test a production-representative prototype — ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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BMDS: THAAD Program

Technology and Design Maturity

The THAAD program's major components—the fire control and communications system, interceptor, launcher, and radar—are mature, and the prime contractor has released all of the expected design drawings. However, the number of design drawings has increased by approximately 30 percent since production started in December 2006, due in part to design changes for a safety system called an optical block, which prevents inadvertent launches, and associated changes to the flight sequencing assembly, which houses the optical block. According to program officials, the program considered further design changes, which were estimated to cost approximately $150 million, to the optical block in fiscal year 2011 to make it more producible. However, program management decided not to make those changes because of improved manufacturing performance and program funding constraints. In addition, the current design was demonstrated in an October 2011 flight test and in other testing needed to support an upcoming materiel release decision. Therefore, the program determined that the benefits of continuing the redesign no longer justified the cost.

Production Maturity

MDA awarded a contract for its first two initial operational batteries in December 2006 before developmental testing of all of the system's critical components had been completed. Production issues have delayed interceptor deliveries for the first two batteries by 18 months and have cost the program nearly $40 million. We have previously reported that design changes and producibility issues prevented the interceptor subcontractor from demonstrating the program's planned production rate. The program devised a new testing process to increase production and, according to program officials, the production-rate goal was met in early fiscal year 2012. However, they noted that production rates might be artificially high because the program was able to amass other subcomponents while it was working through interceptor production issues. Consequently, the program still must demonstrate that it can steadily produce at this rate.

Other Program Issues

THAAD conducted its first operational flight test in October 2011—a significant event for the program. Army and DOD test and evaluation organizations were both involved to ensure that the test's execution and results were representative of the operational environment for the fielded system. During the test, the THAAD system engaged and simultaneously intercepted two short-range ballistic missile targets. Army and MDA test organizations will use this test to conduct an operational assessment of the THAAD system. DOD's independent test organization will also use the results to evaluate THAAD's operational effectiveness.

The THAAD program is expecting the system to be approved for conditional materiel release to the Army in the second quarter of fiscal year 2012. For materiel release to occur, the Army must certify that the batteries are safe, suitable, and logistically supported. Conditional materiel release is an interim step in the Army's process and was originally expected to occur in September 2010, but was delayed first by interceptor safety issues, and more recently by the decision to consider data from THAAD's October 2011 operational flight test. A date for the Army's full materiel release decision has not been established. According to program officials, MDA cannot set a target date until it receives the Army's definitive list of conditions that need to be met and funding to address them.

Program Office Comments

In commenting on a draft of this assessment, MDA provided technical comments, which were incorporated as appropriate.

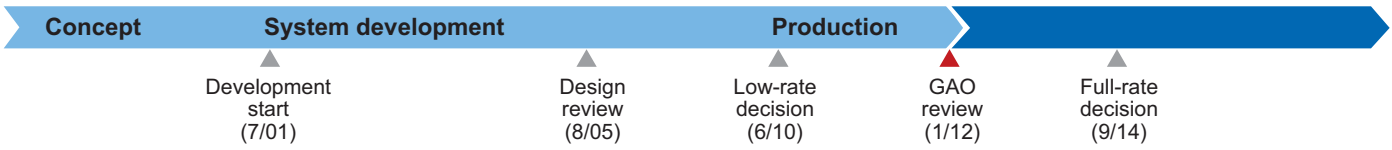
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C-130 Avionics Modernization Program (AMP)

The Air Force's C-130 AMP will standardize and upgrade the cockpit and avionics for the three combat configurations of the C-130 fleet. The upgrades are intended to ensure that the C-130 can satisfy the navigation and safety requirements it needs to operate globally. The program will also replace many systems that are no longer supportable due to diminishing manufacturing resources. These efforts are expected to increase the reliability, maintainability, and sustainability of the upgraded aircraft.



Source: U.S. Air Force.



Program Essentials

Prime contractor: Boeing
Program office: Wright-Patterson AFB, OH
Funding needed to complete:
R&D: $42.2 million
Procurement: $3,890.4 million
Total funding: $3,932.6 million
Procurement quantity: 208

Program Performance (fiscal year 2012 dollars in millions)

	As of 07/2001	Latest 12/2010	Percent change
Research and development cost	$775.4	$1,948.3	151.3
Procurement cost	$3,356.8	$4,256.0	26.8
Total program cost	$4,132.3	$6,204.3	50.1
Program unit cost	$7.962	$28.074	252.6
Total quantities	519	221	-57.4
Acquisition cycle time (months)	NA	NA	NA

The C-130 AMP entered production in 2010; however, it experienced a greater number of design changes than anticipated in fiscal year 2011 as new software was added to address deficiencies found in testing. The program's critical technologies are mature and a 2008 production readiness review concluded that production processes were mature and ready to start initial production. The program plans to award a second low-rate production contract and that contractor will compete with Boeing for the full-rate production contract. Maturity of production processes for the second source will be assessed prior to the contract award. The full-rate production decision has slipped from February 2013 to September 2014 to provide the second contractor sufficient hands-on experience with AMP kit installation to compete. Officials reported that during the delay, Boeing will also address software issues.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match	
• Demonstrate all critical technologies in a relevant environment	●
• Demonstrate all critical technologies in a realistic environment	●
• Complete preliminary design review	●
Product design is stable	
• Release at least 90 percent of design drawings	●
• Test a system-level integrated prototype	●
Manufacturing processes are mature	
• *Demonstrate critical processes are in control*	
• Demonstrate critical processes on a pilot production line	●
• Test a production-representative prototype	●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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C-130 AMP Program

Technology and Design Maturity

The C-130 AMP's critical technologies are mature and its design appears stable; however, the program experienced a somewhat greater number of design changes than anticipated in fiscal year 2011. According to the program office, all of the expected engineering drawings for the C-130 AMP combat delivery configuration were releasable to manufacturing, but a software build was added to the program to address problems found in developmental testing. Specifically, testers found that the core avionics were not well adapted to the C-130's tactical missions and crew workload needed to be reduced during airdrop and low-level operations, as well as those flown in certain formations. The software to address these deficiencies will not be completed and evaluated in time to be included in initial operational test and evaluation. Program officials said the software will be tested beginning in August 2012, a month after operational testing is scheduled to be completed. Officials expect software testing to be completed in advance of the program's full-rate production decision.

Production Maturity

The C-130 AMP received approval to enter low-rate production in June 2010—2 years after a production readiness review concluded that the processes used by Boeing and an Air Force air logistics center were mature and ready to start initial production. Three aircraft have received the AMP modification and the program is meeting or exceeding the quality metrics on which it provided data. However, the program did not assess the manufacturing readiness of key suppliers prior to production. Program officials plan to do so in 2012 and will develop manufacturing maturity plans as needed in order to demonstrate the suppliers' readiness to begin full-rate production.

According to program officials, Boeing will provide all 26 low-rate initial production AMP kits and up to nine installations for the first five production lots. An Air Force logistics center will install kits for the first and second lots of production. Installation of kits for lots 3 through 5 will be completed by Boeing and an Air Force logistics center, as well as a second industry source, to facilitate competition with Boeing for the full-rate production contract. Program officials expect to award a contract to the second contractor in January 2012. Program officials reported that the maturity of production processes of contractors being considered for lots 3 through 5 will be assessed prior to the contract award.

Other Program Issues

The program's full-rate production decision has been delayed 19 months, from February 2013 to September 2014. Program officials stated the delay was necessary to provide a second contractor sufficient hands-on experience with AMP kit installation prior to the contract award for full-rate production. They reported that the program added a fifth low-rate production lot to provide time for the second contractor to accumulate this experience and avoid a production break. The second contractor will compete with Boeing for the full-rate production contract to build and install the AMP kits. An Air Force air logistics center will continue to install AMP kits during full-rate production as well. Program officials stated the delay in full-rate production will also give the program adequate time to complete and test the additional software build.

Program Office Comments

In commenting on a draft of this assessment, the Air Force stated that a source-familiarization phase is being implemented during low-rate initial production to provide a second contractor with sufficient hands-on AMP kit installation experience. The second contractor will then compete with Boeing in a limited competition for full-rate production. Officials also noted that in December 2010, the full-rate production decision was moved from February 2013 to September 2014 to provide the second contractor sufficient hands-on experience prior to proposal submittal to ensure a robust competition. The Air Force also provided technical comments, which were incorporated as appropriate.

GAO Response

After we completed our assessment, DOD proposed cancelling the C-130 AMP program in the President's Budget for Fiscal Year 2013.

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CH-53K - Heavy Lift Replacement

The Marine Corps' CH-53K heavy-lift helicopter is intended to transport armored vehicles, equipment, and personnel to support operations deep inland from a sea-based center of operations. The CH-53K is expected to replace the legacy CH-53E helicopter and provide increased range and payload, survivability and force protection, reliability and maintainability, and coordination with other assets, while reducing total ownership cost.



Source: © 2011 Sikorsky Aircraft Corporation.



Program Essentials

Prime contractor: Sikorsky Aircraft Corporation
Program office: Patuxent River, MD
Funding needed to complete:
- R&D: $3,252.9 million
- Procurement: $16,381.7 million
- Total funding: $19,634.6 million
- Procurement quantity: 196

Program Performance (fiscal year 2012 dollars in millions)

	As of 12/2005	Latest 08/2011	Percent change
Research and development cost	$4,378.9	$6,058.1	38.3
Procurement cost	$12,178.3	$16,381.7	34.5
Total program cost	$16,557.1	$22,439.9	35.5
Program unit cost	$106.136	$112.199	5.7
Total quantities	156	200	28.2
Acquisition cycle time (months)	119	157	31.9

The CH-53K program completed its critical design review in July 2010 with a stable design, but without fully maturing its critical technologies or demonstrating that its design can perform as expected. As a result, the risk of design changes remains. Flight testing is expected to begin in 2014 and the program expects its critical technologies to be demonstrated in a realistic environment by its August 2015 production decision. According to program officials, the program has begun building test aircraft, which should help demonstrate its manufacturing processes before production begins. The CH-53K development contract increased by $724 million to better reflect cost estimates the program has reported since 2009, and several key events were delayed. According to program officials, these changes do not affect the dates of the production decision or initial operational capability.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ● Knowledge attained
- Demonstrate all critical technologies in a realistic environment — ○ Knowledge not attained
- Complete preliminary design review — ● Knowledge attained

Product design is stable

- Release at least 90 percent of design drawings — ● Knowledge attained
- Test a system-level integrated prototype — ○ Knowledge not attained

Manufacturing processes are mature

- *Demonstrate critical processes are in control* — ▪▪▪▪ Information not available
- *Demonstrate critical processes on a pilot production line* — ▪▪▪▪ Information not available
- *Test a production-representative prototype* — ▪▪▪▪ Information not available

Not applicable

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CH-53K Program

Technology Maturity

The CH-53K program began system development in 2005 with immature critical technologies. After 4 years in development, the program's two current critical technologies—the main rotor blade and the main gearbox—were determined to be nearing maturity in February 2010 after being demonstrated in a relevant environment. The program expects these technologies to be demonstrated in a realistic environment by its planned August 2015 production decision. Flight testing of the program's four engineering development models is expected to begin in 2014.

Design Maturity

The CH-53K design appears stable, but it has not been demonstrated using a prototype to show that it will perform as expected. This will not occur until at least 2013. According to the program office, all of the CH-53K's expected design drawings are releasable. However, the continuing maturation of the program's critical technologies could result in design changes as testing progresses.

Production Maturity

According to program officials, the CH-53K program has begun building developmental aircraft and a ground test vehicle. These test articles are being assembled in the same facility where production of the CH-53K is planned to take place. Production of the ground test vehicle began in July 2011 and the first of four engineering development models entered the production line in January 2012. Additionally, program officials stated the completion of the ground test vehicle has been delayed because of problems with the quality of the main gear box castings. However, they believe these problems have been corrected.

Other Program Issues

The CH-53K development contract has increased in cost and several key events have been delayed. Program officials reported that in July 2011, the contract's estimated cost was increased by $724 million to $3.4 billion. According to Defense Contract Management Agency officials, the estimated contract costs increased because of several factors including the need for additional flight test hours and spare parts, increased material costs, and design complexity. The contract was also changed from cost-plus award fee to cost-plus incentive fee for the remaining period of performance. The incentive fees are tied to specific cost and schedule goals. In August 2011, the contract's schedule was rebaselined and several key production and testing events were delayed. For example, the delivery dates for the program's engineering development models were moved back and its first flight was delayed from 2013 to 2014. According to program officials, these contract changes will not affect the dates for the CH-53K's production decision or delivery of an initial operational capability.

In 2008, the Marine Corps directed the CH-53K program to increase the number of planned aircraft from 156 to 200 to support an increase in strength from 174,000 to 202,000 Marines. In February 2011, the Secretary of Defense testified that the number of Marine Corps troops may decrease by up to 20,000 beginning in fiscal year 2015. According to Marine Corps officials, a force structure review has been conducted to assess the required quantity of aircraft and that review determined that the requirement for 200 aircraft is still valid despite the proposed manpower reduction.

Program Office Comments

In commenting on a draft of this assessment, the Marine Corps provided technical comments, which were incorporated as appropriate.

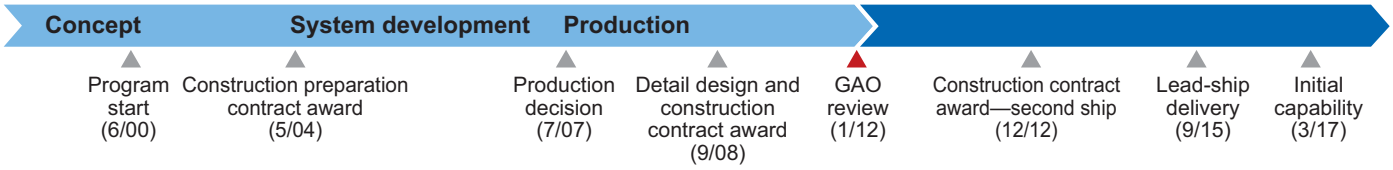
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CVN 78 Class

The Navy's CVN 78 class of nuclear-powered aircraft carriers are being designed to improve operational efficiency, enable higher sortie rates, and reduce manpower through the use of advanced propulsion, aircraft launch and recovery, and survivability technologies. The Navy awarded a contract for detail design and construction of the lead ship, CVN 78, in September 2008 and expects it to be delivered by September 2015. The Navy plans to award the construction contract for CVN 79 in December 2012 and CVN 80 by the end of 2017.



Source: U.S. Navy.



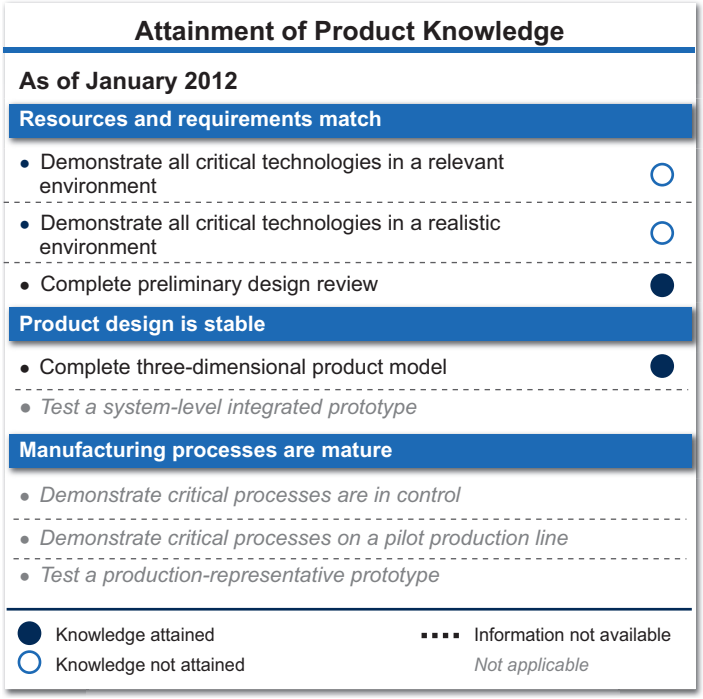
Program Essentials

Prime contractor: Huntington Ingalls Industries–Newport News
Program office: Washington, DC
Funding needed to complete:
R&D: $827.7 million
Procurement: $16,540.9 million
Total funding: $17,368.6 million
Procurement quantity: 2

Program Performance (fiscal year 2012 dollars in millions)

	As of 04/2004	Latest 08/2011	Percent change
Research and development cost	$4,803.3	$4,646.8	-3.3
Procurement cost	$30,770.8	$29,346.8	-4.6
Total program cost	$35,574.1	$33,993.6	-4.4
Program unit cost	$11,858.040	$11,331.185	-4.4
Total quantities	3	3	0.0
Acquisition cycle time (months)	137	155	13.1

When the CVN 78 construction contract was awarded in September 2008, the program had several immature technologies and an incomplete three-dimensional product model. The ship's model is now complete, but 7 of the program's 13 critical technologies still have not been tested in a realistic environment. The electromagnetic aircraft launch system (EMALS) and dual-band radar continue to pose cost and schedule risks and neither system will be fully integrated and tested until after they are on-board. CVN 78's procurement cost has grown by about 10 percent over the past 3 years. Cost growth has been driven by construction cost increases, which the program largely attributes to the immaturity of the ship's technologies and design when the construction contract was awarded. The cost growth may require the program to request additional funding or reduce the ship's capabilities.



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CVN 78 Class Program

Technology Maturity

Seven of the CVN 78 program's 13 current critical technologies have not been tested in a realistic, at-sea environment, including two technologies—EMALS and the dual-band radar—which continue to pose risks. According to program officials, EMALS has successfully launched F/A-18E, T-45C, C-2A, and E-2D aircraft during testing; however, the system has not demonstrated the required level of reliability because of the slow correction of problems discovered earlier in testing. In addition, according to officials, EMALS motor generators have only been tested in a group of 4, rather than the group of 12 that will make up the system. A test of the complete system will not take place until it is aboard the ship. The dual-band radar also will not complete testing until after it is aboard the ship, which presents a risk if the system does not work as intended. The radar is required for ship installation starting in March 2013, but the program does not expect to complete testing the multifunction radar component until early 2013 or begin testing the volume-search radar component until May 2013. Some radar subsystems will not be tested until aboard the CVN 78. In addition, less dual-band radar testing has been done than anticipated because the Navy eliminated the volume-search component of the radar from the DDG 1000 Destroyer program, which the CVN 78 had planned to leverage. CVN 78 will now be the first ship to operate with this radar, but as of August 2011, the Navy had not yet planned for carrier-specific testing. Program officials also noted that the Evolved Sea Sparrow Missile will be demonstrated in a relevant environment by March 2012, at which point all critical technologies will have been demonstrated in a relevant environment.

Design Maturity

The CVN 78 program completed its three-dimensional product model in November 2009—over a year after the award of the construction contract. At the time of the September 2008 contract award, only 76 percent of the ship's three-dimensional product model was complete and the shipbuilder had already begun construction of at least 25 percent of the ship's structural units under its previous construction preparation contract. Program officials noted that while there had been concerns about the ability of the ship's jet blast deflectors to work effectively with the carrier variant of the Joint Strike Fighter, these concerns have been addressed and will not require major design changes. Additional design changes are still possible as EMALS and other systems continue testing.

Production Maturity

Procurement costs for CVN 78 have grown by about 10 percent over the past 3 years. A key driver is an increase in construction costs. According to the program, 83 percent of the ship's structural units are complete, constituting almost 27 percent of the expected labor hours. However, the program estimates that the labor hours to complete the ship will be 4 million more than the 40 million hours originally budgeted. The program believes the cost and labor-hour increases are largely due to the immaturity of the ship's technologies and design when the construction contract was awarded. Program officials also cited problems such as late material deliveries, an unexpected need for more structural support to achieve a thinner deck structure, and material deficiencies on developmental components such as valves. According to the program, the growth in construction costs may require requests for additional funding or a reduction of the ship's capabilities.

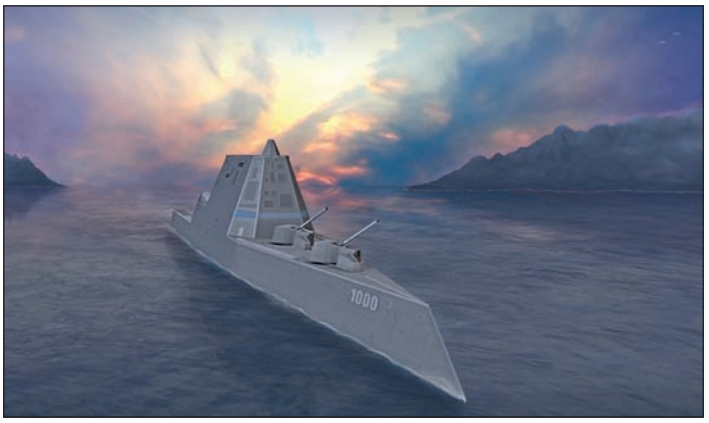
Program Office Comments

In commenting on a draft of this assessment, the program noted that dual-band radar testing, while impacted by DDG 1000 decisions on volume-search radar, is fully funded and will complete land-based tests and begin shipboard testing prior to delivery.

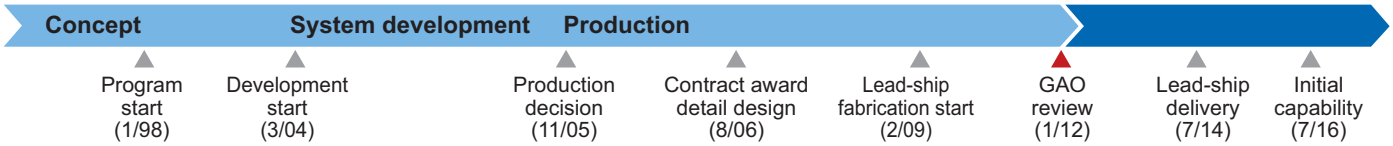
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DDG 1000 Destroyer

The Navy's DDG 1000 destroyer is a multimission surface ship designed to provide advanced land-attack capability in support of forces ashore and littoral operations. The ship will feature a low radar profile, an advanced gun system, and a total ship computing environment intended to improve the speed of command and reduce manning. Fabrication has begun on the first two ships and is planned to begin on the third ship in fiscal year 2012.



Source: U.S. Navy.



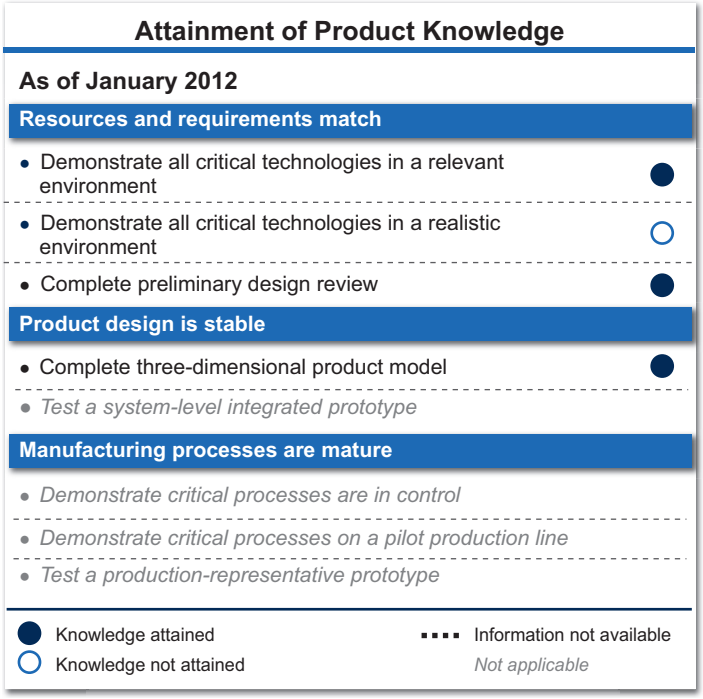
Program Essentials

Prime contractor: BAE Systems, Bath Iron Works, Huntington Ingalls Industries, Raytheon
Program office: Washington, DC
Funding needed to complete:
R&D: $995.6 million
Procurement: $1,418.1 million
Total funding: $2,413.6 million
Procurement quantity: 0

Program Performance (fiscal year 2012 dollars in millions)

	As of 01/1998	Latest 08/2011	Percent change
Research and development cost	$2,277.9	$10,378.4	355.6
Procurement cost	$32,522.1	$10,607.2	-67.4
Total program cost	$34,800.0	$20,985.6	-39.7
Program unit cost	$1,087.500	$6,995.214	543.2
Total quantities	32	3	-90.6
Acquisition cycle time (months)	128	222	73.4

The DDG 1000 design is stable and all three ships are in or will soon be in fabrication. However, the program is still conducting development work on several of its critical technologies and most of them will not be fully mature and demonstrated in a realistic environment until after their installation on the ship. One of the technologies—the advanced gun system's long-range land-attack projectile—continued to experience delays due to issues with its rocket motor. The Navy plans to finalize and test the rocket motor design by March 2012. The first two ships are approximately 63 percent and 22 percent complete, respectively. According to program officials, the shipbuilder had to rework some areas on the first ship, which resulted in an 8-week schedule delay, but only minor cost increases. The Navy has noted improvements in fabrication on the second ship.



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DDG 1000 Program

Technology Maturity

The DDG 1000 program is still conducting development work on several of its critical technologies. Three of DDG 1000's 12 critical technologies are currently mature and the integrated deckhouse will be delivered to the first ship for installation in fiscal year 2012. However, the remaining eight technologies will not be demonstrated in a realistic environment until after ship installation. The Navy has completed a successful full-power test of the integrated power system—one of these eight technologies—and plans a follow-on test in fiscal year 2012. Another critical technology—the total ship computing environment—consisted initially of six software releases. According to program officials, software release 5 has been completed and was used in land-based testing in fiscal year 2011. The program has made changes to release 6, and has prioritized the software needed to support shipyard delivery over the functionality needed for activating the mission systems. This functionality was moved out of the releases and will be developed as part of a spiral. Other key technologies, including the multifunction radar and the advanced gun system, have been delivered to the first ship. However, the gun system's long-range land-attack projectile has encountered delays, primarily due to problems with its rocket motor. The Navy plans to finalize and test the rocket motor design by March 2012. The Navy has performed several guided flight tests using older rocket motor designs, which demonstrated that the projectile can meet its accuracy and range requirements.

Design and Production Maturity

The DDG 1000 design is stable, although the potential for design changes remains until its critical technologies are fully mature. There have been few design changes resulting from lead-ship production, which program officials attribute to a high level of design maturity prior to fabrication. As of January 2012, the Navy estimated that the first ship, which began fabrication in February 2009, was 63 percent complete. The second ship, which began fabrication in March 2010, is 22 percent complete.

Shipbuilders have experienced several challenges in constructing the first and second ships, including issues with the manufacture and installation of certain composite materials. According to program officials, the shipbuilder had to rework some areas, which resulted in an 8-week schedule delay, but only minor cost increases. Program officials noted that the shipbuilder has developed and refined manufacturing and installation processes to reduce the likelihood of rework on the subsequent ships.

Other Program Issues

Following a Nunn-McCurdy unit-cost breach of the critical threshold in 2010, DOD restructured the DDG 1000 program and removed the volume-search radar from the ship's design. The program will modify the multifunction radar to meet its volume-search requirements.

The Navy recently awarded contracts for fabrication of the third ship, its gun system, and software development and integration. In these negotiations, program officials said the Navy leveraged its knowledge about actual costs from the fabrication of the first two ships and from other programs to reduce costs. According to program officials, the Navy is in negotiations for contracts related to the mission systems and other key segments of the third ship.

Program Office Comments

In commenting on a draft of this assessment, Navy officials confirmed that the program was recertified and restructured in June 2010 following a Nunn-McCurdy unit-cost breach and the curtailing of the program to three ships. Since then, the Navy has awarded ship construction contracts for all three ships, including advanced guns and all required software. All critical technologies have been tested in at least a relevant environment. Officials noted that more than 90 percent of the software has been completed through design, code, unit test, and integration and its schedule is aligned to ship activations. Navy officials also said that program reviews by the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics and DOD's Office of Performance Assessment and Root Cause Analyses concluded that the Navy is managing and retiring program risk. The Navy also provided technical comments, which were incorporated as appropriate.

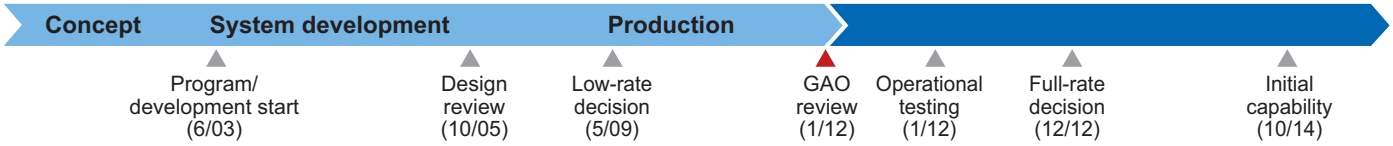
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E-2D Advanced Hawkeye (E-2D AHE)

The Navy's E-2D AHE is an all-weather, twin-engine, carrier-based aircraft designed to extend early warning surveillance capabilities. It is the next in a series of upgrades the Navy has made to the E-2C Hawkeye platform since its first flight in 1971. The key objectives of the E-2D AHE are to improve target detection and situational awareness, especially in the littorals; support theater air and missile defense operations; and provide improved operational availability for the radar system.



Source: U.S. Navy.



Program Essentials

Prime contractor: Northrop Grumman
Program office: Patuxent River, MD
Funding needed to complete:
- R&D: $367.8 million
- Procurement: $10,874.7 million
- Total funding: $11,257.5 million
- Procurement quantity: 60

Program Performance (fiscal year 2012 dollars in millions)

	As of 06/2003	Latest 08/2011	Percent change
Research and development cost	$3,841.0	$4,537.9	18.1
Procurement cost	$10,911.1	$13,167.1	20.7
Total program cost	$14,752.0	$17,747.3	20.3
Program unit cost	$196.694	$236.630	20.3
Total quantities	75	75	0.0
Acquisition cycle time (months)	95	136	43.2

The E-2D AHE's critical technologies are mature, its design is stable, and its production processes have been demonstrated. According to E-2D program office and Defense Contract Management Agency (DCMA) officials, the contractor is also performing well on a variety of production metrics. The program continues to make progress completing development test points and addressing issues identified in the 2010 operational assessment, but it delayed initial operational test and evaluation from November 2011 to January 2012. The program office continues to improve the radar's reliability rate, which is currently 71 hours, but DOD test organizations expressed some concern about whether the radar will be able to meet some reliability and performance measures during initial operational test and evaluation.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match
- Demonstrate all critical technologies in a relevant environment ●
- Demonstrate all critical technologies in a realistic environment ●
- Complete preliminary design review ●

Product design is stable
- Release at least 90 percent of design drawings ●
- Test a system-level integrated prototype ●

Manufacturing processes are mature
- *Demonstrate critical processes are in control*
- Demonstrate critical processes on a pilot production line ●
- Test a production-representative prototype ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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E-2D AHE Program

Technology and Design Maturity

According to the Navy, all five of the E-2D AHE's critical technologies are mature and its design is stable. Program officials told us that an increase in design drawings over the last year was primarily due to changes made to address issues identified during development testing. None of the test discoveries resulted in major changes to the aircraft design, and DCMA officials confirmed that these design changes were relatively minor.

Production Maturity

The E-2D AHE's production processes have been demonstrated. According to the E-2D program office and DCMA officials, the contractor is performing well on a variety of production metrics and the program has not identified any issues that would result in cost or schedule growth on the production contract. The contractor reports monthly to DCMA and the program office on a series of production metrics, such as scrap and rework rates. The program did not identify any critical manufacturing processes associated with the E-2D AHE, nor does the program require the contractor's major assembly site to use statistical process controls to ensure its critical processes are producing high-quality and reliable products because components are assembled using manual processes that do not lend themselves to such measures.

Other Program Issues

The program continues to make progress completing development test points and addressing issues identified in the 2010 operational assessment, but it delayed initial operational test and evaluation from November 2011 to January 2012. Some development test points related to the Cooperative Engagement Capability (CEC) remain to be completed. The CEC is a system that integrates information from multiple sources to track potential targets and is being developed by a separate Navy program office. The E-2D program could not test this capability as scheduled because of late deliveries from the CEC program. The E-2D program has now received the CEC and plans to test it before the start of initial operational testing.

The program office continues to improve the radar's reliability. The E-2D program reported the current radar reliability rate is 71 hours. The radar must achieve a rate of 81 hours prior to the decision to enter full-rate production, which is scheduled for December 2012. DOD test organizations expressed some concern about whether the radar will be able to meet some reliability and performance measures during initial operational test and evaluation. However, initial results from a test exercise conducted in November partially addressed the performance concerns, according to an official at a DOD test organization.

As part of DOD's better-buying-power initiatives, the E-2D AHE program conducted a should cost analysis prior to the negotiation of its third production contract. According to program officials, it used the results of this analysis to achieve a 4.5 percent cost savings on this contract.

Program Office Comments

In commenting on a draft of this assessment, Navy officials noted that the program has completed all the testing required on the E-2D itself before entering initial operational test and evaluation, although some testing of the CEC system remains. The Navy also provided technical comments, which were incorporated as appropriate.

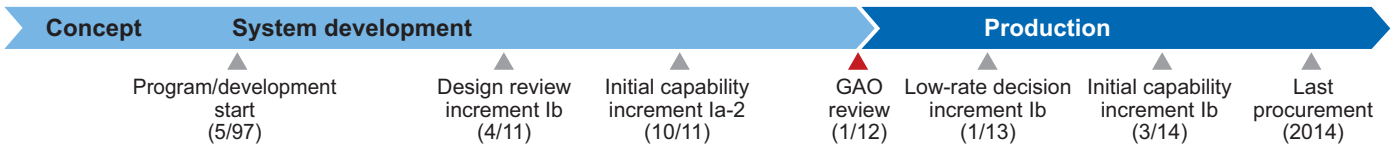
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Excalibur Precision Guided Extended Range Artillery Projectile

The Army's Excalibur is a family of global positioning system–based, fire-and-forget, 155 mm cannon artillery precision munitions intended to provide improved range and accuracy. The near-vertical angle of fall is expected to reduce collateral damage, making it more effective in urban environments. The Army is using a three-phased approach to deliver capabilities. Increment Ia-1 is fielded, Ia-2 is in production, and Ib, which is expected to increase reliability and lower unit costs, will begin production in 2013. We assessed increment Ib.



Source: U.S. Army.



Program Essentials

Prime contractor: Raytheon
Program office: Picatinny Arsenal, NJ
Funding needed to complete:
R&D: $50.2 million
Procurement: $234.9 million
Total funding: $285.1 million
Procurement quantity: 3,455

Program Performance (fiscal year 2012 dollars in millions)

	As of 02/2003	Latest 08/2011	Percent change
Research and development cost	$765.5	$1,068.3	39.6
Procurement cost	$4,010.8	$712.1	-82.2
Total program cost	$4,776.2	$1,780.5	-62.7
Program unit cost	$.062	$.238	282.4
Total quantities	76,677	7,474	-90.3
Acquisition cycle time (months)	136	173	27.2

Total quantities include 3,455 increment Ib projectiles.

The Excalibur program will have to resolve several increment Ib design issues before its planned January 2013 production decision. In August 2010, the Army began system development for increment Ib with its one critical technology nearing maturity. The increment Ib design review was held in April 2011 and while all the expected design drawings were releasable, parts of the design were found to be incomplete and noncompliant. Additional subsystem design reviews will be required to certify the design is complete. The program is conducting a series of tests in advance of its production decision to ensure performance and safety requirements can be met. Reliability testing will not be complete until after production has begun. The program experienced a Nunn-McCurdy unit-cost breach of the critical threshold in 2010 due to a reduction in quantities, but was certified to continue in 2011.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match	
• Demonstrate all critical technologies in a relevant environment	●
• Demonstrate all critical technologies in a realistic environment	●
• Complete preliminary design review	●
Product design is stable	
• Release at least 90 percent of design drawings	●
• Test a system-level integrated prototype	●
Manufacturing processes are mature	
• *Demonstrate critical processes are in control*	
• *Demonstrate critical processes on a pilot production line*	
• *Test a production-representative prototype*	

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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Excalibur Program

Technology Maturity

After an 18-month prototype design and demonstration phase, the Army began system development for increment Ib in August 2010 with its one critical technology—the guidance system—nearing maturity. According to the program office, the guidance system is now mature.

Design Maturity

The Excalibur program will have to resolve several increment Ib design issues before its design can be considered stable. The majority of the increment Ib design is complete and all of the program's current design drawings were released by its April 2011 design review. However, the design review panel indicated that three of the eight projectile subassemblies—the base assembly, fuze safe and arm device, and tactical telemetry module—had incomplete designs. Those subassemblies will require additional subsystem-level design reviews and testing before their designs can be considered complete. Further, although the majority of the design appears to comply with current program requirements, the program does not currently meet requirements related to insensitive munitions, the range of the gun, and the fuze setting timeline. Ensuring compliance with these requirements could require design changes, and the program is uncertain of the total number of drawings that will ultimately be required for the projectile.

The program is beginning integrated developmental and operational testing to prepare for the January 2013 production decision for increment Ib. Design verification testing was conducted in May and July 2011 to characterize the performance and structural integrity of the design for the Ib base as well as to gather aerodynamic data on the latest design. The Army also plans to perform sequential environment tests to evaluate the performance, reliability, and lethality of the projectiles under a broad range of conditions. All performance and safety requirements are expected to be met before the production decision. However, reliability testing will not be complete until after production has begun.

Production Maturity

The lack of a complete and stable design has prevented the Excalibur program from demonstrating the level of manufacturing maturity for increment Ib expected for a program that is preparing to enter production. The increment Ib will use similar manufacturing processes as the increment Ia, which the program assesses as mature. However, according to the increment Ib June 2011 capability production document, final manufacturing processes have not yet been demonstrated at two key suppliers because of incomplete or changing designs.

Other Program Issues

In May 2010, the Army reduced program quantities from 30,000 to 6,264 based on a review of precision munition needs. The resulting unit-cost increase led to a Nunn-McCurdy unit-cost breach of the critical threshold. A January 2011 program review concluded that the program is essential to national security and no alternatives are available to provide the same capability at a lower cost. As a result, in January 2011, the restructured Excalibur program was certified to continue. The restructured program plans to save $24 million by increasing the rate of increment Ib production and using fixed-price contracts with economic price adjustments for steel.

Program Office Comments

In commenting on a draft of this assessment, the Army stated that the program does not currently meet requirements related to insensitive munitions due to the lack of a qualified explosive, and the fuse setting due to a new requirement to clear cryptographic keys prior to loading the new key. Ensuring compliance with the insensitive munitions requirement would require an insensitive explosive qualification program and subsequent warhead qualification, which would delay the program and increase costs. The fuze setting timeline is currently within less than one second of the requirement. Changing the requirement to allow the system to overwrite previously entered keys would allow this requirement to be met. The Army further stated that manufacturing processes will be demonstrated and reviewed prior to the production decision. The Army also provided technical comments, which were incorporated as appropriate.

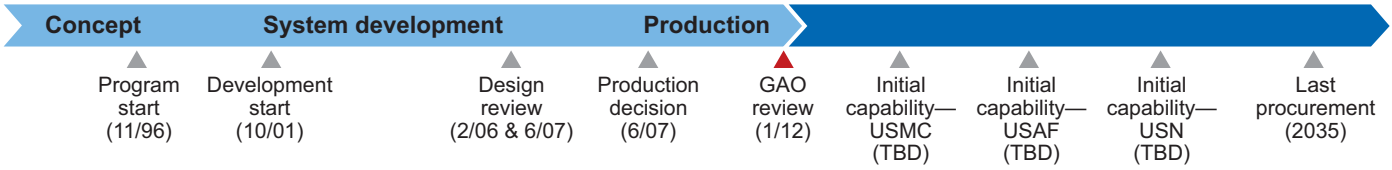
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F-35 Lightning II (Joint Strike Fighter)

DOD's JSF program is developing a family of stealthy, strike fighter aircraft for the Navy, Air Force, Marine Corps, and U.S. allies, with the goal of maximizing commonality to minimize life-cycle costs. The carrier-suitable variant will complement the Navy F/A-18 E/F. The Air Force variant will primarily replace the air-to-ground attack capabilities of the F-16 and A-10, and will complement the F-22. The short take-off and vertical landing variant will replace the Marine Corps F/A-18 and AV-8B aircraft.



Source: 2010 Lockheed Martin.



Program Essentials

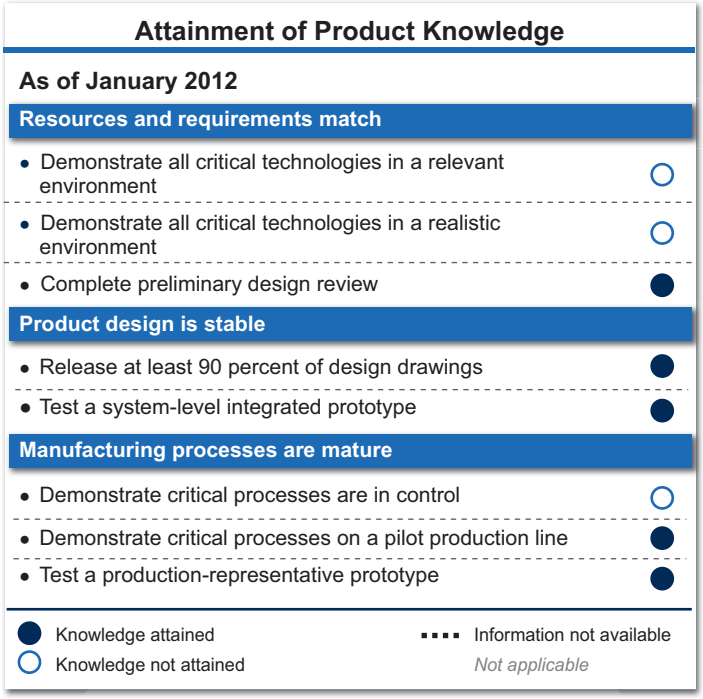
Prime contractor: Lockheed Martin, Pratt and Whitney
Program office: Arlington, VA
Funding needed to complete:
R&D: $10,117.8 million
Procurement: $245,676.5 million
Total funding: $255,970.4 million
Procurement quantity: 2,353

Program Performance (fiscal year 2012 dollars in millions)

	As of 10/2001	Latest 12/2010	Percent change
Research and development cost	$38,976.7	$58,387.6	49.8
Procurement cost	$172,921.4	$267,595.6	54.7
Total program cost	$213,708.2	$326,535.2	52.8
Program unit cost	$74.567	$132.900	78.2
Total quantities	2,866	2,457	-14.3
Acquisition cycle time (months)	116	TBD	NA

Latest column does not fully reflect the restructured JSF program. Costs are expected to grow and the schedule will be extended.

The JSF program has awarded contracts for production aircraft, but it still lacks key knowledge about its technologies and manufacturing processes. Four critical technologies are not mature and present significant development risks as the program integrates and tests them. The program is making progress in flight testing, but much of its developmental and operational testing remains and the risk of future design changes is significant. Manufacturing inefficiencies, parts shortages, and quality issues persist, but there has been some improvement. The program has been restructured to address development challenges, which triggered a Nunn-McCurdy unit-cost breach of the critical threshold. Aircraft quantities have been reduced in the near term to reduce risk and offset increased development funding needs. DOD has not yet approved a new baseline for the program.



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JSF Program

Technology Maturity

The JSF program began system development with none of its eight critical technologies mature; and, according to program officials, four of these technologies—mission systems integration, which includes the helmet-mounted display; the prognostics and health management system; integrated core processor; and integrated support systems—are still not fully mature. Deficiencies in the helmet-mounted display prompted the program to develop a second helmet. The program is also trying to fix the first helmet, which does not currently meet system requirements. Significant development risks remain as the program integrates and tests these technologies.

Design Maturity

The JSF program did not have a stable design at its critical design reviews. The program has now released 96 percent of its total expected design drawings; however, it continues to experience design changes. With most of developmental and operational flight testing still ahead, the risk of future design changes and their potential effects on the program could be significant.

Production Maturity

The JSF program's manufacturing processes have not been fully demonstrated as only 24 percent of the critical processes are in statistical control. The prime contractor has made manufacturing process improvements and some key production metrics are improving. However, manufacturing inefficiencies persist, primarily driven by parts shortages, parts quality issues, and technical changes arising from discoveries during test events, indicating that the aircraft's design and production processes may still lack the maturity needed to efficiently produce aircraft at planned rates. The prime contractor planned to deliver 16 production aircraft in 2011, but only 9 were delivered. Reintroduction of the carrier variant into the production line has resulted in parts shortages and out-of-station work, which can be highly inefficient. The prime contractor is also managing hundreds of suppliers within a global network, which adds to the complexity of producing aircraft efficiently and on-time. In addition, extensive testing remains to be completed and the program could be required to alter production processes, change its supplier base, and retrofit produced and fielded aircraft if problems are discovered.

Other Program Issues

DOD has restructured the JSF program by adding more time and money to address development challenges and reducing near-term quantities to reduce risk and offset the additional development costs. The projected cost of the restructured program triggered a Nunn-McCurdy unit-cost breach of the critical threshold in 2010. At the time of our assessment, the program had not yet completed a DOD review at which time the program's updated cost and schedule estimates may be approved. According to program officials, the services are also assessing the effect of the program changes and have not yet determined new initial operational capability dates for any of the variants.

All but one of the initial test assets have been delivered to their respective test locations, and the program made significantly more progress in flight testing compared to the previous year. The short take-off and vertical landing variant successfully completed initial ship trials. However, the program continues to experience challenges in developing and integrating the large and complex software requirements needed to achieve JSF capabilities, which could slow testing.

Program Office Comments

In commenting on a draft of this assessment, DOD noted that the JSF program has 10 years of development and aircraft in production. In reference to the helmet, officials explained that due to the need to demonstrate at the milestone B recertification that all technologies had been demonstrated in at least a relevant environment, the program is adding a second helmet as a risk-reduction effort while continuing to improve the first helmet. The program has a plan to mitigate development risks for the original helmet through developmental testing. DOD also provided technical comments, which were incorporated as appropriate.

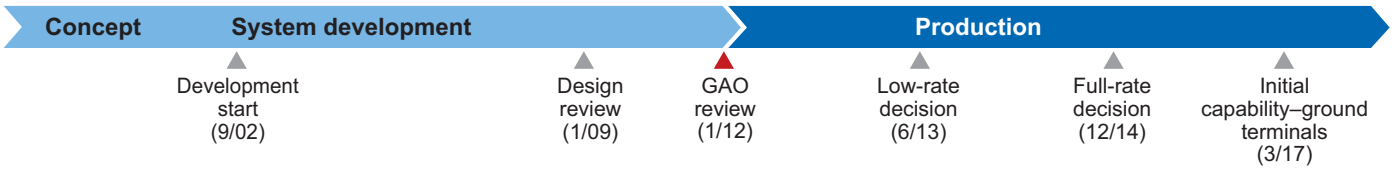
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Family of Advanced Beyond Line-of-Sight Terminals (FAB-T)

The Air Force's FAB-T program plans to provide a family of satellite communications terminals for airborne and ground-based users that will replace many program-unique terminals. It is being designed to work with current and future communications capabilities and technologies. FAB-T is expected to provide voice and data military satellite communications for nuclear and conventional forces as well as airborne and ground command posts, including B-2, B-52, RC-135, E-6, and E-4 aircraft.



Source: U.S. Air Force.



Program Essentials

Prime contractor: Boeing
Program office: Hanscom AFB, MA
Funding needed to complete:
R&D: $571.4 million
Procurement: $2,338.6 million
Total funding: $2,910.0 million
Procurement quantity: 216

Program Performance (fiscal year 2012 dollars in millions)

	As of 12/2006	Latest 08/2011	Percent change
Research and development cost	$1,537.1	$2,338.7	52.2
Procurement cost	$1,651.4	$2,349.6	42.3
Total program cost	$3,188.5	$4,688.3	47.0
Program unit cost	$14.762	$19.058	29.1
Total quantities	216	246	13.9
Acquisition cycle time (months)	129	174	34.9

The latest cost data do not reflect the current cost of the program. A new acquisition program baseline has not yet been approved.

The FAB-T program has gained key knowledge about its critical technologies and design, but it faces several cost, schedule, and development challenges. In 2010, the program extended development and has since delayed production by more than 3 years. The program's software development schedule is still unrealistic. There has been an increase in productivity, but development may be completed 4 to 8 months behind the new schedule. In addition, a high-priority presidential and national voice conferencing requirement has not yet been put under contract. The program will likely breach critical Nunn-McCurdy unit-cost thresholds unless it can achieve significant savings from its revised acquisition strategy, which includes competition for FAB-T development and production. There will be continued uncertainty about the program's cost until a new acquisition program baseline is approved.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ●

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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FAB-T Program

Technology Maturity

According to the FAB-T program, all six of its critical technologies are mature. These technologies have been demonstrated in recent testing—both in-flight and with a satellite simulator.

Design Maturity

The FAB-T's design is currently stable; however, design changes are likely as the program addresses new requirements. The program reported that 98 percent of its total expected design drawings were releasable, but the number of design changes was somewhat greater than anticipated in fiscal year 2011. In addition, the U.S. Strategic Command has requested that a new, high-priority requirement for presidential and national voice conferencing be added to the program. Program officials stated that requirements development and design activities related to this capability began in October 2011, but the engineering changes to the terminal will not be put under contract until spring 2012.

Software development and testing remain major challenges for the program. An April 2011 independent review team found that the software development schedule could not be met without extraordinary productivity growth. In response, program officials told us that they have put in place metrics to manage the effort, revised the test schedule, and increased the government's presence at the contractor's facility. According to program officials, there has been an increase in productivity; however, the program is still behind schedule and development could be completed 4 to 8 months late.

Other Program Issues

The FAB-T program was restructured in 2010 and its acquisition strategy is being revised, but a new acquisition program baseline that reflects these changes and their projected costs has not yet been approved. As part of the restructuring, the program extended its system development phase and delayed its production decision by more than 3 years to June 2013. In October 2010, an independent review team noted that the program was likely in breach of critical Nunn-McCurdy unit-cost thresholds; however, a breach has not yet been reported by the program. The FAB-T program plans to change its acquisition strategy to competitively award contracts for development and production. Program officials said they expect to achieve significant savings in production by using this approach. They also stated that a recent independent cost estimate showed substantial cost growth in the program, but it did not reflect the competitive strategy, which is still under review. A new independent cost estimate, which includes the competitive strategy and new voice conferencing requirement, is expected to be conducted by October 2012.

Due to uncertainty about FAB-T, the Air Force stopped work on contracts related to its integration with the B-2 and B-52—the two bomber platforms for which it is designed. According to officials, both programs are considering alternatives to transmit data through AEHF satellites, which is an important capability for strategic platforms. However, FAB-T might not be able to provide its full range of planned communications capabilities if the bomber programs pursue alternatives since some of its capabilities are based on the interaction of bomber aircraft with intelligence, surveillance, and reconnaissance aircraft and ground terminals.

Program Office Comments

In commenting on a draft of this assessment, the Air Force stated that the FAB-T program is executing the Under Secretary of Defense for Acquisition, Technology and Logistics' January 2012 acquisition decision memorandum, which directed it to establish a competitively awarded fixed-price development and production approach by placing priority on the air and ground command post terminals to provide a presidential and national voice conferencing capability. In addition, the memorandum also directed the program to complete an independent cost estimate and revised acquisition program baseline prior to the award of an alternate source. In parallel with executing the memorandum, the program office is considering converting the current cost-plus award fee contract into a firm fixed-price contract in order to reduce the government's cost risk. The Air Force also provided technical comments, which were incorporated as appropriate.

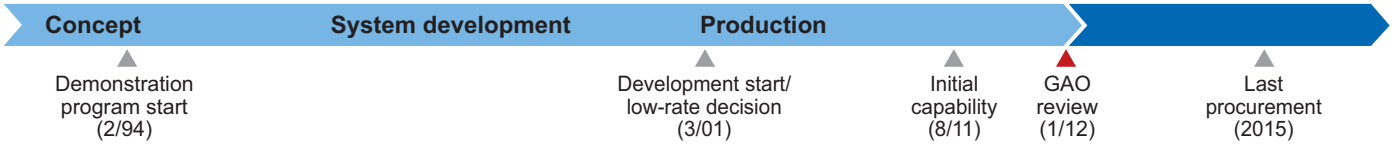
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Global Hawk (RQ-4A/B)

The Air Force's Global Hawk is a high-altitude, long-endurance unmanned aircraft that provides intelligence, surveillance, and reconnaissance capabilities. The Global Hawk will replace the U-2. After a successful technology demonstration, the system entered development and limited production in March 2001. The early RQ-4A, similar to the original demonstrators, was retired in 2011, leaving a fleet of the larger and more capable RQ-4Bs. We assessed the RQ-4B, which is being produced in 3 configurations—block 20, 30, and 40.



Source: Northrop Grumman.



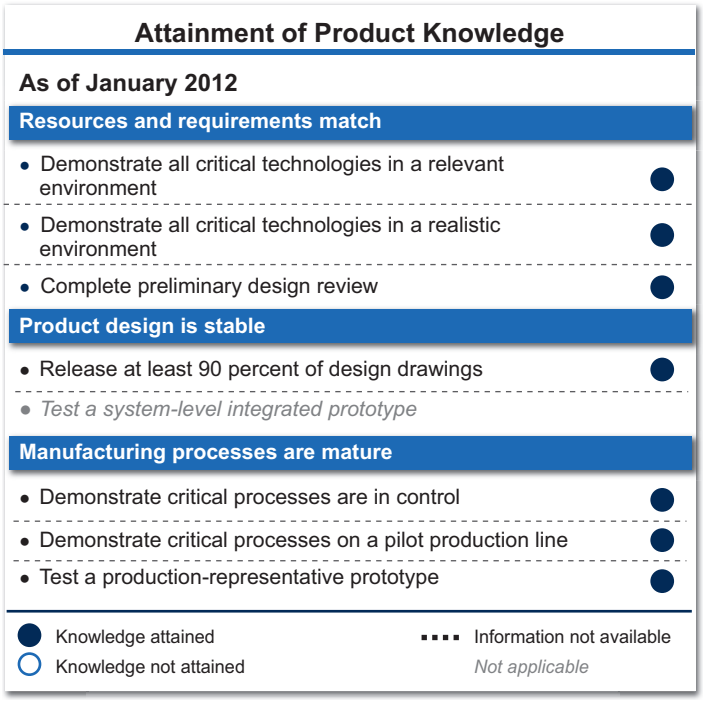
Program Essentials

Prime contractor: Northrop Grumman
Program office: Wright-Patterson AFB, OH
Funding needed to complete:
R&D: $1,657.1 million
Procurement: $3,098.9 million
Total funding: $4,789.4 million
Procurement quantity: 13

Program Performance (fiscal year 2012 dollars in millions)

	As of 03/2001	Latest 10/2011	Percent change
Research and development cost	$1,041.6	$4,769.3	357.9
Procurement cost	$4,318.8	$7,877.4	82.4
Total program cost	$5,392.0	$12,811.6	137.6
Program unit cost	$85.588	$232.938	172.2
Total quantities	63	55	-12.7
Acquisition cycle time (months)	55	125	127.3

The Global Hawk program has utilized a concurrent testing and production strategy, which put it at increased risk of cost growth. The program procured all of its block 20 and more than half of its block 30 aircraft before completing operational testing in 2010 and plans to procure all of its block 40 aircraft before it begins operational testing in 2013. In May 2011, the Director, Operational Test and Evaluation, found that the block 30 system was not operationally effective or suitable and provided several recommendations to improve the aircraft's capability and reliability. The program has addressed most of the test findings. The program also reported a critical Nunn-McCurdy cost breach to Congress in April 2011 and has been restructured. The planned dates for remaining key events have been delayed by an additional 6 months or more and the number of aircraft has been decreased to 55.



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Global Hawk Program

Technology, Design, and Production Maturity

The critical technologies for the RQ-4B are mature, its basic airframe design is stable, and its manufacturing processes are mature and in statistical control. The RQ-4B aircraft is being produced in three configurations. Block 20 aircraft are equipped with an enhanced imagery intelligence payload, block 30 aircraft have both imagery and signals intelligence payloads, and block 40 aircraft will have an advanced radar surveillance capability. All six block 20 aircraft have been produced and production continues on block 30 and block 40 aircraft. However, the program must still successfully test one of its key capabilities for block 40 aircraft—the multiple platform radar—to ensure it performs as expected. Developmental testing of the multiple platform radar is now underway, but the program remains at risk for late design changes if problems are discovered in testing.

Other Program Issues

The Global Hawk program has utilized a concurrent testing and production strategy, which put it at increased risk of cost growth. The program procured all of its block 20 and more than half of its block 30 aircraft by the time it completed operational testing in December 2010. On the basis of the results of this testing, the Director, Operational Test and Evaluation, reported in May 2011 that the block 30 system was neither operationally effective nor operationally suitable for conducting near-continuous, persistent intelligence, surveillance, and reconnaissance based on the Air Force Concept of Employment, and made several recommendations to improve the system's capabilities, situational awareness, and reliability. According to program officials, they have addressed most of the problems identified in operational testing and have plans in place to correct the remainder. Initial operational capability was declared for block 30 aircraft in August 2011. The program also plans to procure all of its block 40 aircraft before its projected start of operational testing in October 2013, putting it at increased risk of costly retrofits if problems are discovered.

In 2011, the Global Hawk program reported a Nunn-McCurdy unit-cost breach of the critical cost growth threshold and was restructured. The program office attributed the cost growth to changes in the quantities of block 30 and block 40 aircraft, increases in support costs, and the revised architecture of its ground station and communication systems. DOD also pointed to the presence of known, but unfunded, requirements and an unrealistic schedule as root causes for much of the cost growth. The restructured program includes four separate subprograms—block 10/20, block 30, block 40, and ground station and communications. The block 30 and 40 subprograms will hold new production decision reviews in early 2012. The ground station and communications subprogram is scheduled to begin system development in summer 2013. The program also has five performance requirements that were part of its existing baseline that will not be available in the required timeline. As a result of actions taken in DOD's fiscal year 2012 budget and the Nunn-McCurdy process, the planned quantities for the program have been decreased from 77 aircraft to 55 aircraft and aircraft procurement is scheduled to be completed in 2015.

Program Office Comments

In commenting on a draft of this assessment, the Air Force stated that in 2011 the program deployed its block 30 systems and they are operational in theater. The program is also addressing challenges to increase reliability, availability, maintainability, and effective time-on-station metrics for the system. In addition to commenting on this assessment, the Air Force provided technical comments, which we incorporated where appropriate.

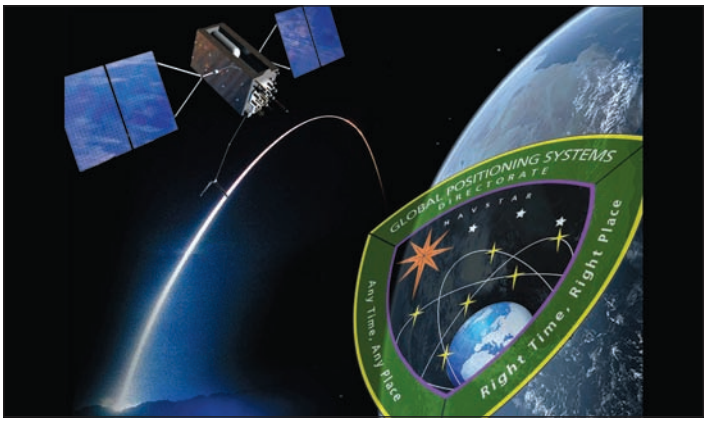
GAO Response

In January 2012, DOD announced its plan to terminate the Global Hawk block 30 system in fiscal year 2013, due to the high cost associated with the program.

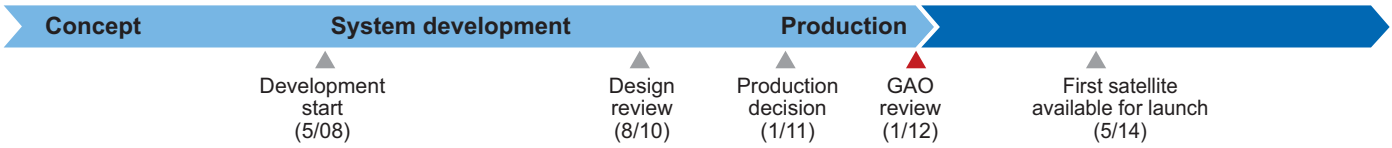
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Global Positioning System (GPS) III

The Air Force's Global Positioning System (GPS) III program plans to develop and field a new generation of satellites to supplement and eventually replace GPS satellites currently in use. Other programs will develop the ground system and user equipment. GPS III will be developed incrementally. We assessed the first increment, which intends to provide capabilities such as a stronger military navigation signal to improve jamming resistance and a new civilian signal that will be interoperable with foreign satellite navigation systems.



Source: U.S. Air Force.



Program Essentials

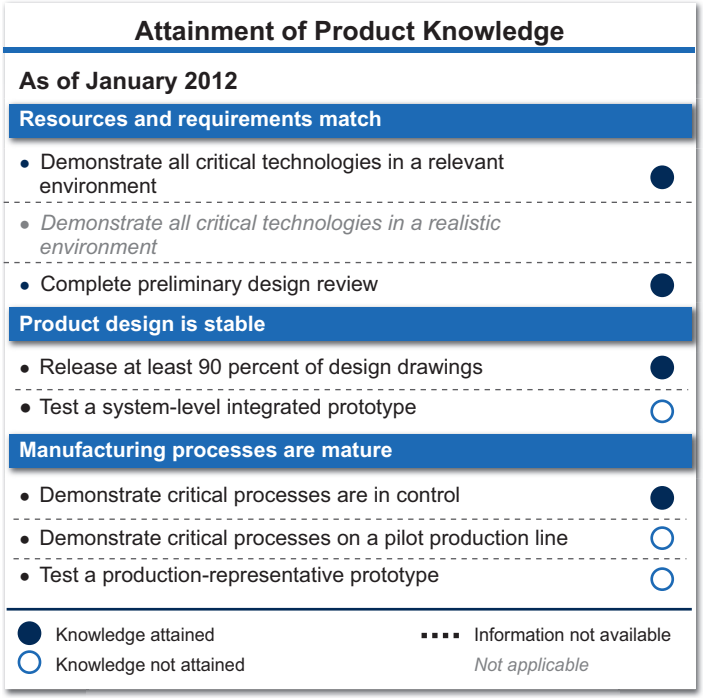
Prime contractor: Lockheed Martin
Program office: El Segundo, CA
Funding needed to complete:
- R&D: $924.6 million
- Procurement: $1,435.0 million
- Total funding: $2,359.6 million
- Procurement quantity: 6

Program Performance (fiscal year 2012 dollars in millions)

	As of 05/2008	Latest 08/2011	Percent change
Research and development cost	$2,524.2	$2,694.8	6.8
Procurement cost	$1,417.2	$1,515.8	7.0
Total program cost	$3,941.4	$4,210.6	6.8
Program unit cost	$492.672	$526.323	6.8
Total quantities	8	8	0.0
Acquisition cycle time (months)	NA	NA	NA

We could not calculate acquisition cycle times for the first increment of the GPS III program because initial operational capability will not occur until satellites from a future increment are fielded.

The GPS III entered production in January 2011 with mature technologies and some of the knowledge needed to ensure the system would work as intended and could be manufactured efficiently. A complete satellite was not tested prior to the production decision, but the program is developing prototypes of the spacecraft and payload to prove out production processes and identify and solve issues prior to integrating and testing the first space vehicle. The GPS III is experiencing cost growth and the contractor is behind schedule, but the program does not expect these delays to affect the launch of the first satellite. There are risks to the program launching some satellites as planned. The GPS III ground control system is not scheduled for delivery until 15 months after the first scheduled launch and it is unclear whether an interim capability will be delivered in time.



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GPS III Program

Technology and Design Maturity

The GPS III program's critical technologies are mature and its design is stable. The critical technologies changed as the program developed its design, but all eight current technologies have been demonstrated in a relevant environment. The GPS program office reported that the number of design changes since its design review has been much less than anticipated. In addition, according to the program office, some of the system's flight software has completed qualification testing and other software deliverables are on schedule.

Production Maturity

The GPS III program captured some of the knowledge needed to ensure the system would work as intended and could be manufactured efficiently before its January 2011 production decision. In 2011, the program office reported a level of manufacturing process maturity that indicated that its processes were in control when a production decision was made. A complete GPS III satellite was not tested prior to the production decision, but the program is developing prototypes of the spacecraft and payload to prove out production processes and identify and solve issues prior to integrating and testing the first space vehicle.

Other Program Issues

The GPS III program has adopted several practices to reduce program risk. It has maintained stable requirements and is being managed using a "back to basics" approach, which features rigorous systems engineering, use of military specifications and standards, and an incremental approach to providing capability. However, the GPS III program is currently experiencing cost growth and the contractor is behind schedule. In November 2011, the contractor's estimated cost at completion for the development and production of the first two satellites was over $1.4 billion or 18 percent greater than originally estimated; the program office estimated the cost to be about $1.6 billion. The Air Force has cited multiple reasons for the projected contract cost increases including reductions in the program's production rate; greater than expected efforts to produce engineering products compliant with more stringent parts, materials, and radiation testing requirements; test equipment delays; and inefficiencies in the development of both the navigation and communication payload and satellite bus. The contractor is also behind in completing some tasks, but the program does not expect these delays to affect the launch of the first satellite.

The GPS directorate has taken steps to mitigate GPS III's dependence on the development schedule for the next-generation GPS ground control system, the OCX, which is being managed as a separate major defense acquisition program, but some GPS III launches could be affected if OCX is delayed. The contractor plans to deliver GPS OCX Block I in August 2015—15 months after the first planned GPS III satellite launch. The GPS directorate is funding the development of a launch and checkout system that will provide an earlier command and control capability for the first GPS III satellite, but it unclear when this system will be delivered. According to GPS directorate officials, this system will not enable the new capabilities offered by GPS III satellites, including a jam-resistant military signal and three new civil signals. GPS program officials stated previously that they would prefer not to launch a second satellite until the capabilities of the first one are fully tested. Although the Air Force has slowed its planned pace of launches for GPS III so that there should not be a rapid succession of launches within 2 years of the first GPS III launch, further delays in the OCX program could still affect the dates of some GPS III launches.

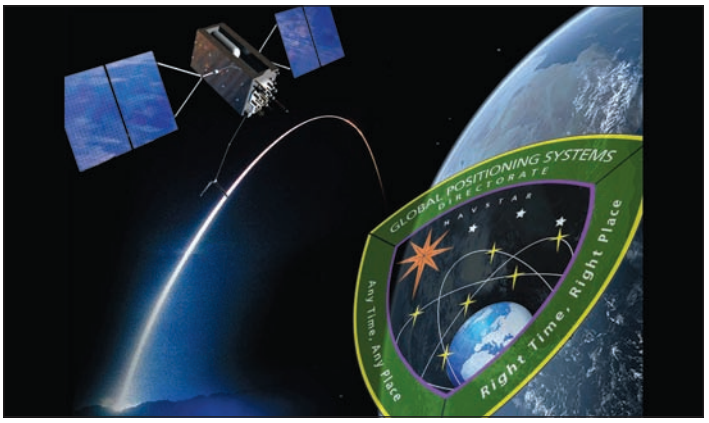
Program Office Comments

In commenting on a draft of this assessment, the GPS III program provided technical comments, which were incorporated as appropriate.

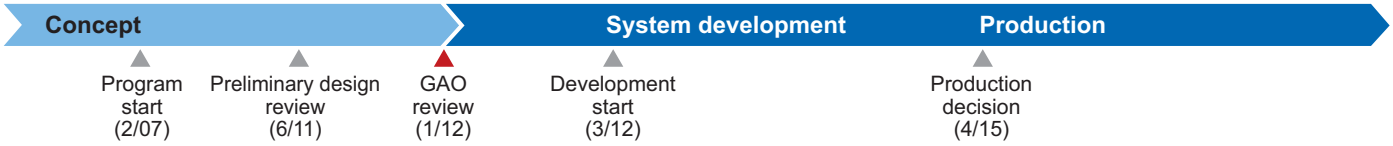
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GPS III OCX Ground Control Segment

The Air Force's next-generation GPS control segment, referred to as OCX, will provide command, control, and mission support for the GPS Block II and III satellites. OCX is expected to ensure reliable and secure delivery of position and timing information to GPS military and civilian users. The Air Force plans to develop OCX in four blocks, with each block delivering upgrades as they become available. We assessed the first block, which will support the operation of GPS Block II and Block III satellites.



Source: U.S. Air Force.



Program Essentials

Prime contractor: Raytheon
Program office: El Segundo, CA
Funding FY12 to FY16:
R&D: $1,583.9 million
Procurement: $35.6 million
Total funding: $1,619.5 million
Procurement quantity: NA

Program Performance (fiscal year 2012 dollars in millions)

	As of	Latest 09/2011	Percent change
Research and development cost	NA	$2,538.5	NA
Procurement cost	NA	$35.6	NA
Total program cost	NA	$2,574.1	NA
Program unit cost	NA	NA	NA
Total quantities	NA	NA	NA
Acquisition cycle time (months)	NA	NA	NA

Table includes costs from program inception through fiscal year 2016.

GPS OCX plans to enter system development in March 2012 with some of the recommended knowledge about its requirements and technologies. The program held a preliminary design review in June 2011 and its critical technologies are nearing maturity. The Air Force awarded a cost-reimbursement contract for Blocks I and II in February 2010 before it received approval to formally enter system development. The first two software packages have been completed, but the complexity of the software development effort has proven challenging. The GPS OCX will not be fielded in time to support the first GPS III satellite, which is scheduled for launch in May 2014. As a result, the GPS directorate is funding an effort to provide an earlier command and control capability, but this system will not enable the new capabilities offered by that satellite.

Attainment of Product Knowledge

Projected as of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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GPS OCX Program

Technology Maturity

According to program officials, the GPS OCX plans to enter system development in March 2012 with its 14 critical technologies nearing maturity. However, these technologies will not be fully tested and demonstrated in a realistic environment until the program makes its production decision. The program held a preliminary design review in June 2011, which was completed in August 2011, and has addressed most of the issues that were identified during the review. The remaining issues, which the program deems low risk, relate to better defining certain requirements, including those for reliability. The program office developed mitigation plans to address these issues and an independent review team approved the plans as well as the design and architecture of the OCX system.

Other Program Issues

The complexity of the GPS OCX software development effort has proven challenging and two current software efforts were started behind schedule. According to the program office, the GPS OCX contract requires the delivery of six Block I software iterations by February 2015 and two Block II software iterations by March 2016. According to program officials, the first and second Block I iterations were completed on schedule; however, the third iteration was started later than planned and is expected to be completed later than originally scheduled as well. Preliminary work has begun on the fourth iteration, which is also running behind schedule. The primary reasons for the delay in the delivery of the third iteration, and the late start of the fourth iteration, were the difficulty of developing new code, as well as the contractor's focus on getting through the preliminary design review process, which, according to program officials, required more work than the contractor originally anticipated.

According to program officials, because of the complexity of the GPS OCX software, the program has instituted a rigorous testing process to identify and address defects early in each iteration. The program expects that this process will reduce the number of defects discovered in higher-level integration and testing, which can be more costly to resolve. This testing approach has already identified a number of defects in the early iterations, and the number of defects that are being found during integration testing has been lower than expected.

The contractor plans to deliver GPS OCX Block I in August 2015—15 months after the first planned GPS III satellite launch. As a result, the GPS directorate is funding the development of a launch and checkout system that will provide an earlier launch and command and control capability for the first GPS III satellite. According to GPS directorate officials, this system will not enable the new capabilities offered by GPS III satellites, including a jam-resistant military signal and three new civil signals. The program released a request for proposal for the launch and checkout system in April 2011 and awarded the effort in December 2011. The launch and checkout system is expected to cost about $30 million through 2015. Any delay in the delivery of the launch and checkout system could potentially cause the Air Force to delay the launch of the first GPS III satellite.

Program Office Comments

The Air Force provided technical comments, which were incorporated as appropriate.

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Gray Eagle Unmanned Aircraft System

The Army's MQ-1C Gray Eagle will perform reconnaissance, surveillance, target acquisition, and attack missions either alone or with other platforms such as the Longbow Apache helicopter. In 2010, the Army changed the number of Gray Eagle systems from 13 company-sized units with 12 aircraft to 31 platoons with 4 aircraft. Each platoon will also include payloads, data terminals, and other ground support equipment. The program consists of block 1 systems and two less-capable Quick Reaction Capability systems. We assessed block 1.



Source: General Atomics Aeronautical Systems, Inc.



Program Essentials

Prime contractor: General Atomics Aeronautical Systems, Inc.
Program office: Redstone Arsenal, AL
Funding needed to complete:
R&D: $226.1 million
Procurement: $2,089.0 million
Total funding: $3,006.9 million
Procurement quantity: 16

Program Performance (fiscal year 2012 dollars in millions)

	As of 04/2005	Latest 08/2011	Percent change
Research and development cost	$344.9	$946.2	174.4
Procurement cost	$670.4	$3,400.2	407.2
Total program cost	$1,015.2	$5,158.9	408.2
Program unit cost	$203.046	$166.416	-18.0
Total quantities	5	31	520.0
Acquisition cycle time (months)	50	TBD	NA

Total quantities include 31 platoon sets with 4 aircraft each. The program will also buy 21 aircraft to replace those lost through attrition and 7 training aircraft, for a total of 152.

The Gray Eagle program began production in February 2010 with three of its five critical technologies not yet mature and manufacturing processes that still exhibited production risks. The program has demonstrated two of those technologies in a realistic environment and expects to demonstrate the third one in fiscal year 2012. A March 2011 aircraft accident resulted in hardware and software changes. Some of the changes required retrofits to systems already produced. As a result of the accident, the Army delayed the program's initial operational test and evaluation and full-rate production decision. To avoid a production break, the Army plans to award a third low-rate production contract in May 2012. It now plans to procure more than half of the total aircraft before the system is fully tested.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ●

Manufacturing processes are mature

- Demonstrate critical processes are in control — ○
- Demonstrate critical processes on a pilot production line — ●
- Test a production-representative prototype — ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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Gray Eagle Program

Technology Maturity

The Gray Eagle entered production in February 2010 without all five of its critical technologies mature. An Army technology readiness assessment, which was approved by the Office of the Director, Defense Research and Engineering, in 2009, concluded that three of those technologies—automatic take-off and landing, manned-unmanned teaming, and the tactical common data link—had not been fully demonstrated in an operational environment. According to the program office, the automatic take-off and landing system is now mature, and manned-unmanned teaming was demonstrated in 2011 with an Apache helicopter controlling Gray Eagle. However, the tactical common data link is still not fully mature. The program office stated that the data link encryption capability was successfully tested in 2011, but its air data relay capability has been deferred until fiscal year 2012.

Design Maturity

The program office believes the Gray Eagle design is currently stable; however, the program has experienced a significant increase in design drawings due to issues identified during testing and other technical changes. The program has made modifications to the system's software and hardware following a March 2011 accident and system testing. The Army has installed the software changes on aircraft that were in production as well as fielded aircraft, and plans to make hardware changes that include redesigning the aircraft's rudders. The program office stated that it does not yet know the cost or schedule for completing these modifications.

Production Maturity

Gray Eagle began production in February 2010 with manufacturing processes that had been demonstrated on a pilot production line, but still exhibited production risks. An independent Army assessment of the program's production readiness in 2009 stated that manufacturing process maturity was satisfactory and manufacturing infrastructure met or exceeded requirements for low-rate initial production. It is unclear whether the Army expects planned hardware redesigns to affect the maturity of the Gray Eagle's production processes. If tooling or other manufacturing changes are necessary, its production processes could be affected.

Other Program Issues

The March 2011 accident involving an MQ-1C in testing has delayed several key program events. According to the program office, the accident investigation made it difficult to accumulate flight hours and conduct the soldier training needed to support initial operational test and evaluation in October 2011. The Army now plans to start operational testing in August 2012. As a result of the delay in operational testing, the program's full-rate production decision was postponed from August 2012 to March 2013. The Army has already awarded two low-rate production contracts in 2010 and 2011 for 55 aircraft. To avoid a break in production, the Army is planning to seek approval to award a third low-rate contract for 29 aircraft in May 2012. Based on the current program schedule, the Army will procure more than half of the total planned aircraft before the system's operational effectiveness and suitability is fully tested during initial operational test and evaluation.

Program Office Comments

In commenting on a draft of this assessment, the program office stated the Gray Eagle baseline design is mature. The program also indicated that changes to the system's software and hardware are planned improvements as new payloads and capabilities are integrated. Additionally, the program office noted that the automatic take-off and landing system and tactical common data link have been demonstrated because deployed units have been operating with these technologies. The program anticipates that the data link's air data relay capability will be operationally tested in August 2012 and manned-unmanned teaming with an Apache Block III helicopter will be operationally tested in March 2012. The program also provided technical comments, which were incorporated as appropriate.

GAO Response

The program office considers the Gray Eagle baseline design mature, but the tactical common data link's full capabilities have not yet been tested. Additionally, as the program office noted, the Army will be modifying the aircraft tail rudder and elevator. Until the data link is fully mature and all design changes have been developed and incorporated, the program's cost and schedule remain at risk.

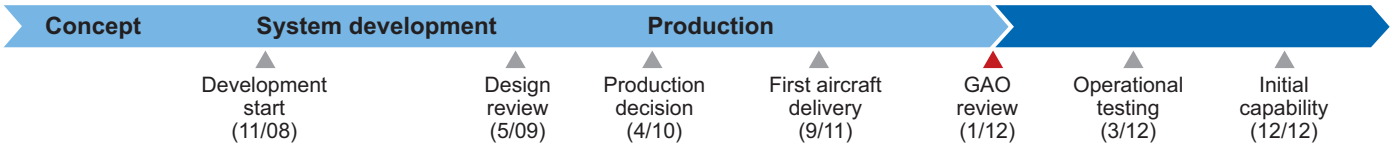
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HC/MC-130 Recapitalization Program

The Air Force's HC/MC-130 Recapitalization program will replace aging Air Force HC-130P/N and Air Force Special Operations Command MC-130E/P/W/H aircraft with a multimission tactical aircraft that is based on the KC-130J platform. The primary mission of HC/MC-130J aircraft will be to provide aerial refueling. It will also position, supply, resupply, and recover specialized tactical ground units. The program includes a base configuration and three increments that provide additional capabilities.



Source: Lockheed Martin.



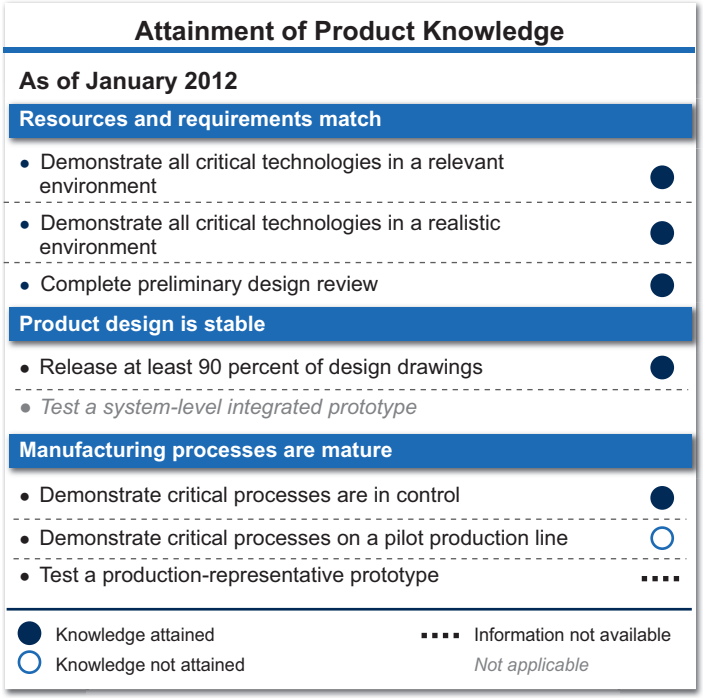
Program Essentials

Prime contractor: Lockheed Martin
Program office: Wright-Patterson AFB, OH
Funding needed to complete:
R&D: $82.6 million
Procurement: $9,532.4 million
Total funding: $9,812.7 million
Procurement quantity: 91

Program Performance (fiscal year 2012 dollars in millions)

	As of 03/2010	Latest 12/2010	Percent change
Research and development cost	$153.2	$152.8	-0.3
Procurement cost	$7,699.3	$12,621.9	63.9
Total program cost	$8,364.2	$13,090.8	56.5
Program unit cost	$113.029	$107.302	-5.1
Total quantities	74	122	64.9
Acquisition cycle time (months)	NA	NA	NA

The HC/MC-130J program entered production in April 2010 with mature critical technologies, a stable design, and manufacturing processes that were in control. The HC/MC-130J design is derived from the KC-130J aerial refueling tanker, and shares many of the same technologies; the system that allows it to receive fuel in-flight and the electro-optical/infrared turret mount are unique. According to program officials, the HC/MC-130J has completed developmental testing and is scheduled to enter operational testing in March 2012. Operational testing will be conducted with increment 1–configured aircraft, which make up 10 of the planned total 122 aircraft. The program plans limited testing for increment 2, which will primarily focus on the integration of Large Aircraft Infrared Counter Measures (LAIRCM). Twenty-five increment 2 aircraft are already under contract.



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HC/MC-130 Recapitalization Program

Technology Maturity

The HC/MC-130 Recapitalization program entered system development in November 2008 with both of its critical technologies mature. Several of the HC/MC-130J's technologies are common with the KC-130J, including the rotor wing aerial refueling system. According to program officials, the two HC/MC-130J critical technologies—the electro-optical/infrared turret mount and the universal aerial refueling receptacle slipway installation (UARRSI)—are unique to the aircraft. The UARRSI allows the HC/MC-130J to receive fuel in-flight, extending the range of the aircraft.

Design Maturity

The HC/MC-130J design is stable and over 90 percent of its drawings were released by the time the program held its critical design review in May 2009. The HC/MC-130J is about 90 percent common with the C-130J, which has contributed to the aircraft's design maturity and stability.

Production Maturity

The HC/MC-130J program entered production in April 2010 with manufacturing processes that were in control. In addition, program officials told us that rework rates for repairs and defects is trending downward and have been within the expected range. A combination of a labor force unaccustomed to the aircraft and a ramp-up in production contributed to the rework rates—factors common across the C-130J platform.

Other Program Issues

According to program officials, the HC/MC-130J successfully completed developmental testing on base-configured aircraft in August 2011, slightly ahead of schedule. Operational testing—scheduled to begin in March 2012—will be conducted on increment 1–configured aircraft, which make up 10 of the planned total 122 aircraft in the program. Program officials stated that the Office of the Director, Operational Test and Evaluation, certified increment 1 aircraft as being production-representative, which would make it appropriate for use in operational testing. Program officials noted that several software- and hardware-related watch items identified during contractor testing must be resolved prior to the start of operational testing; however, they described these items as relatively minor and easily correctable.

According to program officials, there will be limited testing of increment 2–configured aircraft. This testing will be focused primarily on the integration of the LAIRCM system. Although the basic LAIRCM system is in production, recently concluded testing on LAIRCM's upgraded missile warning system revealed deficiencies that may affect integration with HC/MC-130J. The HC/MC-130J program includes 40 increment 2 aircraft, 25 of which have already been placed under contract.

Due to the extended budget impasse for fiscal year 2011, the program office stated that it did not have sufficient authority under the continuing resolution to award a contract for nine aircraft as planned. In order to avoid a production break, the Air Force redirected approximately $500 million from other programs for the procurement of these aircraft. According to program offices, had an award not been made before the contractor's proposal expired in May 2011 the program would have been delayed by more than a year.

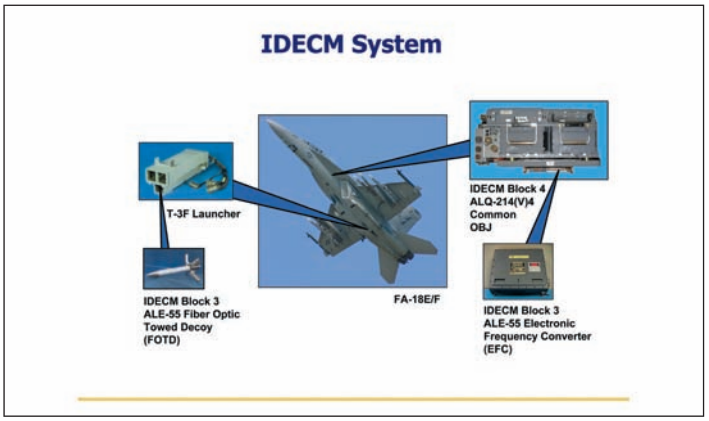
Program Office Comments

In commenting on a draft of this assessment, the Air Force provided technical comments, which were incorporated as appropriate.

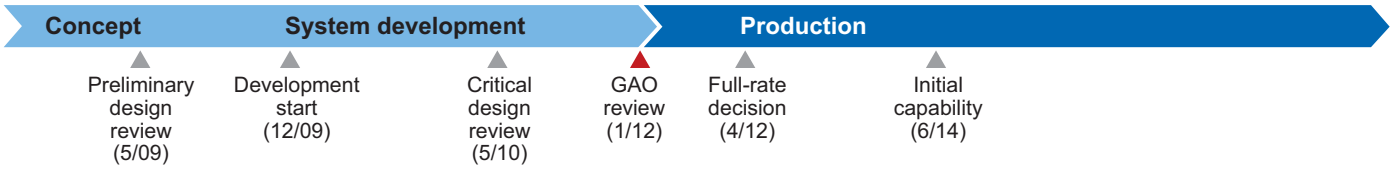
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Integrated Defensive Electronic Countermeasures (IDECM) Block 4

The Navy's IDECM is a radio-frequency, self-protection electronic countermeasure to improve the survivability of F/A-18 aircraft against guided threats during air-to-ground/surface and air-to-air missions. IDECM consists of onboard components that receive and process radar signals and onboard and offboard jammers. IDECM is being developed incrementally; each block improves its jamming or decoy capabilities. The Navy has fielded three IDECM blocks; block 4 will extend onboard jamming capabilities for F/A-18C/D aircraft. We assessed block 4.



Source: U.S. Navy.



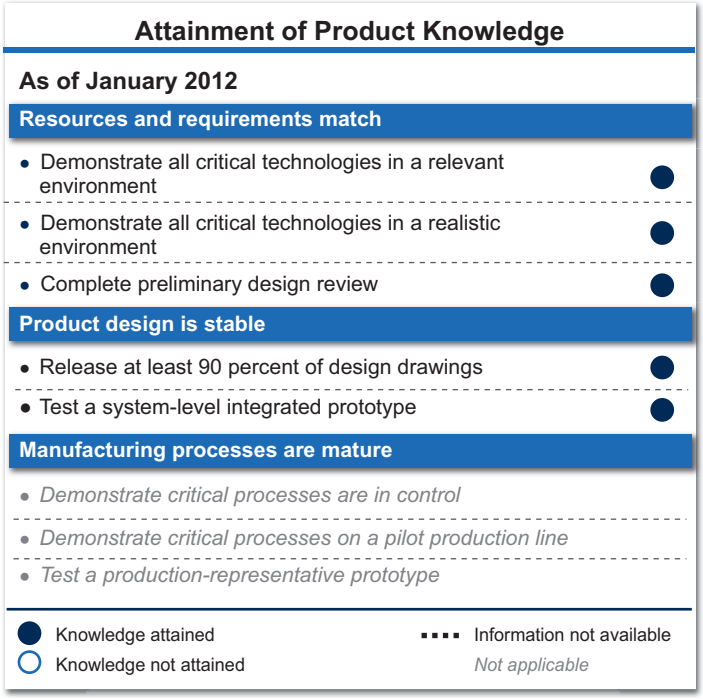
Program Essentials

Prime contractor: ITT Electronic Systems
Program office: Patuxent River, MD
Funding needed to complete:
- R&D: $121.4 million
- Procurement: $569.5 million
- Total funding: $690.9 million
- Procurement quantity: 190

Program Performance (fiscal year 2012 dollars in millions)

	As of 06/2008	Latest 10/2011	Percent change
Research and development cost	$220.2	$252.0	14.5
Procurement cost	$474.2	$569.5	20.1
Total program cost	$694.4	$821.5	18.3
Program unit cost	$4.340	$4.324	-0.4
Total quantities	160	190	18.8
Acquisition cycle time (months)	59	54	-8.5

IDECM block 4 expects to begin production in April 2012 with mature technologies and a stable design. Block 4 primarily replaces the previous IDECM onboard jammer with a lightweight repackaged version. There is some concurrency risk on the program, which could drive costly design changes or retrofits if the redesigned jammer does not perform as intended. The Navy has no plans for low-rate initial production and will proceed to full-rate production before it completes ground and flight testing. Program officials stated that this concurrency is necessary in order to maintain the production line from block 3 to block 4 and to meet the June 2014 initial operational capability date. In addition, program officials noted that block 4 production will be limited initially to 19 units and the production rate will only increase once testing is completed.



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IDECM Block 4 Program

Technology Maturity

IDECM block 4 began system development in 2009 as an engineering change proposal to the existing block 3 onboard jammer. Block 4 will reconfigure the ALQ-214 (V)3 onboard jammer, currently only installed in the F/A-18E/F aircraft, to a common configuration—ALQ-214 (V)4—to be installed on F/A-18C/D and F/A-18E/F aircraft. In April 2009, a technology readiness assessment concluded that there were no critical technologies in the ALQ-214 (V)4 and that the system was based on mature technologies.

Design and Production Maturity

IDECM block 4's design is stable; however, there is still risk in the IDECM block 4 program because it expects to begin production in April 2012 before developmental testing is completed. The block 4 onboard jammer is a redesign of the jammer used in earlier blocks. This redesign was driven by the need to reduce weight in order to accommodate the IDECM onboard system on F/A-18C/D aircraft. The block 4 onboard jammer will perform the same function as found in IDECM blocks 2 and 3, but with a different form. The Navy expects to transition from block 3 production to block 4 production before the system completes ground and flight testing. The program will proceed directly into full-rate production. This concurrent production and testing strategy could drive costly design changes or retrofits, or both, to units in production if the redesigned jammer does not perform as intended. Officials stated that this concurrency is necessary in order to maintain the production line and to meet the June 2014 initial operational capability date for block 4. To mitigate the concurrency risk, Navy officials stated that block 4 production will be limited to 19 systems in 2012, with production rates increasing to as many as 40 systems per year following completion of testing.

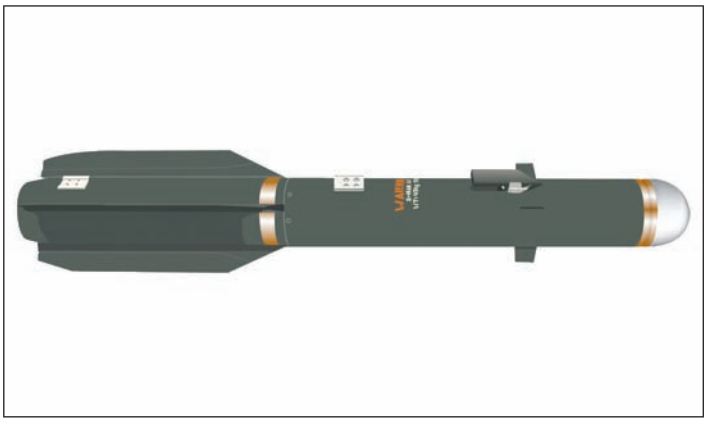
Program Office Comments

In commenting on a draft of this assessment, the Navy stated that the block 4 configuration will begin full-rate production in fiscal year 2012. The IDECM program office believes the cost risks associated with this production decision are low. While the production line transition to the new block 4 configuration will occur prior to the completion of flight testing in 2013, all testing will be completed prior to delivery of the production hardware and fleet introduction in 2014. To date, 13 systems have been delivered and utilized in developmental testing. In addition, the Navy noted that the firm fixed-price production contract requires the contractor to deliver assets that incorporate any design changes identified during testing. According to the Navy, the contractor would be required to retrofit changes into any assets already built at no additional cost to the government. The Navy also noted that the increase in the block 4 research and development cost estimate is associated with an additional requirement for an improved jamming capability against advanced threats. The increase in the procurement cost estimate is associated with a requirement for additional quantities.

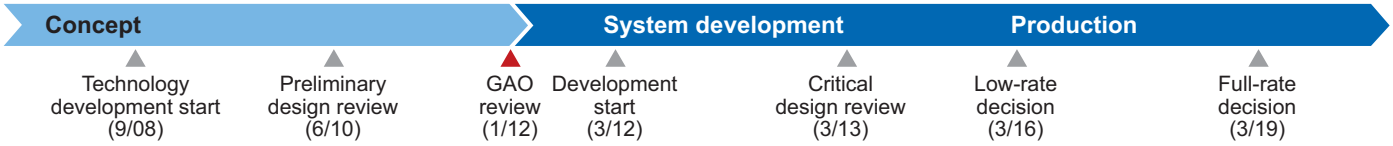
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Joint Air-to-Ground Missile (JAGM)

The Joint Air-to-Ground Missile is a joint Army/Navy program with Marine Corps participation. The missile will be air-launched from helicopters and fixed-wing aircraft and designed to target tanks; light armored vehicles; missile launchers; command, control, and communications vehicles; bunkers; and buildings. It is intended to provide line-of-sight and beyond line-of-sight capabilities and can be deployed in a fire-and-forget mode or a precision attack mode. JAGM will replace Hellfire, Maverick, and air-launched TOW missiles.



Source: Department of Defense.



Program Essentials

Prime contractor: TBD
Program office: Redstone Arsenal, AL
Funding needed to complete:
- R&D: $1,176.5 million
- Procurement: $5,113.0 million
- Total funding: $6,289.5 million
- Procurement quantity: 35,303

Program Performance (fiscal year 2012 dollars in millions)

	As of	Latest 11/2011	Percent change
Research and development cost	NA	$1,767.0	NA
Procurement cost	NA	$5,113.0	NA
Total program cost	NA	$6,880.0	NA
Program unit cost	NA	$.194	NA
Total quantities	NA	35,422	NA
Acquisition cycle time (months)	NA	TBD	NA

JAGM is expected to enter system development in 2012 with some of the recommended knowledge about its technology and requirements; however, the program's future is uncertain because of concerns about its affordability. According to the program office, the program held a preliminary design review in June 2010 and its five critical technologies are nearing maturity. However, an independent technology readiness assessment indicated that at least one technology has not reached this level of maturity. The program office incorporated a provision in the request for proposal for the system development contract that may mitigate the technology risk by requiring both competing contractors to submit two rocket motor designs. According to program officials, the program plans to award a contract in March 2012, despite ongoing uncertainty regarding the future of the program.

Attainment of Product Knowledge

Projected as of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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JAGM Program

Technology Maturity

According to the program office, JAGM's five critical technologies are expected to be nearing maturity and demonstrated in a relevant environment before a decision is made to start system development. The critical technologies include a multimode seeker for increased countermeasure resistance, boost-sustain propulsion for increased standoff range, a multipurpose warhead for increased lethality, an inertial measurement unit for improved navigation and flight control, and guidance and control software. However, an independent technology readiness assessment indicated at least one of these technologies has not reached this level of maturity. We cannot identify the assessed maturity levels of individual technologies because the program is currently conducting a competition for its system development contract. According to program officials, the technology readiness assessment will be updated prior to development start based on contractors' proposals.

The program office incorporated a provision in the request for proposal that may mitigate some of the program's technology risk by requiring both competing contractors to submit two rocket motor designs. The government also planned to complete environmental and safety tests using eight rocket motors from each contractor during the technology development phase. The tests were intended to examine the rocket motors under the extremes of the expected operational environment to ensure they can perform safely and effectively. The tests were expected to be complete by December 2011.

Other Program Issues

The future of the JAGM program is uncertain because of concerns about its affordability. Army officials have stated that the service might not be able to afford JAGM, despite having a validated requirement for it. According to Army officials, the Hellfire missile, which JAGM is intended to replace, has been performing well in combat operations, and given budget constraints, the Army may prefer to extend its use indefinitely rather than pursue JAGM as a next generation solution. However, according to program officials, an analysis of alternatives completed in August 2011 indicated that JAGM is the most cost-effective solution to address warfighter needs. Program officials stated that the program plans to continue executing to its fiscal year 2012 budget plan. The Army will continue to field Hellfire missiles to meet the needs of the warfighter, while the Navy will rely on both Maverick and Hellfire missiles until the future of JAGM is determined.

According to program officials, the program plans to award its system development contract in March 2012, notwithstanding the uncertainty regarding JAGM's future. The program has received approval to conduct a limited competition between its two technology development contractors. It had intended to award the contract in December 2010; however, the release of the request for proposal was delayed until April 2011 because the program's acquisition strategy and requirements needed to be updated to reflect the cancellation of the Armed Reconnaissance Helicopter, the addition of the OH-58 Kiowa as a replacement platform, and new guidance on affordability.

Program Office Comments

The JAGM program office concurred with this assessment and provided technical comments, which were incorporated as appropriate.

GAO Response

After our assessment was completed, the President's Budget for Fiscal Year 2013 extended JAGM's technology development phase by 27 months to address affordability issues and reduce risk prior to system development.

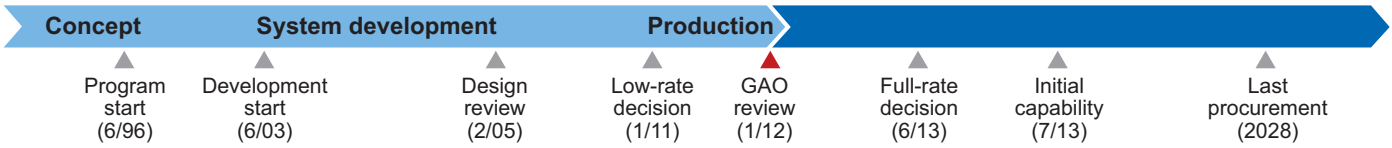
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Joint Air-to-Surface Standoff Missile Extended Range (JASSM-ER)

The Air Force's JASSM-ER program plans to field a next-generation cruise missile capable of destroying the enemy's war-sustaining capability from outside its air defenses. JASSM-ER missiles are low-observable, subsonic, and have a range greater than 500 miles. They provide both fighter and bomber crews the ability to strike heavily defended targets early in a campaign. JASSM-ER is a follow-on program to the JASSM baseline program. The two missiles' hardware is 70 percent common and their software is 95 percent common.



Source: U.S. Air Force.



Program Essentials

Prime contractor: Lockheed Martin
Program office: Eglin AFB, FL
Funding needed to complete:
R&D: $65.5 million
Procurement: $3,389.3 million
Total funding: $3,454.9 million
Procurement quantity: 2,470

Program Performance (fiscal year 2012 dollars in millions)

	As of 04/2011	Latest 08/2011	Percent change
Research and development cost	$272.7	$272.7	0.0
Procurement cost	$3,457.7	$3,457.3	0.0
Total program cost	$3,730.5	$3,730.0	0.0
Program unit cost	$1.474	$1.474	0.0
Total quantities	2,531	2,531	0.0
Acquisition cycle time (months)	NA	NA	NA

JASSM-ER was approved to begin production in January 2011 with mature critical technologies, a stable design, and production processes that had been demonstrated, but were not in control. The JASSM-ER appears to have overcome past reliability issues and, according to program officials, the missile's design has been proven in flight testing. However, an engine oil leak was discovered in December 2011 that required the program office to return 13 engines to the manufacturer for corrective action, causing a 3- to 4-month delay in operational testing. In response to a warfighter request, the program is considering a significant increase in production rates starting in 2016. The program will need additional funding in the short term to increase production rates, but doing so could shorten production by 3 years and save about $521 million.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- *Complete preliminary design review*

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ●

Manufacturing processes are mature

- Demonstrate critical processes are in control — ○
- Demonstrate critical processes on a pilot production line — ●
- Test a production-representative prototype — ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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JASSM-ER Program

Technology Maturity

According to the program office, the JASSM-ER's five critical technologies—the engine lube system, engine system, fuse, low observable features, and global positioning system—are mature and have been tested in a realistic environment using a production-representative test missile.

Design Maturity

The JASSM-ER's design appears stable and the program seems to have overcome past reliability issues. The number of JASSM-ER configuration changes has decreased over time and, according to the program office, there was only 1 major configuration change and 16 minor configuration changes in the last year, 1 of which was related to the missile's reliability. In addition, according to program officials, the missile's design has been proven in testing; 10 out of 11 flight tests have been successful.

Despite the JASSM-ER's initial operational test success, testing has been put on hold because of problems with the missile's engine. An engine oil leak was discovered in December 2011 and all engines used in the operational test program were returned to the manufacturer to have corrective actions installed. These corrective actions will cause a 3- to 4-month delay in operational testing. However, program officials are optimistic that the program's full-rate production decision will not be affected because the full-rate decision is not scheduled until June 2013.

Production Maturity

The JASSM-ER entered production in January 2011 with processes that had been demonstrated, but were not in control. Prior to the production decision, the Air Force assessed that the JASSM-ER's manufacturing readiness was at the level recommended by DOD guidance for the start of low-rate production. However, the program's manufacturing readiness level did not indicate that its production processes were in statistical control. The program does not collect data on its critical manufacturing processes because the program was initiated using a total system performance responsibility arrangement, but the contractor does share some manufacturing data with the program office to prove it is meeting the missile's specification requirements. The contractor has implemented a process verification program with suppliers for the baseline missile to ensure that proper production processes are being followed. Program officials stated that the process verification program is not a contractual requirement, but rather a technique the contractor considers a best practice. According to program officials, process verification will also be used on the JASSM-ER.

Other Program Issues

Program officials stated that a combatant command has requested that more JASSM-ER missiles be delivered earlier than planned. To accommodate this request, program officials explained that JASSM-ER is scheduled to receive additional funding starting in fiscal year 2016 to pay for an additional 150 missiles per year. This rate increase may allow the program to shorten the production schedule by 3 years and save about $521 million. To attain these savings, program officials said the missile will need to reach its economic order quantity of 360 missiles per year by 2016 and continue at that production rate through the end of its production schedule.

Program Office Comments

In commenting on a draft of this assessment, Air Force officials stated the JASSM-ER engine oil leak anomalies were identified in the production facility during missile assembly. Program office and Air Force testers jointly determined that the most-prudent course of action would be to delay operational testing until the issue could be solved. A root cause and corrective action have been identified and all operational testing and future production missiles will include the corrective actions. Operational testing is expected to resume in June 2012, with no risk to accomplishing full-rate production in June 2013. The Air Force also provided technical comments, which were incorporated as appropriate.

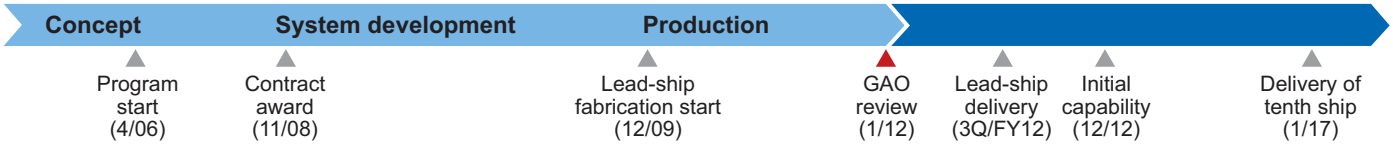
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Joint High Speed Vessel (JHSV)

JHSV is a joint Army and Navy program to acquire a high-speed, shallow-depth vessel for rapid intratheater transport. The ship, which is based on a commercial design, will be capable of operating without relying on shore-based infrastructure. The program received approval to build 18 ships in October 2008, including 10 in low-rate initial production. Nine of the 10 vessels are under contract and two are under construction. The lead ship was scheduled for delivery in December 2011 and will now be delivered in spring 2012.



Source: Austal USA.



Program Essentials

Prime contractor: Austal USA
Program office: Washington, DC
Funding needed to complete:
R&D: $23.0 million
Procurement: $2,202.8 million
Total funding: $2,225.9 million
Procurement quantity: 11

Program Performance (fiscal year 2012 dollars in millions)

	As of 02/2009	Latest 12/2010	Percent change
Research and development cost	$128.4	$138.0	7.4
Procurement cost	$3,507.9	$3,536.1	0.8
Total program cost	$3,636.4	$3,674.1	1.0
Program unit cost	$202.020	$204.116	1.0
Total quantities	18	18	0.0
Acquisition cycle time (months)	48	50	4.2

The JHSV program began lead-ship fabrication in December 2009 with its critical technologies mature, but without a stable design. Only 9 of the ship's 44 design zones were complete in the three-dimensional product model. According to program officials, all 44 design zones were completed 9 months later in September 2010. The lead ship was launched in September 2011; however, according to the shipbuilder's data, the cost and schedule of the ship have been affected by an increase in the ship's weight. According to the Navy, delivery of the lead ship was to occur in December 2011 and will now occur in the spring of 2012. According to program officials, the Navy is reviewing the number of JHSVs required for future operations, and program quantities could change.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable

- Complete three-dimensional product model — ●
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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JHSV Program

Technology and Design Maturity

The JHSV program began lead-ship fabrication in December 2009 with all 18 of its critical technologies mature and demonstrated in a realistic environment, but without a stable design. Only 9 of the ship's 44 three-dimensional design zones were complete. This level of maturity falls short of GAO's best practices, which call for achieving a complete and stable three-dimensional product model before construction begins to minimize the risk of design changes and the subsequent costly rework and out-of-sequence work these changes can drive. According to program officials, all 44 zones were completed in September 2010, 9 months after fabrication began. However, as of August 2011, the American Bureau of Shipping had not yet completed acceptance of the JHSV design because some drawings that support functional and structural design were still outstanding.

Production Maturity

According to program officials, the JHSV program does not use critical manufacturing processes to measure production maturity. Instead, it monitors quality metrics of specific trades such as welding, monitors the contractor's earned value management data, and measures the current schedule against the production schedule. Additionally, the program demonstrated its manufacturing processes by building one of the ship's modules in the shipbuilder's new manufacturing facility. The lead ship was launched in September 2011 and, according to program officials, was 90 percent complete at that time. Construction of the second ship began September 2010, and was about 25 percent complete as of August 2011. According to shipbuilder data, a significant increase in the weight of the ship has negatively affected its construction cost and schedule by requiring additional material, production and engineering work, and design efforts. According to the Navy, delivery of the lead ship has been delayed and will now occur in the spring of 2012.

Austal USA, the shipyard that is constructing JHSV, is also building one version of the Littoral Combat Ship. According to officials, as a result of corrosion found in the water jet propulsion area of that ship, the JHSV program has conducted corrosion reviews and is applying the lessons learned from the Littoral Combat Ship to mitigate the potential for corrosion.

Other Program Issues

As a result of discussions with the Army in December 2010, the Navy assumed the role of life cycle manager and will operate all current and future JHSVs, including the five planned for procurement by the Army, on all missions. According to program officials, a requirements study is intended to determine the total quantity of JHSVs needed to support operations for both military services. The December 2010 selected acquisition report for the JHSV program lists a total quantity of 18 ships, including the 5 Army vessels; however, the Navy's May 2011 30-year shipbuilding plan lists a total of 21 ships.

Program Office Comments

In commenting on a draft of this assessment, the Navy stated that the JHSV design is based on existing commercial platforms, and the design was 90 percent complete at the start of construction. The Navy further stated that GAO's best practices notwithstanding, sufficient production information from the two-dimensional design drawings and three-dimensional model has been developed to support production. Significant production risk has been avoided by implementing proven commercial production design and technology, ensuring stable requirements, minimizing change, and through pursuit of cost reduction and efficiency. In addition, the President's Budget for Fiscal Year 2013 reduced the total number of ships to be procured to 10. The Navy also provided technical comments, which were accounted for as appropriate.

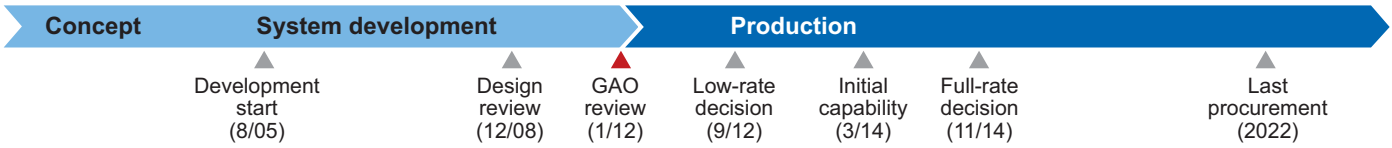
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Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS)

The Army's JLENS is designed to provide over-the-horizon detection and tracking of land-attack cruise missiles and other targets. The Army is developing JLENS in two spirals. Spiral 1 is complete and served as a test bed to demonstrate the concept. Spiral 2 will utilize two aerostats with advanced sensors for surveillance and tracking, as well as mobile mooring stations, communication payloads, and processing stations. JLENS will provide surveillance and targeting support to other systems, such as Patriot and Standard Missile-6. We assessed Spiral 2.



Source: U.S. Army.



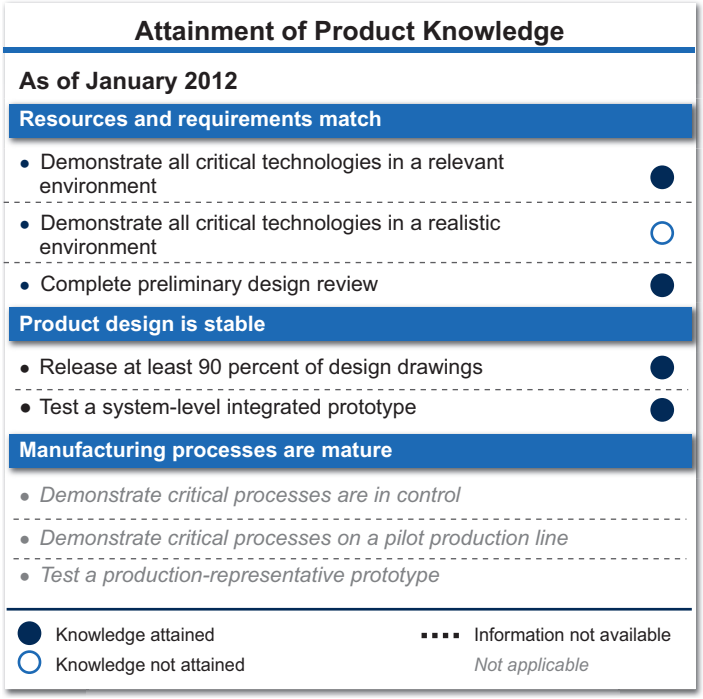
Program Essentials

Prime contractor: Raytheon
Program office: Redstone Arsenal, AL
Funding needed to complete:
R&D: $634.1 million
Procurement: $5,199.4 million
Total funding: $5,948.7 million
Procurement quantity: 14

Program Performance (fiscal year 2012 dollars in millions)

	As of 08/2005	Latest 12/2010	Percent change
Research and development cost	$2,005.5	$2,523.2	25.8
Procurement cost	$4,588.7	$5,199.4	13.3
Total program cost	$6,665.9	$7,857.8	17.9
Program unit cost	$416.619	$491.112	17.9
Total quantities	16	16	0.0
Acquisition cycle time (months)	97	103	6.2

According to program officials, JLENS will enter production in September 2012 with mature technologies, a stable design, and proven production processes. Early problems with the software for the system's fire control radar—a critical technology—delayed the program's entry into developmental test and put the production decision date at risk. The JLENS design appears stable and some key production planning and test activities are complete, but the potential for design changes remains until the maturity of key components has been demonstrated and they have been successfully integrated and tested. In September 2010, an aerostat accident resulted in the loss of one of the JLENS platforms. The accident, as well as recent system integration challenges, delayed the program's production decision by 6 months and resulted in a Nunn-McCurdy unit-cost breach of the significant threshold.



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JLENS Program

Technology Maturity

JLENS entered system development in August 2005 with only one of its five critical technologies mature. Two additional technologies—the communications processing group and platform—are now mature, and the program expects to demonstrate the fire control radar and surveillance radar in a realistic environment before production begins. Many of the JLENS radar technologies have legacy components. However, sensor software items related to signal processing, timing, and control, as well as element measurement, are not yet mature and problems have surfaced in software verification testing. Program officials said a decision to use newer technology introduced unexpected problems that could delay demonstration tests and the integration of both the radars' components.

Design Maturity

The JLENS design appears stable, but the potential for design changes will remain until key JLENS components have been integrated and tested. The recently resolved software problems associated with the fire control radar indicate that the system may still be immature and is at risk of not meeting system performance requirements. These issues could further delay planned tests, as well as the program's production decision. Although the program has had some success, including the first flight demonstration of the aerostat in August 2009, the program must still complete a series of tests integrating the sensors and processing station. An aerostat accident in September 2010 resulted in only minor damage to the mobile mooring station, but the aerostat and associated avionics and electronics were destroyed and important tests to assess the maturity of the system's design had to be postponed. In addition, the Army deployed one aerostat and mobile mooring station for combatant command exercises for the warfighter, which removed an important test asset from the program.

Production Maturity

The JLENS program projects that JLENS will enter production in September 2012 with all 15 of its critical manufacturing processes mature and stable. According to the program office, 12 of the program's critical manufacturing processes are currently in control. The JLENS program has also completed a number of key activities that are essential to effective production management, including updating its manufacturing plan and addressing areas such as supplier capabilities and risks, cost, quality control, materials, producibility, and workforce skills.

Other Program Issues

The JLENS program is working to address several risks that could affect the program's cost, schedule, and performance. First, due to the aerostat accident, JLENS program officials estimate a program effect of $8 million to $10 million. Second, schedule effects resulting from resolution of problems with the fire control radar software are expected to delay several key tests and put the program's production decision at risk. Third, the program experienced a Nunn-McCurdy unit-cost breach of the significant threshold and expects that integration and test delays could further increase costs. Finally, the JLENS program could be affected by alignment with the Army's Integrated Air and Missile Defense program. As part of the integrated strategy, the Army extended the system development phase for JLENS by 12 months.

Program Office Comments

In commenting on a draft of this assessment, the JLENS program provided technical comments, which were incorporated as appropriate.

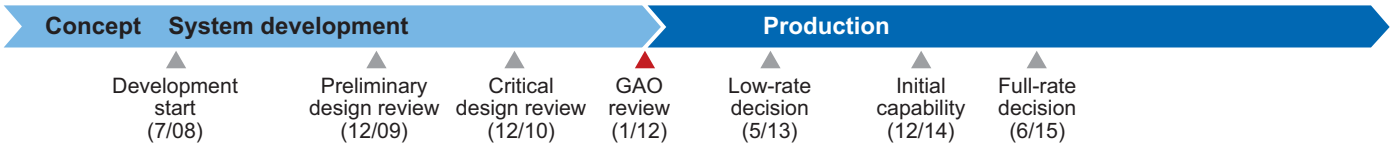
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Joint Precision Approach and Landing System (JPALS)

JPALS Increment 1 is a Navy-led program developing a GPS-based aircraft landing system to replace current radar-based systems on its ships. It is designed to provide reliable precision approach and landing capability in adverse environmental conditions and improved interoperability. Increment 1A is the ship-based system and increment 1B will integrate JPALS with sea-based aircraft. Both increments are needed to provide a capability. We assessed increment 1A.



Source: Department of Defense.



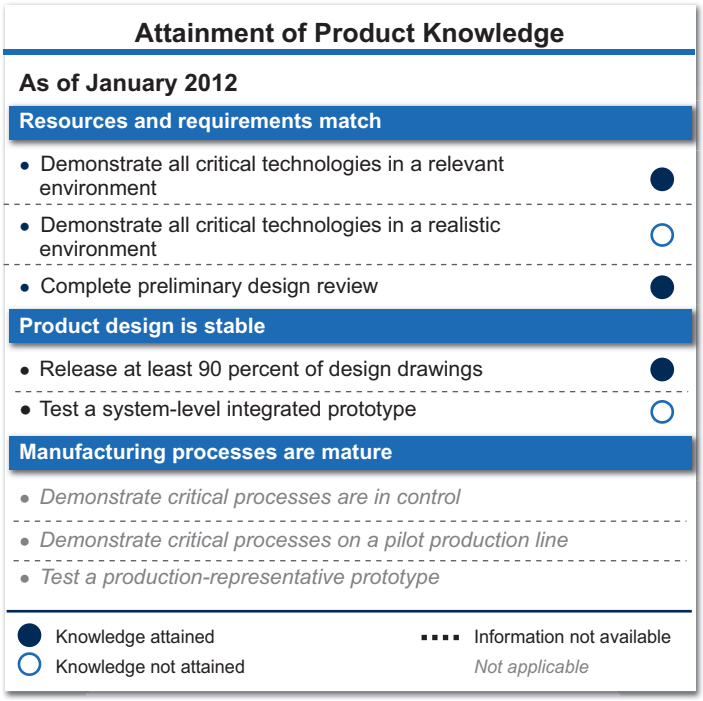
Program Essentials

Prime contractor: Raytheon
Program office: Lexington Park, MD
Funding needed to complete:
- R&D: $183.9 million
- Procurement: $222.7 million
- Total funding: $406.6 million
- Procurement quantity: 26

Program Performance (fiscal year 2012 dollars in millions)

	As of 07/2008	Latest 08/2011	Percent change
Research and development cost	$792.1	$753.5	-4.9
Procurement cost	$213.2	$222.7	4.4
Total program cost	$1,012.3	$983.3	-2.9
Program unit cost	$27.359	$26.575	-2.9
Total quantities	37	37	0.0
Acquisition cycle time (months)	75	77	2.7

The JPALS program completed its critical design review in December 2010, but did not demonstrate that the design can perform as expected. As a result, the risk of design and software changes remains. JPALS functionality is software-based. According to program officials, the program has completed software qualification testing for four of five JPALS subsystems. Completion of testing of the ship processing software, which provides much of JPALS' functionality, has been delayed until March 2012 to incorporate an algorithm update. The program will begin integrated testing of a system prototype in January 2012 without this update. The program has delivered its first three engineering development models, with five more scheduled through 2012. Increment 1B, which integrates JPALS into sea-based aircraft, is planned to begin system development in 2012.



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JPALS Program

Technology Maturity

JPALS Increment 1A began system development in July 2008 with its two critical technologies nearing maturity. Program officials expect both to be mature and demonstrated in a realistic environment by its May 2013 production decision. JPALS functionality is software-based, with over 850,000 lines of code expected in the final system as of August 2011—an increase of almost 57,000 lines of code since its December 2010 critical design review. According to program officials, all seven JPALS software blocks were completed in late August 2011 and the program has completed software qualification testing for four of five JPALS subsystems. Officials also noted that expected completion of testing for the ship processing software, which provides much of JPALS's functionality, has been delayed until March 2012 to allow the program time to integrate an updated version of an algorithm component. Any additional delays with this software testing could affect the JPALS test readiness review—a key program event—scheduled for April 2012.

Design Maturity

The JPALS design is currently stable, but it has not been demonstrated using a prototype to show that it will perform as expected. The risk of design and software changes will remain until the design shows it can meet requirements. The JPALS program held its critical design review in December 2010 and has released all of its expected design drawings to manufacturing. However, the program will not begin integrated testing of a system prototype until January 2012, and this testing will not include the ship processing software.

Production Maturity

The JPALS program plans to take steps to demonstrate the maturity of its manufacturing processes prior to beginning production. The program will demonstrate its manufacturing processes on a pilot production line and will demonstrate that the system will work as intended in a reliable manner by testing a fully configured production-representative prototype. The program accepted delivery of its first engineering development model in December 2010 and its second and third during 2011. Five additional models are scheduled for delivery through 2012, with initial models designated for land-based facilities testing and subsequent models for ship installation and testing. According to officials, the program's planned production decision was delayed from February 2013 to May 2013, primarily due to the availability of CVN 77 for ship-based testing.

Other Program Issues

The JPALS program has not updated key acquisition documents for increment 1A and 1B. When increment 1A was approved to enter system development in 2008, the Under Secretary of Defense for Acquisition, Technology and Logistics stated that its test and evaluation master plan should be updated prior to its preliminary design review, which was held in December 2009. Program officials stated that they have revised the plan, and expect it to be finalized by the program's test readiness review. Increment 1B is scheduled to enter system development in 2012, but the program does not currently have an approved acquisition strategy.

The increment 1A program will integrate JPALS onto 20 existing ships; incorporating JPALS on new ships under construction is the responsibility of those respective programs.

Program Office Comments

In commenting on a draft of this assessment, the JPALS program office noted that increment 1A is currently preparing for entry into formal integrated testing. There have been no requirement changes, and the December 2010 critical design review concluded the program's technical baseline is stable, and performance, cost, and schedule risks are acceptable. All requests for action from the critical design review have been closed. The program completed early testing of the GPS subsystems on board LHD 1 in July 2011, mitigating several program risks prior to beginning formal testing. The program office received a production-representative ship system engineering development model in October 2011 and three functionally-representative avionics test kits in November 2011. To date, the program has continued to meet all cost, schedule, and performance thresholds. The program also provided technical comments, which were incorporated as appropriate.

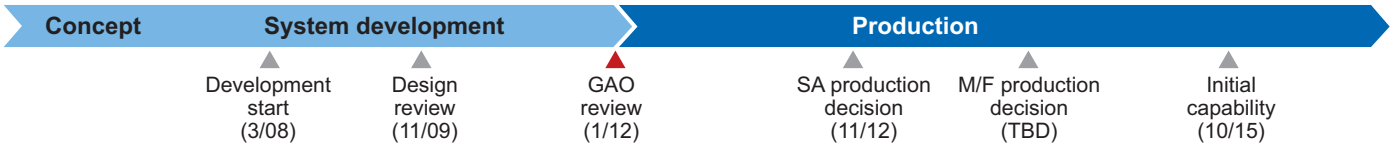
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Airborne and Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS)

DOD's JTRS program is developing software-defined radios that will interoperate with existing radios and increase communications and networking capabilities. The AMF program will develop radios and associated equipment for integration into nearly 160 different types of aircraft, ships, and fixed stations. The program was developing two radios based on a common architecture: a 2-channel small airborne radio and 4-channel maritime/fixed station radio. DOD has suspended development work on the 4-channel radio.



Source: Lockheed Martin.



Program Essentials

Prime contractor: Lockheed Martin
Program office: San Diego, CA
Funding needed to complete:
R&D: $593.7 million
Procurement: $6,203.8 million
Total funding: $6,797.5 million
Procurement quantity: 26,878

Program Performance (fiscal year 2012 dollars in millions)

	As of 10/2008	Latest 08/2011	Percent change
Research and development cost	$1,945.0	$1,957.0	0.6
Procurement cost	$6,209.0	$6,203.8	-0.1
Total program cost	$8,154.1	$8,160.8	0.1
Program unit cost	$.301	$.301	0.1
Total quantities	27,102	27,102	0.0
Acquisition cycle time (months)	80	91	13.8

The program office reported quantities in terms of channels rather than radios.

The AMF JTRS program plans to enter production in November 2012, but it remains at risk for late and costly design changes until its critical technologies have been demonstrated in a realistic environment and other risks have been resolved. Growth in the processing requirements for one key AMF JTRS waveform—the wideband networking waveform—could require a hardware redesign. However, the program will not be able to determine whether one is needed until summer 2012 when the contractor demonstrates the waveform on an engineering development model. The AMF JTRS program has been directed by the Under Secretary of Defense for Acquisition, Technology and Logistics to restructure and delay further development of the maritime/fixed station radio because of unacceptable schedule delays and cost growth. Program officials are currently preparing a restructure plan.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match	
• Demonstrate all critical technologies in a relevant environment	●
• Demonstrate all critical technologies in a realistic environment	○
• Complete preliminary design review	●
Product design is stable	
• Release at least 90 percent of design drawings	●
• Test a system-level integrated prototype	●
Manufacturing processes are mature	
• *Demonstrate critical processes are in control*	
• *Demonstrate critical processes on a pilot production line*	
• *Test a production-representative prototype*	

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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AMF JTRS Program

Technology Maturity

DOD approved the AMF JTRS program for entry into system development in March 2008 with all five of its critical technologies nearing maturity. According to the program, the maturity of these technologies has not changed. The program will not conduct a technology readiness assessment prior to the small airborne radio's production decision, as previously planned, because it is no longer required by DOD.

Design Maturity

The AMF JTRS design is currently stable; however, the program remains at risk for design changes until its critical technologies have been demonstrated in a realistic environment and other risks have been resolved. AMF JTRS' ability to meet its performance requirements is dependent on waveforms from the JTRS Network Enterprise Domain program. Growth in the processing requirements for one key AMF JTRS waveform—the wideband networking waveform—could result in design changes. According to program officials, the issue can be addressed by either making the waveform run more efficiently on the radio through software changes—the preferred solution—or by introducing a more-capable processor into the radio, which would require a hardware redesign. The program will not be able to determine whether the waveform's processing requirements can be reduced enough through efficiency gains until the contractor demonstrates the waveform on a small airborne engineering development model. There is a risk the delivery of the hardware for these models will be delayed. According to program officials, the Navy's Operational Test and Evaluation Force will conduct an operational assessment of the small airborne radio in preparation for its production decision, which is scheduled for November 2012.

According to the program office, AMF JTRS is on track to receive its security certification from the National Security Agency in early fiscal year 2013, but it will require an additional certification for its next software build, which includes functionality related to two key waveforms.

Production Maturity

The AMF JTRS program plans to begin production in November 2012 with manufacturing processes that have been demonstrated, but are not in control. A joint government-contractor assessment team has conducted manufacturing readiness level assessments—which include assessing statistical process controls—at each manufacturing site. The program's projected level of manufacturing readiness indicates that not all statistical process controls will be in place at the start of production. Program officials reported that the prime contractor qualified a second manufacturing source.

Other Program Issues

In September 2011, the Under Secretary of Defense for Acquisition, Technology and Logistics directed that the AMF JTRS program be restructured because of unacceptable schedule delays and cost growth. The development of the maritime/fixed station radio was delayed and the Joint Requirements Oversight Council was requested to reconsider the requirement. According to the program, the military services have agreed that the small airborne radio can meet the maritime/fixed station requirements. In addition, the program was directed to restructure the AMF JTRS contract to reduce the government's cost risk for completing development of the small airborne radio and limit work to key waveforms.

Program Office Comments

In commenting on a draft of this assessment, AMF JTRS program officials provided technical comments, which were incorporated as appropriate.

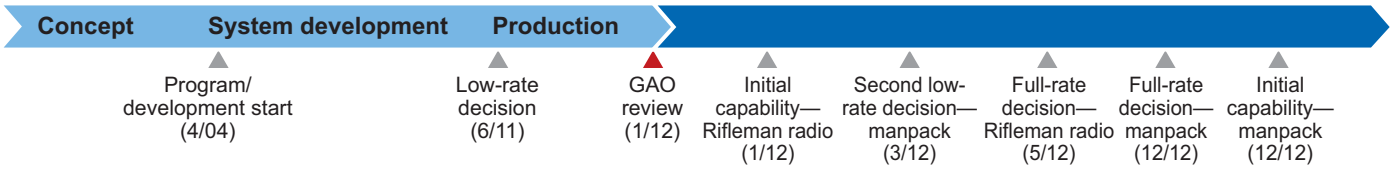
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Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS)

DOD's JTRS program is developing software-defined radios that will interoperate with existing radios and increase communications and networking capabilities. The JTRS HMS program is currently developing four radios: the Rifleman radio and small form fit radio D for unclassified use and the manpack radio and small form fit radio B for use in a classified domain. A subset of the manpack radios will be interoperable with the Mobile User Objective System (MUOS), a satellite communication system that will support radio terminals worldwide.



Source: General Dynamics C4S.



Program Essentials

Prime contractor: General Dynamics C4 Systems, Inc.
Program office: San Diego, CA
Funding needed to complete:
R&D: $352.5 million
Procurement: $7,022.1 million
Total funding: $7,374.6 million
Procurement quantity: 264,019

Program Performance (fiscal year 2012 dollars in millions)

	As of 05/2004	Latest 11/2011	Percent change
Research and development cost	$544.7	$1,272.3	133.6
Procurement cost	$9,492.8	$7,085.7	-25.4
Total program cost	$10,037.5	$8,357.9	-16.7
Program unit cost	$.031	$.031	1.0
Total quantities	328,674	270,951	-17.6
Acquisition cycle time (months)	85	104	22.4

The JTRS HMS program entered production in June 2011 without demonstrating or assessing the maturity of all its critical technologies and with a lower level of manufacturing readiness than recommended by guidance. According to the program, its radio designs are stable; however, the program is still making software changes, and reliability and heat-related issues were identified in a June/July 2011 manpack test event. Manpack production was initially limited to 100 radios because of concerns about its maturity and performance in testing. A second production decision is expected for the manpack radio in March 2012. The estimated cost of the program has increased by $3.5 billion from what the program reported in 2010 as quantities increased to meet military service needs and to fulfill some of the requirements of the cancelled JTRS Ground Mobile Radios program.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ○
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ●

Manufacturing processes are mature

- Demonstrate critical processes are in control — ○
- Demonstrate critical processes on a pilot production line — ○
- Test a production-representative prototype — ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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JTRS HMS Program

Technology Maturity

The JTRS HMS Rifleman radio entered production in June 2011 without demonstrating the maturity of one of its critical technologies—the soldier radio waveform—in a realistic environment. The program office does not expect the assessment of the manpack radio's four critical technologies to be completed until April 2012.

Design Maturity

According to the JTRS HMS program, its radio designs are stable; however, the program is still demonstrating its critical technologies, making software changes, and addressing reliability and heat-related issues. The National Security Agency (NSA) has requested that the program modify some of its software code as part of its certification process. NSA certification, which is required due to JTRS's information-assurance needs, was expected to be complete for both radios by the end of 2011. Additionally, reliability and heat-related issues were identified in June/July 2011 manpack testing. Program officials attributed the problems to poor training of radio operators and do not anticipate that design changes will be needed to address them. The Under Secretary of Defense for Acquisition, Technology and Logistics has stated that the reliability and heat issues are significant risks for the manpack and limited its initial procurement to 100 radios. A second production decision is planned for March 2012 followed by operational testing in May 2012. The Rifleman radio also fell short of its reliability requirement in testing conducted in early 2011. However, according to program officials, the radio's performance was consistent with its reliability growth plan and they expect the radio will exceed its reliability requirements during operational testing, which is expected to be complete by February 2012.

Production Maturity

The JTRS manpack and Rifleman radios entered production in June 2011 at a lower level of maturity than DOD's manufacturing readiness level deskbook recommends. However, the program did demonstrate the production process for the Rifleman radio. According to the program office, the maturity of JTRS HMS manufacturing processes have been steadily increasing, so processes once deemed critical are now considered either key or standard processes.

Other Program Issues

The HMS program has experienced several changes to the number and types of radios it plans to buy since the start of development. Initially, the program planned to buy 328,674 radios at a cost of $10 billion. In 2010, the number of radios was 215,961 and the cost was $4.9 billion. In 2011, quantities and cost increased to 270,951 and $8.4 billion to accommodate requests for more radios from the military services and to fulfill some of the requirements of the cancelled JTRS Ground Mobile Radios program. At the same time, the program stopped developing two small form fit radios and the 2-channel handheld radio. Unit costs have increased for the remaining small form fit and manpack radios, and could continue to grow for future manpack variants. While the program office expects that competition will lower the procurement unit cost, program officials noted that delays in the MUOS program will likely have negative effects on the manpack radio's research and development cost and schedule. According to program officials, congressional funding reductions in fiscal year 2012 will also delay future releases of the manpack radio—including the MUOS-capable variant—and reduce planned radio purchases.

Program Office Comments

In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated as appropriate.

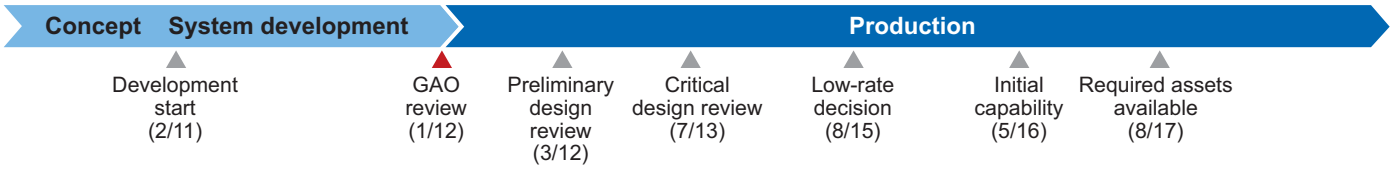
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KC-46 Tanker Modernization Program

The KC-46 tanker program is the first of three planned phases to replace the Air Force's fleet of KC-135 tankers, which have been its primary aerial refueling aircraft for more than 50 years. The initial purchase of 179 KC-46 aircraft is intended to replace roughly one-third of the KC-135 fleet's current capability. In addition to aerial refueling, the aircraft are being designed as a multirole platform supporting global attack, airlift, aircraft deployment, special operations, aeromedical evacuation, and combat search and rescue.



Source: © 2011 Boeing. All rights reserved.



Program Essentials

Prime contractor: Boeing
Program office: Wright-Patterson AFB, OH
Funding needed to complete:
R&D: $6,055.9 million
Procurement: $33,502.6 million
Total funding: $43,283.6 million
Procurement quantity: 175

Program Performance (fiscal year 2012 dollars in millions)

	As of 08/2011	Latest 08/2011	Percent change
Research and development cost	$6,899.4	$6,899.4	0.0
Procurement cost	$33,502.6	$33,502.6	0.0
Total program cost	$44,127.2	$44,127.2	0.0
Program unit cost	$246.520	$246.520	0.0
Total quantities	179	179	0.0
Acquisition cycle time (months)	78	78	0.0

According to the Air Force, the development risk for the KC-46 is low to moderate because it will utilize a commercial derivative aircraft and maturing technologies; the integration of military software and hardware with the aircraft is the primary risk. The KC-46 tanker program entered system development in February 2011 with its three critical technologies nearing maturity. The program was granted a waiver to enter development without conducting a preliminary design review, but the program plans to hold this review in March 2012. The program also plans to have a stable design by its July 2013 critical design review. The KC-46 program is using a fixed-price incentive contract for development with options for production. The program office noted that stable requirements and funding will be key to mitigating potential cost growth.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ○

Product design is stable

- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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KC-46 Program

Technology Maturity

According to an independent technology readiness assessment, KC-46 entered system development with its three critical technologies nearing maturity. These technologies are a three-dimensional display to monitor and enable aerial refueling activities, and two types of software being developed to increase situational awareness and enable automatic aircraft rerouting to avoid potential threats. The integration of military hardware and software on the KC-46 aircraft's commercial derivative airframe has been identified as the primary technical risk for the program. Other technical risks include software development and the redesign of wing aerial refueling pods. In addition, the Federal Aviation Administration will have to certify both the Boeing 767-2C airframe and KC-46 tanker for air worthiness.

Design Maturity

The KC-46 tanker is a commercial derivative aircraft estimated to be 80 percent common with the Boeing 767 family of commercial platforms in terms of the airframe, and about 80 percent common with other Boeing commercial platforms in terms of system components. The KC-46 program did not require a technology development phase because it was assessed as having low to moderate development risk, and thus, did not hold a preliminary design review prior to beginning system development. The program received a waiver for this requirement and plans to hold this review in March 2012—about 13 months after development start. We have previously reported that holding a preliminary design review prior to development start can ensure requirements are well-defined and feasible. The program completed its system functional review—a predecessor to this review—in November 2011 resulting in no significant changes to program requirements. The program plans to demonstrate the system's design is stable and have 90 percent of KC-46 design drawings released by its projected July 2013 critical design review.

Production Maturity

The KC-46 program will not collect statistical process control data for critical manufacturing processes, but indicated that production maturity will be assessed using manufacturing readiness levels—a tool used to support assessments of manufacturing risks.

The significant concurrency between development, testing, and production activities poses a schedule risk for the KC-46 program. Following a successful initial production decision, the Air Force plans to exercise the first two production contract options. After the options are exercised, Boeing will be required to provide the Air Force with a total of 18 operationally ready aircraft 78 months after development contract award, which would be by August 2017. Further contract options are planned to continue through 2027. According to program officials, the government will hold Boeing accountable to the terms and conditions of the contract and seek consideration from Boeing if they do not perform to the contract requirements.

Other Program Issues

The Air Force awarded a $4.4 billion fixed-price incentive (firm target) contract to Boeing with a $4.9 billion ceiling price for four development aircraft with options for the remaining 175 planned production aircraft. The options establish firm-fixed pricing for low-rate initial production lots and not-to-exceed pricing for full-rate production lots. The program office cites stable requirements and funding as keys to mitigating potential cost growth.

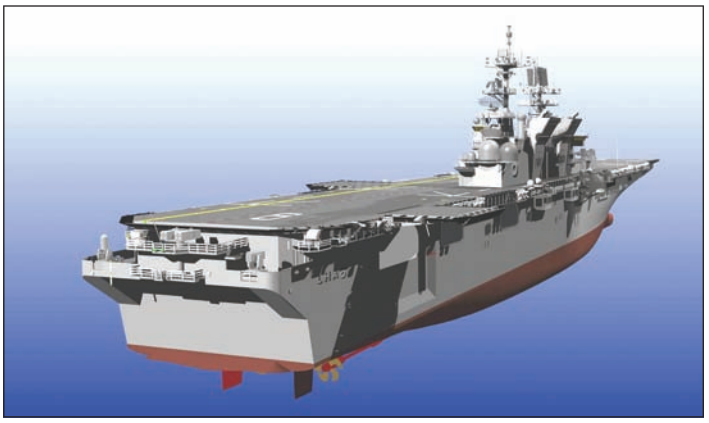
Program Office Comments

In commenting on a draft of this assessment, DOD stated the program mitigated the greatest KC-46 risk to the taxpayer—cost growth and open ended financial liability—by negotiating the competitive fixed-price incentive development contract with firm-fixed and not-to-exceed pricing for production. In addition, the program is mitigating the development schedule risk by maintaining tight oversight of contract execution to ensure Boeing delivers on its contract commitments. DOD also stated the KC-46 program is being managed in an event-based manner and the approval to begin production is not driven by a contractually required date. DOD will mitigate the risk posed by concurrency by ensuring that adequate testing is completed prior to the production decision in addition to the contract provision requiring Boeing to incorporate fixes to issues found during testing into production aircraft at no additional cost. DOD and the Air Force also provided technical comments, which were incorporated as appropriate.

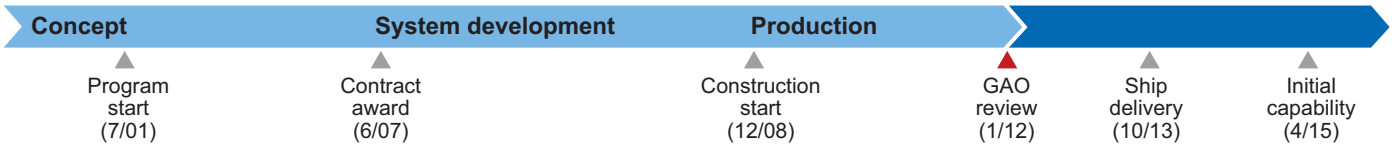
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LHA Replacement Amphibious Assault Ship

The Navy's LHA 6 class will replace the LHA 1 *Tarawa*-class amphibious assault ships. LHA 6 is a modified variant of the fielded LHD 8. It will feature enhanced aviation capabilities and is designed to support all afloat Marine Corps aviation assets in an expeditionary strike group. LHA 6 construction began in December 2008 and ship delivery is expected in October 2013. The LHA 6 class includes three ships. Navy officials expect to award the construction contract for LHA 7 by May 2012, with construction start planned for April 2013.



Source: U.S. Navy.



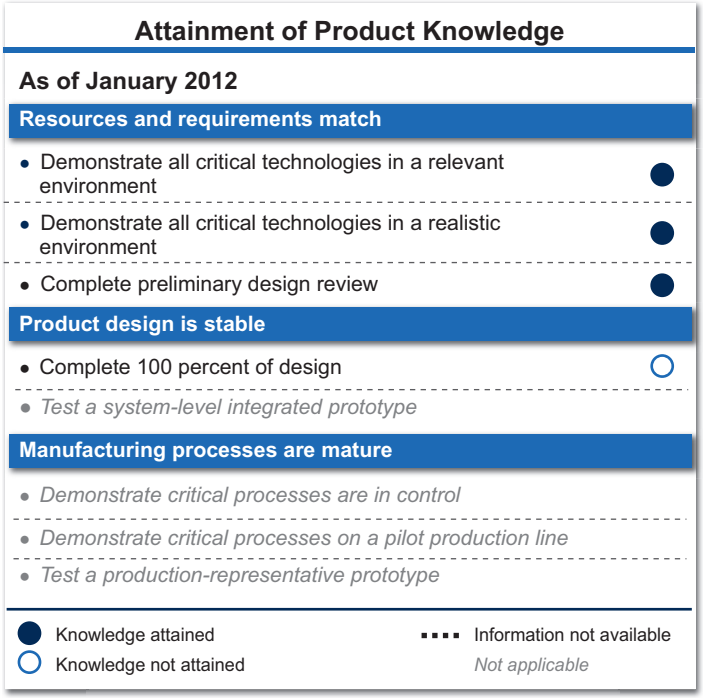
Program Essentials

Prime contractor: Huntington Ingalls Industries
Program office: Washington, DC
Funding needed to complete:
R&D: $97.3 million
Procurement: $5,627.9 million
Total funding: $5,726.2 million
Procurement quantity: 1

Program Performance (fiscal year 2012 dollars in millions)

	As of 01/2006	Latest 12/2010	Percent change
Research and development cost	$220.9	$350.9	58.8
Procurement cost	$2,959.2	$9,742.8	229.2
Total program cost	$3,180.2	$10,095.2	217.4
Program unit cost	$3,180.150	$3,365.053	5.8
Total quantities	1	3	200.0
Acquisition cycle time (months)	146	165	13.0

LHA 6 began construction in December 2008 with mature critical technologies, but a design that was only 65 percent complete. As of August 2011, the LHA 6 design was 98 percent complete and its construction was 52 percent complete. The shipbuilder is projecting an additional 6-month delay in the delivery of the ship, which is now expected in October 2013. According to the program office, this delay was caused by design quality issues—which have resulted in high levels of rework during construction—shortfalls in skilled-trade labor at the shipyard, problems implementing new shipbuilder business systems, and delays in receiving key materials. The LHA 6 program may also incur additional cost growth if postdelivery rework of the ship's deck is necessary to cope with the intense, hot downwash from the Joint Strike Fighter, which began shipboard testing in October 2011.



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LHA 6 America Class Program

Technology Maturity

All LHA critical technologies were mature when the program awarded its construction contract in June 2007. Although not considered critical technologies, the program has identified six key subsystems necessary to achieve LHA 6's full capabilities. Five of these subsystems are mature. The sixth, the Joint Precision Approach and Landing System, a Global Positioning System–based aircraft landing system, is still in development. LHA 6 can still meet its operational requirements without this system by using backup aviation control systems. The program office had also previously identified the machinery control system as a potential risk because the LHD 8 program, which is responsible for developing it, was experiencing delays in its development. However, according to program officials, the system's development, testing, and delivery are progressing on or ahead of LHA 6's schedule needs. Shipboard integration testing of the machinery control system is scheduled to begin in the second quarter of 2012.

Design and Production Maturity

The LHA 6 began construction in December 2008 with only 65 percent of its design complete, and subsequent design quality issues have caused a greater number of design changes than anticipated and high levels of rework during construction. The shipbuilder is also projecting an additional 6-month delay in the delivery of LHA 6, which is now expected in October 2013. As of August 2011, the LHA 6 design was 98 percent complete and its construction was 52 percent complete. The LHA 6's rework rate is more than twice that of the LHD 8—the last amphibious assault ship built—at the same stage of construction. According to program officials, LHA 6 has experienced a significant number of physical interference issues during construction that have required modifications, including ripping out of completed work, and caused work to stop at times. The program office attributes the high level of rework to insufficient quality checks of drawings prior to construction start. According to the program, shortfalls in skilled-trade labor at the shipyard, problems implementing new shipbuilder business systems, and delays in receiving key materials have also contributed to the projected delay in the delivery of the ship. Program officials said the manning situation at the shipyard has improved after the delivery of other Navy and Coast Guard ships.

LHA 7 will have a design that is very similar to LHA 6. The ship will include a new firefighting system and updates to the radar and the command, control, communications, computers, and intelligence systems. Design changes to LHA 8 are projected to be more significant because the Navy is expected to include a well deck on the ship, which would accommodate landing and attack craft, but negatively affect aviation capabilities such as fuel storage space.

Other Program Issues

LHA 6 may experience further cost growth due to issues related to the deployment of the Joint Strike Fighter. Specifically, postdelivery rework of the ship's deck may be necessary to cope with the heat from the aircraft's exhaust and downwash, which could warp the deck or damage deck equipment. In October 2011, the Navy began at-sea testing on the USS *Wasp* to determine how LHA 6 and other JSF-capable ships may need to modify their flight decks.

Program Office Comments

In commenting on a draft of this assessment, the Navy stated that LHA 6, awarded under a fixed-price contract, was 60 percent complete as of February 2012 and on track to be delivered in fiscal year 2014. The Navy also stated that LHA 6 experienced a higher rework rate than LHD 8 at the same stage of construction for two main reasons. First, the shipbuilder performed more work at an earlier phase by increasing the amount of preoutfitting in the ship compared to LHD 8. More rework is being experienced earlier in construction, where it is less expensive to perform. LHD 8 experienced the majority of rework at later construction phases. Second, the significant physical interference issues during construction have required modification. Shipbuilder quality performance is improving in electrical cable installation, hull joint fit-up, and weld quality, and several construction milestones, such as stern release, have been achieved ahead of schedule. Test procedure development is also ahead of schedule. The Navy also provided technical comments, which were incorporated as appropriate.

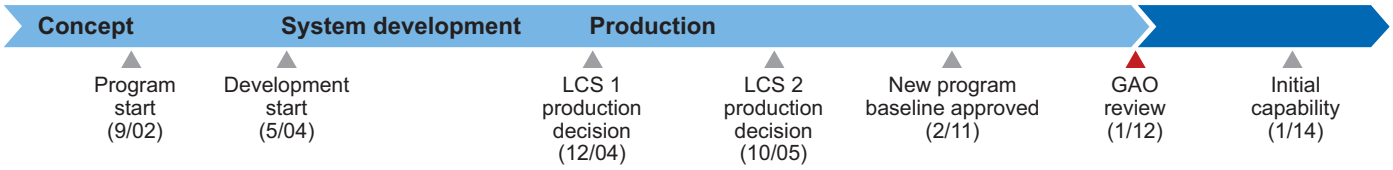
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Littoral Combat Ship (LCS)

The Navy's LCS is designed to perform mine countermeasures, antisubmarine warfare, and surface warfare missions. It consists of the ship itself, or seaframe, and the mission package it deploys. The Navy bought the first four seaframes in two unique designs. In December 2010, the Navy changed its planned strategy of choosing one design for future ships and instead, subsequently awarded a contract for a block buy of up to 10 ships to both contractors. We assessed both seaframe designs.



Sources: Lockheed Martin (left); General Dynamics (right).



Program Essentials

Prime contractor: Austal USA, General Dynamics, Lockheed Martin
Program office: Washington, DC
Funding needed to complete:
R&D: $1,112.5 million
Procurement: $25,001.1 million
Total funding: $26,325.2 million
Procurement quantity: 47

Program Performance (fiscal year 2012 dollars in millions)

	As of 05/2004	Latest 12/2010	Percent change
Research and development cost	$887.0	$3,520.1	296.9
Procurement cost	$471.6	$29,136.1	6,078.2
Total program cost	$1,358.6	$32,867.8	2,319.3
Program unit cost	$339.6	$597.596	76.0
Total quantities	4	55	1,275.0
Acquisition cycle time (months)	41	116	182.9

Cost data are for the seaframe only. The 2004 estimate corresponds with program initiation. It was pre–milestone B and did not reflect the full 55-ship program. Research and development funding includes detail design and construction of two ships.

The LCS program is entering a period of steady production and has demonstrated the maturity of most of its critical technologies; however, it continues to make design and production process changes. The Navy started construction of LCS 1 and 2 without a stable design and has had to incorporate design changes on follow-on seaframes. The Navy believes it has identified measures to address cracking on the LCS 1's superstructure and hull and corrosion issues on LCS 2 that can be achieved within the program's budget. DOD's Office of the Director, Cost Assessment and Program Evaluation, has stated that the program may be at risk for cost growth because its approved cost estimate reflects competitive pricing from recent contracts that may not materialize in the future.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- Complete three-dimensional product model — ●
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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LCS Program

Technology Maturity

Sixteen of the 19 critical technologies for both LCS designs are mature and have been demonstrated in a realistic environment. Three technologies—LCS 1's overhead launch and retrieval system and LCS 2's aluminum structure and trimaran hull—are nearing maturity. The LCS 1 overhead launch and retrieval system, which is essential to antisubmarine warfare and mine countermeasures missions, has moved weight equivalent to a mission system, but has not yet demonstrated its maturity by loading and offloading an actual mission module vehicle. Program officials stated that a test of the Remote Multi-Mission Vehicle with the launch and recovery system has not been scheduled and will depend on the availability of LCS 1 and the vehicle. Developmental testing for the vehicle is scheduled for 2013. In addition, program officials believe that LCS 2's aluminum structure and trimaran hull are mature because the ship is operational. However, an April 2010 independent technology readiness assessment did not reach the same conclusion about the aluminum structure, in part because of the inability to assure a 20 year service life.

Design and Production Maturity

The Navy started construction of LCS 1 and 2 without a stable design and has had to incorporate design and production changes into follow-on seaframes. When the LCS 1 and 2 construction contracts were awarded, the basic and functional design of each seaframe were respectively only 20 percent and 15 percent complete. Construction began 1 to 2 months following these contract awards. This concurrent design-build strategy ultimately led to increases in construction costs.

LCS 1 has been in operation for about 3 years and the Navy has discovered cracks in the superstructure and hull. The program office indicated that the cracks occurred either in high stress areas on the ship or due to workmanship issues, such as welding deficiencies. Program officials stated that all cracks have been fixed and design changes and improved production processes, such as improving accessibility in welding areas, are being developed. The design changes, which decrease the stress on parts of the ship, will also be made on LCS 3, which is almost complete, as well as future seaframes. The Navy also reported corrosion on LCS 2, which has been in operation for over a year, due to insufficient insulation between the aluminum hull and the steel water jet. The Navy plans to install a system to mitigate the deterioration of metals on LCS 2 and future seaframes. The Navy believes these measures are sufficient to address the cracking and corrosion issues and can be done within the program's budget.

Other Program Issues

The LCS's approved program baseline is based on a cost estimate that is lower than an independent cost estimate from the Office of the Director, Cost Assessment and Program Evaluation. The Under Secretary of Defense for Acquisition, Technology and Logistics stated that the approved cost estimate is reasonable as it reflects the expectation that recent competitive pricing will continue for future contracts. The Director, Cost Assessment and Program Evaluation, expressed concern that this approach puts the program at risk for future cost growth if these savings do not materialize.

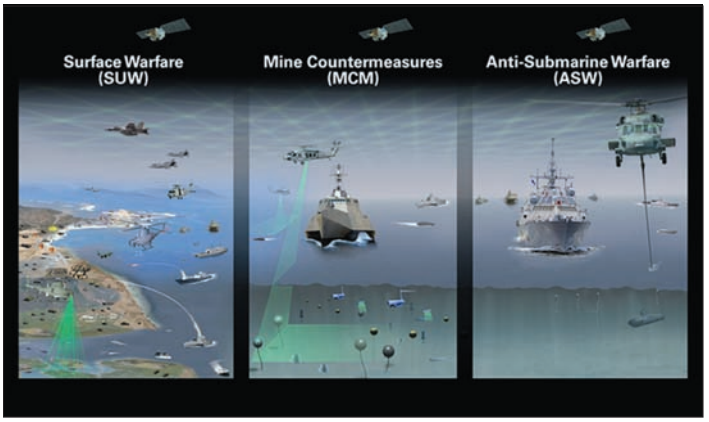
Program Office Comments

In commenting on a draft of this assessment, the Navy stated that it has retired the increased construction costs associated with the concurrent design/build period. The Navy noted that due to the complex nature of ship design and construction, lead ships generally have design changes that are incorporated into follow-on ships as a result of extensive testing and ship underway lessons learned. That is common practice in ships, even with a stable baseline, as evidenced by changes incorporated in the DDG 51 Class. LCS 3 and 4 have experienced minimal design changes and reflect learning, with both shipbuilders investing in their shipyards. LCS 3 is 99 percent complete and will deliver in June 2012. LCS 4 was about 80 percent complete at launch and was christened in January 2012. LCS 5 completed a detail design review and a production readiness review and its fabrication began in August 2011. LCS 6 followed suit and started fabrication in August 2011. Technical comments provided by the Navy were incorporated as appropriate.

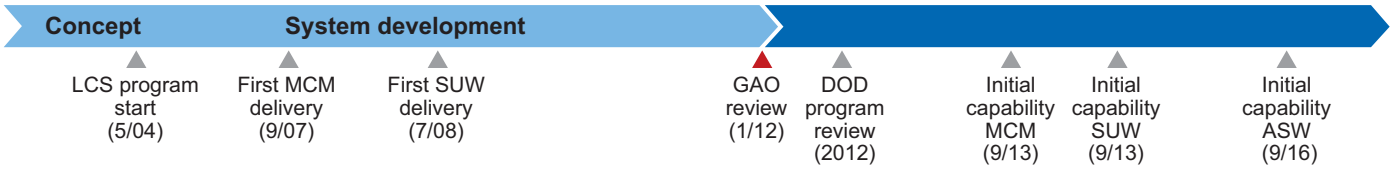
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Littoral Combat Ship–Mission Modules

The Navy's Littoral Combat Ship (LCS) will perform mine countermeasures (MCM), surface warfare (SUW), and antisubmarine warfare (ASW) missions using mission modules. Modules include weapons and sensors operating from MH-60 helicopters and unmanned vehicles, which will be launched and recovered from both LCS seaframes. The mission modules program is separate from the LCS seaframe for management and reporting purposes. The Navy has defined increments of MCM, SUW, and ASW capability that it plans to deliver incrementally, over time.



Source: © Northrop Grumman Corporation.



Program Essentials

Prime contractor: Multiple
Program office: Washington, DC
Funding FY12 to FY16:
R&D: $657.4 million
Procurement: $969.3 million
Total funding: $1,626.7 million
Procurement quantity: 18

Program Performance (fiscal year 2012 dollars in millions)

	As of 08/2007	Latest 09/2011	Percent change
Research and development cost	$491.8	$1,652.4	236.0
Procurement cost	$3,259.2	$1,228.0	-62.3
Total program cost	$3,751.0	$2,880.4	-23.2
Program unit cost	NA	NA	NA
Total quantities	64	65	1.6
Acquisition cycle time (months)	NA	NA	NA

Costs are from program start through fiscal year 2016. The program's cost estimate has been updated by the Navy and a baseline will be set after DOD's upcoming review of the program.

The MCM, SUW, and ASW mission modules, at full capability, require a total of 24 critical technologies, including sensors, vehicles, and weapons—none of which, at full capability, have been tested on board LCS in a realistic environment. In addition, some of the sensors, vehicles, and weapons that the Navy previously assessed as mature are being replaced because of poor performance or increasing costs. The Navy is continuing developmental testing but has yet to begin operational testing. The Navy has accepted delivery of two partially capable MCM and SUW mission modules, each, for a total of four. In 2012, the Navy plans to accept delivery of a total of three MCM and SUW mission modules and also plans to procure two more partially capable modules. The Navy plans to procure 24, and deliver 9, LCS seaframes by 2016, before delivering a single fully capable mission module.

Attainment of Product Knowledge

Projected as of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ▪▪▪▪
- Demonstrate all critical technologies in a realistic environment — ▪▪▪▪
- Complete preliminary design review — ●

Product design is stable

- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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LCS Modules Program

Mine Countermeasures (MCM)

The Navy has accepted delivery of two partially capable MCM mission modules and, in 2012, expects to accept delivery of a module and procure another module. The Navy plans to begin operational testing onboard LCS in 2012, but the contents of the MCM module are still changing to address cost and capability concerns. For example, the remote minehunting system (RMS), comprised of an underwater vehicle and sonar, experienced a Nunn-McCurdy unit-cost breach in 2009. Further, the Navy has found performance issues, in part because the equipment required to launch and recover the underwater vehicle is not reliable and sonar performance does not currently meet threshold requirements. Since the Navy already purchased 10 underwater vehicles and determined there is no better alternative, RMS will remain in the module. The Navy is currently executing a plan to improve its reliability and then plans to begin producing the upgraded RMS in 2015. The rapid airborne mine clearance system was initially part of the MCM module, but was removed because of performance problems when destroying below-surface mines. The Navy plans to replace it by 2017. The Navy has also removed the unmanned surface vehicle (USV) and unmanned influence sweep system from its upcoming mission module. The USV design does not meet requirements, requiring a 6-year effort to improve the system's capabilities. The Navy has also deferred delivery of two other MCM systems.

Surface Warfare (SUW)

The Navy has accepted delivery of two partial SUW modules, including two 30 millimeter guns and a prototype of an 11-meter small boat. In 2012, the Navy plans to accept delivery of two and procure one more partial module. The Navy has replaced the cancelled Non-Line-of-Sight Launch System—which had a proposed range of 21 nautical miles—with the Griffin missile, which according to officials, will initially have a range of 3 miles. The Navy will not incorporate a surface-to-surface missile that can meet the module's requirements until after 2017 following a full and open competition.

Antisubmarine Warfare (ASW)

In 2008, the Navy took delivery of one partially capable ASW module at a cost of over $200 million, but subsequently cancelled plans to continue procuring the module and is redesigning it. According to program officials, the new design includes a variable-depth sonar and towed array, unmanned aerial vehicle, helicopter, and torpedo countermeasure. These ASW technologies are in use by another navy, but they have not been adapted for use with LCS. In 2012, the Navy will begin engineering analysis of the new ASW module, followed by development start in 2013 and initial delivery in fiscal year 2016.

Other Program Issues

The Navy plans to purchase 24, and deliver 9, LCS seaframes by 2016; however, it will not have a single fully capable mission module at that time. As of September 2011, the program planned to conduct a key DOD review in January 2012; however, this review, which includes a program cost estimate and technology maturity assessment, has been delayed to an unspecified date in 2012.

Program Office Comments

In commenting on a draft of the assessment, the program office did not concur with our assessment of the LCS Mission Modules; specifically with regard to the state of development and maturity of the mission modules. The program believes that recent testing has been very successful. For example, the MCM module has recently completed developmental and end-to-end testing to neutralize mines. The SUW module supported deployment of LCS 1 on missions that resulted in the capture of cocaine. From inception, the program has remained stable, fielding systems as they achieve the required level of maturity. The few systems experiencing issues are being replaced with alternative systems or are targets of increased focus and attention. The program also provided technical comments, which were incorporated as appropriate.

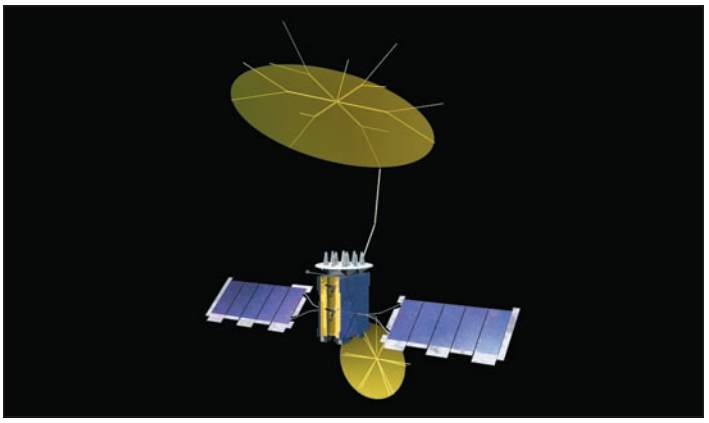
GAO Response

Major elements of each of the three mission modules have yet to be demonstrated and there are unknowns about their cost and performance. Until the program demonstrates these capabilities in a realistic environment, the program will be at increased risk of cost growth, schedule delays, and performance shortfalls.

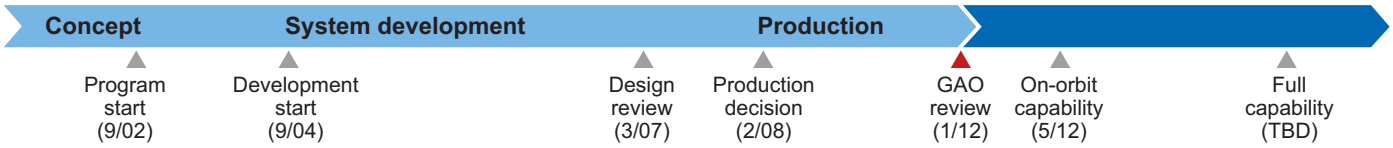
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Mobile User Objective System (MUOS)

The Navy's MUOS, a satellite communication system, is expected to provide a worldwide, multiservice population of mobile and fixed-site terminal users with increased narrowband communications capacity and improved availability for small terminal users. MUOS will replace the Ultra High Frequency (UHF) Follow-On (UFO) satellite system currently in operation and provide interoperability with legacy terminals. MUOS consists of a network of satellites and an integrated ground network. We assessed both the space and ground segments.



Source: © 2007 Lockheed Martin.



Program Essentials

Prime contractor: Lockheed Martin Space Systems
Program office: San Diego, CA
Funding needed to complete:
R&D: $470.1 million
Procurement: $1,125.1 million
Total funding: $1,595.2 million
Procurement quantity: 1

Program Performance (fiscal year 2012 dollars in millions)

	As of 09/2004	Latest 08/2011	Percent change
Research and development cost	$3,647.7	$4,218.3	15.6
Procurement cost	$3,035.0	$2,694.3	-11.2
Total program cost	$6,721.3	$6,978.2	3.8
Program unit cost	$1,120.222	$1,163.035	3.8
Total quantities	6	6	0.0
Acquisition cycle time (months)	90	116	28.9

The latest cost data do not reflect the current cost of the program. A new acquisition program baseline has not yet been approved.

The MUOS program's critical technologies are mature, its design is stable, and its manufacturing process maturity is increasing. The first satellite has been delivered and is expected to begin on-orbit operations in May 2012—26 months later than planned at development start. The delivery of MUOS capabilities remains time-critical due to the past operational failures of two UFO satellites. If the first satellite is launched as scheduled, the risk of UHF communications capabilities falling below required levels will be substantially reduced. However, users will not be able to utilize many MUOS capabilities until two MUOS satellites are in orbit and because of delays in the development and testing of a new waveform and fielding of user terminals. MUOS user terminal procurement and fielding are managed by separate programs.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment ●
- *Demonstrate all critical technologies in a realistic environment*
- Complete preliminary design review ●

Product design is stable

- Release at least 90 percent of design drawings ●
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- Demonstrate critical processes on a pilot production line ○
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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MUOS Program

Technology, Design, and Production Maturity

The MUOS program's critical technologies are mature, its design is stable, and its manufacturing process maturity is increasing. The first satellite has been delivered and four other satellites are being built. Despite some delays, system-level thermal vacuum testing—used to demonstrate the performance of the payload and spacecraft in a simulated space environment—has been completed for the first satellite. In addition, the design flaws that we reported on last year—including unwanted signal interference caused by UHF reflectors and the hinges that connect solar panels and booms in the solar array wing assembly—have been resolved. These components have been reworked and tested; final signal interference testing results were completed in November 2011. According to the program office, the production maturity of the first MUOS satellite is high. The program has experienced quality problems in the past that resulted in cost increases and schedule delays. However, the number of manufacturing defects on the space segment has decreased slightly over time as the maturity of the manufacturing process has increased. We could not assess whether MUOS critical manufacturing processes were in control because the program does not collect statistical process control data.

Other Program Issues

The first MUOS satellite has been delivered for a planned February 2012 launch. Current UHF communication capabilities are predicted to provide the required availability level until the first MUOS satellite begins on-orbit operations—planned for May 2012. The MUOS program has taken actions to address a potential capability gap caused by earlier, unexpected UFO satellite failures by activating dual digital receiver unit operations on a UFO satellite, leasing commercial UHF satellite services, initiating international partner agreements to share UHF satellite capacity, and planning to enhance digital receiver unit operations on the second through fifth MUOS satellites.

According to the program office, its top challenge is synchronizing deliveries of the MUOS space and ground segments with compatible Joint Tactical Radio System (JTRS) terminals. Launching the first MUOS satellite is important to sustain current UHF communications capability, but there is a risk that MUOS capabilities will be significantly underutilized because of delays in the JTRS program's development and delivery of the new MUOS waveform and radio terminals. Over 90 percent of the MUOS's planned capability is enabled by the new waveform and JTRS terminals, including increases in the amount of data that can be transmitted and the ability to transmit both voice and data. Operational testing of the JTRS terminals has been delayed to February 2014. An independent review team assessed potential options for completing development of the MUOS waveform and the plan forward is being finalized.

In 2009, a Navy-initiated review of the MUOS program found that while it was technically sound, its schedule was optimistic and its budget was inadequate. As a result, the program developed new cost and schedule baselines. The new baseline has been under revision since December 2009, but has not yet been approved.

Program Office Comments

In commenting on a draft of this assessment, the Navy provided technical comments, which were incorporated as appropriate.

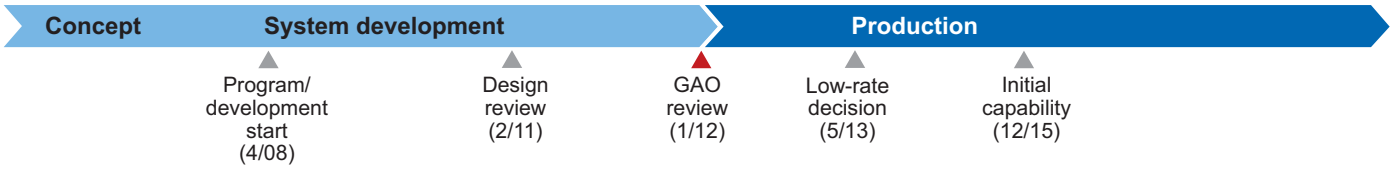
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MQ-4C Broad Area Maritime Surveillance (BAMS) Unmanned Aircraft System (UAS)

The Navy's MQ-4C BAMS UAS is intended to provide a persistent maritime intelligence, surveillance, and reconnaissance (ISR) capability even when no other naval forces are present. BAMS UAS will operate from five land-based sites worldwide. It will be part of a family of maritime patrol and reconnaissance systems that recapitalizes the Navy's airborne ISR assets. Follow-on increments of the program will add a signals intelligence capability and upgrade the system's communication relay. We assessed Increment 1.



Source: Northrop Grumman.



Program Essentials

Prime contractor: Northrop Grumman Systems Corporation
Program office: Patuxent River, MD
Funding needed to complete:
- R&D: $1,657.1 million
- Procurement: $9,413.9 million
- Total funding: $11,422.2 million
- Procurement quantity: 65

Program Performance (fiscal year 2012 dollars in millions)

	As of 02/2009	Latest 12/2010	Percent change
Research and development cost	$3,141.7	$3,245.6	3.3
Procurement cost	$9,323.4	$9,413.9	1.0
Total program cost	$12,847.6	$13,052.4	1.6
Program unit cost	$183.537	$186.463	1.6
Total quantities	70	70	0.0
Acquisition cycle time (months)	92	92	0.0

The BAMS UAS program's critical technologies are mature and its design is stable; however, the program does not plan to demonstrate that the design performs as expected until April 2012—more than a year after the critical design review. According to program officials, the second BAMS UAS system development aircraft, which will begin testing in 2012, will be the first aircraft with a full sensor suite and the air-to-air radar subsystem. In November 2011, the BAMS UAS program received approval to build three systems and ground stations, in part to demonstrate its manufacturing processes prior to its planned May 2013 production decision. According to program officials, the BAMS air vehicle is based on the Air Force's RQ-4B Global Hawk with some structural changes to the airframe, but none of these require significant changes to manufacturing processes.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ○

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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BAMS UAS Program

Technology Maturity

The BAMS UAS program's critical technologies are mature. DOD and the Navy certified that all BAMS UAS technologies had been demonstrated in a relevant environment before the start of system development, and an April 2011 technology readiness assessment concluded that its one critical technology—a hydrocarbon sensor—was mature. This sensor is identical to one that has been developed for the Navy's P-8A program. The maturity of the BAMS air-to-air radar subsystem, which will enable its sense and avoid capabilities, has not been assessed.

Design Maturity

The BAMS UAS design is stable; however, the program does not plan to demonstrate the design performs as expected by testing an integrated prototype until April 2012—more than a year after the critical design review. According to the program office, 97 percent of the air vehicle's expected design drawings are releasable to manufacturing and all subsystem critical design reviews have been completed. The second BAMS UAS system development aircraft, which will begin testing in 2012, will be the first aircraft with a full sensor suite and the air-to-air radar subsystem.

The BAMS UAS program poses a significant software development challenge, utilizing nearly 8 million lines of code, of which more than 20 percent will be newly developed for the program. Program officials cited software development as a primary risk for one subsystem, the air-to-air radar, but noted that they still expect it to be ready for the program's planned operational assessment in 2013.

Production Maturity

In November 2011, the BAMS UAS program received approval to build three air vehicles and associated ground stations, in part to demonstrate its manufacturing processes prior to production. According to program officials, the program also plans to assess manufacturing maturity and risks, using manufacturing readiness levels, before its planned production decision in May 2013. The BAMS aircraft is based on the Air Force's Global Hawk RQ-4B, which is in production, and uses sensor components and entire subsystems from other platforms. There are some structural changes to the airframe, but none of these require significant changes to manufacturing processes.

Other Program Issues

The BAMS UAS program has not reported any negative effects as a result of past challenges in the Global Hawk program; however, we did not assess the effect of the proposed cancellation of the Global Hawk Block 30 program. According to the BAMS UAS program office, the performance and reliability issues experienced by the Global Hawk during operational testing have already been addressed for the BAMS UAS. In addition, the BAMS UAS program has reported to the Navy on the potential cost effects of reduced Global Hawk procurements, which occurred after that program experienced a Nunn-McCurdy unit-cost breach of the critical threshold in 2011. Despite changes to the Global Hawk program, the BAMS UAS program is continuing to investigate potential areas of commonality with it, including a common ground control station architecture, a consolidated maintenance hub, and colocated basing for both UASs abroad. The Navy acquired three additional Global Hawk Block 10 aircraft divested by the Air Force. These aircraft will be used to provide additional parts support to maintain the BAMS demonstrator capability supporting overseas operations until BAMS UAS reaches initial operating capability scheduled for 2015.

Program Office Comments

In commenting on a draft of this assessment, the Navy stated that, while the software development, system integration, and integrated test efforts pose challenges for the BAMS UAS program in the coming years, proactive risk mitigation and detailed cost and schedule management to this point have provided the basis for successful completion of upcoming program milestones. According to officials, the program benefits from strong support within the Department of the Navy, fills a tremendous need for intelligence, surveillance, and reconnaissance capability, and is on track for initial operational capability in fiscal year 2016. Additionally, the Navy provided technical comments, which were incorporated as appropriate.

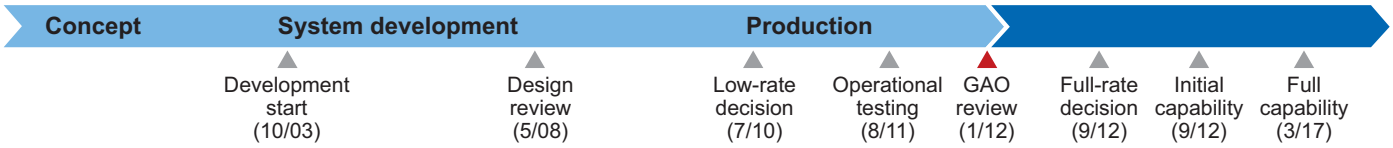
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Navy Multiband Terminal (NMT)

The Navy's NMT is a next-generation maritime military satellite communications terminal that will be installed in existing ships, submarines, and shore sites. NMT is designed to work with the Air Force's Advanced Extremely High Frequency (AEHF) satellite system to provide protected and survivable satellite communications to naval forces. Its multiband capabilities will also enable communications over existing military satellite communication systems, such as Milstar, Wideband Global SATCOM, and the Defense Satellite Communications System.



Source: © 2008 Raytheon.



Program Essentials

Prime contractor: Raytheon
Program office: San Diego, CA
Funding needed to complete:
R&D: $41.1 million
Procurement: $992.6 million
Total funding: $1,033.8 million
Procurement quantity: 189

Program Performance (fiscal year 2012 dollars in millions)

	As of 12/2006	Latest 08/2011	Percent change
Research and development cost	$697.2	$666.2	-4.4
Procurement cost	$1,623.7	$1,214.4	-25.2
Total program cost	$2,321.0	$1,880.7	-19.0
Program unit cost	$6.970	$6.186	-11.2
Total quantities	333	304	-8.7
Acquisition cycle time (months)	107	107	0.0

The NMT program entered production in July 2010 with mature critical technologies, a stable design, and production processes that had been demonstrated, but were not in control. The program will complete a manufacturing readiness assessment to demonstrate its maturity prior to its full-rate production decision, targeted for September 2012. According to the program office, the number of design changes in fiscal year 2011 was greater than anticipated as a result of test failures. The NMT program's software lines of code also increased after the Navy added a capability to support communication with the Enhanced Polar System. NMT completed initial operational test and evaluation in August 2011, and DOD's independent test organization found that the system was operationally effective, but not operationally suitable because it did not meet certain reliability requirements during the test.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment ●
- Demonstrate all critical technologies in a realistic environment ●
- Complete preliminary design review ●

Product design is stable

- Release at least 90 percent of design drawings ●
- Test a system-level integrated prototype ●

Manufacturing processes are mature

- Demonstrate critical processes are in control ○
- Demonstrate critical processes on a pilot production line ●
- Test a production-representative prototype ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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NMT Program

Technology Maturity

The NMT program's two critical technologies—a multiband antenna feed and monolithic microwave integrated circuit power amplifiers for Q-band and Ka-band communication frequencies—are mature.

Design Maturity

The NMT's design is stable and the program has released all of its expected design drawings. According to the program office, the number of design changes in fiscal year 2011 was greater than anticipated because two subassemblies were redesigned to address failures in testing. The overall effect of these changes on the program was minor. The NMT program's software lines of code have increased since the start of production because the Navy requested that the program add a capability to support communication with the Enhanced Polar System. Overall, software integration testing is over 95 percent complete with over 98 percent of the defects resolved.

Production Maturity

The NMT program office began production in July 2010 with processes that had been demonstrated on a pilot line, but were not in control. The program estimates that three of its five processes are now in statistical control. According to the program office, a production readiness review will be performed prior to the NMT's full-rate production decision, which is expected to occur in September 2012. The program will also complete a manufacturing readiness assessment to demonstrate that it is mature enough for full-rate production.

Other Program Issues

NMT completed initial operational test and evaluation in August 2011. The Navy's and DOD's independent test organizations found that NMT was operationally effective, but not operationally suitable because it did not meet certain reliability requirements. The program has identified corrective actions to address the shortfalls. As a result of the test findings, program officials stated they will extend low-rate production and delay the full-rate production decision from December 2011 to September 2012.

NMT is dependent on AEHF satellites to test its full range of capabilities. The first AEHF satellite was launched in August 2010; however, a satellite propulsion system anomaly delayed the satellite from reaching its planned orbit until October 2011. AEHF delays directly affect the ability of the NMT program to test its extended-data-rate communications capability. According to NMT program officials, risk-reduction testing was conducted using an advanced AEHF simulator; on-orbit testing was completed with Milstar satellites; and ground testing of low-, medium-, and extended-data-rate capabilities was done with the second AEHF satellite. The second AEHF satellite is expected to launch in April 2012, and follow-on operational testing, which will include on-orbit AEHF satellites, will begin in early fiscal year 2014. In the interim, program officials stated that fielded NMT systems can provide value by accessing existing satellite communication systems such as the Defense Satellite Communications System, Milstar, Wideband Global SATCOM, Interim Polar, and UFO satellite constellations. The realization of the NMT's full operational capability has been delayed 2 years to 2017 to better align with the warfighter's needs.

Program Office Comments

In commenting on a draft of this assessment, the Navy stated that the NMT program is in low-rate initial production, moving toward a full-rate production decision. The program will demonstrate the fixes for the shortfalls identified in initial operational test and evaluation through verification testing, including on operational platforms. The Navy further stated that NMT is committed to providing deployed naval commanders with assured access to secure, protected command and control and communication capabilities to support the exchange of warfighter-critical information. NMT will support the Navy's net-centric FORCEnet architecture and act as an enabler for transforming operational capability available to the warfighter. The Navy also provided technical comments, which were incorporated as appropriate.

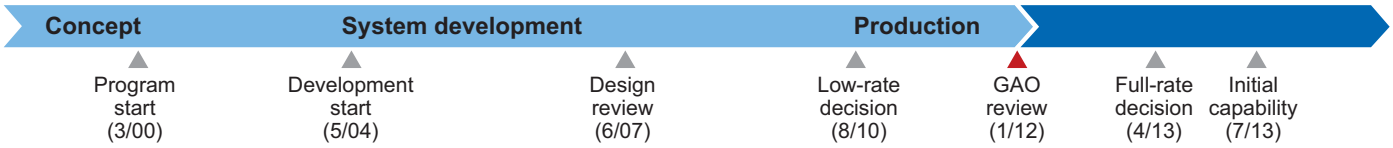
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P-8A Poseidon

The Navy's P-8A Poseidon is a Boeing commercial derivative aircraft that will replace the P-3C Orion. Its primary roles are antisubmarine warfare; antisurface warfare; and intelligence, surveillance, and reconnaissance. The P-8A is a part of a family of systems that share the integrated maritime patrol mission and support the Navy's maritime warfighting capability. The program plans to field capabilities in three increments. We assessed increment one and made observations on increment two.



Source: U.S. Navy.



Program Essentials

Prime contractor: Boeing
Program office: Patuxent River, MD
Funding needed to complete:
R&D: $1,232.4 million
Procurement: $20,087.9 million
Total funding: $21,839.0 million
Procurement quantity: 104

Program Performance (fiscal year 2012 dollars in millions)

	As of 05/2004	Latest 08/2011	Percent change
Research and development cost	$7,531.5	$8,215.3	9.1
Procurement cost	$23,365.2	$24,157.2	3.4
Total program cost	$31,034.3	$32,969.3	6.2
Program unit cost	$269.864	$270.240	0.1
Total quantities	115	122	6.1
Acquisition cycle time (months)	160	160	0.0

The P-8A entered production in August 2010 with mature technologies, a stable design, and proven production processes. The program is conducting its remaining development activities concurrently with production, which puts the program at increased risk of experiencing late and costly design changes. The number of design drawings has increased slightly in the last year to address deficiencies discovered during testing. The manufacturing processes for the P-8A airframe are proven. The processes for key aircraft subsystems have also been assessed as generally mature, although the program has experienced quality issues with some of them. The Navy has identified the execution of testing as a risk, which program officials stated has delayed the start of initial operational test and evaluation from April to June 2012. The program is taking steps to reduce this schedule pressure.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ●

Manufacturing processes are mature

- Demonstrate critical processes are in control — ●
- Demonstrate critical processes on a pilot production line — ●
- Test a production-representative prototype — ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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P-8A Program

Technology Maturity

The P-8A entered production in August 2010 with mature technologies. The current critical technology, the hydrocarbon sensor, has been tested in ground-based applications and program officials indicated that flight testing will occur in fiscal year 2012. The program also noted that it has begun flight testing the ESM digital receiver and the sonobuoy launcher, two technologies that were previously identified as being critical but are no longer designated as such based on their use in other platforms.

The P-8A program has been authorized to incorporate a set of capabilities initially planned as a separate increment into the baseline program primarily because these improvements will entail the integration of mature technologies into the aircraft.

Design Maturity

The program entered production with a stable design; however, system development efforts are continuing concurrently with production, putting the program at increased risk of late and costly design changes. The number of design drawings has increased slightly since August 2010 as a result of deficiencies discovered during testing. Program officials stated that they are still determining how to incorporate changes identified during developmental testing into the initial production aircraft, noting that the strategy will depend upon the availability of funding.

Production Maturity

The manufacturing processes for the P-8A have been proven. The program demonstrated its airframe manufacturing processes on a commercial line prior to entering into production. The manufacturing readiness levels associated with the P-8A's main subsystems indicate their processes are also generally mature, although the program has encountered quality issues with the on-board inert gas generator system and auxiliary fuel tanks, which are currently being addressed by the prime contractor. Delivery of the first production aircraft is scheduled for February 2012.

Other Program Issues

The P-8A airframe has been designated a commercial item. As a result, the contractor is not required to submit cost or pricing data to the government. Program officials stated that this designation has not affected recent contract negotiations, and the program negotiated a 10 percent lower unit cost on its second production contract. The commercial item designation has also generated concerns in the past from the Defense Contract Management Agency (DCMA) about the government's access to production facilities and its ability to conduct surveillance. However, DCMA has started reporting on aircraft quality at the Boeing commercial facility in Washington responsible for the wing, tail, aircraft assembly, and engine installation.

The operational assessment of the P-8A conducted prior to production start found that the system demonstrated the expected level of maturity, but it also identified a number of shortfalls, including sonobuoy and weapons deployment. The Director, Operational Test and Evaluation, noted that some of these shortfalls degraded mission performance, and, if not addressed, may pose a risk to the program successfully completing initial operational test and evaluation. The Navy and DCMA have also identified the execution of testing as a risk, which program officials stated has delayed the start of initial operational test and evaluation from April to June 2012. The program is focused on maintaining flight test execution rates while it pursues opportunities to reduce this schedule pressure.

Program Office Comments

In commenting on a draft of this assessment, the Navy stated that the program continues to execute its test plan in preparation for the start of initial operational test and evaluation. Testing has been an identified risk as a result of inefficiencies in execution; however, extensive corrective actions have been implemented to manage this risk. Program officials said that although the corrective actions have improved the efficiency of test execution, the program has adjusted the start of initial operational test and evaluation from April 2012 to June 2012, which is still within the program's approved baseline. In addition, the program is working to capture, correct, and test deficiencies identified in testing and manage this risk. The Navy also provided technical comments, which were incorporated as appropriate.

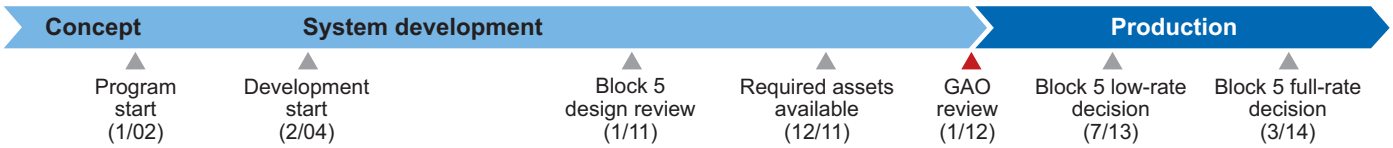
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Reaper Unmanned Aircraft System (UAS)

The Air Force's MQ-9 Reaper is a multirole, medium-to-high-altitude endurance unmanned aircraft system capable of flying at higher speeds and higher altitudes than its predecessor, the MQ-1 Predator A. The Reaper is designed to provide a ground-attack capability to find, fix, track, target, engage, and assess small ground mobile or fixed targets. Each system consists of four aircraft, a ground control station, and a satellite communications suite. We assessed the increment I block 5 configuration and made observations on block 1.



Source: U.S. Air Force.



Program Essentials

Prime contractor: General Atomics Aeronautical Systems, Inc.
Program office: Wright-Patterson AFB, OH
Funding needed to complete:
R&D: $420.5 million
Procurement: $7,962.6 million
Total funding: $8,473.5 million
Procurement quantity: 240

Program Performance (fiscal year 2012 dollars in millions)

	As of 02/2008	Latest 08/2011	Percent change
Research and development cost	$420.1	$920.3	119.1
Procurement cost	$2,111.5	$10,848.3	413.8
Total program cost	$2,637.1	$11,918.7	352.0
Program unit cost	$25.115	$29.871	18.9
Total quantities	105	399	280.0
Acquisition cycle time (months)	79	94	19.0

The block 1 Reaper is in production, but the block 5 production decision was delayed 2 years to July 2013 to allow time for the program to fully integrate and test upgrades, such as system power increases, modernized crew stations, and improvements to the primary data link. Although the Reaper's critical technologies are mature and all design drawings have been released, the block 5 is still at risk for design changes until its upgrades are integrated and tested. According to program officials, operational testing for block 5 was also delayed 1 year to November 2013. This testing will include an evaluation of the block 1's hunter and net-ready capabilities, which were not included in its initial operational testing in 2008. The user is reevaluating its requirements and strategy for managing future Reaper upgrades; the increment II program was to begin in fiscal year 2012.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ○

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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Reaper Program

Technology Maturity

The Reaper's block 1 and block 5 critical technologies are considered mature. An Air Force technology readiness assessment conducted in 2010 identified two critical technologies for the block 5 configuration—a high-capacity starter/generator and modified engine—and assessed them as mature. In addition to these critical technologies, there are other key enhancements for block 5 that are expected to improve the capability of the system, including upgrades to the radar, data link, sensor, landing gear, and ground control stations. These upgrades must still be successfully integrated and tested on the MQ-9 system. The production decision for the block 5 has been delayed by 2 years to July 2013 because of concerns about software delays and the amount of developmental and integration testing remaining.

Design Maturity

According to the program office, the Reaper design is stable and all the expected design drawings have been released; however, the block 5 is still at risk for design changes until its upgrades are integrated and tested on the MQ-9 system. The transition from block 1 to block 5 increased the number of design drawings by about 20 percent, which program officials attribute primarily to the relocation of radio antennas to the wingtips and a redesign of the avionics bay. The program office conducted a critical design review for block 5 in January 2011. Program officials expect to close all the action items, the most significant of which involves testing the aircraft's airworthiness with the relocated antennas, by early 2012.

Production Maturity

The block 1 Reaper is in production and the production processes for block 5 are approaching the level of maturity recommended for low-rate initial production. The Air Force has contracted for 117 block 1 aircraft, about 30 percent of its total requirement, and has conducted several manufacturing reviews of the contractor's facilities and determined that the production capacity is sufficient to meet the expected demand.

Other Program Issues

Since inception, the MQ-9 program has been challenged to meet the warfighter's changing needs. Quantities have increased dramatically and performance requirements continue to change. The program is currently incorporating several urgent operational requirements from the warfighter and officials expect other capabilities, such as the advanced signals intelligence payload sensor, to be added to the program. Although block 1 initial operational testing was done in 2008, problems with the radar and network prevented testers from evaluating the system's hunter and net-ready capabilities—two of its three key requirements. Testing of these capabilities was deferred until block 5 operational testing, which is currently planned for November 2013, a 1-year delay. The program also received approval to reduce or defer 12 required block 5 capabilities related to aircraft endurance, radar performance, and reliability, among other areas. According to the program office, none of these changes present a high operational risk for the system and some of them may be addressed in future upgrade efforts. According to program officials, the user is currently reevaluating its requirements and strategy for managing future Reaper upgrades. The increment II program, which included Small Diameter Bomb integration, automatic take-off and landing, deicing, and national airspace certification, was to begin in fiscal year 2012. According to program officials, the user is evaluating the feasibility of satisfying these requirements by upgrading the current configuration.

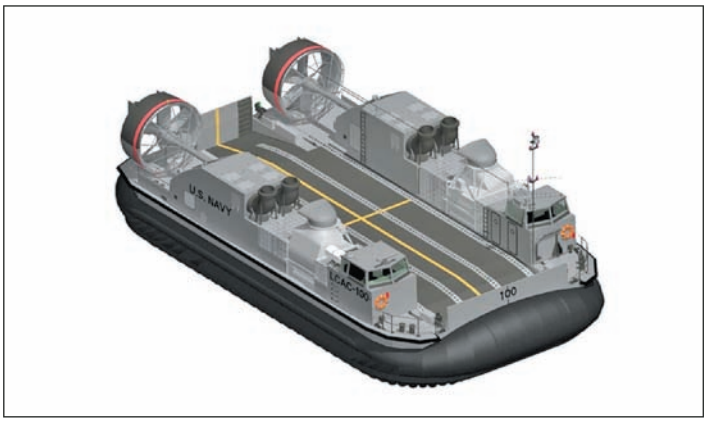
Program Office Comments

In commenting on a draft of this assessment, the Air Force stated that the program office is working to accelerate the low-rate initial production decision from July 2013 to June 2012. In order to accomplish this, the contractor has accelerated the first block 5 aircraft retrofit by 6 months and is focusing on developing software for the block 5 to allow for earlier verification. This accelerated date is also based upon tailoring of acquisition documents and schedule assumptions identified in the draft acquisition strategy that will require approval from the Office of the Secretary of Defense. The Air Force further stated that the increment II program is currently unfunded. The Air Force is reevaluating requirements and its strategy for future program upgrades.

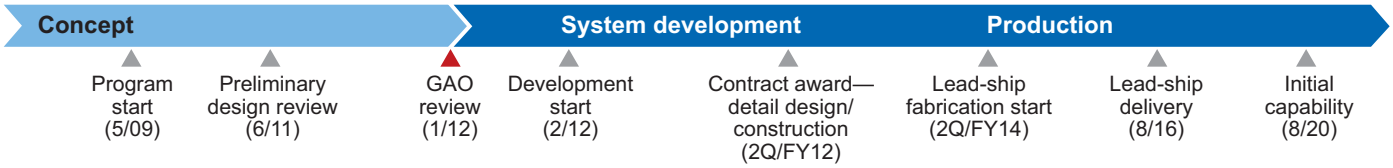
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Ship to Shore Connector (SSC)

The Navy's SSC is an air-cushioned landing craft intended to transport personnel, weapon systems, equipment, and cargo from amphibious vessels to shore. SSC is the replacement for the Landing Craft, Air Cushion (LCAC), which is approaching the end of its service life. The SSC will deploy in Navy well deck amphibious ships, such as the LPD 17 class, and will be used for assault and nonassault operations. It is expected to operate independent of tides, water depth, underwater obstacles, ice, mud, or beach conditions.



Source: U.S. Navy.



Program Essentials

Prime contractor: TBD
Program office: Washington, DC
Funding needed to complete:
R&D: TBD
Procurement: TBD
Total funding: TBD
Procurement quantity: 72

Program Performance (fiscal year 2012 dollars in millions)

	As of	Latest 08/2011	Percent change
Research and development cost	NA	$442.7	NA
Procurement cost	NA	$3,947.6	NA
Total program cost	NA	$4,412.9	NA
Program unit cost	NA	$60.451	NA
Total quantities	NA	73	NA
Acquisition cycle time (months)	NA	135	NA

The SSC program has attained the level of knowledge about technology and design requirements needed to support the award of a detail design and construction contract for the lead craft, which is planned for the second quarter of fiscal year 2012. A 2010 technology readiness assessment found the program's one critical technology to be mature, and designated two technologies as watch items until a contractor selects the actual technologies to be used. According to the program office, the SSC is the first Navy-led ship design in 15 years and the Navy plans to provide two-dimensional extracted drawings from the design model to the contractor, who will then complete the design to prepare for production. The SSC is also being designed for affordability and the Navy has identified several performance tradeoffs to lower costs.

Attainment of Product Knowledge

Projected as of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable

- *Complete three-dimensional product model*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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SSC Program

Technology Maturity

The SSC program expects to award a detail design and construction contract in the second quarter of fiscal year 2012 with its one critical technology—the fire suppression system—mature. A 2010 technology readiness assessment by the Navy found this technology to be mature because the system had been extensively tested in an LCAC engine module modified to have similar characteristics to the SSC. In addition, the canisters that are part of the fire suppression system are commercially used and will not be modified for use on the SSC. Based on the technology readiness assessment, the Navy also decided that several other technologies should not be considered critical. For example, program officials stated the assessment did not identify the composite shaft as a critical technology because the composite material is already used on a Littoral Combat Ship. Other items, such as the gas turbine and the command, control, communications, computer, and navigation system were not designated critical because mature systems that meet all SSC requirements are available. However, these two technologies will remain on a watch list until the contractor selects the actual technologies to be used. According to program officials, there is a reasonable chance that the contractor could propose new technologies that require additional development if they have the potential to reduce cost.

Design Maturity

The Navy plans to stabilize the SSC design before the start of construction. According to program officials, after award of the detail design and construction contract, the Navy will provide two-dimensional extracted drawings from the design model to the contractor who will then complete the design of the craft for production. The Navy's request for proposal for detail design and construction requires the contractor to hold a production readiness review before the start of construction to demonstrate design maturity. Specifically, the contractor must demonstrate that both the functional design is 100 percent complete and the detailed production work packages are at least 95 percent complete before production start.

Other Program Issues

According to the program office, the SSC is the first Navy-led ship design in 15 years. The goal of the Navy-led design was to improve the capacity and maintainability of the SSC compared to the legacy LCAC, while reducing costs. To assist with this goal, the Navy conducted an analysis of the LCAC which focused on reducing total ownership cost while maintaining certain essential capabilities such as speed. Through this analysis, the Navy identified several performance trades. For example, the Navy identified a change to the cargo deck width which will allow for the use of nondevelopmental engines; this change is expected to lower life-cycle costs. The SSC is also expected to have greater lift, a lower fuel consumption rate, and less expected maintenance than the LCAC.

The Navy is conducting a full and open competition for the SSC detail design and construction contract. The Navy plans to award a fixed-price incentive contract for the detail design and construction of the lead craft, which is expected to be delivered by August 2016. The lead craft will be for testing and training and the contract is expected to have options for eight additional SSCs.

Program Office Comments

In commenting on a draft of this assessment, the Navy stated that the SSC is a technically mature, low risk program poised for successful entry into system development, program initiation, and detail design and lead craft construction contract award. The Navy also provided technical comments, which were incorporated as appropriate.

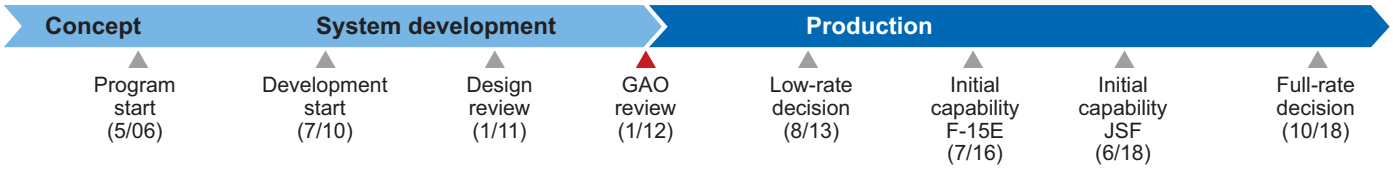
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Small Diameter Bomb (SDB) Increment II

The Air Force's Small Diameter Bomb (SDB) Increment II is planned to provide attack capability against mobile targets in adverse weather from standoff range. It combines radar, infrared, and semiactive laser sensors in a multi-mode seeker to acquire, track, and engage targets. It uses airborne and ground data links to update target locations as well as GPS and an inertial navigation system to ensure accuracy. SDB II will be integrated with F-15E, Navy and Marine Corps' Joint Strike Fighter (JSF), and other aircraft, such as the F-22A.



Source: © 2009 Raytheon Company.



Program Essentials

Prime contractor: Raytheon
Program office: Eglin AFB, FL
Funding needed to complete:
R&D: $850.1 million
Procurement: $3,053.1 million
Total funding: $3,903.2 million
Procurement quantity: 17,000

Program Performance (fiscal year 2012 dollars in millions)

	As of 10/2010	Latest 08/2011	Percent change
Research and development cost	$1,644.8	$1,642.5	-0.1
Procurement cost	$3,057.3	$3,053.1	-0.1
Total program cost	$4,702.1	$4,695.6	-0.1
Program unit cost	$.274	$.274	-0.1
Total quantities	17,163	17,163	0.0
Acquisition cycle time (months)	72	72	0.0

The SDB II program completed its critical design review in January 2011 with a stable design, but without fully maturing its critical technologies or demonstrating that the design can perform as expected. As a result, the risk of design changes remains. A postdesign review identified several risks related to weapon effectiveness verification, target classification, seeker reliability, and JSF integration. The program office is working to address each of these risks and plans to begin evaluating the reliability and performance of the weapon through flight testing in March 2012. However, the program's biggest risk—integration with the JSF—will not be resolved until after production begins. The program faces a shortfall in funding, and program officials are considering modifying the fixed-price incentive contract or the current scope of work to align with the funding profile.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ○

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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SDB II Program

Technology Maturity

The SDB II program entered system development in July 2010 with all four of its critical technologies—the target classifier, multimode seeker, net-ready data link, and payload (warhead/fuze)—nearing maturity. Although the program has completed its critical design review, it is just beginning to further demonstrate these technologies through subsystem testing. According to the program office, subsystem testing is progressing well. Prototype testing is scheduled to begin in February 2012 and will demonstrate the weapon's ability to interface with the required aircraft and the seeker's performance.

Design Maturity

The SDB II design is currently stable, but it has not been demonstrated using a prototype to show that it will perform as expected. The risk of design changes will remain until the design shows it can meet requirements and other risks are addressed. The program completed its critical design review in January 2011 with 97 percent of its design drawings releasable. A postdesign review identified several risks related to weapon effectiveness verification, target classification, seeker reliability, and integration with the JSF. The program office is working to address each of these risks. In addition, the SDB II is scheduled to begin flight testing on the F-15E in March 2012; according to the program office, these tests will help to increase its confidence in the reliability and performance of the weapon. The SDB II program plans to conduct 11 free-flight test events prior to obtaining approval to begin production, which is currently scheduled to occur in August 2013.

According to the postdesign review and program officials, the top risk for the SDB II program is integration of the weapon with the JSF. The SDB II, which is carried in the JSF's internal weapons bay, was designed to operate in the environment specified in JSF design documents. However, the weapons bay environment has not been validated through testing. If the JSF cannot meet its design specifications, then the SDB II program may not meet its requirements for weapon effectiveness or availability on that aircraft; it might also have to consider design changes. This issue will not be resolved prior to the SDB II's planned August 2013 production decision and could affect the program's full-rate production in 2018. SDB II integration on the JSF is planned to begin in fiscal year 2015 and operational testing is planned for 2017.

Production Maturity

The SDB II program plans to take several steps to demonstrate the maturity of its manufacturing processes prior to beginning production. The program will demonstrate its critical manufacturing processes on a pilot production line and demonstrate that the system will work as intended in a reliable manner by testing a fully configured production-representative prototype.

Other Program Issues

The SDB II program office is managing a $53 million funding shortfall in fiscal year 2011, which could have programmatic and contractual implications. The SDB II contract is an incrementally funded, fixed-price incentive contract, and program officials stated that the funding shortfall could mean that the next part of the work will have to be deferred or the contract will need to be renegotiated or terminated.

Program Office Comments

In commenting on a draft of this assessment, the Air Force and Navy provided technical comments, which were incorporated as appropriate.

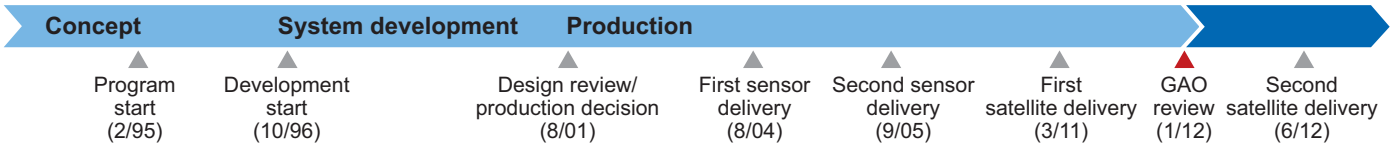
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Space Based Infrared System (SBIRS) High Program

The Air Force's SBIRS High satellite system is being developed to replace the Defense Support Program and perform a range of missile warning, missile defense, technical intelligence, and battlespace awareness missions. SBIRS High will consist of four satellites in geosynchronous earth orbit (GEO), two sensors on host satellites in highly elliptical orbit (HEO), two replenishment satellites and sensors, and fixed and mobile ground stations. We assessed the space segment and made observations about the ground segment.



Source: © 2007 Lockheed Martin Corporation.



Program Essentials

Prime contractor: Lockheed Martin
Program office: El Segundo, CA
Funding needed to complete:
R&D: $2,131.3 million
Procurement: $3,599.4 million
Total funding: $5,743.9 million
Procurement quantity: 2

Program Performance (fiscal year 2012 dollars in millions)

	As of 10/1996	Latest 07/2011	Percent change
Research and development cost	$4,376.3	$11,586.3	164.7
Procurement cost	$0.0	$6,429.3	NA
Total program cost	$4,596.5	$18,266.7	297.4
Program unit cost	$919.301	$3,044.443	231.2
Total quantities	5	6	20.0
Acquisition cycle time (months)	86	TBD	NA

The 1996 data show no procurement cost as the Air Force planned to use research and development funds to buy all five satellites. The cost of the two HEO replenishment sensors is not included in either column.

The first SBIRS satellite was launched in May 2011—roughly 9 years later than planned—however, it lacks some key capabilities. The satellite was launched without a fully developed ground system or the flight software needed to automatically recover if an unforeseen failure occurs. According to program officials, the ground system will not be able to meet all of its operational requirements until at least 2018. The satellite recovery software will be uploaded to the satellite on-orbit once it is complete, expected in August 2012. The first satellite has begun on-orbit testing, but its planned operational certification in late 2012 will likely be delayed to early 2013. The program expects the cost of the third and fourth satellites to grow significantly. A new program baseline, which includes revised cost estimates and satellite and ground system delivery milestones, awaits DOD approval.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- *Demonstrate all critical technologies in a realistic environment*
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- Demonstrate critical processes are in control — ▪▪▪▪
- Demonstrate critical processes on a pilot production line — ○
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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SBIRS High Program

Technology, Design, and Production Maturity

According to the SBIRS program office, the system's critical technologies are mature, its design is stable, and its manufacturing processes have been proven; however, the program continues to experience quality problems that have required rework on the first two satellites. Functional testing on the first satellite in 2009 revealed solder fractures on some hardware components and testing on the second satellite in 2011 has uncovered anomalies and erratic performance on similar components. In both cases, some rework has been required to the satellites; however, program officials do not expect that these issues will result in significant cost growth or schedule delays. System-level testing on the second satellite has begun and the program expects it to be delivered in June 2012. Its launch date has yet to be determined.

The SBIRS program plans to make slight changes to the design of its two HEO replenishment sensors, addressing parts obsolescence and electromagnetic interference issues that affected the operation of its first two sensors. Replenishment sensors are scheduled for delivery and integration onto host satellites in fiscal years 2012 and 2015.

Other Program Issues

The first GEO satellite, and likely second, will be launched and operating on-orbit before the program can fully leverage the satellites' capabilities. The SBIRS program opted to launch the first GEO satellite in May 2011 before the ground system, which processes data from the satellite's infrared sensors, was fully developed. According to the program office, it did so to provide some capability to users sooner. Ground system development has proved more difficult than anticipated and officials say the system will not be able to fully meet its operational requirements until at least 2018. In the meantime, ground system capabilities will be fielded incrementally. According to the Defense Contract Management Agency, the flight software development effort is still experiencing challenges and delays. The first satellite was launched without all of the planned flight software functionality, including, for example, a capability that allows the satellite to automatically recover without ground intervention from a "fault-mode" in the event of an unforeseen failure. The program intends to upload this software to the first satellite on-orbit after it completes development. According to the Defense Contract Management Agency, on-orbit check out activities, for example, system-level testing and calibration, are currently 6 weeks behind schedule, which could delay the operational certification of the first satellite, planned for late 2012.

According to the SBIRS program, production of the third and fourth satellites may experience significant cost growth and schedule delays due to development challenges, test failures, and technical issues. The Air Force is projecting a cost overrun of $438 million and 1-year delay for these two satellites. The program plans to award a sole-source contract to the same prime contractor to build the fifth and sixth satellites. The SBIRS program has revised its acquisition program baseline, which will include revised cost estimates and new satellite and ground system delivery milestones, but DOD has yet to approve it.

Program Office Comments

In commenting on a draft of this assessment, the program office stated that the first satellite launched with all the software needed to support vehicle health and safety. Sensors on the first satellite are collecting higher-quality data than expected. The satellite is moving to its operational location, and officials expect trial operations to last from November 2012 to January 2013. The follow-on production contract is delivering flight hardware, but is experiencing cost and schedule pressure due to parts obsolescence and technical issues. Officials attribute this to an 8-year production gap between the first two satellites and the third and fourth. The revised acquisition program baseline is final as of January 2012. The acquisition strategy for the fifth and sixth satellites is pending, and the program is seeking approval to release requests for proposals and contract awards. The program office also provided technical comments, which were incorporated as appropriate.

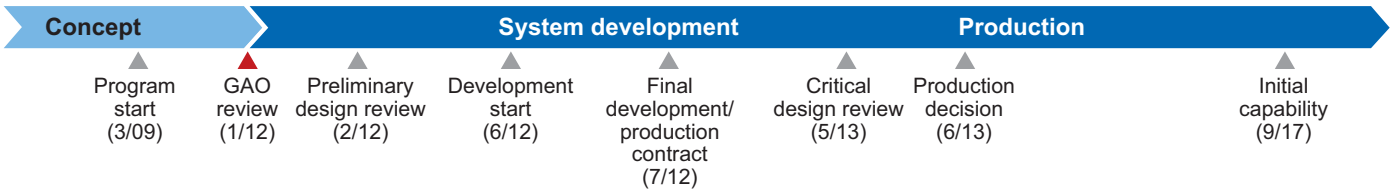
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Space Fence

The Air Force's Space Fence will be a new system of large ground-based radars that replaces the Air Force's aging Space Surveillance System. It will use higher radio frequencies to detect and track smaller Earth-orbiting objects. The system will consist of two geographically dispersed radars to help ensure effective space surveillance coverage for low inclinations. The system's enhanced capabilities are expected to significantly increase the number of orbiting objects detected and tracked.



Source: U.S. Air Force.



Program Essentials

Prime contractor: Lockheed Martin, Raytheon
Program office: Hanscom AFB, MA
Funding needed to complete:
R&D: TBD
Procurement: TBD
Total funding: TBD
Procurement quantity: 1

Program Performance (fiscal year 2012 dollars in millions)

	As of	Latest 08/2011	Percent change
Research and development cost	NA	TBD	NA
Procurement cost	NA	TBD	NA
Total program cost	NA	TBD	NA
Program unit cost	NA	TBD	NA
Total quantities	NA	2	NA
Acquisition cycle time (months)	NA	103	NA

In May 2010, the program office estimated the Space Fence's total cost would be over $3 billion; an updated estimate has not been provided.

The Space Fence program office expects to have gained key knowledge about its technology and requirements before it enters system development in June 2012. Its four critical technologies are nearing maturity and it will hold a preliminary design review prior to development start. The current technology development phase involves multiple contractors and competitive prototyping demonstrations. The program plans to award a single contract for system development and production in July 2012. The first Space Fence radar site is scheduled to provide an initial operational capability by the end of fiscal year 2017—2 years later than originally planned—and the Air Force will be required to support the existing surveillance system longer than anticipated. A new data-processing system is also being developed by a separate program to accommodate the increased volume of data from Space Fence.

Attainment of Product Knowledge

Projected as of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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Space Fence Program

Technology Maturity

The Space Fence program expects its four critical technologies to be nearing maturity before it enters system development in June 2012. The technologies include a software algorithm for estimating orbits and several radar technologies—a high-efficiency power amplifier; low-cost distributed receiver; and scalable digital beam former that allows antennas to work in concert to create sufficient power to conduct the space surveillance and tracking mission. Mature backup technologies that have potentially higher acquisition or operating costs also exist, but program officials do not believe they will be needed. According to the program, the Space Fence will be one of the largest phased array radars ever built, and the key risks are related to its size and the integration of technology components into a viable system at an affordable cost. According to the program office, its technology development efforts, which involve multiple contractors, will allow the program to thoroughly examine the contractors' designs and their associated costs, while reducing technical risk and improving confidence in the producibility of the key technologies and components.

Other Program Issues

The Space Fence program maintained competition through technology development and plans to competitively award a single contract for system development and production. In June 2009, the Air Force competitively awarded three $30 million firm fixed-price contracts to begin technology development, one of which was subsequently terminated after a reduction in program funding. After a full and open competition, the two other contractors were each awarded another contract in January 2011, for a maximum of $214 million, to continue technology development. The Space Fence program plans to conduct a full and open competition and award a single contract for system development and production in July 2012. According to the program office, the release of the request for proposal for this contract has been delayed from December 2011 to April 2012 because DOD now requires a program review to be held before its release. However, the program office believes the contract can still be awarded on schedule. The program office plans to award a firm fixed-price contract for system development activities through the planned May 2013 critical design review, with options for all subsequent efforts, including radar production.

The first Space Fence radar site is scheduled to provide initial operational capability by the end of fiscal year 2017—2 years later than planned—because current program funding levels do not support an earlier date. As a result, the Air Force will be required to support the existing surveillance system longer than anticipated. It is currently assessing ways to keep the system in operation until the Space Fence is ready. The second Space Fence site will provide a full operational capability by 2020.

A new data-processing capability is being developed by a separate program to accommodate the increased volume of data from Space Fence. According to the Space Fence program office, this program is currently being restructured and should be fielded in time to support Space Fence.

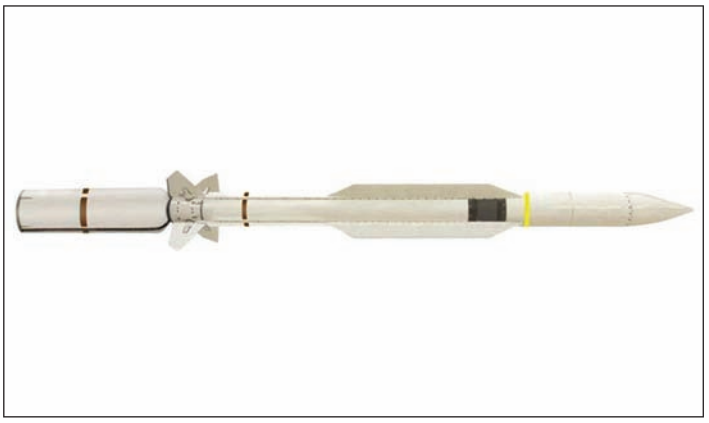
Program Office Comments

In commenting on this draft, the program office noted that it generally concurred with our assessment. The program noted that a technology readiness assessment is ongoing and the Space Fence preliminary design review is on schedule to be completed by the end of February 2012. The program also provided technical comments, which were incorporated as appropriate.

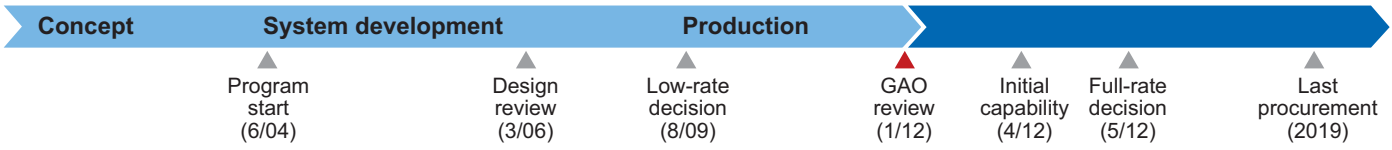
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Standard Missile-6 (SM-6) Extended Range Active Missile (ERAM)

The Navy's Standard Missile-6 (SM-6) is a surface-to-air missile launched from Aegis ships. It is designed to provide ship self-defense, fleet defense, and theater air defense against aircraft, ships, and missiles at various altitudes over land and sea. It will provide an over-the-horizon engagement capability and improved capabilities at extended ranges by combining legacy Standard Missile and Advanced Medium-Range Air-to-Air Missile (AMRAAM) technology. We assessed SM-6 block 1. Follow-on blocks will be developed to meet future threats.



Source: Raytheon Missile Systems.



Program Essentials

Prime contractor: Raytheon Missile Systems
Program office: Arlington, VA
Funding needed to complete:
R&D: $7.6 million
Procurement: $4,808.9 million
Total funding: $4,816.6 million
Procurement quantity: 1,111

Program Performance (fiscal year 2012 dollars in millions)

	As of 07/2004	Latest 12/2010	Percent change
Research and development cost	$1,073.8	$973.5	-9.3
Procurement cost	$4,626.4	$5,323.2	15.1
Total program cost	$5,700.2	$6,296.7	10.5
Program unit cost	$4.750	$5.247	10.5
Total quantities	1,200	1,200	0.0
Acquisition cycle time (months)	75	94	25.3

The SM-6's highly concurrent testing and production strategy puts the program at increased risk of cost growth and schedule delays. The program has 89 missiles under contract, but it has not yet demonstrated that its manufacturing processes are in control or the missile is reliable, suitable, and effective in its operational environment. The program has experienced numerous developmental and operational test failures. Program officials stated that root causes have been identified and corrective actions will be addressed during follow-on testing. The program plans to request approval to enter full-rate production in May 2012; and the Under Secretary of Defense for Acquisition, Technology and Logistics will have to determine whether additional flight testing is needed, or if the current risks on the program will continue to be carried forward into full-rate production.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ●

Manufacturing processes are mature

- Demonstrate critical processes are in control — ○
- Demonstrate critical processes on a pilot production line — ●
- Test a production-representative prototype — ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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SM-6 Program

Technology and Design Maturity

According to the program office, all SM-6 critical technologies are mature and its design is stable; however, the program is still at risk of late design changes because of repeated test failures. The program obtained approval to conduct limited developmental testing because the risk of integrating the legacy AMRAAM missile seeker with the Standard Missile was perceived to be low. However, over half of the SM-6's at-sea developmental flight tests experienced anomalies or resulted in failure with multiple issues attributed to these legacy components. A May 2011 operational test readiness assessment concluded that the program faced a high risk of failure in operational testing and recommended additional developmental testing. The program proceeded with operational testing in June 2011 and the missile failed 5 of 12 tests. According to program officials, all failures have had root causes discovered, and corrective actions will be verified during follow-on operational testing, which is scheduled to occur after the program's planned May 2012 full-rate production decision. The Navy's operational test organization plans to issue its assessment of operational testing by April 2012 to support the full-rate production review.

Production Maturity

The SM-6 program has proven out its production processes, but has not yet demonstrated that its critical processes are in control or that the missiles being produced perform reliably. According to the program, the sample size needed for measuring process control will not be achieved until 2014.

Other Program Issues

The SM-6's highly concurrent testing and production strategy puts the program at increased risk of cost growth and schedule delays. The program has made a significant investment before demonstrating that the design meets performance requirements and that the missile is reliable, suitable, and effective in its operational environment. In 2009, the program obtained approval from the Under Secretary of Defense for Acquisition, Technology and Logistics to begin low-rate production of up to 19 missiles before completing developmental testing. To minimize risks, the Under Secretary required the program to complete developmental testing and obtain approval prior to awarding additional contracts. The Under Secretary subsequently approved the award of two additional low-rate production contracts before this testing was complete. After numerous developmental test failures, the program carried a significant level of risk into operational testing where the high failure rate continued. The program plans to seek approval for full-rate production in May 2012 and to award a full-rate production contract with options through fiscal year 2016. The Under Secretary will have to determine whether additional flight testing is needed, or if the risks on the program will continue to be carried forward into full-rate production. Further, multiple SM-6 capabilities will not be tested until full-rate production is well underway. According to officials, the program plans to have 387 of 1,200 missiles under contract by the end of fiscal year 2014. This is before the SM-6 will be tested with the Naval Integrated Fire Control–Counter Air System, which enables its over-the-horizon capabilities.

Program Office Comments

In commenting on a draft of this assessment, the Navy disagreed with our assertions that the program is at risk of design changes because of repeated test failures; that the program has not demonstrated that its critical processes are in control and that the missile meets performance requirements; and that multiple capabilities will not be tested until full-rate production is well underway. According to program officials, the missile design is mature and stable, and all flight failures and anomalies are understood with corrective actions in place or in progress. The program office also provided technical comments, which were incorporated as appropriate.

GAO Response

According to program officials, the SM-6 design is stable; however, the program has not yet demonstrated that the system is reliable, suitable, and effective in its operational environment. Our reviews of DOD weapon systems confirm that production costs are minimized when a fully integrated, capable prototype is demonstrated to show that the system will work as intended in a reliable manner.

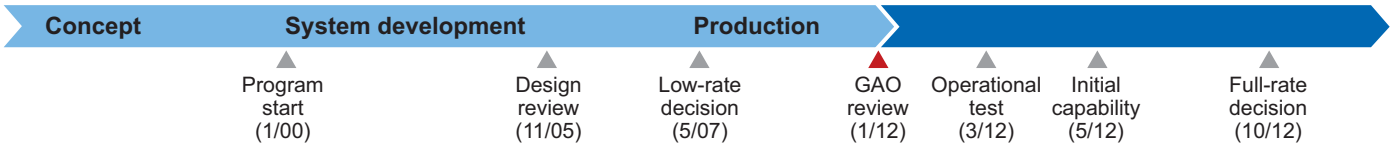
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Vertical Take-off and Landing Tactical Unmanned Aerial Vehicle (VTUAV)

The Navy's VTUAV is intended to provide real-time imagery and data in support of intelligence, surveillance, and reconnaissance missions. A VTUAV system is composed of up to three air vehicles with associated sensors, two ground control stations, one recovery system, and spares and support equipment. The air vehicle is launched and recovered vertically, and operates from ships and land. The VTUAV is being designed as a modular, reconfigurable system that supports various operations, including surface, antisubmarine, and mine warfare.



Source: Northrop Grumman.



Program Essentials

Prime contractor: Northrop Grumman
Program office: Patuxent River, MD
Funding needed to complete:
- R&D: $16.2 million
- Procurement: $1,582.8 million
- Total funding: $1,599.0 million
- Procurement quantity: 145

Program Performance (fiscal year 2012 dollars in millions)

	As of 12/2006	Latest 09/2011	Percent change
Research and development cost	$598.0	$682.1	14.1
Procurement cost	$1,682.6	$1,933.2	14.9
Total program cost	$2,615.4	$2,615.4	0.0
Program unit cost	$14.776	$14.945	1.1
Total quantities	177	175	-1.1
Acquisition cycle time (months)	104	148	42.3

The VTUAV program continues to experience delays as a result of issues identified during testing. According to the program, it has made hardware and software changes to address the issues and improve the reliability, maintainability, and availability of the air vehicle and ground control station. The program has delayed the planned start of operational testing to March 2012 and could have difficulty demonstrating certain aspects of the system's effectiveness and suitability. DOD's independent test organization and military commanders have stated that the system provides a valuable capability, but the test organization has expressed concerns about data link reliability and launch delays. The program is planning several aircraft upgrades, including a multimode maritime radar, forward-firing weapon, and larger airframe to improve endurance, payload, and carrying capacity.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match
- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable
- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ●

Manufacturing processes are mature
- Demonstrate critical processes are in control — ▪▪▪▪
- Demonstrate critical processes on a pilot production line — ●
- Test a production-representative prototype — ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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VTUAV Program

Technology Maturity

The VTUAV program did not identify any critical technologies. According to the program office, it relies on common, mature technologies.

Design Maturity

The VTUAV design appears stable and the program has released all its expected drawings; however, the program has made a number of software and hardware changes to correct issues identified in developmental testing. According to the program, the main issues in testing were related to the reliability, maintainability, and availability of the air vehicle and the control station. Several critical components experienced unanticipated failures, but were corrected with software or hardware improvements. As a result of the problems highlighted during developmental testing, the VTUAV program delayed the planned start of operational test and evaluation until March 2012. The program plans to reach initial operational capability in May 2012 and enter full-rate production in October 2012—more than 2 years later than planned.

Production Maturity

The VTUAV program's production processes have been demonstrated, but we could not assess whether its critical processes are in control. The program does not collect data on statistical process controls or assess process capabilities using manufacturing readiness levels. As of fiscal year 2011, the program planned to convert eight Army aircraft bought under the Future Combat Systems into Navy VTUAV aircraft.

Other Program Issues

The VTUAV program may have difficulty demonstrating its effectiveness and suitability in operational testing. An early fielding report by the Director, Operational Test and Evaluation, concluded that the VTUAV can be a valuable intelligence-gathering asset, but forces should not depend on it to provide time-sensitive support to ground forces because of the fragile nature of the data link and frequent launch delays. According to the report, a primary reason for these delays is multiple ground control station configurations, which makes it difficult for the program to identify and correct the root causes of problems and replicate failure modes to assist the operator in troubleshooting issues. According to the program office, the VTUAV's deployments aboard the USS *Halyburton* and in Afghanistan have demonstrated the military utility of the system, and the operational commands in Afghanistan have requested doubling the VTUAV capability there. The Navy recently lost a VTUAV aircraft in Libya due to enemy actions.

The VTUAV program is planning several upgrades of the system. For example, the program is planning to acquire a multimode maritime radar and forward-firing weapon for installation on the aircraft using a rapid acquisition process that enables the capabilities to be delivered to the warfighter quickly. Both capabilities will be acquired as a part of the current program and will undergo a formal quick-reaction assessment in fiscal year 2013 prior to their planned deployment. In addition, the program plans to buy 28 upgraded aircraft with a larger airframe to improve endurance, payload, and future carrying capacity.

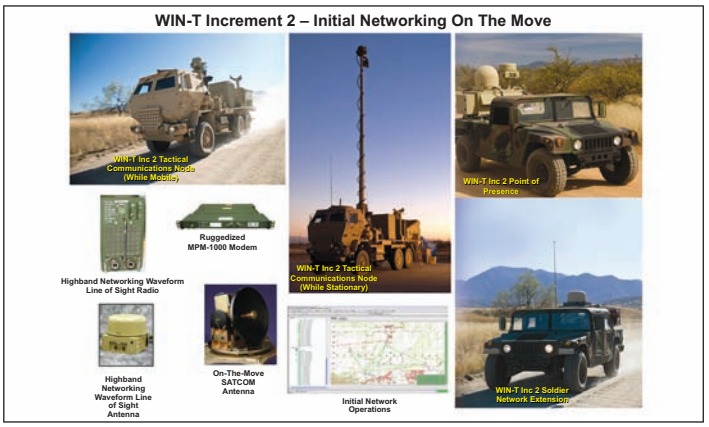
Program Office Comments

The program office concurred with this assessment.

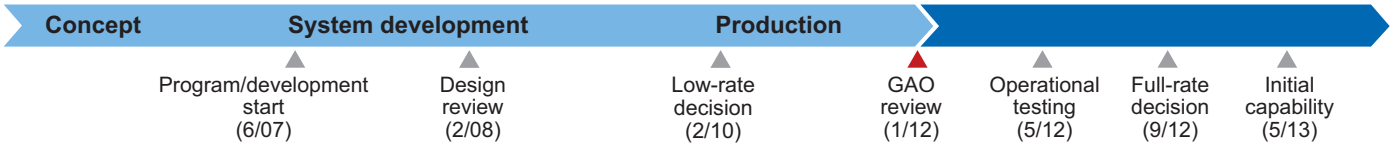
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Warfighter Information Network-Tactical (WIN-T) Increment 2

WIN-T is the Army's high-speed and high-capacity backbone communications network. WIN-T connects Army units with higher levels of command and provides the Army's tactical portion of the Global Information Grid. WIN-T was restructured following a March 2007 Nunn-McCurdy unit-cost breach of the critical threshold, and will be fielded in four increments. The second increment will provide the Army with an initial networking on-the-move capability.



Source: U.S. Army.



Program Essentials

Prime contractor: General Dynamics C4 Systems, Inc.
Program office: Aberdeen Proving Ground, MD
Funding needed to complete:
R&D: $29.3 million
Procurement: $4,803.2 million
Total funding: $4,832.5 million
Procurement quantity: 2,390

Program Performance (fiscal year 2012 dollars in millions)

	As of 10/2007	Latest 12/2010	Percent change
Research and development cost	$238.6	$279.2	17.0
Procurement cost	$3,469.8	$5,773.5	66.4
Total program cost	$3,708.4	$6,052.7	63.2
Program unit cost	$1.959	$2.127	8.6
Total quantities	1,893	2,846	50.3
Acquisition cycle time (months)	50	71	42.0

The WIN-T Increment 2 entered production in February 2010 with mature critical technologies, a stable design, and production processes that had been demonstrated, but were not in control. The program's assessment of its manufacturing readiness level indicates that it has not yet demonstrated the capability recommended by DOD guidance to begin full-rate production, which is currently planned for September 2012. The program has been working to address performance and reliability shortfalls revealed in a March 2009 limited user test. According to the program office, production qualification testing has been successful, and the program believes it will demonstrate the required performance and reliability during initial operational testing, which is scheduled to begin in May 2012.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match	
• Demonstrate all critical technologies in a relevant environment	●
• Demonstrate all critical technologies in a realistic environment	●
• Complete preliminary design review	●
Product design is stable	
• Release at least 90 percent of design drawings	▪▪▪▪
• Test a system-level integrated prototype	●
Manufacturing processes are mature	
• Demonstrate critical processes are in control	○
• Demonstrate critical processes on a pilot production line	●
• Test a production-representative prototype	●

● Knowledge attained ▪▪▪▪ Information not available
○ Knowledge not attained *Not applicable*

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WIN-T Increment 2 Program

Technology Maturity

All 15 WIN-T Increment 2 critical technologies were mature by its February 2010 production decision. In November 2009, the Director, Defense Research and Engineering, concurred with an independent review team's assessment of the program, noting that tests conducted by the Army show that each of WIN-T Increment 2's critical technologies have been demonstrated in a realistic environment.

Design Maturity

According to the WIN-T program, it has integrated and tested its key technologies and subsystems, which demonstrates that the system's design is capable of working as intended. The program office does not track the other metric we use to measure design maturity—the number of releasable drawings—because WIN-T is primarily an information technology integration effort. Instead, design performance is measured through a series of component, subsystem, configuration item, and network-level test events designed to demonstrate performance at increasing levels of system integration, and design stability is measured through problem-tracking report trends.

Production Maturity

The WIN-T program began production in February 2010 with manufacturing processes that had been demonstrated on a pilot production line, but were not in control. The program's assessment of its manufacturing readiness level does not indicate that its production processes are in statistical control or that the program has demonstrated that the capability recommended by DOD guidance is in place to begin full-rate production, which is currently planned for September 2012. According to the WIN-T program, it uses commercially available products and does not have any critical manufacturing processes.

Other Program Issues

According to the WIN-T program, it has addressed the deficiencies identified in its March 2009 limited user test and is prepared to begin initial operational testing on schedule in May 2012. During the limited user test, WIN-T Increment 2 failed to demonstrate the ability to support mobile operations as well as the required capabilities in forested terrain. WIN-T Increment 2 operational effectiveness was degraded because the program's concept of operations, organizational structure, and manning were not adequate to operate and troubleshoot the network. Further, the test concluded that the WIN-T Increment 2 did not meet its operational reliability requirements because three critical components demonstrated poor reliability. After this test, DOD's Director, Operational Test and Evaluation, recommended that the Army improve the performance of the Increment 2 waveforms, provide greater training to soldiers, refine its tactics and manning levels for Increment 2, and aggressively pursue a reliability growth program for WIN-T Increment 2 components to ensure its success in initial operational testing. According to the program office, production qualification testing conducted by the contractor in early 2011 indicated that the system is on target to meet its minimum performance requirements. Reliability issues were identified during that testing, but the program believes that each of the program's configuration items is meeting its reliability growth target, and that the program will demonstrate required performance and reliability during upcoming initial operational testing.

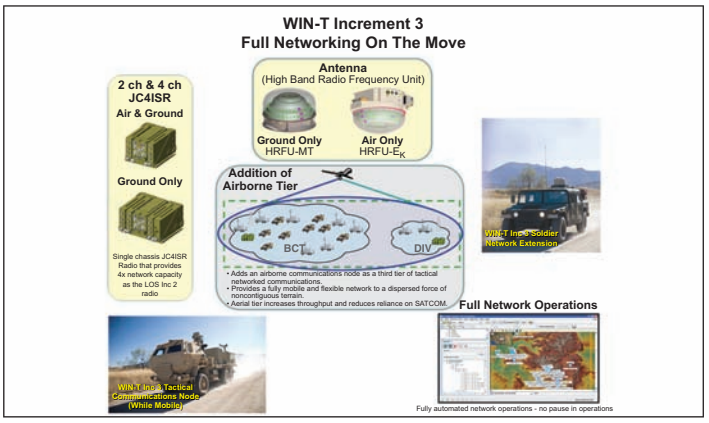
Program Office Comments

In commenting on a draft of this assessment, the Army provided technical comments, which were incorporated as appropriate.

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Warfighter Information Network-Tactical (WIN-T) Increment 3

WIN-T is the Army's high-speed and high-capacity backbone communications network. WIN-T connects Army units with higher levels of command and provides the Army's tactical portion of the Global Information Grid. WIN-T was restructured following a March 2007 Nunn-McCurdy unit-cost breach of the critical threshold, and will be fielded in four increments. The third increment will provide the Army a full networking on-the-move capability.



Source: U.S. Army.



Program Essentials

Prime contractor: General Dynamics C4 Systems, Inc.
Program office: Aberdeen Proving Ground, MD
Funding needed to complete:
R&D: $890.3 million
Procurement: $11,649.1 million
Total funding: $12,539.4 million
Procurement quantity: 3,168

Program Performance (fiscal year 2012 dollars in millions)

	As of 05/2009	Latest 12/2010	Percent change
Research and development cost	$2,687.4	$2,222.3	-17.3
Procurement cost	$13,680.3	$11,649.1	-14.8
Total program cost	$16,367.7	$13,871.4	-15.3
Program unit cost	$4.701	$4.325	-8.0
Total quantities	3,482	3,207	-7.9
Acquisition cycle time (months)	165	187	13.3

The WIN-T Increment 3 program will not demonstrate the maturity of all its critical technologies until its planned April 2015 production decision. Three of the program's 20 critical technologies are currently mature and 15 are nearing maturity. Of the two remaining technologies, one was rated as nearing maturity by an independent review team; but in 2009, the Director, Defense Research and Engineering, concluded that the technology's ambiguous requirements made it difficult to state whether it had been adequately demonstrated. The Army has since revisited its requirements. According to the Army, the other technology—a cryptographic device—will be demonstrated by its system-level design review. The WIN-T Increment 3 schedule is likely to be negatively affected by an almost 40 percent reduction in planned funding for fiscal year 2012.

Attainment of Product Knowledge

As of January 2012

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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WIN-T Increment 3 Program

Technology Maturity

The WIN-T Increment 3 program will not demonstrate the maturity of all of its critical technologies in a realistic environment until its planned April 2015 production decision. An April 2009 review of the Army's technology readiness assessment for WIN-T Increment 3 by the Director, Defense Research and Engineering (DDR&E), concluded that, of the program's 20 critical technologies, 3 were mature, 15 were nearing maturity, and 2—the Quality of Service Edge Device (QED) and High Assurance Internet Protocol Encryptor (HAIPE) version 3.X—could not be formally rated.

The Army has rated the QED as nearing maturity; however, DDR&E concluded that this technology had ambiguous requirements that made it difficult to state whether it had been adequately demonstrated. DDR&E noted that while the Army had demonstrated that the QED technology met requirements under most conditions, in one stressing scenario, it did not. DDR&E representatives have stated in the past that it is unlikely that any network can meet this requirement in all environments. Since the QED technology was shown to be robust and capable of meeting its requirement in most scenarios, DDR&E recommended that the Army clarify the user's requirements for this technology by its system-level design review, currently scheduled for August 2014. According to a program official, the Army's Training and Doctrine Command has revisited the user requirements; however, it will still wait to reassess the QED's maturity until the system-level design review. According to the Army, the QED technology has been demonstrated in recent WIN-T Increment 2 production qualification tests. It is anticipated that the technology used in WIN-T Increment 2 can be applied to WIN-T Increment 3 with little or no changes to the existing functionality.

HAIPE version 3.X was not available to be assessed at the time of DDR&E's review; however, a National Security Agency (NSA) official has since said it is mature. HAIPE is a device that encrypts and encapsulates Internet protocol packets so that they can be securely transported over a network of a different security classification. DDR&E has notified the Army that the maturity of the HAIPE version 3.X technology should be established to DDR&E's satisfaction before it is transitioned into WIN-T Increment 3. HAIPE 3.1 is currently being used in the WIN-T Increment 2 network. According to the Army, this version has introduced some network efficiencies, but the HAIPE version 4.1 will be needed to support the full set of network efficiencies required by WIN-T Increment 3. The maturity of these critical technologies will be demonstrated in a realistic environment by the April 2015 production decision. The Army will clarify the user's requirements for these technologies by its system-level design review, currently scheduled for October 2012.

Other Program Issues

The WIN-T Increment 3 schedule is likely to be negatively affected by reductions in its planned funding for fiscal year 2012. The joint explanatory statement accompanying the Department of Defense Appropriations Act, 2012, recommended $183 million for WIN-T Increment 3 research, development, test, and evaluation funding, a 40 percent reduction from the budget request of $298 million. The Army explained that as a result of this reduction, the program has modified the program strategy to reflect a two-phased approach. The initial aerial tier capability is planned for the low-rate production decision in fiscal year 2015 and the full aerial tier capability supporting full networking on-the-move is planned for the full-rate production decision in fiscal year 2018.

Program Office Comments

In commenting on a draft of this assessment, the Army provided technical comments, which were incorporated as appropriate.

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Advanced Extremely High Frequency (AEHF) Satellite

The Air Force's AEHF satellite system will replenish the existing Milstar system with higher-capacity, survivable, jam-resistant, worldwide, secure communication capabilities for strategic and tactical warfighters. The program includes six satellites and a mission control segment. Terminals used to transmit and receive communications are acquired separately by each military service. AEHF is an international program that includes Canada, the United Kingdom, and the Netherlands.



Source: © 2009 Lockheed Martin Corporation. All rights reserved.

Current Status

The first AEHF satellite was launched in August 2010 and was expected to reach its planned orbit in about 3 months, but a propulsion system anomaly delayed the satellite's arrival on orbit. The Air Force used other propulsion systems designed to control and reposition the satellite to raise it into its intended orbit, a process it estimated would take 10 to 12 months. However, the program office, in conjunction with the user community, decided to extend the satellite's ascent to save fuel for on-orbit operations and the satellite reached its planned orbit in late October 2011. The satellite will go through about a 100-day checkout and testing period before it becomes available for operations.

The launch of the second and third AEHF satellites was delayed after the problems with the first satellite were discovered, but they have now been cleared for flight. The program office and prime contractor determined the propulsion system anomaly on the first satellite was most likely caused by debris in the system's oxidizer fuel line introduced during the manufacturing process. The second and third satellites, which were already built, were tested to confirm there were no similar blockages. The estimated launch dates for these satellites are April 2012 and the fall of 2013 respectively. The fourth satellite is under contract and is scheduled to be available for launch in 2017. The Air Force plans on procuring the fifth and sixth satellites using a block-buy acquisition strategy intended to produce savings that would be reinvested in research and development for follow-on systems. The Air Force requested congressional approval for the block buy in its fiscal year 2012 budget request. The last two satellites are tentatively expected to be available for launch in 2018 and 2019. In 2009, DOD announced the cancellation of the Transformational Satellite Communications System—the planned follow-on to AEHF. In June 2011, DOD commissioned an internal study to address follow-on programs for AEHF and the Wideband Global SATCOM communications programs, which will lead to a subsequent analysis of alternatives.

Estimated Total Program Cost: $14,082.8 million
Research and development: $7,759.4 million
Procurement: $6,323.4 million
Quantity: 6

Next Major Program Event: Launch of second AEHF satellite, April 2012

Program Office Comments: In commenting on a draft of this assessment, the Air Force noted that satellite command and control was transitioned from Milstar to the AEHF mission control segment in June 2011. The Air Force also provided technical comments, which were incorporated as appropriate.

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B-2 Defensive Management System (DMS) Modernization

The Air Force's B-2 DMS modernization program is expected to upgrade the aircraft's 1980s-era analog defensive management system to a digital capability. The program is intended to improve the frequency coverage and sensitivity of the electronic warfare suite, update pilot displays, and enhance in-flight replanning capabilities for avoiding unanticipated air defense threats. It is also expected to improve the reliability and maintainability of the DMS system and, as a result, the B-2's readiness rate.



Source: U.S. Air Force.

Current Status

The B-2 DMS program was approved to enter technology development in August 2011. On the basis of an analysis of alternatives, the Air Force elected to fully modernize the B-2 DMS using a single-step rather than an incremental acquisition approach to deliver the intended capability. Using a single-step acquisition strategy can increase risk on a program because it can add complexity to design and software efforts. The B-2 DMS program is also implementing a rapid acquisition initiative, which it believes can reduce its acquisition cycle from 10 to 7 years and lower its cost by over $500 million. The initiative includes: (1) conducting early software prototyping; (2) reducing the time required for flight testing by utilizing a flying test bed for risk reduction, improving test-range access, and expediting test data analysis; and (3) improving installation times by using antennas that conform to the B-2 design. The program's current funding plan and schedule do not reflect the anticipated benefits of the initiative. According to the B-2 program office, it expects DOD to assess the program's progress in achieving the initiative's objectives before the start of system development, and will adjust the program's cost and schedule targets accordingly.

The B-2 DMS program office has identified five critical technologies, three of which are mature or nearing maturity. The program expects the two other technologies—the low-observable antennas for the B-2 leading edges and associated receivers—to be nearing maturity by the start of system development. The program does not plan to develop prototypes of the full B-2 DMS, but instead plans to prototype the antenna subsystems, which it believes presents a key technical risk. The program also identified the stringent nuclear hardening requirements of the B-2 design as a technical risk.

Estimated Total Program Cost: $1,979.9 million
Research and development: $1,259.1 million
Procurement: $720.8 million
Quantity: 20

Next Major Program Event: System development start, fourth quarter fiscal year 2013

Program Office Comments: The program was provided a draft of this assessment and had no comments.

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B-2 Extremely High Frequency SATCOM Capability, Increment 2

The Air Force's B-2 EHF SATCOM is a satellite communication system designed to upgrade the aircraft's ultra-high-frequency system to ensure secure communication. The system has three increments. Each one is expected to be a major defense acquisition program. Increment 2 is designed to provide connectivity by adding low-observable antennas and radomes to the aircraft. It is also intended to include separate, nonintegrated Family of Advanced Beyond Line-of-Sight Terminals (FAB-T) and related hardware integral to the EHF SATCOM capability.



Source: U.S. Air Force.

Current Status

The B-2 EHF Increment 2 program is in technology development, but some work on the program has stopped. The program began a component advanced development effort in March 2008 that includes systems engineering, requirements analysis, technology maturation, and preliminary design activities. In August 2011, program officials told us that work related to FAB-T was halted because that program was experiencing FAB-T delivery delays. In October 2011, work on the active electronically scanned array (AESA) antenna system also ceased because of funding uncertainties for fiscal year 2012. While work on the antenna system resumed in December 2011, this was the latest in a series of delays for the Increment 2 program. The program's schedule before work stopped showed system development beginning in April 2013—3 years later than first planned—and production starting after the U.S. Strategic Command's identified need date of 2017.

If and when the B-2 EHF Increment 2 program fully resumes, FAB-T will continue to pose a significant risk. Program officials told us that a terminal, like FAB-T, is significant to the Increment 2 program because it handles the aircraft's communication with EHF satellites, analogous to how a phone or cable modem handles communication with the internet. The Air Force and the Increment 2 program office are looking at ways to mitigate the risk. Program officials told us the Air Force began exploring a potential alternate source for FAB-T in 2011, and the Increment 2 program office was investigating a different approach to secure communication that would not involve the EHF frequency or FAB-T.

In addition to FAB-T, antenna technology maturation is a program risk. The AESA antenna system the program is developing has several critical technologies that are still immature. The program does have a plan to mature these technologies prior to beginning system development in April 2013, but it does not have a backup antenna technology option should AESA not mature as expected.

Estimated Total Program Cost: $2,367.6 million
Research and development: $1,641.2 million
Procurement: $726.4 million
Quantity: 20

Next Major Program Event: System development start, April 2013

Program Office Comments: In commenting on a draft of this assessment, the B-2 program office provided technical comments, which were incorporated as appropriate.

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BMDS: Aegis BMD Standard Missile-3 Block IIB

MDA's Aegis Ballistic Missile Defense (BMD) system is a sea- and land-based system being developed to defend against missiles of all ranges. It includes a radar, command and control systems, and Standard Missile-3 (SM-3) missiles. We reviewed the SM-3 Block IIB, which is planned to provide U.S. homeland defense through early intercept capability against some long-range ballistic missiles and regional defense against intermediate-range ballistic missiles. The SM-3 Block IIB is planned to be fielded in the 2020 time frame as part of the European Phased Adaptive Approach.



Source: Missile Defense Agency.

Current Status

The SM-3 Block IIB program entered technology development in July 2011 and awarded three contracts to conduct trade studies, define missile configurations, and produce development plans. One contractor will be selected for system development in 2013. The SM-3 Block IIB program is developing advance seeker and other technologies that cut across the SM-3's variants through a technology risk-reduction program.

According to a tentative schedule, the SM-3 Block IIB program plans to enter system development prior to holding a preliminary design review, raising the possibility of cost and schedule growth. The program is conducting a series of reviews to receive engineering insight into each contractor's design. While these reviews will provide important knowledge, we have reported that before starting system development, programs should hold key engineering reviews, culminating in the preliminary design review, to ensure that the proposed design can meet defined, feasible requirements within cost, schedule, and other system constraints. Beyond the crosscutting technologies the program is developing, it is taking steps to develop technology maturation plans that will include demonstrating technologies in a relevant environment using a representative model or prototype before the SM-3 Block IIB enters system development. The three contractors' plans are expected to outline the level of investment required to demonstrate this degree of technology maturity by 2014. Program officials have not yet defined the specific critical technologies for the SM-3 Block IIB, which could hamper these efforts. Unlike most major defense acquisition programs, MDA programs are not required to demonstrate technologies in a relevant environment prior to system development, so decision makers will have to hold the program accountable for ensuring the technologies mature as intended.

Estimated Total Program Cost (fiscal years 2012 to 2016, research and development): $1,673.0 million

Next Major Program Event: System development start, fiscal year 2014

Program Office Comments: In commenting on a draft of this assessment, MDA noted the SM-3 Block IIB's primary mission is early intercept of long-range ballistic missiles. One system development contract will be competitively awarded in fiscal year 2014. MDA has identified key missile technologies and made investments to reduce development risks. Prior to system development, there will be a government-only system requirements review. MDA also provided technical comments, which were incorporated as appropriate.

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Combat Rescue Helicopter (CRH)

The Air Force's Combat Rescue Helicopter (CRH) program, formerly called HH-60 Recapitalization, is an effort to replace aging HH-60G Pave Hawk helicopters. The CRH's primary mission is to recover personnel from hostile or denied territory; it will also conduct humanitarian, civil search and rescue, disaster relief, and noncombatant evacuation missions. The program is the second effort to replace the HH-60G. The first, the Combat Search and Rescue Replacement Vehicle (CSAR-X), was cancelled because of cost concerns in 2009.



Source: U.S. Air Force.

Current Status

The CRH program expects to receive its materiel development decision by February 2012. The Air Force expects that the CRH will be an existing production helicopter with modifications that utilize existing mature technologies or subsystems requiring limited integration. As a result, the program's acquisition strategy calls for it to bypass technology development and enter the acquisition process at system development. The Secretary of the Air Force endorsed the program's acquisition approach in April 2011, but requested that the program refine its fiscal year 2013 cost and schedule estimates before moving forward. The program office made these refinements through market research and requests for information from industry. The program plans to issue a request for proposal and award a contract in 2013. According to the program office, the CRH will undergo DOD's new pre–system development review to determine whether the program's plans are executable, affordable, and reflect sound business practices before a request for proposal is issued.

In order to address a critical shortfall in HH-60G aircraft, the Air Force has also initiated an Operational Loss Replacement (OLR) program, which will modify Army UH-60Ms to provide additional HH-60 aircraft to meet current fleet size requirements. These HH-60 aircraft are expected to remain in operation until the CRHs are fully deployed. CRHs are expected to begin being deployed on or before 2018.

Estimated Total Program Cost (fiscal years 2012 to 2016): $2,128.3 million
Quantity: 112

Next Major Program Event: Materiel development decision, February 2012

Program Office Comments: In commenting on a draft of this assessment, the Air Force generally concurred with our assessment, but stressed the fact that the CRH and OLR programs are two separate acquisition efforts. The OLR is designed to maintain the capability of the current HH-60 fleet, while the CRH is designed to provide improved capability in the future. The Air Force also provided technical comments, which were incorporated as appropriate.

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Common Infrared Countermeasure (CIRCM)

The Army's CIRCM, the next generation of the Advanced Threat Infrared Countermeasures (ATIRCM), will be used with the Common Missile Warning System (CMWS) and a countermeasure dispenser capable of employing expendables, such as flares and chaff, to defend aircraft from infrared-guided missiles. The CIRCM program will develop a laser-based countermeasure system for rotary-wing, tilt-rotor, and small fixed-wing aircraft across DOD. CIRCM is one of three subprograms that make up the ATIRCM/CMWS major defense acquisition program.



Source: U.S. Army.

Current Status

The CIRCM program entered technology development in January 2012 after earlier prototyping efforts did not produce a system mature enough to enter system development. The CIRCM subprogram began in 2009 when the Under Secretary of Defense for Acquisition, Technology and Logistics supported the Army's decision to restructure the ATIRCM/CMWS program. At that time, the Under Secretary determined that aircraft survivability equipment development needed better coordination of service efforts, more emphasis on competitive prototyping, and a greater focus on reducing ownership cost by increasing reliability. In June 2009, the Army received approval to award five contracts to provide prototype systems for testing. After testing the five prototypes, the Army concluded that the systems were not mature enough for entry into system development. The Army subsequently decided that the program should proceed with a technology development phase that will include additional prototyping efforts to further mature CIRCM technologies. The Army released the final request for proposal for the CIRCM technology development phase in February 2011 and proposals were due in May 2011. The Army awarded two contracts in January 2012. According to the Army, there are several risks for CIRCM in technology development, including immature technologies that could result in an inability to meet a key performance requirement and the weight of the system, which may be too heavy for small aircraft. The Army has mitigation plans in place to address these issues and plans to update its risk assessment once the winning contractors and their designs are known.

Estimated Total Program Cost: $3,448.9 million
Research and development: $754.8 million
Procurement: $2,694.1 million
Quantities: 1,076

Next Major Program Event: Technology development contract award, January 2012

Program Office Comments: In commenting on a draft of this assessment, the Army provided technical comments, which were incorporated as appropriate.

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Common Vertical Lift Support Platform (CVLSP)

The Air Force's Common Vertical Lift Support Platform (CVLSP) is expected to replace the current fleet of UH-1N helicopters with 93 vertical lift aircraft that can provide improved speed, range, and survivability. CVLSP will support a variety of missions including nuclear security operations and mass passenger transport in the National Capital Region. Initial operational capability for the CVLSP aircraft is planned for fiscal year 2015.



Source: U.S. Air Force.

Current Status

In May 2010, the CVLSP program received its materiel development decision and, in August 2011, the Air Force approved the program's acquisition strategy. The Air Force plans to use full and open competition to identify, select, and procure an in-production, nondevelopmental, commercial- or government-off-the-shelf aircraft. As a result, the program plans to bypass system development and enter the acquisition process at production. Air Force market research found that multiple aircraft currently in production could meet CVLSP requirements and industry has the capacity to produce the aircraft at the desired rates. Program officials noted that because all of the candidate aircraft are in production and operational use, their associated subsystems and critical technologies are considered mature. As a result, the Air Force expects that the program's total research and development cost will only be $33.5 million, primarily to support testing.

At the time the Air Force approved the CVLSP acquisition strategy, the program office was planning to issue a draft request for proposal in September 2011 and a final one in January 2012, award a contract in December 2012, and hold a low-rate initial production decision review in June 2013. However, the release of the draft request for proposal has been delayed indefinitely as the Air Force reviews all of its programs and budget in light of the fiscal constraints currently facing the entire federal government. According to program officials, senior Air Force leadership will decide if and when to release the draft request for proposal. The effect of the delay on the program's plans depends on the eventual timing of the release and the direction from Air Force leadership that accompanies it.

Estimated Total Program Cost: $3,626.3 million
Research and development: $33.5 million
Procurement: $3,561.1 million
Quantities: 93

Next Major Program Event: Release of the draft request for proposal, TBD

Program Office Comments: The program office concurred with this assessment.

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DDG 51 Destroyer

The DDG 51 destroyer is a multimission surface ship designed to operate against air, surface, and subsurface threats. After an approximate 4-year production break, the Navy restarted Flight IIA production and plans to buy 10 ships between fiscal years 2010 and 2015. The Navy will begin buying a new version—Flight III—in fiscal year 2016. Flight III is expected to include the Air and Missile Defense Radar (AMDR)—which is being developed under a separate Navy program—and have an increased focus on ballistic and cruise missile defense.



Source: U.S. Navy.

Current Status

In 2011, the Navy awarded contracts for three Flight IIA ships with an option for a fourth ship to restart DDG 51 production. Construction of the first ship—DDG 113—began in July 2011. The production break resulted in fewer industrial base issues than the Navy expected; however, the amount budgeted for the first three restart ships is $1.8 billion (in constant fiscal year 2012 dollars) more than for the last three ships built. According to the Navy, the ships will not have significant design changes, but will carry an upgraded Aegis combat system, which is currently being developed. The upgrade is expected to enable limited simultaneous, integrated ballistic and cruise missile defense and is the most complex Aegis upgrade ever undertaken. Recent delays in the effort have increased the likelihood the program may still be resolving software defects when it is installed on DDG 113. Further, test plans show that the Navy will certify the upgrade is mission-ready without validating with simultaneous live-fire tests that it can perform its new integrated air and missile defense mission.

The Navy is still determining which technologies will be included on Flight III. To date, the Navy has identified AMDR as the only major technology upgrade for Flight III, and technical studies indicate that few of the technologies developed for the DDG 1000 program are likely to be included on it. AMDR may add significant design and construction risk to Flight III and limit future upgrades based on its size and power and cooling requirements. Program officials stated that a decision has not been made about AMDR's size, which will affect the ship's missile defense capabilities and how much its power and cooling capabilities need to be increased. Further, the Navy has not determined the level of oversight that the Flight III program will have or at which—if any—milestone the program will enter the DOD acquisition cycle.

Estimated Total Program Cost (fiscal years 2010 to 2016): $17,755.6 million
Research and development: $797.6 million
Procurement: $16,958.0 million
Quantity: 11

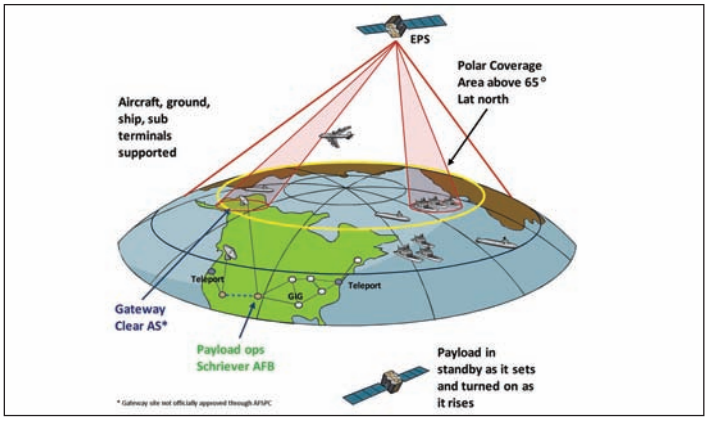
Next Major Program Event: AMDR system development start, October 2012

Program Office Comments: In commenting on a draft of this assessment, the Navy stated that the last three ships built were part of a multiyear procurement, while the DDG 113 was a sole-source procurement and the next three ships were awarded through a limited competition, which may affect a comparison of their costs. Further, these ships, unlike earlier ones, include ballistic missile defense capability. The Navy also commented that the Aegis upgrade will be sufficiently mature to support DDG 113 shipbuilding milestones. The Navy also provided technical comments, which were incorporated as appropriate.

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Enhanced Polar System (EPS)

The Air Force's Enhanced Polar System will provide next-generation protected extremely high frequency (EHF) satellite communications in the polar region. It will replace the current Interim Polar System and serve as a polar adjunct to the Advanced EHF system. EPS consists of two EHF payloads hosted on classified satellites, a gateway to connect modified Navy Multiband Terminals to other communication systems, and a control and planning segment.



Source: LinQuest Corporation.

Current Status

The EPS program's entry into system development has been delayed by over 3 years, although the payload has moved forward with development activities to keep it on track with the scheduled launch of its classified host satellites. EPS was initiated in 2006 to fill the gap left by the cancellation of the Advanced Polar System. In 2007, the Under Secretary of Defense for Acquisition, Technology and Logistics directed the program to proceed to system development in order to synchronize the program's payload schedule with the host satellite production timeline. Payload development proceeded in 2008, but the program's entry into system development has been delayed. According to the program office, the latest delays have occurred because funding constraints required the program to reduce the capabilities of the control and planning segment and gateway and amend the EPS acquisition strategy. Once the revised acquisition strategy is approved, the program plans to award a development contract for the control and planning segment that would lead to a preliminary design review in the first quarter of fiscal year 2013 and a system development decision at the end of fiscal year 2013.

There is a risk that the payload will be on orbit before the control and planning segment is available. The payload, which consists of about 20 separate units such as processors and antennas, has been in development for several years and all of its critical technologies are mature. As each payload unit is flight qualified, they are delivered to the host for integration into the satellites, which are expected to be on-orbit in fiscal years 2015 and 2017. Program officials acknowledged that it will be a challenge to develop and build the control and planning segment, needed for the system to be fully functional, by the time the payloads reach orbit.

Estimated Total Program Cost: $1,530.0 million
Research and development: $1,468.3 million
Procurement: $61.7 million
Quantity: 2 payloads

Next Major Program Event: System development decision for control and planning segment and gateway, fourth quarter fiscal year 2013

Program Office Comments: The EPS program office provided technical comments, where were incorporated as appropriate.

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Expeditionary Fighting Vehicle (EFV)

The Marine Corps' EFV was being developed to transport troops from ships offshore to inland locales at higher speeds and from longer distances than the Assault Amphibious Vehicle 7A1 (AAV 7A1), which it was supposed to replace. It was to have two variants—a troop carrier for 17 combat-equipped Marines and 3 crew members and a command vehicle to manage combat operations. In January 2011, the Secretary of Defense announced the cancellation of the EFV due to technology problems, development delays, and cost increases.



Source: U.S. Marine Corps.

Current Status

The EFV program has been cancelled and an official reported that the EFV contract will end in September 2012. Shutdown activities, which will cost about $200 million, are ongoing and will include harvesting technologies and conducting habitability, firepower, water speed, durability, and mine blast testing on EFV vehicles.

Despite the EFV's cancellation, the Marine Corps has determined that it still needs an amphibious assault vehicle with greater capabilities than the legacy AAV 7A1 and is conducting an analysis of alternatives to explore options for replacing that vehicle. In September 2011, DOD's Office of Cost Assessment and Program Evaluation issued guidance directing that this analysis include five options: the cancelled EFV (about $18 million per unit), a new amphibious vehicle, a new land-mission focused vehicle which will need to be transported from ship to the shore via another watercraft, upgrades to the legacy AAVs to address identified gaps in the vehicle's survivability, and upgrades to the legacy AAVs to address other capability gaps such as water and land mobility, networking, and lethality. The Marine Corps also noted that the analysis will consider relaxing the EFV's requirements to make the new solution more affordable. For example, the analysis assumes a reduction in the ship-to-shore launch distance from 25 nautical miles, which was required of the EFV, to a range of 12 to 25 nautical miles. A shorter launch distance would place Navy amphibious transport ships at greater risk to shore-based threats. The analysis of alternatives is expected to be complete before the end of fiscal year 2012.

Estimated Total Program Cost (through fiscal year 2011): $3,704.9 million

Next Major Program Event: EFV contract expiration, September 2012

Program Office Comments: The Marine Corps was provided a draft of this assessment and did not offer any comments.

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F-22 Modernization Increment 3.2B

The Air Force's F-22A Raptor is the only operational fifth-generation air-to-air and air-to-ground fighter/attack aircraft. This aircraft integrates stealth; supercruise; and advanced avionics, maneuverability, and weapons in one platform. The Air Force established the F-22A modernization and improvement program in 2003 to add enhanced air-to-ground, information warfare, reconnaissance, and other capabilities and improve the reliability and maintainability of the aircraft. The Air Force is upgrading the F-22A fleet in four increments.



Source: U.S. Air Force.

Current Status

The first F-22A modernization increment has been fielded. Operational testing for the second increment was delayed between March and September 2011 because of the stand-down of the entire F-22 fleet after a fatal crash, test range unavailability, and a technical issue relating to ground support equipment. Increment 3.2A—the third increment—began developing software for electronic protection, combat identification, and Link 16 communication upgrades in November 2011, with fielding planned to begin in 2014. Program officials reported in December 2011 that increment 3.2A was slightly ahead of its current schedule.

The fourth program increment, increment 3.2B, is expected to begin system development as a separate major defense acquisition program in fiscal year 2013. This increment plans to field AIM-9X and AIM-120D missiles and upgrade electronic protection, targeting capabilities, and communication capabilities by 2017. The 3.2B increment will benefit from investments that have already been made in the modernization program, including requirements and risk-reduction analyses and the development of hardware needed to integrate new capabilities.

The Air Force identified three critical technologies for increment 3.2B. The two technologies that will be used to integrate the AIM-9X missile with the aircraft are in the early stages of development and have only been tested in a lab environment. The Air Force expects these technologies to be demonstrated in a relevant environment by the start of system development. The third technology, which is needed to improve the ability to locate ground targets, has already been demonstrated in a relevant environment.

Estimated Total Program Cost: $1,567.5 million
Research and development: $1,040.9 million
Procurement: $526.6 million
Quantity: 143
Note: The program cost is for increment 3.2B. The total cost estimate for all of F-22's modernization increments and improvements is $12.7 billion.

Next Major Program Event: System development start, December 2012

Program Office Comments: The Air Force provided technical comments, which were incorporated as appropriate.

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Ground Combat Vehicle (GCV)

The Army's Ground Combat Vehicle (GCV) is the cornerstone of its combat vehicle modernization strategy. The first variant is intended to be the service's next infantry fighting vehicle, replacing a portion of the current Bradley fleet. The Army wants GCV to provide a full-spectrum capability to perform offensive, defensive, stability, and support operations; carry a 9-soldier squad; emphasize force protection; and be available within 7 years of beginning technology development.



Source: U.S. Army.

Current Status

In August 2011, the Under Secretary of Defense for Acquisition, Technology and Logistics approved the GCV program's entry into a 24-month technology development phase with the goals of reducing overall risk and achieving an affordable, feasible, and operationally effective preliminary design. During technology development, the Army plans to utilize a three-pronged approach that includes an updated analysis of alternatives; an assessment of selected nondevelopmental vehicles, such as an upgraded Bradley vehicle; and contractor efforts to build and demonstrate key subsystem prototypes. The Army awarded technology development contracts to two contractor teams. However, work could not begin until a bid protest from a third contractor team was resolved. The Army expects to have a preliminary design review within 18 months of beginning technology development and, at that point, according to an Army official, should be ready to determine whether GCV will be an entirely new vehicle or a modified existing vehicle.

In March 2011, we raised questions about the Army's strategy for the GCV program related to how urgently it is needed, the robustness of the analysis of alternatives, its cost and affordability, the plausibility of its schedule, and the maturity of the technologies to be used. DOD addressed some of these areas when it approved the program to enter technology development, but resolving others will be a major challenge for the Army. The Under Secretary of Defense for Acquisition, Technology and Logistics made approval of the program contingent upon the Army ensuring a procurement unit cost of $13 million per vehicle and a 7-year schedule for the first production vehicle to be delivered—both ambitious goals. The Army has encouraged contractors to use mature technologies in their designs, which we have found to be a key determinant to program success.

Estimated Total Program Cost: $31,589.9 million
Research and development: $6,789.7 million
Procurement: $24,800.2 million
Quantities: 30 (development), 1,874 (procurement)

Next Major Program Event: System development start, December 2013

Program Office Comments: The program office provided technical comments, which were incorporated as appropriate.

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Joint Light Tactical Vehicle (JLTV)

The Army and Marine Corps' Joint Light Tactical Vehicle is a family of vehicles being developed to replace the High Mobility Multipurpose Wheeled Vehicle (HMMWV) for some missions. The JLTV is expected to provide better protection for passengers against current and future battlefield threats, increased payload capacity, and improved automotive performance over the up-armored HMMWV; it must also be transportable. Two- and four- seat variants are planned with multiple mission configurations.



Source: Department of Defense.

Current Status

On the basis of the knowledge gained in technology development, the Army and Marine Corps made changes to JLTV requirements. In October 2008, the Army awarded three technology development contracts with the goal of defining requirements, reducing risks, and shortening the length of system development. The contractors delivered prototype vehicles in May 2010 and testing was completed in June 2011. On the basis of the results, the Army and Marine Corps concluded that the original JLTV requirements were not achievable and its cost would be too high. For example, the JLTV could not meet requirements for both protection levels and transportability because of weight. The services have relaxed part of the requirement to transport the vehicle by helicopter at high altitude and at certain temperatures, which will permit a heavier vehicle to be transported. As a result of the requirements changes, the Army and Marine Corps will shift some missions intended for JLTV to the HMMWV.

The JLTV program has also made changes to its acquisition strategy. The Army and Marine Corps had planned to follow a traditional acquisition approach and enter system development in January 2012. The services now plan to use a tailored approach that includes awarding contracts to up to three vendors to build 20 vehicles, extensively testing those vehicles, and proceeding to production. Contract award is scheduled for June 2012. Contractors will have 12 months to build and deliver their prototypes, after which the government will spend 15 months testing them. A decision to begin production is planned for second quarter fiscal year 2015. DOD sees this approach as saving time and money; however, it forgoes the activities typically done early in system development that demonstrate the product's design is mature and will meet requirements. As a result, the Army and Marine Corps are at risk of discovering that the vehicles are still not mature late in the program.

Estimated Total Program Cost: TBD

Next Major Program Event: Contract award, June 2012

Program Office Comments: In commenting on a draft of this assessment, the program stated that as requirements were adjusted to reflect more achievable and cost-effective thresholds, system development could be shortened by leveraging existing designs. The program will focus the selection criteria on mature designs that manage the risks. Robust testing will allow sufficient opportunities for contractors to address issues throughout testing. The program also provided technical comments, which were incorporated as appropriate.

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Joint Tactical Radio System (JTRS) Ground Mobile Radios (GMR)

DOD's JTRS program was developing software-defined radios intended to interoperate with selected radios and increase communications and networking capabilities. The JTRS GMR program was developing radios for ground vehicles and the software needed to operate them. The JTRS GMR contract also included the development of the wideband networking waveform. In October 2011, DOD terminated the JTRS GMR program. It plans to pursue an alternative strategy to meet ground vehicle networking and communications requirements.



Source: Department of Defense.

Current Status

In October 2011, the JTRS GMR program was terminated when the Acting Under Secretary of Defense for Acquisition, Technology and Logistics decided not to certify it to continue after a Nunn-McCurdy unit-cost breach of the critical threshold. The Under Secretary attributed the unit-cost growth to a reduction in quantity, an inadequate analysis of the program's affordability at its inception, a series of contractor and program execution issues, and the addition of new information-assurance requirements. The Under Secretary also noted that it was unlikely that the JTRS GMR program could meet its requirements in an affordable manner and may not meet some requirements at all. The radio had performed poorly during testing, prompting the test unit to conclude that its development should end and it should not be fielded. Finally, an assessment of alternative options found that a competitive market had emerged with the potential to deliver radios that meet the Army's capability needs at a reduced cost.

In order to meet networking requirements for ground vehicles, DOD plans to pursue a two-pronged approach. First, the current JTRS GMR contractor will continue development through March 2012 when the term of the contract ends, which will allow for completion of the JTRS GMR's National Security Agency information assurance certification, its operating environment software, and the wideband networking waveform. Second, DOD established a new program to test and evaluate low-cost, nondevelopmental radios with reduced size, weight, and power with a plan to field them in fiscal year 2014. In November 2011, the Navy Space and Naval Warfare Systems Command, on behalf of the JTRS Joint Program Executive Office, released a draft request for proposal for this new program to seek input from industry, with the expectation that a formal solicitation will be released in February 2012.

Estimated Total Program Cost (through fiscal year 2011): $1,832.3 million

Next Major Program Event: NA

Program Office Comments: The JTRS Joint Program Executive Office was provided a draft of this assessment and did not offer any comments.

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Nett Warrior

The Army's Nett Warrior program is an integrated situational awareness system for use during combat operations. It was to consist of a radio furnished by the government and several contractor-developed items including a hands-free display, headset, and computer. According to program officials, the program is being restructured to deliver useable increments of capability sooner and for less money. The Army now plans to procure a commercially developed system that is considerably smaller and lighter.



Source: U.S. Army.

Current Status

The Nett Warrior program is being restructured based on concerns about its affordability and performance in testing. The program was approved to enter technology development in February 2009 and planned to proceed directly to production in fiscal year 2011. The Army awarded cost-plus-fixed-fee contracts to three contractors for a suite of prototype equipment, which included a hands-free display, headset, computer, navigation equipment, antenna, and cables, that would eventually integrate with a government-furnished JTRS Rifleman radio. These prototypes underwent developmental testing and were evaluated in an October 2010 limited user test. Program officials indicated that a number of performance issues were revealed during testing and the size, weight, and power demands of the system resulted in it having little to no overall operational benefit. In September 2011, the Army decided to restructure the program, and program officials stated that a stop work order was issued for all three contractors.

Program officials further stated that the Army now plans to provide soldiers with commercially based, smart phone–type devices connected to a JTRS Rifleman radio. According to the Army, moving to a commercial solution will significantly reduce the cost and weight of the Nett Warrior capability. Before the restructuring, the program was projected to cost $1.936 billion to develop and acquire 74,197 sets of equipment. Program officials indicate that the new system is projected to reduce costs by as much as 60 percent and, as a result, the program is no longer considered a major defense acquisition. The new system was evaluated in the Army's semiannual network integration evaluation that concluded in November 2011. The Army plans to utilize the results from this test to inform a competitive procurement, which will then be followed by additional testing and the planned deployment of an incremental capability in fiscal year 2013.

Estimated Total Program Cost: TBD

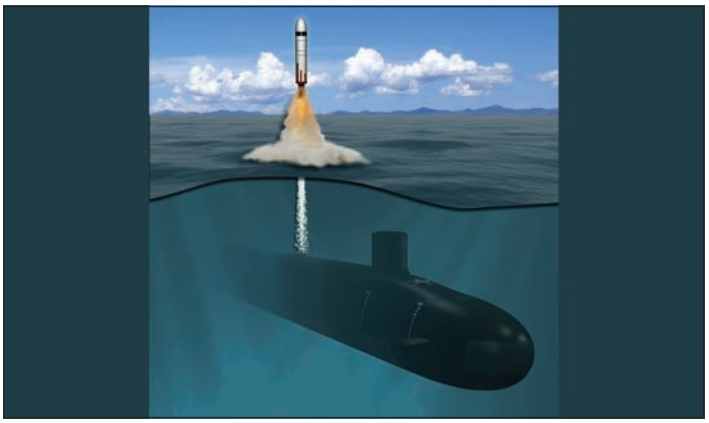
Next Major Program Event: Production decision, March 2012

Program Office Comments: In commenting on a draft of this assessment, the program office acknowledged the requirement changes the program has experienced, which serve to emphasize the potential benefits provided by commercially developed equipment solutions. The program office also provided technical comments, which were incorporated as appropriate.

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Ohio-Class Replacement (OR)

The Navy's *Ohio*-class Replacement (OR) will replace the current fleet of *Ohio*-class ballistic missile submarines (SSBN) as they begin to retire in 2027. The Navy began research and development in 2008, in order to avoid a gap in sea-based nuclear deterrence between the *Ohio*-class's retirement and the production of a replacement. The Navy is working with the United Kingdom to develop a common missile compartment for use on OR and the United Kingdom's replacement for the Vanguard SSBN. OR will initially carry the Trident II missile.



Source: © 2010 General Dynamics Electric Boat.

Current Status

The OR program began technology development in January 2011. Affordability has been an early focus of the program. Due to its high cost, Navy officials have stated the OR program could stress Navy shipbuilding budgets in the 2020 to 2030 time frame. Program officials stated that they are trying to reduce the average procurement unit cost from an estimated $5.6 billion to $4.9 billion (in fiscal year 2010 dollars). The program is considering procuring OR as part of a block buy with the *Virginia*-class submarine to reduce procurement costs by an estimated 13 percent, and is lining up its production schedule to match that program in case this option is pursued. The Navy also decided to use 16 87-inch diameter tubes per submarine, which, while fewer than the *Ohio*-class, is expected to reduce costs while meeting the anticipated future strategic requirement based on arms reduction trends. According to the program, a four-way competition is ongoing to develop prototype tubes and efficient manufacturing processes for outfitting these tubes into the hull, including the use of a "quad pack" configuration that could reduce cost and construction time.

According to Navy officials, they are currently defining requirements and conducting early design work for the program with Electric Boat as the design agent responsible for the overall ship design and Huntington Ingalls Industries as a subcontractor. For example, the Navy is planning to use a new X-stern aft control surface configuration for steering the submarine, pending successful testing. This design is expected to provide the desired maneuverability and increase maintainability. OR may also use electric propulsion, which would help improve the submarine's stealthiness because it uses fewer moving parts. Program officials said they plan to have the three-dimensional design complete prior to starting construction on the lead ship to minimize rework, delays, and the potential for cost growth.

Estimated Total Program Cost: $90,433.5 million
Research and development: $11,142.8 million
Procurement: $79,290.7 million
Quantity: 12

Next Major Program Event: Preliminary design review, March 2014

Program Office Comments: The Navy provided technical comments, which were incorporated as appropriate.

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Patriot/Medium Extended Air Defense System (MEADS) Combined Aggregate Program (CAP) Fire Unit

The Army's Patriot/Medium Extended Air Defense System (MEADS) Combined Aggregate Program was a ground-mobile system intended to provide low- to medium-altitude air and missile defense to counter tactical ballistic missiles, cruise missiles, or other air-breathing threats. It included Patriot missile upgrades with a new battle management system, launchers, radars, and reloaders. MEADS is being codeveloped by the United States, Germany, and Italy.



Source: Lockheed Martin/MBDA/LFK (MEADS International).

Current Status

In February 2011, the Office of the Secretary of Defense proposed ending U.S. involvement in the MEADS program before development had been completed. In making its decision, DOD cited lingering concerns about the high degree of risk in the program and its affordability. DOD still plans to provide $803.7 million in funding through fiscal year 2013 for design and development activities, as required by the terms of its existing memorandum of understanding with its international partners.

Since MEADS development cannot be completed with the funding currently provided under the memorandum of understanding, the program office will instead work towards a demonstration of capabilities, which includes two planned flight tests. Much of the remaining development effort will be focused on the multifunction fire control radar, launcher, and battle management system. Program officials stated that launcher development is on track, but the battle management software is delayed and the multifunction radar still faces hardware challenges. Further delays in the development of these items could cause the program to reduce the number of planned flight tests to one. The program has stopped developing the system support vehicle, MEADS network radio, and reloader. It has also curtailed development of the surveillance radar, but plans to provide a low-cost prototype with 50 percent of the planned active electronics of the full radar design for the demonstration. Program officials stated that the surveillance radar is the most important item for the United States because it can potentially be leveraged for other systems. Program elements, such as the near-vertical launcher and a cooling technology for rotating phased-array radars, also might prove useful on other air and missile defense programs.

Estimated Total Program Cost (through fiscal year 2013): $3,280.4 million

Next Major Program Event: First flight test, November 2012

Program Office Comments: In commenting on a draft of this assessment, the Army stated that limited activities may continue into fiscal year 2014 and beyond. For example, international and U.S.-only contract closeout activities and data archiving may extend beyond fiscal year 2013. Additionally, the European partners may continue MEADS element development, which would require U.S. support through foreign military sales.

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Presidential Helicopter (VXX)

The Navy's VXX program is intended to develop a presidential helicopter replacement fleet that will provide transportation for the President, Vice President, heads of state, and others as directed. The VXX fleet will replace the current fleet of VH-3D and VH-60N helicopters. The initial replacement effort, the VH-71, was terminated in June 2009 due to excessive cost growth and schedule delays, but the requirement to field a replacement remained. The Navy is also taking steps to extend the life of the current VH-3D/VH-60N fleet and streamline the VXX acquisition strategy.



Source: U.S. Navy.

Current Status

In June 2010, the VXX program received its materiel development decision and began assessing alternatives to replace the existing VH-3D/VH-60N helicopter fleet. The Navy completed and provided to DOD the results of its analysis of alternatives in March 2011. DOD officials reviewed the results and determined that the Navy's analysis study did not find an acceptable—that is, cost-effective—solution. The Office of the Secretary of Defense (OSD) and the Navy subsequently decided to update the analysis of alternatives using an acquisition strategy that might result in a more timely and affordable program using additional guidance provided by OSD in December 2011. This strategy is based on leveraging mature technologies that will be developed outside of the VXX program before including them on VXX aircraft. DOD officials stated that the new analysis of alternatives will also include revised configurations that will satisfy a refined set of requirements. The program has been delayed until this analysis is completed.

As a result of the termination of the VH-71 and delay of the VXX effort, the legacy Presidential helicopter fleet will be upgraded and its service life will be extended. The upgrades will address many, but not all, of the capability gaps of the legacy fleet. The Navy plans to conduct a service life extension program (SLEP) on the legacy fleet that will extend their service life by 4,000 hours. The VH-3D and VH-60N will receive these modifications, including structural enhancements, during their routine overhaul cycles. The SLEP will allow the aircraft to operate until replacement aircraft are fielded, which the Navy wants to accomplish as quickly as possible as it has stated that the capability shortfalls of the current fleet cannot be otherwise overcome.

Estimated Total Program Cost: TBD

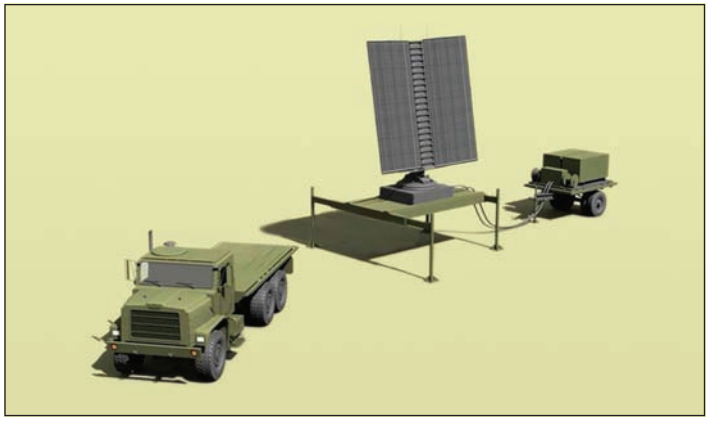
Next Major Program Event: Revised VXX analysis of alternatives, TBD

Program Office Comments: The program office concurred with the assessment and provided technical comments, which were incorporated as appropriate.

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Three Dimensional Expeditionary Long Range Radar (3DELRR)

The Air Force's 3DELRR will be the long-range, ground-based sensor for detecting, identifying, tracking, and reporting aircraft and missiles for the Joint Forces Air Component Commander. It will provide real-time data and support a range of expeditionary operations in all types of weather and terrain. It is being acquired to replace the Air Force's AN/TPS-75 radar systems. The Marine Corps is considering 3DELRR as a potential replacement to the AN/TPS-59 to support the Marine Air-Ground Task Force Commander.



Source: U.S. Air Force.

Current Status

The 3DELRR program entered technology development in May 2009. The Air Force awarded two contracts for competing prototypes and plans to conduct a full and open competition and award a single cost-plus incentive fee contract for additional technology development activities. These activities include defining the preliminary system design, conducting a preliminary design review, producing a functioning system prototype for a capability demonstration, and other risk-reduction activities. The contract will also include options for system development, which is expected to begin in the first quarter of fiscal year 2014, and initial production. The program office reported that it has delayed the release of the request for proposal for this contract indefinitely due to its ongoing revision of the 3DELRR acquisition strategy. The revision is focused on the program's affordability and plans for competition.

The 3DELRR program is focused on reducing technical risk before beginning system development and has identified eight critical technologies. In April 2011, an independent review team reported that the program successfully demonstrated its critical technologies between both prototypes, though program officials noted the technologies still need to be integrated and demonstrated as a system. The program's technology development strategy calls for these technologies to be nearing maturity and demonstrated in a relevant environment at the start of system development. The program also expects to complete a preliminary design review prior to system development. Initial operational capability for the radar is targeted for approximately 2020.

Estimated Total Program Cost: $2,124.0 million
Research and development: $754.6 million
Procurement: $1,369.4 million (Air Force only)
Quantities: 35 (Air Force only)

Next Major Program Event: Contract award, TBD

Program Office Comments: The program office concurred with this assessment.

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Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS) System

The Navy's UCLASS is expected to enable a single aircraft carrier to conduct sustained operations including intelligence, surveillance, and reconnaissance (ISR), as well as targeting, strike, and bomb damage assessment. The system will address a gap in persistent sea-based ISR with precision strike capabilities. It includes upgrades to carrier infrastructure and systems, upgrades to existing command and control systems, and an unmanned aerial vehicle.



Source: U.S. Navy.

Current Status

The UCLASS program received its materiel development decision in July 2011. The program aims to achieve a limited initial capability in 2018 using existing capabilities that the Navy believes can be leveraged to support a UCLASS platform. The feasibility of this strategy will depend, in part, on the success of Navy's Unmanned Combat Air System Aircraft Carrier Demonstration (UCAS-D). The UCAS-D program's scope consists of design, development, integration, and demonstration of a carrier-suitable, low-observable, unmanned combat air system platform in support of a future acquisition program. UCAS-D will demonstrate carrier operations, including autonomous aerial refueling, as well as mature critical technologies needed to operate and integrate the aircraft with the ship. The analysis of alternatives for the UCLASS program, which was planned to be completed in January 2012, assumes that the UCAS-D program is successful in maturing technologies required to conduct launch, recovery, and carrier-controlled airspace operations and that the technologies can be applied to the UCLASS. Although the UCAS-D aircraft is not scheduled to demonstrate a carrier landing until 2013, F/A-18 flight test points from June 2011 have demonstrated the unmanned landing technology that will be incorporated into the UCLASS design. The program is considering cost and performance trade-offs such as endurance, payload, speed, sensors, and survivability to ensure the system is affordable and can provide limited initial capability by 2018. The analysis of alternatives will also likely address options for incrementally growing capabilities over time through the use of modular ISR and precision strike mission packages. Officials stated that it is critical that a request for proposal be released in fiscal year 2012 for the program to achieve a 2018 limited initial capability.

Estimated Total Program Cost: TBD
Research and development (fiscal years 2012 to 2016): $2,422.7 million
Quantity: TBD

Next Major Program Event: Technology development start, September 2012

Program Office Comments: In commenting on a draft of this assessment, the Navy stated that UCLASS system design is informed by UCAS-D activities and successful UCAS-D surrogate carrier tests have proven the technologies that inform the UCLASS carrier and system specifications. These specifications support the UCLASS request for proposal release in fiscal year 2012. The President's Budget for Fiscal Year 2013 adjusts the schedule and associated funding to provide an intial capability by 2020 instead of 2018. The Navy also provided technical comments, which were incorporated as appropriate.

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Agency Comments and Our Evaluation

DOD provided written comments on a draft of this report. The comments are reprinted in appendix VI. We also received technical comments from DOD, which have been addressed in the report as appropriate.

In its comments, DOD stated it appreciates our efforts to develop improved methods and metrics but, while it does not disagree with the data used, still does not fully agree with those methods and metrics. In particular, DOD states that the aggregate cost growth measures in the report fail to adequately address when, why, and how cost growth occurred. Specifically, DOD stated that the report does not make obvious in the aggregate measures or discussion that the portfolio changes every year. In addition, DOD commented that the cost of programs often increase or decrease for reasons other than overly optimistic planning, faulty estimating, or poor execution, such as changing requirements, funding incremental upgrades, changing inventory goals, and adjustments to production rates.

We believe the report includes observations that directly address each of these areas. We report the aggregate cost growth for DOD's 2011 portfolio of major defense acquisition programs over the last year, the past 5 years, and since programs' first full estimates. Our assessment also makes a number of observations that seek to determine the reasons for that aggregate cost growth, including examining how much of the procurement cost growth in the past year was due to changes in quantities and identifying the link between development cost growth for programs in production and incremental upgrades to these systems. Finally, the report includes analysis of how the portfolio has changed over the past year, how it is likely to change in the next fiscal year, and how this may affect both the number of programs and cost of DOD's portfolio of major defense acquisition programs.

We are sending copies of this report to the Secretary of Defense; the Secretaries of the Army, Navy, and Air Force; the Director of the Office of Management and Budget; and interested congressional committees. In addition, the report will be made available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staff have any questions concerning this report, please contact me at (202) 512-4841. Contact points for our offices of Congressional Relations and Public Affairs may be found on the last page

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of this report. Staff members making key contributions to this report are listed in appendix VII.



Michael J. Sullivan
Director, Acquisition and Sourcing Management

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List of Committees

The Honorable Carl Levin
Chairman
The Honorable John McCain
Ranking Member
Committee on Armed Services
United States Senate

The Honorable Daniel Inouye
Chairman
The Honorable Thad Cochran
Ranking Member
Subcommittee on Defense
Committee on Appropriations
United States Senate

The Honorable Howard P. McKeon
Chairman
The Honorable Adam Smith
Ranking Member
Committee on Armed Services
House of Representatives

The Honorable C.W. Bill Young
Chairman
The Honorable Norman D. Dicks
Ranking Member
Subcommittee on Defense
Committee on Appropriations
House of Representatives

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Scope and Methodology

Analysis of the Cost Performance of DOD's Portfolio of Major Defense Acquisition Programs

This report contains observations on the cost and schedule performance of the Department of Defense's (DOD) fiscal year 2011 major defense acquisition program portfolio. To develop these observations, we obtained and analyzed data from Selected Acquisition Reports (SAR) and other information in the Defense Acquisition Management Information Retrieval (DAMIR) Purview system, referred to as DAMIR.[1] We refer to programs with SARs dated December 2010 as the 2011 portfolio. We converted cost information to fiscal year 2012 dollars using conversion factors from the DOD Comptroller's National Defense Budget Estimates for Fiscal Year 2012 (table 5-9). Data for the total planned investment of major defense acquisition programs were obtained from DAMIR, which we aggregated for all programs using fiscal year 2012 dollars. To calculate cost remaining to completion we used funding stream data obtained from DAMIR on the programs in the 2011 portfolio to determine what funds had been allocated in prior years for all activities and how much funding is required for the program to complete its acquisition. The Missile Defense Agency's (MDA) Ballistic Missile Defense System (BMDS) is excluded from our analysis of the 2011 portfolio.

We also collected and analyzed data on the composition of DOD's major defense acquisition program portfolio. To determine changes in that portfolio, we compared the programs that issued SARs in December 2010 with the list of programs that issued SARs in December 2009. To assess the cost effect of changes to the major defense acquisition portfolio, we calculated the estimated total acquisition cost for the six programs exiting the portfolio and for the four programs entering the portfolio. To project the number and cost of programs expected to be in the 2012 portfolio, we used data from the December 2010 and September 2011 SARs to identify the programs leaving the portfolio and their estimated cost. We used data from DOD's 2011 Major Defense Acquisition Program list, program offices, and DOD's fiscal year 2012 budget request to estimate the number and cost of programs expected to enter the 2012 portfolio.

To compare the cost of major defense acquisition programs over the past year, 5 years, and from first full estimates, we collected data from December 2010, December 2009, and December 2005 SARs; acquisition

[1]DAMIR Purview is an executive information system operated by the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics / Acquisition Resources and Analysis.

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program baselines; and program offices. We retrieved data on research, development, test, and evaluation; procurement; and total acquisition cost estimates for the 96 major defense acquisition programs in the 2011 portfolio. We divided some SAR programs into smaller elements, because DOD reports performance data on them separately, resulting in a total of 99 programs and subelements. We analyzed the data to determine the change in research and development, procurement, and total acquisition costs from the first full estimate, generally development start, to the current estimate. For the programs that did not have a development estimate, we compared the current estimate to the production estimate. Also, for the shipbuilding programs that had a planning estimate, we compared the current estimate to the planning estimate. For programs that began as non–major defense acquisition programs, the first full estimate we used as a baseline may be different than the original baseline contained in DOD SARs. When comparable cost and schedule data were not available for programs, we excluded them from the analysis. To calculate cost growth incurred over the past year, from 2010 to 2011, we calculated the difference between the December 2009 and December 2010 SARs for programs older than 1 year. For programs less than a year old, we calculated the difference between December 2010 and first full estimates. We converted all dollar figures to fiscal year 2012 constant dollars. We took a similar approach for calculating cost growth incurred from 2006 to 2011. We also obtained schedule information and calculated the cycle time from program start to initial operational capability; delay in obtaining initial operational capability; and the delay in initial capability as a percentage of total cycle time. Finally, we extracted data on program acquisition unit cost to determine whether a program's buying power had increased or decreased.

To calculate the amount of procurement cost growth attributable to quantity changes, we isolated the change in procurement quantities and the prior average procurement unit cost for programs over the past year. For those programs with a change in procurement quantities, we calculated the amount attributable to quantity changes as the change in quantity multiplied by the average procurement unit cost for the program a year ago. The resulting dollar amount is considered a change due solely to shifts in the number of units procured and may overestimate the amount of change expected when quantities increase and underestimate the expected change when quantities decrease as it does not account for other effects of quantity changes on procurement such as gain or loss of learning in production that could result in changes to unit cost over time or the use or absence of economic orders of material. However, these

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changes are accounted for as part of the change in cost not due to quantities. An average procurement unit cost was not included in last year's SAR for the Littoral Combat Ship program. We calculated an average procurement unit cost for the program using the procurement quantities and funding up through fiscal year 2010 included in this year's SAR.

To evaluate program performance against high-risk criteria discussed by DOD, the Office of Management and Budget (OMB), and GAO, we calculated how many programs had less than a 2 percent increase in total acquisition cost over the past year, less than a 10 percent increase over the past 5 years, and less than a 15 percent increase from first full estimates using data from December 2010, December 2009, and December 2005 SARs; acquisition program baselines; and program offices. For programs that began as non–major defense acquisition programs, the first full estimate we used as a baseline may be different than the original baseline contained in DOD SARs. For programs with multiple subprograms presented in the SARs we calculated the net effect of the subprograms to reach an aggregate program result.

Through discussions with DOD officials responsible for the database and confirming selected data with program offices, we determined that the SAR data and the information retrieved from DAMIR were sufficiently reliable for our purposes.

Analysis of Selected DOD Programs Using Knowledge-Based Criteria

Our analysis of how well programs are adhering to a knowledge-based acquisition approach focuses on 37 major defense acquisition programs that are in development or the early stages of production.

To assess the knowledge attained by key decision points (system development start or detailed design contract award for shipbuilding programs, critical design review or fabrication start for shipbuilding programs, and production start), we collected data from program offices about their knowledge at each point. In particular, we focused on the eight programs that entered these key acquisition points in 2011 and evaluated their adherence to knowledge-based practices. We did not validate the data provided by the program offices, but reviewed the data and performed various checks to determine that they were reliable enough for our purposes. Where we discovered discrepancies, we clarified the data accordingly.

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Programs in our assessment were in various stages of the acquisition cycle, and not all of the programs provided knowledge information for each point. Programs were not included in our assessments if relevant decision or knowledge data were not available. For each decision point, we summarized knowledge attainment for the number of programs with data that achieved that knowledge point. Our analysis of knowledge attained at each key point includes factors that we have previously identified as being key to a knowledge-based acquisition approach, including holding early systems engineering reviews, testing an integrated prototype prior to the design review, using a reliability growth curve, planning for manufacturing, and testing a production-representative prototype prior to making a production decision. Additional information on how we collected these data is found in the product knowledge assessment section of this appendix. See appendix IV for a list of these practices.

Analysis of Acquisition Reform Implementation

To determine how DOD has begun to implement acquisition reforms, we obtained and analyzed the revised DOD 5000.02 acquisition instruction, the Weapon Systems Acquisition Reform Act of 2009, and the September 14, 2010, Under Secretary of Defense for Acquisition, Technology and Logistics memorandum on better buying power as well as the subsequent memorandums clarifying and implementing that guidance.

We analyzed data from surveys received from the 37 active and 16 future major defense acquisition programs in our assessment to determine the extent to which programs were implementing requirements for holding systems engineering reviews; developing competitive prototypes; maturing critical technologies; considering trade-offs among cost, schedule, and performance objectives before development start; and establishing affordability targets and "should cost" analyses. We also collected information on whether these programs are planning to incorporate competition into their acquisition strategies.[2]

[2]The statutory requirement is that the acquisition strategy for each major defense acquisition program include measures to ensure competition, or the option of competition, throughout the life cycle of the program. Weapon Systems Acquisition Reform Act of 2009, Pub. L. No. 111-23, § 202. The survey question with respect to this requirement for major defense acquisition programs read "Does the program's acquisition strategy call for competition between Milestone B and the completion of production?" For future programs the question read "Does the program's technology development strategy or acquisition strategy call for competition between Milestone B and the completion of production?" When programs answered "no" to the question, we interpreted that answer to mean that the program is not planning to incorporate competition, or the option of competition, after development start into the acquisition strategy.

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To collect data from future major defense acquisition programs—including cost and schedule estimates, technology maturity, and planned implementation of acquisition reforms—we distributed an electronic survey to 22 programs planning to become major defense acquisition programs and enter system development or bypass system development and start production. Both the surveys for current and future major defense acquisition programs were sent by e-mail in an attached Microsoft Word form that respondents could return electronically. We received responses from August to October 2011. During the course of our review, we dropped six future programs from this analysis; four because of schedule changes that prevented them from entering technology development in 2011, one due to program cancellation, and one because the program did not respond fully to our data request. Therefore, our assessment of future major defense acquisition programs consists of 16 programs that will likely become major defense acquisition programs and are nearing system development start or proceeding directly to a production decision.

To ensure the reliability of the data collected through our surveys, we took a number of steps to reduce measurement error, nonresponse error, and respondent bias. These steps included conducting two pretests for the future major defense acquisition program survey and three pretests for the major defense acquisition program survey by phone prior to distribution to ensure that our questions were clear, unbiased, and consistently interpreted; reviewing responses to identify obvious errors or inconsistencies; conducting follow-up to clarify responses when needed; and verifying the accuracy of a sample of keypunched surveys.

To determine the amount DOD plans to invest in future major defense acquisition programs before entering system development or, for those planning to bypass system development, production, we collected budget data from the President's Budget for Fiscal Years 2007 through 2012 for each of the 16 future major defense acquisition programs we reviewed. For each program, we summed all planned funding from program start through, but not including, the fiscal year of the planned start of system development or production. We obtained the planned start date of system development from the survey we submitted to 16 future major defense acquisition programs or other program office documentation. For two programs that were planning to bypass system development, we used the planned date of production start. For the 92 current major defense acquisition programs that reported a system development or production start date in their December 2010 SAR, we used annual funding stream data from DAMIR to calculate the investment made in each program from

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program start through, but not including, the fiscal year of the start of system development or production start for programs that bypassed system development. We converted both sets of numbers to fiscal year 2012 constant dollars using conversion factors from the DOD Comptroller's National Defense Budget Estimates for Fiscal Year 2012 (table 5-9).

Individual Assessments of Weapon Programs

In total, this report presents individual assessments of 68 weapon programs. A table listing these programs is found in appendix VII. Out of these programs, 48 are captured in a two-page format discussing technology, design, and manufacturing knowledge obtained and other program issues. Thirty-seven of these 48 two-page assessments are of major defense acquisition programs, most of which are in development or early production; 5 assessments are of elements of MDA's BMDS; and 6 assessments are of programs that were projected to become major defense acquisition programs during or soon after our review. The remaining 20 programs are described in a one-page format that describes their current status. These programs include 14 future major defense acquisition programs, 2 major defense acquisition programs that are well into production, 1 element of MDA's BMDS, and 3 major defense acquisition programs that were recently terminated. Over the past several years, DOD has revised policies governing weapon system acquisitions and changed the terminology used for major acquisition events. To make DOD's acquisition terminology more consistent across the 68 program assessments, we standardized the terminology for key program events. For most individual programs in our assessment, "development start" refers to the initiation of an acquisition program as well as the start of engineering and manufacturing development. This coincides with DOD's milestone B. A few programs in our assessment have a separate "program start" date, which begins a pre–system development phase for program definition and risk-reduction activities. This "program start" date generally coincides with DOD's former terminology for milestone I or DOD's current milestone A. The "production decision" generally refers to the decision to enter the production and deployment phase, typically with low-rate initial production. The "initial capability" refers to the initial operational capability—sometimes called first unit equipped or required asset availability. For shipbuilding programs, the schedule of key program events in relation to acquisition milestones varies for each program. Our work on shipbuilding best practices has identified the detailed design contract award and the start of lead ship fabrication as the points in the acquisition process roughly equivalent to development start and design

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review for other programs. For MDA programs that do not follow the standard DOD acquisition model but instead develop systems' capabilities incrementally, we identify the key technology development efforts that lead to an initial capability.

For each program we assessed in a two-page format, we present cost, schedule, and quantity data at the program's first full estimate and an estimate from the latest SAR or the program office reflecting 2011 data where they were available. The first full estimate is generally the cost estimate established at milestone B—development start; however, for a few programs that did not have such an estimate, we used the estimate at milestone C—production start—instead. For shipbuilding programs, we used their planning estimates if those estimates were available. For systems for which a first full estimate was not available, we only present the latest available estimate of cost and quantities. For the other programs assessed in a one-page format, we present the latest available estimate of cost and quantity from the program office.

For each program we assessed, all cost information is presented in fiscal year 2012 dollars. We converted cost information to fiscal year 2012 dollars using conversion factors from the DOD Comptroller's National Defense Budget Estimates for Fiscal Year 2012 (table 5-9). We have depicted only the program's main elements of acquisition cost—research and development and procurement. However, the total program cost also includes military construction and acquisition-related operation and maintenance costs. Because of rounding and these additional costs, in some situations, total cost may not match the exact sum of the research and development and procurement costs. The program unit costs are calculated by dividing the total program cost by the total quantities planned. In some instances, the data were not applicable, and we annotate this by using the term "not applicable (NA)." The quantities listed refer to total quantities, including both procurement and development quantities.

The schedule assessment for each program is based on acquisition cycle time, defined as the number of months between program start and the achievement of initial operational capability or an equivalent fielding date. In some instances the data were not yet available, and we annotate this by using the term "to be determined (TBD)" or "NA."

The information presented on the "funding needed to complete" is from fiscal year 2012 through completion and, unless otherwise noted, draws

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on information from SARs or on data from the program office. In some instances, the data were not available, and we annotate this by the term "TBD" or "NA." The quantities listed refer only to procurement quantities. Satellite programs, in particular, produce a large percentage of their total operational units as development quantities, which are not included in the quantity figure.

The intent of these comparisons is to provide an aggregate, or overall, picture of a program's history. These assessments represent the sum of the federal government's actions on a program, not just those of the program manager and the contractor. DOD does a number of detailed analyses of changes that attempt to link specific changes with triggering events or causes. Our analysis does not attempt to make such detailed distinctions.

Product Knowledge Data on Individual Two-Page Assessments

In our past work examining weapon acquisition issues and best practices for product development, we have found that leading commercial firms pursue an acquisition approach that is anchored in knowledge, whereby high levels of product knowledge are demonstrated by critical points in the acquisition process. On the basis of this work, we have identified three key knowledge points during the acquisition cycle—system development start, critical design review, and production start—at which programs need to demonstrate critical levels of knowledge to proceed. To assess the product development knowledge of each program at these key points, we reviewed data-collection instruments and surveys submitted by programs; however, not every program had responses to each element of the data-collection instrument or survey. We also reviewed pertinent program documentation and discussed the information presented on the data-collection instrument and survey with program officials as necessary.

To assess a program's readiness to enter system development, we collected data on critical technologies and early design reviews. To assess technology maturity, we asked program officials to apply a tool, referred to as Technology Readiness Levels (TRL), for our analysis. The National Aeronautics and Space Administration originally developed TRLs, and the Army and Air Force science and technology research organizations use them to determine when technologies are ready to be handed off from science and technology managers to product developers. TRLs are measured on a scale from 1 to 9, beginning with paper studies of a technology's feasibility and culminating with a technology fully integrated into a completed product. See appendix V for TRL definitions. Our best-

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practices work has shown that a TRL 7—demonstration of a technology in a realistic environment—is the level of technology maturity that constitutes a low risk for starting a product development program.[3] For shipbuilding programs, we have recommended that this level of maturity be achieved by the contract award for detailed design.[4] In our assessment, the technologies that have reached TRL 7, a prototype demonstrated in a realistic environment, are referred to as mature or fully mature. Those technologies that have reached TRL 6, a prototype demonstrated in a relevant environment, are referred to as approaching or nearing maturity. Satellite technologies that have achieved TRL 6 are assessed as fully mature due to the difficulty of demonstrating maturity in a realistic environment—space. In addition, we asked program officials to provide the date of the preliminary design review. We compared this date to the system development start date.

In most cases, we did not validate the program offices' selection of critical technologies or the determination of the demonstrated level of maturity. We sought to clarify the TRLs in those cases where information existed that raised concerns. If we were to conduct a detailed review, we might adjust the critical technologies assessed, their readiness levels demonstrated, or both. It was not always possible to reconstruct the technological maturity of a weapon system at key decision points after the passage of many years. Where practicable, we compared technology assessments provided by the program office to assessments conducted by officials from the Office of the Assistant Secretary of Defense for Research and Engineering.

To assess design stability, we asked program officials to provide the percentage of design drawings completed or projected for completion by the design review, the production decision, and as of our current assessment.[5] In most cases, we did not verify or validate the percentage of engineering drawings provided by the program office. We clarified the

[3]GAO, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*, GAO/NSIAD-99-162 (Washington, D.C.: July 30, 1999); GAO, *Best Practices: Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes*, GAO-01-288 (Washington, D.C.: Mar. 8, 2001).

[4]GAO, *Best Practices: High Levels of Knowledge at Key Points Differentiate Commercial Shipbuilding from Navy Shipbuilding*, GAO-09-322 (Washington, D.C.: May 13, 2009).

[5]GAO, *Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*, GAO-02-701 (Washington, D.C.: July 15, 2002).

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percentage of drawings completed in those cases where information that raised concerns existed. Completed drawings were defined as the number of drawings released or deemed releasable to manufacturing that can be considered the "build to" drawings. For shipbuilding programs, we asked program officials to provide the percentage of the three-dimensional product model that had been completed by the start of lead ship fabrication, and as of our current assessment.[6] To gain greater insights into design stability, we also asked program officials to provide the date they planned to first integrate and test all key subsystems and components into a system-level integrated prototype. We compared this date to the date of the design review. We did not assess whether shipbuilding programs had completed integrated prototypes.

To assess production maturity, we asked program officials to identify the number of critical manufacturing processes and, where available, to quantify the extent of statistical control achieved for those processes.[7] In most cases, we did not verify or validate the information provided by the program office. We clarified the number of critical manufacturing processes and the percentage of statistical process control where information existed that raised concerns. We used a standard called the Process Capability Index, a process-performance measurement that quantifies how closely a process is running to its specification limits. The index can be translated into an expected product defect rate, and we have found it to be a best practice. We also used data provided by the program offices on their manufacturing readiness levels (MRL) for process capability and control, a subthread tracked as part of the manufacturing readiness assessment process recommended by DOD, to determine production maturity. We assessed programs as having mature manufacturing processes if they reported an MRL 9 for that subthread—meaning, that manufacturing processes are stable, adequately controlled, and capable. To gain further insights into production maturity, we asked program officials whether the program planned to demonstrate critical manufacturing processes on a pilot production line before beginning low-rate production. We also asked programs on what date they planned to begin system-level development testing of a fully configured, production-representative prototype in its intended environment. We compared this

[6]GAO-09-322.

[7]GAO-02-701.

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date to the production start date. We did not assess production maturity for shipbuilding programs.

Although the knowledge points provide excellent indicators of potential risks, by themselves they do not cover all elements of risk that a program encounters during development, such as funding instability. Our detailed reviews on individual systems normally provide a more comprehensive assessment of risk elements.

We conducted this performance audit from August 2011 to March 2012, in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

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Changes in DOD's 2011 Portfolio of Major Defense Acquisition Programs over Time

Table 6 shows the change in research and development cost, procurement cost, total acquisition cost, and average delay in delivering initial operational capability for the Department of Defense's (DOD) 2011 portfolio of major defense acquisition programs. The table presents changes that have occurred on these programs in the last year, the last 5 years, and since their first full cost and schedule estimates.

Table 6: Changes in DOD's 2011 Portfolio of Major Defense Acquisition Programs over Time

Fiscal year 2012 dollars in billions

	1 year comparison (2010 to 2011)	5 year comparison (2006 to 2011)	Since first full estimate (baseline to 2011)
Increase in total research and development cost	$14 billion 4 percent	$39 billion 14 percent	$113 billion 54 percent
Increase in total procurement cost	$61 billion 5 percent	$192 billion 19 percent	$321 billion 36 percent
Increase in total acquisition cost	$74 billion 5 percent	$233 billion 17 percent	$447 billion 40 percent
Average delay in delivering initial capabilities	1 month 2 percent	9 months 11 percent	23 months 32 percent

Source: GAO analysis of DOD data.

Notes: Data were obtained from DOD's Selected Acquisition Reports. In a few cases data were obtained directly from program offices. Not all programs had comparable cost and schedule data and these programs were excluded from the analysis where appropriate. Portfolio performance data do not include costs of developing Missile Defense Agency elements. Total acquisition cost includes research and development, procurement, acquisition operation and maintenance, and system-specific military construction costs.

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Current and First Full Cost Estimates for DOD's 2011 Portfolio of Major Defense Acquisition Programs

Table 7 contains the current and first full total acquisition cost estimates (in fiscal year 2012 dollars) for each program or element in the Department of Defense's (DOD) 2011 major defense acquisition program portfolio. We excluded elements of the Missile Defense Agency's Ballistic Missile Defense System because comparable current and first full cost estimates were not available. For each program we show the percent change in total acquisition cost from the first full estimate, as well as over the past year and 5 years.

Table 7: Current Cost Estimates and First Full Cost Estimates for DOD's 2011 Portfolio of Major Defense Acquisition Programs

Fiscal year 2012 dollars in millions

Program	Current total acquisition cost	First full total acquisition cost	Change in total acquisition cost from first full estimate (percent)	Change in total acquisition cost within the past year (percent)	Change in total acquisition cost within the past 5 years (percent)
Advanced Extremely High Frequency (AEHF) Satellite	$14,083	$6,370	121.1%	7.4%	106.6%
Advanced Threat Infrared Countermeasure/Common Missile Warning System (ATIRCM/CMWS)	4,853	3,414	42.2	1.7	-11.6
AGM-88E Advanced Anti-Radiation Guided Missile (AARGM)	1,902	1,601	18.8	2.7	20.7
AH-64D Longbow Apache	14,773	6,132	140.9	0.3	34.8
AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM)	23,582	10,931	115.7	-2.8	38.2
AIM-9X/Air-to-Air Missile	3,750	3,144	19.3	2.9	12.5
Airborne and Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS)	8,221	8,154	0.8	-1.4	0.8
Airborne Signals Intelligence Payload (ASIP) - Baseline	554	347	59.5	-0.1	NA
Apache Block IIIA (AB3A)	10,737	7,242	48.3	0.0	48.3
Apache Block IIIB New Build	2,215	2,370	-6.5	-6.5	-6.5
Army Integrated Air & Missile Defense (Army IAMD)	5,529	5,029	9.9	9.9	9.9
B-2 Extremely High Frequency SATCOM Capability, Increment 1	625	710	-11.9	-0.4	-11.9
B-2 Radar Modernization Program (RMP)	1,284	1,339	-4.1	-3.1	2.3
Black Hawk (UH-60M)	25,169	12,970	94.1	13.0	19.9

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(Continued From Previous Page)

Fiscal year 2012 dollars in millions

Program	Current total acquisition cost	First full total acquisition cost	Change in total acquisition cost from first full estimate (percent)	Change in total acquisition cost within the past year (percent)	Change in total acquisition cost within the past 5 years (percent)
Block IV Tomahawk (Tactical Tomahawk)	6,943	2,116	228.1	-0.1	54.8
Broad Area Maritime Surveillance (BAMS) Unmanned Aircraft System (UAS)	13,052	12,848	1.6	-1.3	1.6
C-130 Avionics Modernization Program (AMP)	6,204	4,132	50.1	1.0	25.7
C-130J Hercules	15,397	949	1522.5	-1.0	79.5
C-27J Spartan	2,260	3,912	-42.2	13.2	-42.2
C-5 Avionics Modernization Program (AMP)	1,282	1,103	16.2	-4.3	30.1
C-5 Reliability Enhancement and Reengining Program (RERP)	7,442	10,905	-31.8	-0.2	-29.3
CH-47F Improved Cargo Helicopter (CH-47F)	14,475	3,220	349.6	5.4	16.0
CH-53K - Heavy Lift Replacement	22,440	16,557	35.5	0.9	35.6
Chemical Demilitarization-Assembled Chemical Weapons Alternatives (Chem Demil-ACWA)	10,173	2,642	285.0	26.2	118.3
Chemical Demilitarization-U.S. Army Chemical Materials Agency (Chem Demil-CMA)	27,743	15,542	78.5	-4.0	-3.5
Cobra Judy Replacement (CJR)	1,825	1,631	11.9	0.1	12.6
Cooperative Engagement Capability (CEC)	5,209	2,943	77.0	1.4	2.5
CVN 78 Class	33,994	35,574	-4.4	-2.0	4.0
DDG 1000 Destroyer	20,986	34,800	-39.7	4.4	-41.7
DDG 51 Destroyer	101,819	15,186	570.5	6.3	29.3
E-2D Advanced Hawkeye (E-2D AHE)	17,747	14,752	20.3	-1.9	19.9
EA-18G Growler	11,411	8,976	27.1	-3.1	22.7
Expeditionary Fighting Vehicle (EFV)	3,705	9,157	-59.5	-74.0	-69.7
F/A-18E/F Super Hornet	57,805	81,732	-29.3	4.3	12.5
F-22 Raptor	79,152	91,291	-13.3	0.8	6.1
F-35 Lightning II (Joint Strike Fighter)	326,535	213,708	52.8	13.4	34.1
Family of Advanced Beyond Line-of-Sight Terminals (FAB-T)	4,503	3,188	41.2	12.9	41.2

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Fiscal year 2012 dollars in millions

Program	Current total acquisition cost	First full total acquisition cost	Change in total acquisition cost from first full estimate (percent)	Change in total acquisition cost within the past year (percent)	Change in total acquisition cost within the past 5 years (percent)
Family of Medium Tactical Vehicles (FMTV)	20,048	10,447	91.9	-7.3	13.7
Force XXI Battle Command Brigade and Below (FBCB2)	4,147	2,827	46.7	-0.7	51.8
Global Broadcast Service (GBS)	1,152	576	100.0	1.4	32.7
Global Hawk (RQ-4A/B)	13,992	5,392	159.5	1.5	68.4
Global Positioning System (GPS) III	4,332	3,941	9.9	3.1	9.9
Guided Multiple Launch Rocket System (GMLRS)	5,827	1,768	229.5	-0.4	-57.5
H-1 Upgrades (4BW/4BN)	12,557	3,627	246.3	4.3	55.5
HC/MC-130 Recapitalization Program	13,091	8,364	56.5	56.5	56.5
High Mobility Artillery Rocket System (HIMARS)	2,130	4,361	-51.2	-1.3	-35.8
Increment 1 Early-Infantry Brigade Combat Team	1,277	3,235	-60.5	-59.1	-60.5
Integrated Defensive Electronic Countermeasures (IDECM)	2,379	2,177	23.3	17.1	23.3
Integrated Defensive Electronic Countermeasures (IDECM) Blocks 2/3	1,558	1,483	5.0	0.2	5.0
Integrated Defensive Electronic Countermeasures (IDECM) Block 4	822	694	18.3	16.9	18.3
Joint Air-to-Surface Standoff Missile (JASSM)	7,509	2,318	224.0	2.7	49.9
Joint Direct Attack Munition	6,578	3,419	92.4	1.6	11.6
Joint High Speed Vessel (JHSV)	3,674	3,636	1.0	-1.3	1.0
Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS)	7,858	6,666	17.9	4.9	15.3
Joint Mine Resistant Ambush Protected (MRAP)	41,585	23,136	79.7	12.6	79.7
Joint Precision Approach and Landing System (JPALS)	983	1,012	-2.9	-0.3	-2.9
Joint Primary Aircraft Training System (JPATS)	5,724	3,725	53.7	-3.0	-0.3
Joint Standoff Weapon (JSOW)	5,589	7,947	-55.4	6.0	19.1

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Fiscal year 2012 dollars in millions

Program	Current total acquisition cost	First full total acquisition cost	Change in total acquisition cost from first full estimate (percent)	Change in total acquisition cost within the past year (percent)	Change in total acquisition cost within the past 5 years (percent)
Joint Standoff Weapon (JSOW) Baseline	2,269	2,856	-20.6	1.3	1.3
Joint Standoff Weapon (JSOW) Unitary	3,321	5,091	-34.8	4.7	17.8
Joint Tactical Radio System (JTRS) Ground Mobile Radios (GMR)	16,414	17,422	-5.8	1.9	0.6
Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS)	5,382	10,037	-46.4	10.8	-47.4
Joint Tactical Radio System (JTRS) Network Enterprise Domain (NED)	2,073	981	111.4	2.4	7.4
KC-130J	9,389	9,485	-1.0	-1.0	-1.0
Large Aircraft Infrared Countermeasures (LAIRCM)	459	403	13.8	-0.5	13.8
Lewis and Clark Class (T-AKE) Dry Cargo/Ammunition Ship	6,605	5,283	25.0	-1.2	37.0
LHA Replacement Amphibious Assault Ship	10,095	3,180	217.4	55.7	217.4
Light Utility Helicopter (LUH), UH-72A Lakota	2,000	1,811	10.4	0.1	10.6
Littoral Combat Ship (LCS)	32,868	2,244	NA	NA	NA
LPD 17 Amphibious Transport Dock	18,674	11,712	59.4	0.2	38.1
M982 155mm Precision Guided Extended Range Artillery Projectile (Excalibur)	1,813	4,776	-62.0	-26.7	-19.2
MH-60R Multi-Mission Helicopter	14,703	5,536	165.6	1.0	24.2
MH-60S Fleet Combat Support Helicopter	8,417	3,508	139.9	-0.3	2.2
Mobile User Objective System (MUOS)	6,978	6,721	3.8	0.7	17.5
MQ-1C UAS Gray Eagle	5,159	1,015	408.2	2.0	159.9
Multifunctional Information Distribution System (MIDS)	3,024	1,304	131.8	1.4	19.7
Multi-Platform Radar Technology Insertion Program (MP-RTIP)	1,427	1,796	-20.6	3.1	-17.7
National Airspace System (NAS)	1,658	868	90.9	2.2	5.6

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Fiscal year 2012 dollars in millions

Program	Current total acquisition cost	First full total acquisition cost	Change in total acquisition cost from first full estimate (percent)	Change in total acquisition cost within the past year (percent)	Change in total acquisition cost within the past 5 years (percent)
National Polar-orbiting Operational Environmental Satellite System (NPOESS)	7,272	6,683	8.8	13.6	-47.3
Navstar Global Positioning System (GPS)	9,110	7,206	74.8	-29.7	-2.1
Navstar Global Positioning System (GPS) Space & Control	7,602	6,217	22.3	1.7	1.0
Navstar Global Positioning System (GPS) User Equipment	1,508	989	52.5	-31.4	-3.1
Navy Multiband Terminal	1,881	2,321	-19.0	-7.6	-19.0
P-8A Poseidon	32,969	31,034	6.2	0.4	8.7
Patriot Advanced Capability-3 (PAC-3)	11,581	5,213	122.2	6.0	14.1
PATRIOT/Medium Extended Air Defense System (MEADS) Combined Aggregate Program (CAP)	11,310	26,650	-73.7	-80.2	-70.3
PATRIOT/Medium Extended Air Defense System (MEADS) Combined Aggregate Program (CAP) Fire Unit	3,373	19,363	-82.6	-82.1	-82.1
PATRIOT/Medium Extended Air Defense System (MEADS) Combined Aggregate Program (CAP) Missile	7,937	7,287	8.9	1.9	11.8
Reaper Unmanned Aircraft System (UAS)	11,892	2,637	351.0	5.2	351.0
Remote Minehunting System	1,414	1,442	-1.9	9.2	-1.9
Sea Launched Ballistic Missile - UGM 133A Trident II (D-5) Missile	53,232	51,724	2.9	2.0	4.9
Small Diameter Bomb (SDB) Increment II	4,696	4,702	-0.1	-0.1	-0.1
Space Based Infrared System (SBIRS) High Program	18,339	4,597	299.0	13.2	61.6
Space Based Space Surveillance (SBSS) Block 10	972	872	11.4	3.8	11.4
Standard Missile-6 (SM-6) Extended Range Active Missile (ERAM)	6,297	5,700	10.5	1.2	13.8
Stryker Family of Vehicles (Stryker)	18,213	8,033	126.7	11.1	47.4

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Fiscal year 2012 dollars in millions

Program	Current total acquisition cost	First full total acquisition cost	Change in total acquisition cost from first full estimate (percent)	Change in total acquisition cost within the past year (percent)	Change in total acquisition cost within the past 5 years (percent)
V-22 Joint Services Advanced Vertical Lift Aircraft (OSPREY)	57,211	40,099	42.7	0.5	5.2
Vertical Take-off and Landing Tactical Unmanned Aerial Vehicle (VTUAV)	2,615	2,615	0.0	4.3	0.0
Virginia Class Submarine (SSN 774)	83,746	60,449	38.5	0.4	-6.0
Warfighter Information Network-Tactical (WIN-T) Increment 2	6,053	3,708	63.2	25.7	63.2
Warfighter Information Network-Tactical (WIN-T) Increment 3	13,871	16,368	-15.3	0.8	-15.3
Warfighter Information Network-Tactical (WIN-T) Increment I	4,505	4,087	10.2	10.8	10.2
Wideband Global SATCOM (WGS)	3,674	1,194	207.8	1.7	67.8

Source: GAO analysis of DOD data.

Notes: Data were obtained from DOD's Selected Acquisition Reports, acquisition program baselines, and, in some cases, program offices. Percent change in total acquisition cost for the Littoral Combat Ship program is shown as "NA" because DOD reported incomplete baseline and cost data for the program through 2010.

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Knowledge-Based Acquisition Practices

GAO's prior work on best product-development practices found that successful programs take steps to gather knowledge that confirms that their technologies are mature, their designs stable, and their production processes are in control. Successful product developers ensure a high level of knowledge is achieved at key junctures in development. We characterize these junctures as knowledge points. The Related GAO Products section of this report includes references to the body of work that helped us identify these practices and apply them as criteria in weapon system reviews. The following summarizes these knowledge points and associated key practices.

Knowledge Point 1: Technologies, time, funding, and other resources match customer needs. Decision to invest in product development
Demonstrate technologies to a high readiness level—Technology Readiness Level 7—to ensure technologies will work in an operational environment
Ensure that requirements for product increment are informed by preliminary design review using systems engineering process (such as prototyping of preliminary design)
Establish cost and schedule estimates for product on the basis of knowledge from preliminary design using systems engineering tools (such as prototyping of preliminary design)
Constrain development phase (5 to 6 years or less) for incremental development
Ensure development phase fully funded (programmed in anticipation of milestone)
Align program manager tenure to complete development phase
Contract strategy that separates system integration and system demonstration activities
Conduct independent cost estimate
Conduct independent program assessment
Conduct major milestone decision review for development start
Knowledge Point 2: Design is stable and performs as expected. Decision to start building and testing production-representative prototypes
Complete system critical design review
Complete 90 percent of engineering design drawing packages
Complete subsystem and system design reviews
Demonstrate with system-level integrated prototype that design meets requirements
Complete the failure modes and effects analysis
Identify key system characteristics
Identify critical manufacturing processes
Establish reliability targets and growth plan on the basis of demonstrated reliability rates of components and subsystems

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Conduct independent cost estimate
Conduct independent program assessment
Conduct major milestone decision review to enter system demonstration
Knowledge Point 3: Production meets cost, schedule, and quality targets. Decision to produce first units for customer
Demonstrate manufacturing processes
Build and test production-representative prototypes to demonstrate product in intended environment
Test production-representative prototypes to achieve reliability goal
Collect statistical process control data
Demonstrate that critical processes are capable and in statistical control
Conduct independent cost estimate
Conduct independent program assessment
Conduct major milestone decision review to begin production

Source: GAO.

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Technology Readiness Levels

Technology Readiness Level		Description	Hardware/software	Demonstration environment
1.	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.	None (paper studies and analysis)	None
2.	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.	None (paper studies and analysis)	None
3.	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Analytical studies and demonstration of nonscale individual components (pieces of subsystem)	Lab
4.	Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.	Low-fidelity breadboard. Integration of nonscale components to show pieces will work together. Not fully functional or form or fit but representative of technically feasible approach suitable for flight articles.	Lab
5.	Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.	High-fidelity breadboard. Functionally equivalent but not necessarily form and/or fit (size, weight, materials, etc). Should be approaching appropriate scale. May include integration of several components with reasonably realistic support elements/subsystems to demonstrate functionality.	Lab demonstrating functionality but not form and fit. May include flight demonstrating breadboard in surrogate aircraft. Technology ready for detailed design studies.

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Technology Readiness Level		Description	Hardware/software	Demonstration environment
6.	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated realistic environment.	Prototype. Should be very close to form, fit, and function. Probably includes the integration of many new components and realistic supporting elements/subsystems if needed to demonstrate full functionality of the subsystem.	High-fidelity lab demonstration or limited/restricted flight demonstration for a relevant environment. Integration of technology is well defined.
7.	System prototype demonstration in a realistic environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in a realistic environment, such as in an aircraft, a vehicle, or space. Examples include testing the prototype in a test bed aircraft.	Prototype. Should be form, fit, and function integrated with other key supporting elements/subsystems to demonstrate full functionality of subsystem.	Flight demonstration in representative realistic environment such as flying test bed or demonstrator aircraft. Technology is well substantiated with test data.
8.	Actual system completed and "flight qualified" through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	Flight-qualified hardware	Developmental Test and Evaluation (DT&E) in the actual system application.
9.	Actual system "flight proven" through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.	Actual system in final form	Operational Test and Evaluation (OT&E) in operational mission conditions.

Source: GAO and its analysis of National Aeronautics and Space Administration data.

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Comments from the Department of Defense

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

MAR 14 2012

Mr. Michael J. Sullivan
Director, Acquisition and Sourcing Management
U.S. Government Accountability Office
441 G Street, NW
Washington, DC 20548

Dear Mr. Sullivan:

This is the Department of Defense response to the GAO Draft Report, GAO-12-400SP, "DEFENSE ACQUISITIONS: Assessments of Selected Weapon Programs," dated February 15, 2012 (GAO Code 120990).

The Department notes that this is the 10th annual report on this topic, and we appreciate the positive working relationship we have built with GAO over time and your efforts to develop improved methods and metrics. As you are aware, we still do not fully agree with the GAO cost growth metrics, nor with how GAO measures adequate knowledge for programs to proceed through the acquisition process. We have been making serious strides in getting cost growth under control, and we appreciate that you acknowledge those efforts, including those to implement WSARA and the Better Buying Power initiatives in your report.

We do not disagree with the data used in preparation of your report, or that cost growth, as a simplistic metric, has occurred. What the aggregate measures in the report fail to adequately address are basic questions of when, why, and how it occurred. Nor does the report make obvious in the aggregate measures and discussion, that the portfolio changes every year and the cost of programs often increases or decreases for reasons other than overly optimistic planning, faulty estimating, or poor execution. These are the problems the Department is working aggressively to isolate and address. The Department believes that other "cost growth" sources contributing to the aggregate numbers in the report, such as reacting to changing requirements, funding block or incremental upgrades to fielded systems, changing inventory goals, and adjustments to production rates, need to be segregated from the sources of cost growth the Department is properly focused on. We appreciate your efforts toward this end.

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The Department appreciates the opportunity to comment on the draft report. Please feel free to call me, at 703-614-5737, if you have any questions.

Sincerely,

Nancy L. Spruill

Nancy L. Spruill
Director
Acquisition Resources & Analysis

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GAO Contact and Acknowledgments

GAO Contact

Michael J. Sullivan, (202) 512-4841 or sullivanm@gao.gov

Acknowledgments

Principal contributors to this report were Ronald E. Schwenn, Assistant Director; J. Kristopher Keener; Deanna R. Laufer; Jenny Shinn; and Wendy P. Smythe. Other key contributors included Letisha Antone, David B. Best, Maricela Cherveny, Bruce D. Fairbairn, Arthur Gallegos, William R. Graveline, Kristine R. Hassinger, Julia M. Kennon, C. James Madar, Jean L. McSween, Diana L. Moldafsky, Kenneth E. Patton, Scott Purdy, Rae Ann H. Sapp, Roxanna T. Sun, and Bruce H. Thomas.

The following were responsible for individual programs:

System	Primary staff
Advanced Extremely High Frequency (AEHF) Satellite	Bradley L. Terry
AGM-88 Advanced Anti-Radiation Guided Missile (AARGM)	Scott Purdy, Christopher R. Durbin
Air and Missile Defense Radar (AMDR)	Ioan T. Ifrim, W. Kendal Roberts
Airborne and Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS)	Paul G. Williams
Apache Block IIIA (AB3A)	Helena Brink, Andrea M. Bivens
Army Integrated Air and Missile Defense (IAMD)	Carol T. Mebane, Matt Shaffer
B-2 Defensive Management System (DMS) Modernization	Matthew P. Lea
B-2 Extremely High Frequency SATCOM Capability, Increment 1	Sean D. Merrill, Don M. Springman
B-2 Extremely High Frequency SATCOM Capability, Increment 2	Don M. Springman, Sean D. Merrill
BMDS: Aegis Ashore	Ann F. Rivlin, Luis E. Rodriguez
BMDS: Aegis Ballistic Missile Defense Standard Missile-3 Block IB	Luis Rodriguez, Ann F. Rivlin
BMDS: Aegis Ballistic Missile Defense Standard Missile-3 Block IIA	Ann F. Rivlin, Luis Rodriguez
BMDS: Aegis Ballistic Missile Defense Standard Missile-3 Block IIB	Ann F. Rivlin, Luis Rodriguez
BMDS: Ground-Based Midcourse Defense (GMD)	Steven B. Stern
BMDS: Terminal High Altitude Area Defense (THAAD)	LaTonya D. Miller
C-130 Avionics Modernization Program (AMP)	Cheryl K. Andrew, Kathy Hubbell
CH-53K - Heavy Lift Replacement (HLR)	Robert K. Miller, Marvin E. Bonner
Combat Rescue Helicopter (CRH)	Jessica A. Drucker, J. Andrew Walker
Common Infrared Countermeasures (CIRCM)	Danny G. Owens
Common Vertical Lift Support Platform (CVLSP)	Travis J. Masters, Robert K. Miller
CVN 78 Class	Robert P. Bullock, W. Kendal Roberts

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System	Primary staff
DDG 1000 Destroyer	Gavin Ugale, Deanna R. Laufer
DDG 51 Destroyer	C. James Madar, G. Michael Mikota
E-2D Advanced Hawkeye (E-2D AHE)	Jeffrey L. Hartnett, Teague A. Lyons
Enhanced Polar System (EPS)	Bradley L. Terry
Excalibur Precision Guided Extended Range Artillery Projectile	Wendy P. Smythe
Expeditionary Fighting Vehicle (EFV)	MacKenzie H. Cooper, Jerry W. Clark
F-22 Modernization Increment 3.2B	Sean Seales, Marvin E. Bonner
F-35 Lightning II (Joint Strike Fighter)	LeAnna Parkey, Charlie Shivers
Family of Advanced Beyond Line-of-Sight Terminals (FAB-T)	Alexandra K. Dew
Global Hawk (RQ-4A/B)	Laura Jezewski, Rae Ann H. Sapp
Global Positioning System (GPS) III	Laura T. Holliday
GPS III OCX Ground Control Segment	Arturo Holguin, Jr.
Gray Eagle Unmanned Aircraft System	Tana M. Davis
Ground Combat Vehicle (GCV)	Marcus C. Ferguson
HC/MC-130 Recapitalization Program	Brian T. Smith, Christopher R. Durbin
Integrated Defensive Electronic Countermeasures (IDECM) Block 4	James Kim, Christopher R. Durbin
Joint Air-to-Ground Missile (JAGM)	Carrie W. Rogers, Greg Campbell
Joint Air-to-Surface Standoff Missile Extended Range (JASSM-ER)	John W. Crawford, Michael J. Hesse
Joint High Speed Vessel (JHSV)	Jenny Shinn, J. Kristopher Keener
Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS)	John M. Ortiz
Joint Light Tactical Vehicle (JLTV)	Dayna L. Foster
Joint Precision Approach and Landing System (JPALS)	Stephen V. Marchesani, Sally Williamson
Joint Tactical Radio System (JTRS) Ground Mobile Radios (GMR)	Ann Marie Udale, Guisseli Reyes-Turnell
Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS)	Nathan A. Tranquilli, David A. Garcia
KC-46 Tanker Replacement Program	Wendel K. Hudson, Mary Jo Lewnard
LHA Replacement Amphibious Assault Ship	Celina F. Davidson, Ramzi N. Nemo
Littoral Combat Ship (LCS)	Rebecca A. Wilson, Molly W. Traci
Littoral Combat Ship–Mission Modules	Laurier R. Fish, Mya Dinh, Gwyneth B. Woolwine
Mobile User Objective System (MUOS)	Richard Y. Horiuchi, Desirée E. Cunningham
MQ-4C Broad Area Maritime Surveillance (BAMS) Unmanned Aircraft System (UAS)	W. William Russell IV, Tom Twambly, Joseph Fread
Navy Multiband Terminal (NMT)	Lisa P. Gardner
Nett Warrior	William C. Allbritton
Ohio-Class Replacement (OR)	C. James Madar, G. Michael Mikota
P-8A Poseidon	Kathryn M. Edelman, Lina J. Khan

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System	Primary staff
Patriot/Medium Extended Air Defense System (MEADS) Combined Aggregate Program (CAP) Fire Unit	Ryan D. Stott, Carol T. Mebane
Presidential Helicopter (VXX)	Teakoe S. Coleman, Jerry W. Clark
Reaper Unmanned Aircraft System (UAS)	Rae Ann H. Sapp, Laura Jezewski
Ship to Shore Connector (SSC)	Meghan Hardy, Molly W. Traci
Small Diameter Bomb (SDB) Increment II	Michael J. Hesse, John W. Crawford
Space Based Infrared System (SBIRS) High Program	Claire Buck
Space Fence	Peter E. Zwanzig, Maricela Cherveny
Standard Missile-6 (SM-6) Extended Range Active Missile (ERAM)	Angie Nichols-Friedman, Wiktor Niewiadomski
Three Dimensional Expeditionary Long Range Radar (3DELRR)	Claire Li, Janet McKelvey
Unmanned Carrier-Launched Airborne Surveillance and Strike System (UCLASS)	Julie C. Hadley, Travis J. Masters
Vertical Take-off and Landing Tactical Unmanned Aerial Vehicle (VTUAV)	Leigh Ann Nally, John Lack
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FINAL REPORT

Use of sUAS/UAS to Cost Effectively Monitor Eagle Nesting

ESTCP Project RC18-5046

DECEMBER 2020

Samantha Phillips
Select Engineering Services

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14. ABSTRACT
Dugway Proving Ground (DPG), located in west-central Utah, is a U.S. Department of Defense (DoD) test site for chemical and biological defensive testing; it is also home to multiple breeding pairs of golden eagles (Aquila chrysaetos). The presence of an eagle nest has the potential to stop military testing and training due to potential nest disturbance. It is vital to DPG and similar DoD installations to fully understand the status of in-use eagle nests on military lands. Using Unmanned Aircraft Systems (UAS) and Small Unmanned Aircraft Systems (sUAS), it may be possible to obtain accurate status updates of eagle nests on DoD lands more efficiently than can be accomplished on foot. The DPG Team designed a blind study conducting weekly golden eagle nest surveys on DPG to compare the effectiveness of sUAS, UAS, and ground observers.

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FINAL REPORT
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ACRONYMS AND ABBREVIATIONS

AGATCS	Army Ground Aerial Target Control System
AWR	Airworthiness Release
BGEPA	Bald and Golden Eagle Protection Act
CIO	Chief Information Officer
COTS	Commercial Off The Shelf
DoD	Department of Defense
DPG	Dugway Proving Ground
ETP	Exemption to Policy
FAA	Federal Aviation Administration
HWI	HawkWatch International
MBTA	Migratory Bird Treaty Act
MRTFB	Major Range and Test Facility Base
NDAA	National Defense Authorization Act
PIC	Pilot in Command
POC	Point Of Contact
RIAC	Rapid Integration and Acceptance Center
SES	Select Engineering Services
SIPR	Secret Internet Protocol Router
sUAS	Small Unmanned Aircraft System
TSMO	Threat System Management Office
UAS	Unmanned Aircraft System
USFWS	US Fish and Wildlife Service
UXO	Unexploded Ordinance Training
VLOS	Visual Line-Of-Sight

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ABSTRACT

INTRODUCTION AND OBJECTIVES

Dugway Proving Ground (DPG), located in west-central Utah, is a U.S. Department of Defense (DoD) test site for chemical and biological defensive testing; it is also home to multiple breeding pairs of golden eagles (*Aquila chrysaetos*). The presence of an eagle nest has the potential to stop military testing and training due to potential nest disturbance. It is vital to DPG and similar DoD installations to fully understand the status of in-use eagle nests on military lands. Using Unmanned Aircraft Systems (UAS) and Small Unmanned Aircraft Systems (sUAS), it may be possible to obtain accurate status updates of eagle nests on DoD lands more efficiently than can be accomplished on foot. The DPG Team designed a blind study conducting weekly golden eagle nest surveys on DPG to compare the effectiveness of sUAS, UAS, and ground observers.

TECHNOLOGY DESCRIPTION

The DPG Team conducted weekly golden eagle nest surveys on DPG during the 2019 and 2020 nesting seasons, using a blind study design, to compare the effectiveness of three "survey systems": 1) a ground-based human observer, 2) a commercially available small Unmanned Aircraft System *(sUAS; DJI Matrice M600 and E Mergent RC E900),* and 3) a military-grade UAS platform *(MQ-1C Gray Eagle).*

PERFORMANCE AND COST ASSESSMENT

No single platform was clearly superior across all seasons and periods of observation. During the 2019 season, the sUAS observation team proved the most efficient at locating in-use and unknown nests, but it was more expensive than the ground observer (annual operation cost of approx. $130k for the sUAS, versus $20k for the ground observer). The UAS team did not observe frequently enough to be directly compared but appeared to be most efficient observing well-known nests with lots of metadata to reference. UAS costs were not directly assessed, as they operate as part of a larger installation program. Results differed significantly during the 2020 season after the sUAS platform used in 2019 was prohibited from use under the FY19 National Defense Authorization Act (NDAA). In 2020, the sUAS team had trouble locating nests or identifying status due to the change in platform/payload and was not as efficient as the ground observer. The results indicate that the use of an sUAS is effective but may not yet be able to cost-effectively replace ground monitoring. For instances where the nests are too high or terrain too rugged, sUAS are especially effective. As the cost of the sUAS system is reduced and the policy surrounding flying sUAS in DoD airspace is streamlined, it may become cost-effective compared to on-the-ground monitoring.

IMPLEMENTATION ISSUES

A major implementation issue with the use of sUAS in DoD airspace involves obtaining an Airworthiness Release (AWR) and Exemption to Policy (ETP). Both approvals take time to develop, review, and obtain approval. Good metadata and a member of the team that has experience with eagle behavior and good knowledge of the territory is key to obtaining useful data. The UAS observation method was the most uncertain and it proved to be unreliable as a method of weekly nest observations due to scheduling and payload restrictions. If the nest location was well known, the UAS was by far the fastest and most efficient observation method. However, the nature of the platform's flight and approach patterns made detailed nest metadata critical to the success of the survey.

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EXECUTIVE SUMMARY

INTRODUCTION

Dugway Proving Ground (DPG), located in remote west-central Utah, serves as a Major Range Test and Facility Base (MRTFB) test site for chemical and biological defensive testing, battlefield smokes, and obscurants. In addition, DPG is home to multiple breeding pairs of golden eagles, which are protected under the Bald and Golden Eagle Protection Act (BGEPA) and the Migratory Bird Treaty Act (MBTA). Due to these regulatory drivers, the presence of an eagle nest has the potential to restrict military testing and training if military activity causes nest disturbance. It is therefore vital to the function of DPG and similar DoD testing and training ranges to fully understand the location and status of in-use eagle nests or territories on military lands.

Current survey techniques of nesting golden eagles on DPG and active DoD training properties require long-distance viewing of each nest from the ground at least weekly, which is both time-consuming, costly, and may not always provide a definitive status of nest changes *(Weissensteiner and Poelstra 2015)* due to limited visibility from the ground. Using both military-grade and commercial Unmanned Aircraft Systems (UAS)/Small Unmanned Aircraft Systems (sUAS), it is possible to obtain highly accurate locations and status updates of in-use golden eagle nests on DoD lands, data that is critical to maintaining open testing and training ranges for as much time as possible in the eagle nesting season *(Chabot and Bird 2015, Hodgson et al. 2016, Junda et al. 2015, Weissensteiner and Poelstra 2015)*. The sUAS/UAS can be used to detect new nests in areas that are difficult to see or access from the ground, as well as count nestlings and track nesting milestones in a less time-invasive manner not previously possible *(Weissensteiner and Poelstra 2015)*. All of this can be accomplished with greatly reduced disturbance to the nesting pairs *(through reduced time in the area)*, crucial to the success of sensitive nesters such as the golden eagle *(Chabot and Bird 2015, Scobie and Hugenholtz 2016, Weissensteiner and Poelstra 2015)*.

OBJECTIVES

Select Engineering Services (SES), in coordination with DPG, the Rapid Integration and Acceptance Center (RIAC), Threat Systems Management Office (TSMO), and HawkWatch International (HWI), hereinafter referred to as the DPG Team, developed this technology demonstration to demonstrate the use of sUAS/UAS as a cost-effective way to monitor golden eagles on military installations. Currently it takes approximately 960 hours to conduct on-the-ground monitoring of eagle nests for approximately six months *(based upon actual numbers provided by DPG and SES experience).* The primary objective was to reduce the total hours required to monitor the nests and evaluate the cost-effectiveness of using sUAS/UAS over in-person ground based monitoring. Other objectives of the demonstration included the following:

- Efficiencies of scale to monitor more nests in less time for a lower cost
- Demonstrated the effectiveness of sUAS/UAS versus on-the-ground observation
- Improved quality of still photos and videos for further analysis
- Demonstrated use of sUAS/UAS as safe and low disturbance to the eagles
- Demonstrated use of sUAS/UAS to enable greater access to the nest and ability to collect more detailed data

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- Demonstrated use of sUAS/UAS as more efficient in finding nests in particular settings such as hidden/remote terrain

TECHNOLOGY DESCRIPTION

The DPG Team conducted weekly golden eagle nest surveys on DPG during the 2019 and 2020 nesting seasons to compare the effectiveness of three "survey systems": 1) a ground-based human observer, 2) a commercially available sUAS, and 3) one or more military-grade UAS platform(s). These nest surveys were conducted as a blind study; none of the three teams of observers encountered one another in the field. None exchanged information concerning the nest surveys, and none had any access to data generated by surveys conducted by any of the other teams.

sUAS/UAS Platform Descriptions

In the 2019 study season, a DJI Matrice sUAS platform was procured with an approved DoD software patch, through the Army Ground Aerial Target Control System (AGATCS), in partnership with the TSMO. DJI Zenmuse Z30 cameras were used as the operational payload, with 32x optical zoom allowing for long-range HD observations. This system was approved for use during the 2019 nesting season. However, in December 2019 the National Defense Authorization Act (NDAA) was signed which stated that DoD could not operate or enter into or renew a contract for the procurement of a covered unmanned aircraft system that is manufactured in a covered foreign country. Foreign country was defined as People's Republic of China. sUAS platforms by DoD programs except in the case of sUAS counter-defense testing. This language was strictly interpreted to prevent the use of the modified DJI Matrice that was used the previous year. This led the DPG Team to seek out another option. Through discussions with TMSO, an alternative sUAS was identified for use, the E Mergent RC E900 platform. The two E900s were integrated with Sony FCB-EV7520A camera payloads.

DPG is also home to the Rapid Integration and Acceptance Center (RIAC) which was established by the Project Manager Unmanned Aircraft Systems to create a single location where unmanned and manned aircraft could complete end-to-end testing and integration. DPG coordinated with RIAC to conduct monitoring flights when they were not conducting mission flights. RIAC identified a military UAS platform that would be most suitable for this type of flight plan: the MQ-1C Gray Eagle.

Survey Methods

The DPG Team conducted weekly golden eagle nest surveys on DPG during the 2019 and 2020 nesting seasons to compare the effectiveness of three "survey systems": 1) a ground-based human observer, 2) a commercially available small Unmanned Aircraft System, and 3) one or more military-grade UAS platform(s). The ground-observer was a single vehicle-based biologist; the sUAS system included three personnel *(commercial pilot, observer, and biologist for video monitoring)*; and the military UAS required three personnel *(military pilot, military camera operator, and civilian biologist for video monitoring)*. All three biologists associated with each survey approach had comparable familiarity with existing DPG eagle territories and previous eagle nest monitoring experience.

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The DPG Team generated territory-specific data sheets that specify known nests within 11 known territories on DPG, nest survey order based on historic use patterns, and other detailed survey instructions. The UAS observation team conducted a separate territory and nest survey effort designed to test the platform's capabilities as a precision, on demand survey system for areas with little to no ground access. Two senior DPG environmental staff provided weekly oversight of data collected by all three survey systems and collated survey results to ascertain the weekly "benchmark" status of each territory, and to ensure survey protocols were properly followed. Camera data from a subset of nests were also used to provide retrospective verification and correction of weekly status.

Each annual survey was segmented into two time-periods: the "early season", defined as 10 February–14 April *(9–10 weeks)* and the "late season", defined as 15 April–30 June *(12 weeks)*. The primary goal of the early season surveys was to document "Occupied Territories" (pair of adults present), "In-Use Nests" (nest with eggs or young), and "Vacant Territories" (no in-use nests and no adult birds in territory), while the goal of late season surveys was to track In-Use Nest to "Success" *(at least one nestling surviving to 80% fledge age)* or "Failure" *(terms adapted from Steenhof et al. [2017]).* During the early season, all 11 territories were surveyed every two weeks *(e.g., 6 one week, five the next).* In contrast, late season surveys were restricted to In-Use Nests found during the early season surveys, plus any territories with unresolved status.

For ground and sUAS survey systems, independent teams attempted to survey each nest from outside an 800-m horizontal protective buffer *(as widely prescribed on public lands and suggested by Romin and Muck [2002]).* Biologists associated with each survey system recorded eagle response behavior *(i.e., any agitation or flushing observed while conducting nest surveys).*

Surveys conducted for each platform followed specific territory and nest survey protocols to ensure comparable methods were employed and to facilitate the capture of detailed time-keeping records associated with specific survey tasks. Biologists for each survey system recorded total daily "Survey Time", which began upon departure from English Village *(ground and sUAS)* or initiation of take-off from the DPG airfield (UAS) and continued until return to same location at the end of the survey effort. For each platform, "Territory Survey Time" was noted, starting when entering into a 2km buffer around known nests associated with each territory, and continuing until status was confirmed, and the survey was complete, or a 3-hr time limit was reached. Time spent within each territory involved in "Area Search" *(general scanning overall area for adult and nesting evidence),* "Nest Search" *(prescribed order survey of known nests),* and "Extended Search" *(searching for new or uncatalogued nests)* was also recorded. Surveyors used standardized terminology established in this document and photographic guides to age eagle nestlings *(Driscoll 2010, Hoechlin 1976).*

PERFORMANCE ASSESSMENT

Time to Early Season Status

The ground observer and the sUAS took roughly the same amount of time to determine early season territory occupancy each year, even with the change in sUAS platform in 2020. The UAS platform was rarely able to make definitive determinations within the given time allowed, and its data was subsequently not comparable to the other platforms. Most of the time required by both the sUAS and ground observer was taken by drive time between nests in a territory.

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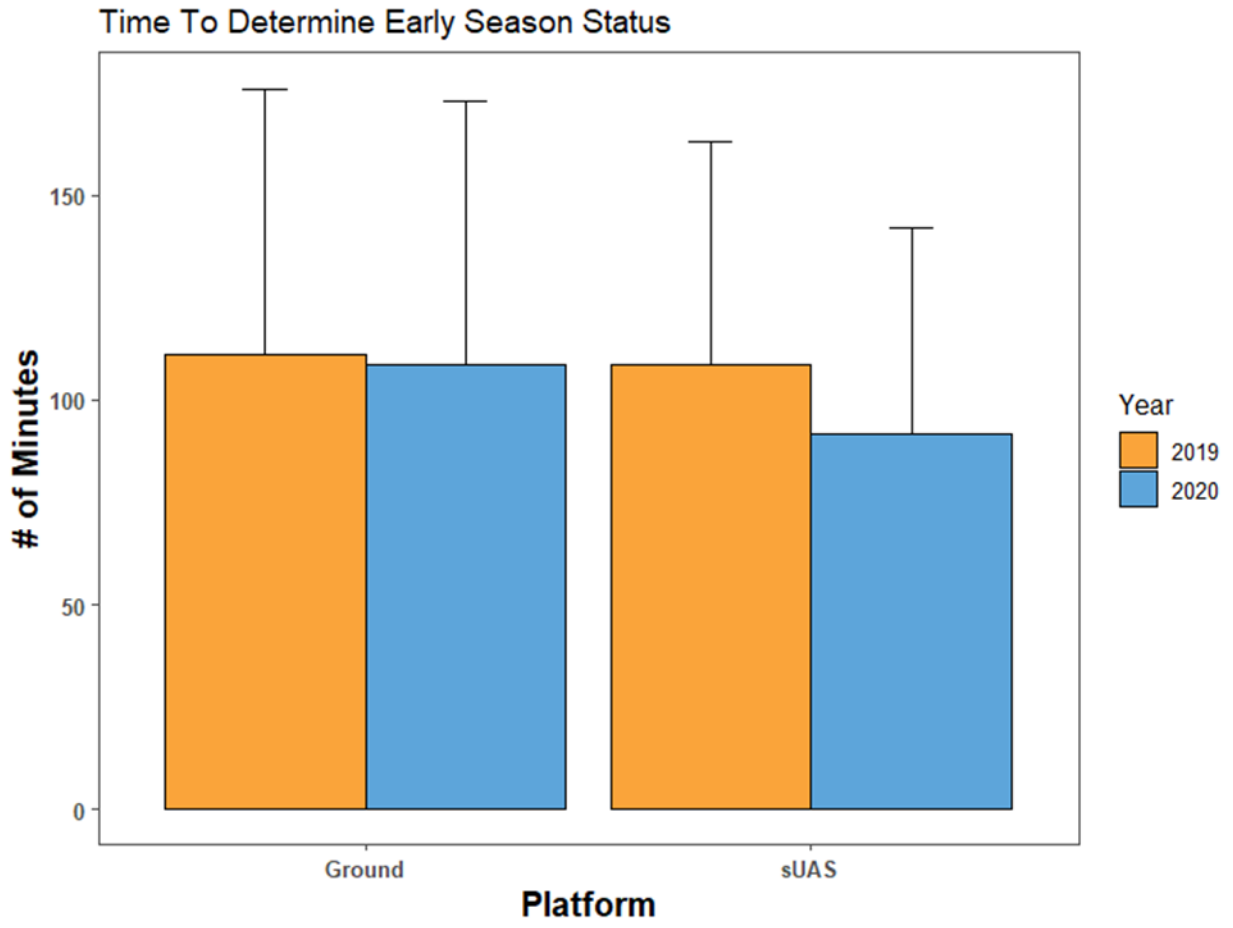


Figure ES-1. Chart Showing the Mean Time in Minutes (+SD) Each Platform Required to Determine the Early Season Occupancy of a Territory.

Date of In-Use Nest Identification

The sUAS platform was roughly equal with the ground observer at detecting in-use nests in 2019. The sUAS platform was able to survey almost every known nest in each assigned territory each week, making it more likely for the platform to detect an incubating eagle within a week of nesting initiation. The ground observer, on the other hand, was forced to rotate which nests were surveyed during each visit due to long hikes over rough terrain. The 2019 UAS was typically not able to identify nest activity due to the low resolution of its payload and the lack of precise nest metadata provided to its pilots and was not compared. In 2020 the sUAS was again roughly equal to the gound observer in nest detection time, despite the sUAS's drop in payload resolution. This indicates that the advantage of visiting more nests outweighed the disadvantage of poor payload resolution. In 2020, the UAS platform was forced to cease surveys before nests became in-use, removing it from this comparison.

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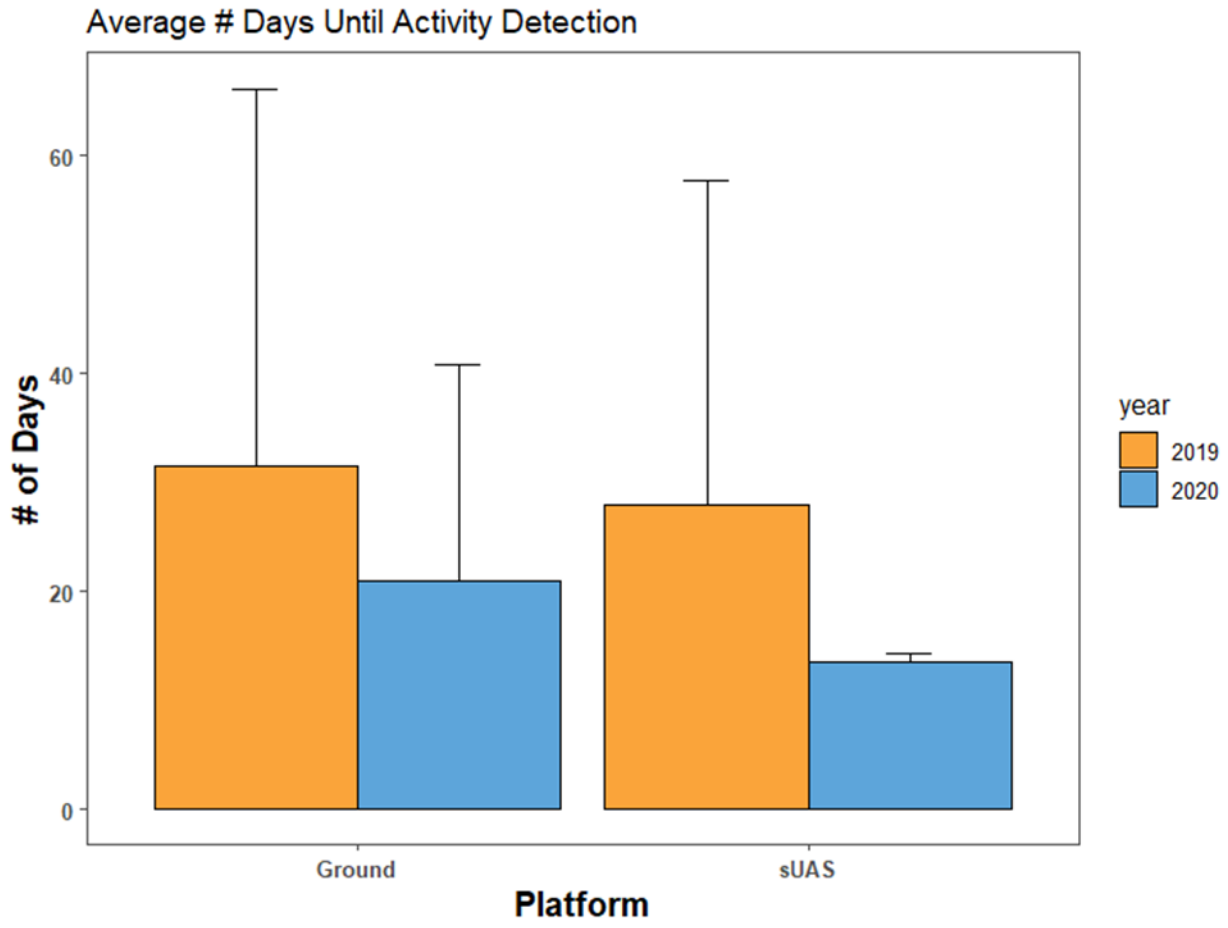
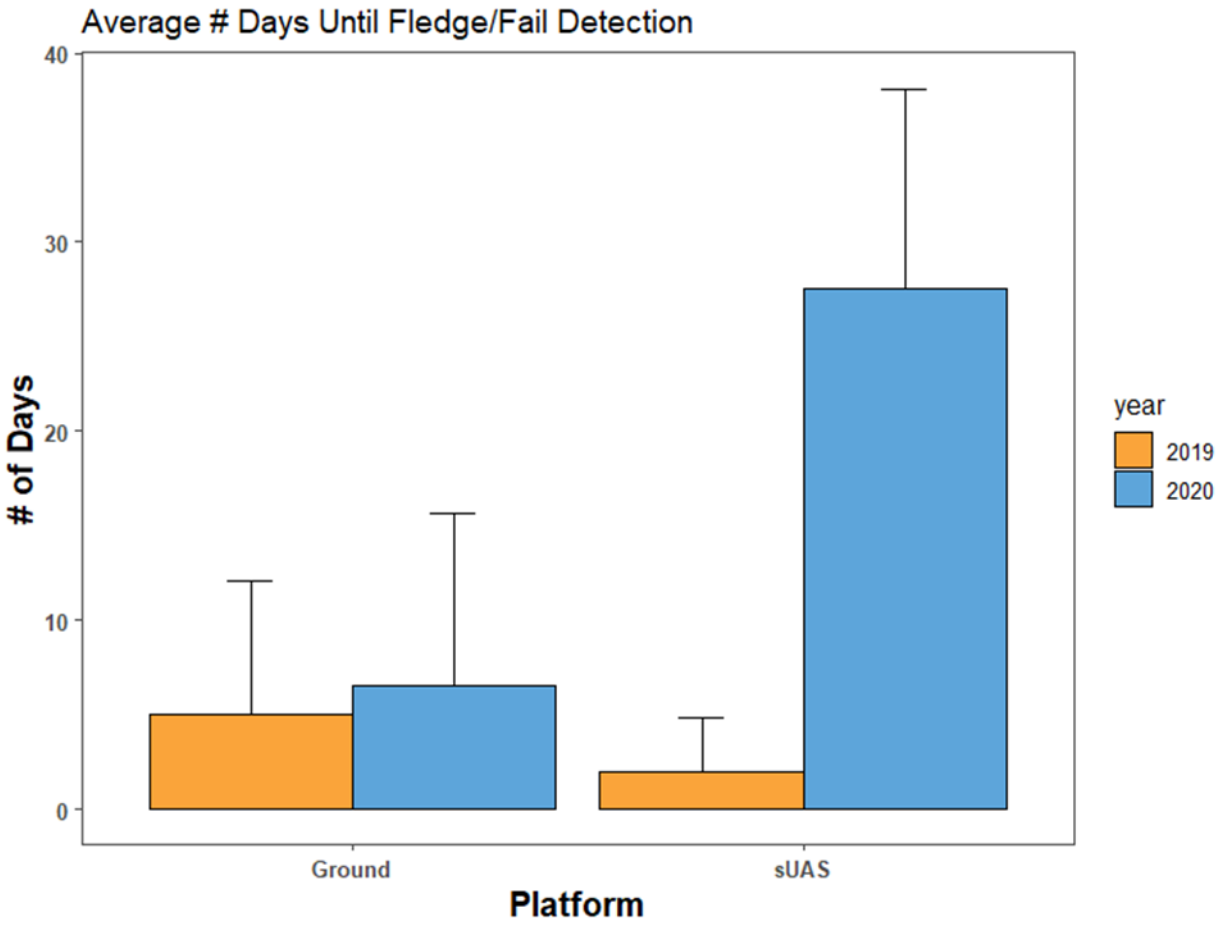


Figure ES-2. Chart Showing the Mean Number of Days (+SD) from Nest Initiation to Activity Detection by Each Platform.

Date of Nest Failure or Fledge Identification

In 2019, the ground observer and sUAS platforms very nearly tied for speed at detecting nest failure or fledge. Both had sufficient quality optics and visitation rates to detect the lack of chicks in a nest almost immediately. The UAS was not compared due to lack of data. By contrast, the ground observer was much faster to detect nest failure or fledge in 2020 than the sUAS. The sUAS's loss of payload resolution made it difficult for the platform to identify the presence or absence of small chicks in a nest. Again, the UAS was forced to cease surveys before nests became in-use, removing it from this comparison.

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ES Figure ES-3. Chart Showing the Mean Number of Days (+SD) from Nest Failure or Fledge to Detection by Each Platform.

Time to Nest Status Update

These models illustrate the differences in nest observation efficiency both between platforms and between years. In 2019, the sUAS displayed a clear efficiency advantage over the ground observer, requiring much less observation time to make a nest status determination, especially in the early nesting season. This is because of the sUAS's ability to view directly into a nest bowl, eliminating the need to wait for a possible incubating eagle to stand or stretch in order to come into view from the ground. As the nesting season went on and chicks got larger, they were easier to see from below, decreasing the advantage of the sUAS. In 2020, the sUAS retained a small advantage over the ground observer, but the poor resolution of the payload meant that the platform had to observe each nest for much longer in order to determine if an object perceived to be in the nest was actually an eagle or if it was simply a pixilation artifact. In addition, the ground observer in 2020 took more time on average as the season went on, mostly due to the fact that one of the in-use nests was located in a high, partially obscured cliff cavity, preventing easy observation at any time.

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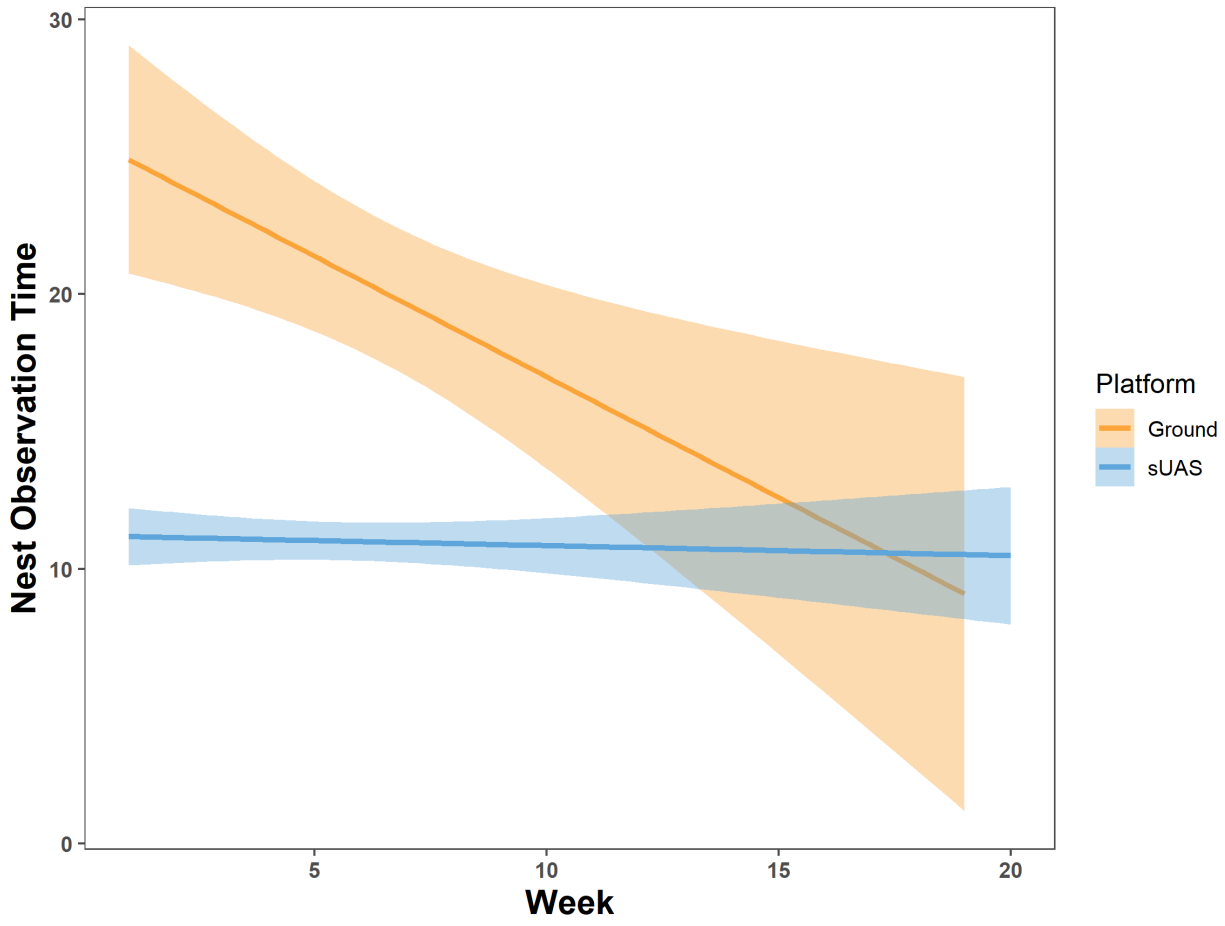


Figure ES-4. Comparison of the Efficiency of a Ground Observer in Minutes (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2019.

The sUAS took vastly less time to determine status during early season, while the ground observer gained efficiency as unused nests were eliminated from the survey round.

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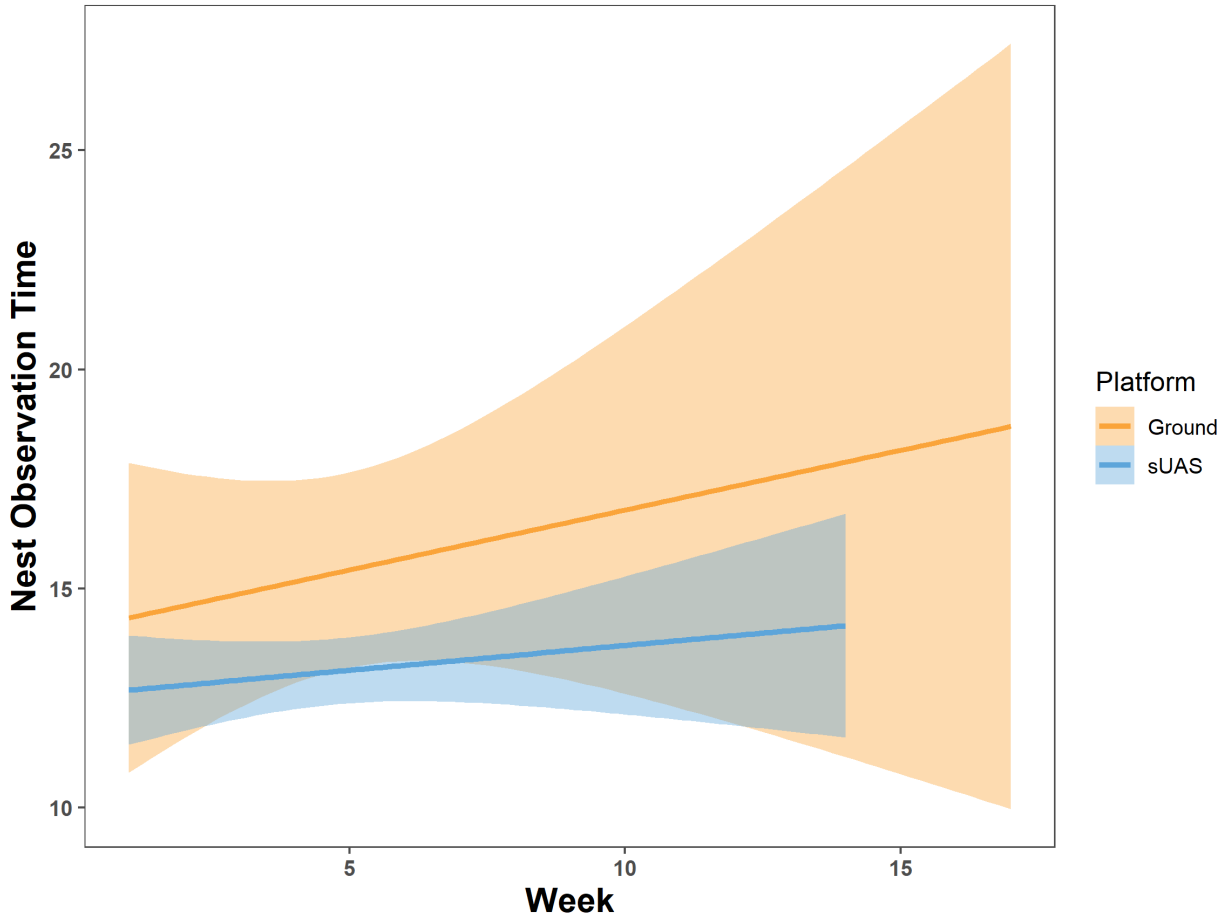


Figure ES-5. Comparison of the Efficiency of a Ground Observer in Minutes (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2020.

The sUAS took less time to determine status on average, but the sUAS's efficiency advantage was much less pronounced than during 2019.

Hypothetical Mission Impact in Days

The hypothetical mission impact of nest area closures and openings is a measure of the precision of each platform in detecting nest status changes. Ideally, an in-use nest will be detected, and an area closure enacted immediately *(within one week or survey period)* upon the start of incubation, and the area opened again immediately upon the failure or fledge of the nest. This minimizes potential mission impacts of unnecessary range closures as well as protecting the nest against potential disturbance.

In 2019, both the ground observer and sUAS platform were slow to detect the activity of RN315, leaving it unprotected for several weeks, although the sUAS was one week quicker in detecting the nest's activity. In addition, the ground observer designated RN315 as fledged prematurely by one week. This resulted in the sUAS being cumulatively more precise in designating range closures in 2019 than the ground observer.

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In 2020, the data is complicated by the fact that both the ground observer and the sUAS monitored nests that the other platform was not capable of reaching, leaving only one nest for direct comparison. The ground observer was slow to detect the activity of RN248A by several weeks but caught the fledge of the nest immediately. The rough terrain and lack of road access in RN248A's territory required the ground observer to ration which nests received a survey visit each week, which resulted in the in-use nest going undetected for several weeks. The sUAS detected the activity of RN029 immediately but was slow to confirm the failure of the nest by several weeks. The low resolution of the platform payload in 2020 made it much more difficult to identify the presence or absence of young chicks from the nest bowl than the presence or absence of an incubating adult. Both platforms were equally precise at determining the status of RN321.

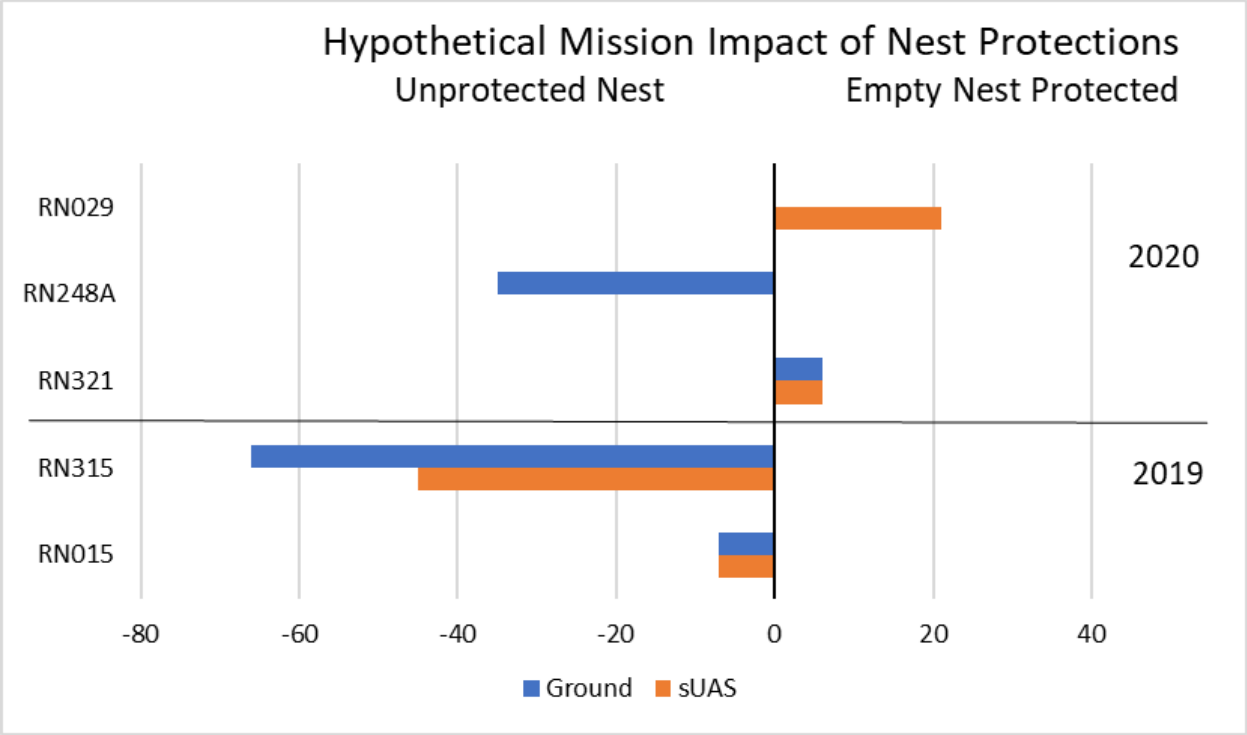


Figure ES-6. Chart Showing the Hypothetical Impact of Nest Area Closures/Openings by Platform and Year.

Quality of Photo/Video Documentation

The DPG Team conducted a qualitative evaluation of how well each platform was able to document nest status in both 2019 and 2020. In 2019, the sUAS platform delivered high resolution video and photo documentation of all nests viewed, as well as footage of the surrounding cliffs for the team to search for previously unknown nests. The photo/video documentation allowed the data managers to confirm nest status before putting range closures in place. By contrast, the UAS platform in 2019 was equipped with a low-resolution payload that hampered the observer's ability to identify nests with confidence. The UAS's thermal imaging capability did allow the observer to spot chicks in in-use nests, however. In 2020, the imaging capabilities of the sUAS and UAS platforms were reversed. The replacement sUAS platform had a downgraded payload resolution due to downlink limitations.

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In addition, it did not have onboard data recording capabilities; the observation team had to record footage from the ground station, and as a result encountered significant issues with poor reception and signal corruption. These limitations resulted in the sUAS team requiring more time on site to determine nest status, and in many cases prevented the team from calling a certain nest status at all. On the other hand, the UAS platform received a significant upgrade to its payload systems, allowing for HD image recording. Unfortunately, the UAS team was forced to cease survey operations after only 2 weeks of monitoring due to the COVID-19 crisis, and the observation team was unable to obtain enough data to present a significant image comparison.



Figure ES-7. A Photo of RN315 As Taken by the sUAS Platform in 2019

(DJI Matrice 600 Pro with Zenmuse Z30 payload).

The photo shows an adult golden eagle sheltering a chick less than a week old.

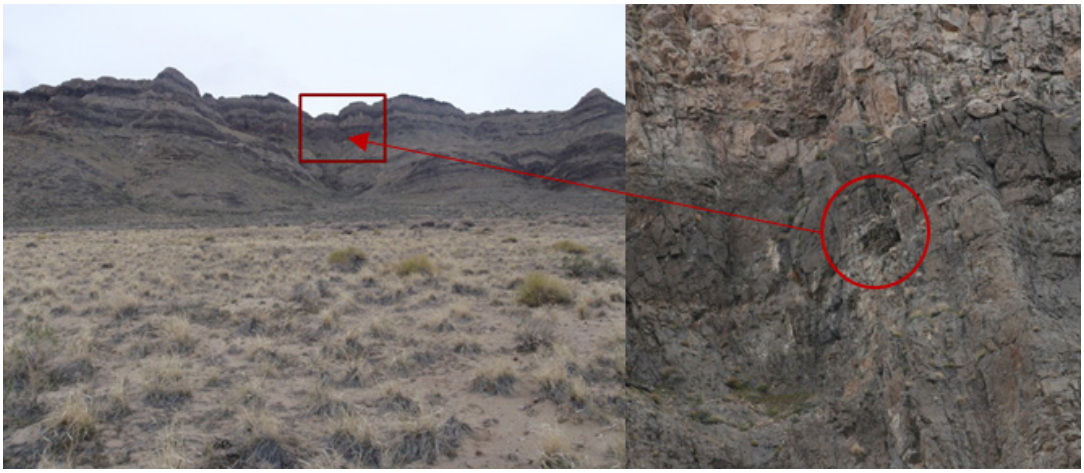


Figure ES-8. A Series of Two Photos Taken by a Ground Observer at Two Different Zoom Levels of RN046.

The first photo shows the distance the observer must view the nest from, as well as the height of the nest on the cliff face. The second photo shows how the ground observer must view the nest from below, even at high zoom.

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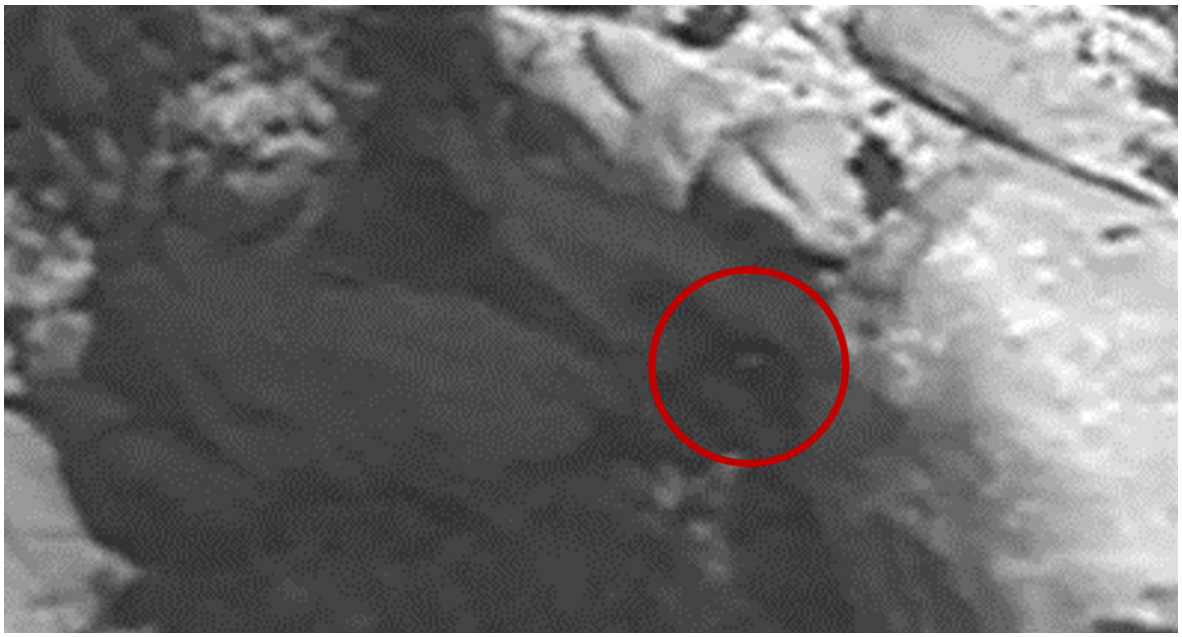


Figure ES-9. A Video Still Taken from the Footage of the UAS Observer Using Thermal Imaging in 2019, Showing RN315 with a Nearly 9-week-old Chick.

The chick is shown as a pale (warm) shape in the middle of a cool cliff face. This image shows the challenges the UAS observer faced with low resolution imagery, and how thermal imaging was able to partially compensate in the late nesting season.



Figure ES-10. A Video Still Taken from the Footage of the sUAS Observer in 2020 (E900 with Sony FCB-EV7520A), Viewing Nest RN248.

The photo shows the low resolution and video artifacts that inhibited the sUAS's ability to make accurate nest activity identifications in 2020.

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Additional Metrics for Success

The results of the mixed-effect logistic regression models indicate that the ground observer and sUAS platform had essentially equal *(high)* accuracy in determining the status of any given nest in 2019. Both platforms were more than 85% likely to determine nest status accurately and confidently in the early season, growing to more than 95% accurate in the late season. This can be attributed to the experience and skill of the ground observer, as well as the ability of the sUAS platform to take high quality documentation photos and video for review. In 2020, the sUAS platform suffered greatly from the drop in payload resolution. It began strongly and was still confidently able to determine when nests were not in-use. However, it struggled to accurately identify when nests were in-use and to determine the difference between an incubating nest and a nest with chicks. The ground observer, on the other hand, displayed almost the same results as in 2019.

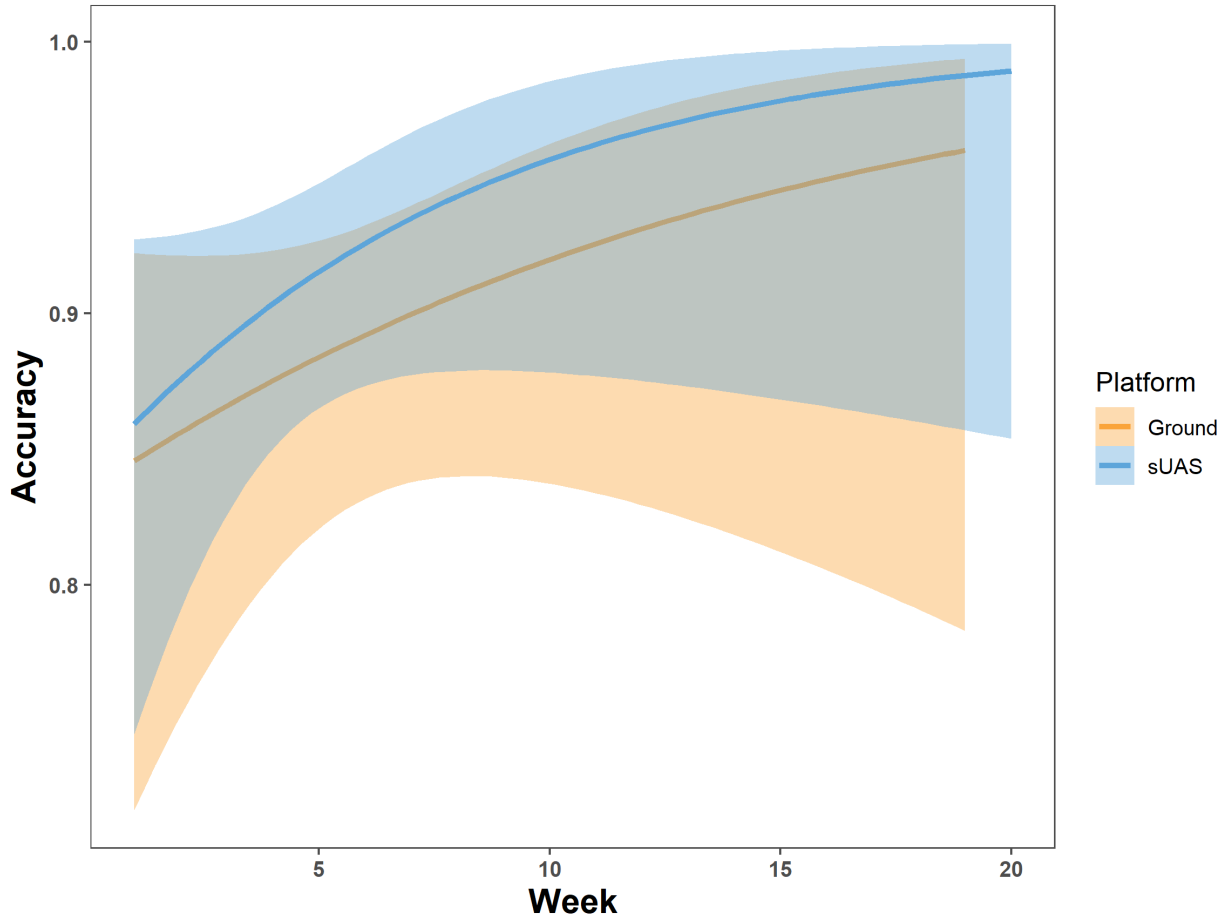


Figure ES-11. Comparison of the Accuracy of a Ground Observer (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2019.

Both platforms gained accuracy as the season went on, remaining roughly equal in accuracy. Error margins represent 95% confidence intervals.

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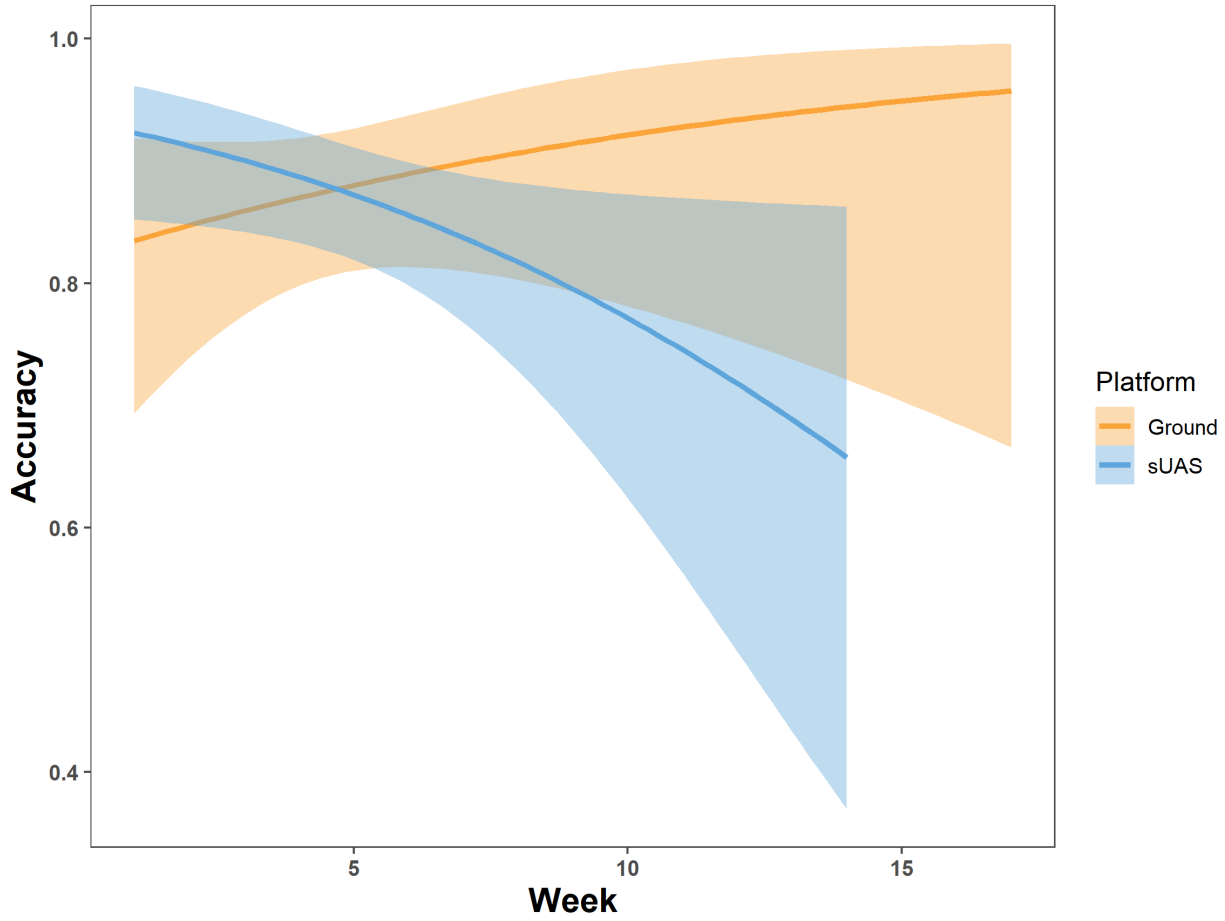


Figure ES-12. Comparison of the Accuracy of a Ground Observer (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2020.

The ground observer gained accuracy during the season, mirroring 2019, while the sUAS lost accuracy. This represents the challenges of identifying an in-use nest's status with a low-resolution payload. Error margins represent 95% confidence intervals.

When determining which platform is most efficient and cost-effective, it is important to take total territory coverage into account, especially in the early nesting season when looking to identify in-use nests. The sUAS platform was able to survey approximately twice as many nests each week than the ground observer in both 2019 and 2020. This grants the sUAS more confidence in accurately calling the occupancy status of early season territories, as well as giving it an advantage in locating in-use nests promptly. This played out in 2019 as the sUAS located one in-use nest a full week before the ground observer. The ground observer had to rotate which nests to observe each week due to time pressure and the lengthy hikes needed to cover some territories. By being unable to cover all known nests each week, the ground observer was slower to identify an in-use nest, leaving it potentially vulnerable to disturbance.

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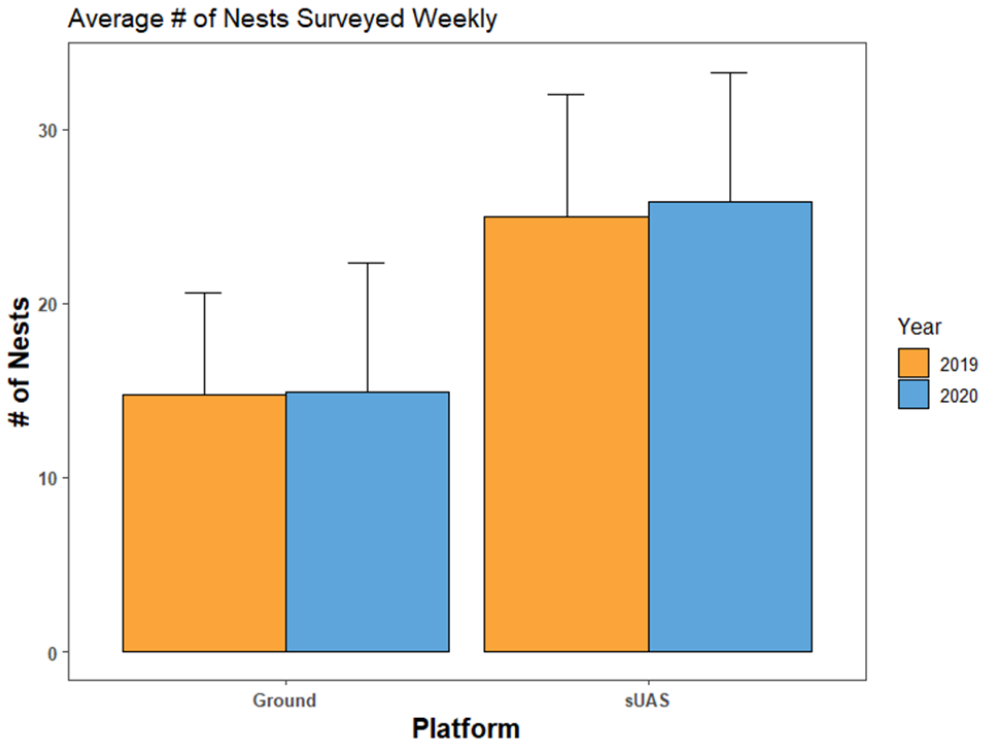


Figure ES-13. Chart Showing the Mean Number of Nests (+SD) Surveyed Each Week During the Early Season.

COST ASSESSMENT

The table below provides a side-by-side comparison of the two sUAS, UAS, on-the-ground monitor and helicopter. Due to the unique circumstances faced during this demonstration, it is assumed that the additional cost for Government support for waiver and oversight would not be necessary for future projects.

Table ES-1. Cost Comparison of Methods with Government Support for Waiver

Cost Elements	sUAS-DJI Matrice	sUAS- E900	UAS	On-The-Ground	Helicopter
Platform	$ 18,139	$ 5,500	NA	NA	$ 216,000
Payload	NA	$ 5,895	NA	NA	NA
Batteries/Chargers	$ 1,528	$ 1,651	NA	NA	NA
Binoculars, scope	$ -	$ -	NA	$ 2,000	$ 2,000
Transportation *(to-from observation locations)*	$ 3,000	$ 3,000	NA	$ 3,130	
Maintenance/Repair	$ 256	$ 893	NA		
Monitoring Labor	$ 55,346	$ 48,840	$ 10,910	$ 14,715	$ 8,640
Waiver Development (*contractor*)	$ 7,000	$ 7,000	NA	NA	
*Govt. waiver prep and sponsor/training/oversight of flights	$ 79,557	$ 61,249	NA	NA	NA
Total	**$ 164,826**	**$ 134,028**	**$ 10,910**	**$ 19,845**	**$ 226,640**

** Cost specific to this project as a result of DoD Memo banning COTS sUAS and FY19 NDAA prohibiting the procurement or operation of Chinese made sUAS.*

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The most significant cost driver is DoD Army sUAS policy. The platform/payload must meet Department of Army cyber security requirements. Each platform must undergo an evaluation and provide an Exemption to Policy (ETP) also referred to as a waiver, to operate in restricted airspace. The cost associated with obtaining an ETP includes labor to develop the ETP application package *(Standard Operating Procedures, System Safety Management Plan, and Memos),* upload through SIPR, and track through the system. The waivers are only for six months. In addition, each sUAS must have an Airworthiness Release.

The prohibition on foreign made sUAS impacts costs because the U.S. market is still developing and has not yet produced a cost competitive commercial sUAS to compete with foreign made sUAS. As the U.S. market matures and purchases increase, this will begin to bring the costs down.

Costs were not directly assessed for much of the UAS platform team, as the operation of the UAS platforms are part of a larger installation program and were made available for the study on a non-interference basis.

Costs are based on golden eagle monitoring on a MRTBF with vast distances between nests and rugged terrain. Breeding season begins in February and goes through June, allowing for a range of temperatures and weather conditions.

The cost comparison assumes that both the sUAS and on-the-ground monitoring start and return from the same location. The time to survey nests and return to the starting location has been recorded.

Industry data on life expectancy of an sUAS is between one and two years or ~200 flights. When first envisioning this project, it was thought that the sUAS would be most cost-effective and could replace the current approach of on-the-ground monitoring. The results from the demonstration show that the use of an sUAS is a good tool to have available but may not yet be able to cost-effectively replace on-the-ground monitoring. However, the sUAS provides benefits over that of the on-the-ground monitor such as photos which can be used to study and accurately age the chicks. The sUAS can also cover more territory than an on-the-ground monitor and access nests that are too high or at a difficult angle to see from the ground. In addition, some of the costs associated with this demonstration can be reduced or eliminated in future use cases, such as costs associated with government waiver oversight. As the cost of the sUAS system is reduced and the policy surrounding flying the sUAS in DoD airspace is streamlined or eliminated, it may become cost-effective compared to on-the-ground monitoring. The use of sUAS compared to helicopter use is cost competitive.

IMPLEMENTATION ISSUES

A major implementation issue with the use of sUAS in DoD airspace involves obtaining an AWR and Exemption to Policy (ETP). This policy seeks to prevent the use of foreign made sUAS based on cybersecurity vulnerabilities. Both approvals take time to develop, review, and obtain approval. Under the 2019 DoD Army policy, a modified DJI Matrice 600 was used to monitor golden eagles after obtaining an ETP. However, because of the FY 2020 NDAA, Section 848 Prohibition on Operation or Procurement of Foreign-Made Unmanned Aircraft Systems, the procurement or use of Chinese made sUAS was prohibited. This led to the use of a different sUAS platform. Each change of platform requires a new AWR and ETP. The ETP can only be granted for six months at a time and the time to obtain an approval may take 45-60 days minimum.

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The sUAS platform used for observation and data collection has real potential for becoming a quick, cost-effective way to monitor the progress of nesting birds in hard-to-reach places. For this platform to work efficiently and in a manner that collects the best data, some points described below had been found over the past two years to help improve the use of this platform.

Good metadata and a member of the team that has experience with eagle behavior and good knowledge of the territory is key to obtaining useful data. A trained eye for these sUAS platforms was able to compensate for finding nests with sometimes less than ideal video streaming quality or lighting situations. A profile containing pictures from multiple angles and distances and GPS coordinates of known nest in the territory was critical to confirming nest locations and to reduce the time that the sUAS team spent locating nests during a flight.

The UAS observation method was the most uncertain upon the start of the 2019 nesting season, and it proved to be unreliable as a method of weekly nest observations due to scheduling and payload restrictions. RIAC allowed the use of their students and platforms on an as-available basis, and other missions, weather concerns, or maintenance frequently bumped nest observations off the schedule. In addition, the sections of airspace the students were scheduled for were often not over the desired areas of range containing eagle nests to be surveyed. It became clear to the DPG Team that rather than using the UAS as a stand-alone observation method, it would be more useful as a precision tool for obtaining rapid nest observations in areas with no ground access or with critical range use planned within the next two weeks.

If the nest location was well known, the UAS was by far the fastest and most efficient observation method due to lack of drive and hiking time between observation points. However, the nature of the platform's flight and approach patterns made detailed nest metadata critical to the success of the survey. UAS platforms must determine an approach angle and loiter point for a territory observation from several kilometers away, requiring the observation team to have precise knowledge of the nest's location reference data, elevation, aspect, bearing from the ideal viewpoint, and topographical inclusion before the nest can be found. The UAS observation team found that landscape level photos combined with detailed descriptions of a nest's location were sufficient to allow for a successful survey.

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1.0 INTRODUCTION

1.1 BACKGROUND

Dugway Proving Ground (DPG), located in remote west-central Utah, serves as a Major Range Test and Facility Base (MRTFB) test site for chemical and biological defensive testing, battlefield smokes, and obscurants. In addition, DPG is home to multiple breeding pairs of golden eagles, which are protected under the Bald and Golden Eagle Protection Act (BGEPA) and the Migratory Bird Treaty Act (MBTA). Due to these regulatory drivers, the presence of an eagle nest has the potential to restrict military testing and training if military activity causes nest disturbance. It is therefore vital to the function of DPG and similar DoD testing and training ranges to fully understand the location and status of in-use eagle nests or territories on military lands.

Current survey techniques of nesting golden eagles on DPG and active DoD training properties require long-distance viewing of each nest from the ground at least weekly, which is both time-consuming, costly, and may not always provide a definitive status of nest changes from incubation to hatching, number of nestlings, nestling condition, etc. *(Weissensteiner and Poelstra 2015)* due to views from the ground. Finding new nests is driven by bird behavior, luck, or significant amounts of time and effort spent traversing rugged terrain on foot. Currently, ranges are required to err on the side of caution if the status of an eagle nest is uncertain, which may lead to increased range closure times. Using both military-grade and commercial Unmanned Aircraft Systems (UAS)/Small Unmanned Aircraft Systems (sUAS), it is possible to obtain highly accurate locations and status updates of in-use golden eagle nests on DoD lands; data that is critical to maintaining open testing and training ranges for as much time as possible in the eagle nesting season *(Chabot and Bird 2015, Hodgson et al. 2016, Junda et al. 2015, Weissensteiner and Poelstra 2015).* The sUAS/UAS can be used to detect new nests in areas that are difficult to see or access from the ground, as well as count nestlings and track nesting milestones in a noninvasive manner not previously possible *(Weissensteiner and Poelstra 2015).* All of this can be accomplished with greatly reduced disturbance to the nesting pairs *(through reduced time in the area),* crucial to the success of sensitive nesters such as the golden eagle *(Chabot and Bird 2015, Scobie and Hugenholtz 2016, Weissensteiner and Poelstra 2015).*

1.2 OBJECTIVE OF THE DEMONSTRATION

Select Engineering Services (SES), in coordination with DPG, the Rapid Integration and Acceptance Center (RIAC), Threat Systems Management Office (TSMO) and HawkWatch International (HWI), hereinafter referred to as the DPG Team, developed this technology demonstration to demonstrate the use of sUAS/UAS as a cost-effective way to monitor golden eagles on military installations. Currently, it takes approximately 960 hours to conduct on-the-ground monitoring of eagle nests for approximately six months *(based upon actual numbers provided by DPG and SES experience).* Much of this time is spent traveling to and from remote sites either by foot or truck. The primary objective was to reduce the total hours required to monitor the nests and evaluate the cost-effectiveness of using sUAS/UAS over in-person ground-based monitoring. Other objectives of the demonstration included the following:

- Efficiencies of scale to monitor more nests in less time for a lower cost
- Demonstrated the effectiveness of sUAS/UAS versus on-the-ground observation

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- Improved quality of still photos and videos for further analysis
- Demonstrated use of sUAS/UAS as safe and low disturbance to the eagles
- Demonstrated use of sUAS/UAS to enable greater access to the nest and ability to collect more detailed data
- Demonstrated use of sUAS/UAS as more efficient in finding nests in particular settings such as hidden/remote terrain

1.3 REGULATORY DRIVERS

Golden eagles are protected under BGEPA and the MBTA. These protections require eagles to be protected against "take," defined as "[to] pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, molest or disturb." In addition, the protections against "take" extend to the nests and eggs of eagles, as well as the adult birds. The conservation status of the golden eagle is currently stable globally, but declining regionally, in both western and eastern U.S. populations *(Hoffman and Smith 2003, Katzner et al. 2012, Smith 2008)*. Additionally, a recent review by the U.S. Fish and Wildlife Service (USFWS) upheld concern over the population status of the golden eagle *(USFWS 2016a),* leading to a "no net loss" standard in the recent revision to the "Eagle Rule" *(USFWS 2016b).* This standard essentially prohibits any "take" of golden eagles or their nests without offsetting such take through the permitting framework. To prevent accidental take of golden eagles, DPG is obligated to monitor its existing population of nesting golden eagles and avoid disturbance, except in cases of specific permitted activities. As DPG can monitor its golden eagle population more effectively and efficiently, the installation will be able to operate with minimal concerns for incurring accidental take.

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2.0 TECHNOLOGY/METHODOLOGY DESCRIPTION

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

The DPG Team conducted weekly golden eagle nest surveys on DPG during the 2019 and 2020 nesting seasons to compare the effectiveness of three "survey systems": 1) a ground-based human observer, 2) a commercially available sUAS, and 3) one or more military-grade UAS platform(s). These nest surveys were conducted as a blind study; none of the three teams of observers encountered one another in the field. None exchanged information concerning the nest surveys, and none had any access to data generated by surveys conducted by any of the other teams.

Golden eagle nest surveys are typically performed by one observer that travels to 11 territories to observe and note status of nesting. A second observer is sometimes used for safety if the terrain/location warrant it. Equipment includes high power binoculars/scope. All observations are documented, on paper, but no pictures or videos are taken. On-the-ground observers are required to undergo unexploded ordinance training (UXO) administered by Dugway range safety officers as well as basic coordination, navigation, and radio ops training specific to DPG.

The sUAS platform DJI Matrice 600 *(Figure 1)* was originally proposed for this project. However, the 23 May 2018 DoD Memo, "Unmanned Aerial Vehicle Systems Cybersecurity Vulnerabilities" was issued, suspending the use of Commercial Off-the-Shelf (COTS) sUAS. In response, a DJI Matrice was procured with an approved DoD software patch, through the Army Ground Aerial Target Control System (AGATCS), in partnership with the Threat System Management Office (TSMO). DJI Zenmuse Z30 cameras were used as the operational payload, with 32x optical zoom allowing for long-range HD observations. This system was approved for use during the 2019 nesting season.



Figure 1. DJI Matrice 600 Pro

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However, in December 2019 the National Defense Authorization Act (NDAA) was signed which called for a complete ban on the procurement and/or use of Chinese made sUAS platforms by DoD programs except in the case of sUAS counter-defense testing *(Appendix 2)*. This language was strictly interpreted to prevent the use of the modified DJI Matrice that was used the previous year. This led the DPG Team to seek out another option. Through discussions with TMSO, an alternative sUAS was identified for use, the E Mergent RC E900 platform *(Figure 2)*. The two E900s were integrated with Sony FCB-EV7520A camera payloads.



Figure 2. E Mergent RC E900

Table 1 below provides a comparison of the two platforms. The two payloads were technically comparable but the Matrice was designed as an integrated system whereas the E900 was integrated with a camera payload after manufacture. The primary differences between the two were the transmission distances, operating frequencies, and the SD card which was in the camera on the Matrice and in the controller tablet of the E900. These differences led to a significant degradation of photo quality from the E900.

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Table 1. A Comparison of the Two sUAS Platforms: The Modified DJI Matrice 600 in 2019 and the E900 Used in 2020

	DJI Matrice 600	E900
Max Transmission Distance	3.1 miles	1.5 miles
Frequency	5.8 GHz	2.4 GHz
Payload Specifications	30x Optical Zoom + 6x Digital zoom 2.13 Mp 1080p Tablet Tap Zoom supported	30x Optical zoom + 12x Digital zoom 2.13 Mp 480p *(functional resolution)* Separate controller for camera
Camera and Interface Abilities	Auto/Manual – Focus, Shutter Priority, Bright Compensation SD card Supported	Auto/Manual - Focus, Shutter priority, Bright Compensation SD card in controller tablet
Batteries	6x 5700 mAh	1x 6S 2200 mAh battery Battery weight – 2490 g *(+/-20g)*
Estimated Flight Time (minutes)	~25 min	~20 min
Max Takeoff Weight (payload capacity)	15.5 kg Payload Capacity - 5.5 kg	10.5 kg Payload Capacity – 4.5 Kg
Max Wind Resistance	18 mph	20 mph

The sUAS team consisted of a pilot-in-command, operator, and observer who was also an ornithologist with in-depth knowledge of the Dugway range and eagles in the area. All three members of the team completed training before the study began consisting of UAS flight theory, platform components, flight controls, operation, troubleshooting techniques, and supervised flight training administered by TSMO. All members of the team underwent unexploded ordinance training (UXO) administered by Dugway range safety officers as well as basic coordination, navigation, and radio ops training specific to DPG.

DPG is also home to the Rapid Integration and Acceptance Center which was established by the Project Manager Unmanned Aircraft Systems to create a single location where unmanned and manned aircraft could complete end-to-end testing and integration. DPG coordinated with RIAC to conduct monitoring flights when they were not conducting mission flights. RIAC identified a military UAS platform that would be most suitable for this type of flight plan. There are approximately 24 Continental United States Army installations with UAS that could potentially be used for monitoring of raptors or other natural resources as part of their ongoing training of UAS pilots.

The UAS was operated by UAS pilots, supported by an ornithologist who provided coordinates and identification/analysis of nests.

2.2 TECHNOLOGY/METHODOLOGY DEVELOPMENT

The DPG Team's technical approach was to demonstrate the cost-effective use of sUAS/UAS to monitor golden eagles by a direct blind comparison between on-the-ground monitoring and sUAS/UAS overflights. A flow diagram for the methodology proposed can be found in Appendix 3, and a detailed overview of the methodology developed can be reviewed in section 5.4 *(Field Testing)*.

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2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/ METHODOLOGY

Currently, on-the-ground monitoring includes one observer visiting each of the 11 territories once or more per week until occupancy is established, the in-use nest is identified, or sufficient monitoring and time of year eliminates the possibility of initiation of nesting activity. In-use nests are tracked with in-person visits once per week for the duration of the breeding season until nest fledge or demonstrable failure. This method is relatively reliable with repeated visits, but is time-consuming, costly, and may not always provide a definitive status on a given day of observation. Also, the changes in nest status are not immediately available, which can cost the military valuable operation days on closed ranges.

The demonstration studied two different sUAS platform/payload systems: a DJI Matrice 600 Pro with a Zenmuse Z30 payload in the 2019 nesting season, and an E Mergent RC E900 prototype with a Sony FCB-EV7520A payload in the 2020 nesting season. The two platforms performed very differently during each nesting season, and each showed its own strengths and limitations.

The DJI Matrice is a commercial off-the-shelf product, and as such was well designed and easy to use. The Matrice was stable and reliable in the field, with robust trouble-shooting procedures and documentation. The integrated Zenmuse camera system provided HD on-board photo and video recording of nests over distances of over 800 meters. The Matrice maintained flight control and video transmission over distances of up to 3 miles, far greater than typical line of sight limits, allowing for remote or obscured nests to be observed efficiently. However, the bulky battery system and low tolerance for temperature extremes limited the Matrice in particularly rugged conditions. The Matrice is also manufactured in China, and as such it is currently restricted from use in DoD restricted airspace except for use in counter-sUAS defense applications. Therefore, this system is no longer available for use in DoD restricted airspace.

The E Mergent RC E900 is a prototype sUAS platform developed for custom DoD applications in partnership with TSMO. The main advantage of the E900 over the commercial DJI Matrice is that it is American made, and as such is currently eligible for consideration of the DoD issued flight waiver. It is also highly customizable to a specific project's needs and can be modified and repaired at will with sufficient technological expertise. However, the E900 is not a fully realized commercial product, and as such it was less refined and reliable than the Matrice. The E900 also lacked the ease of use of the DJI payload controls and software. It was determined that the current iteration of the E900 used for the demonstration lacked the long-range transmission capabilities required, as well as possessing inadequate video stabilization and control operations. Integrating a third-party payload into the E900 system resulted in limited video resolution and recording capabilities. The after-manufacture integration of the camera onto the platform created some photo quality issues. The SD card was located in the controller tablet instead of on the camera, therefore photos/videos would be transmitted to the SD card, which required the images to be reduced from 1080p to 480p.

Furthermore, both sUAS platforms have risk minimization features. Both platforms include user friendly, intuitive flight controls with programmable altitude restrictions, horizontal geofencing, and GPS hold mode to insure platform stability in windy weather. An added GPS failsafe includes a return to home/auto land switch on the controller that initiates an autopilot to land the platform at its original takeoff location with no input from the pilot. Both platforms include real time information such as distance from controller, heading indicator, altitude above takeoff location, and battery performance all on one display. This heads-up information allows separation from nesting areas to help prevent "take" of the birds, or to stay clear of restricted airspace.

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The MQ-1C Gray Eagle was also used when available for nest monitoring in both the 2019 and 2020 nesting seasons *(Figure 3)*. The Gray Eagle fleet on DPG underwent a significant upgrade to their payload systems during the fall of 2019, resulting in much higher resolution video for the 2020 season. This is the first time a military UAS platform has been used to monitor nesting raptors. It was theorized that the high speed and very long observation ranges of the platform would allow it to survey many territories both quickly and thoroughly, with no impact to ground operations in the area. The thermal imaging capabilities of the Gray Eagle platform were also intriguing as a method of detecting chicks *(before they develop insulating adult plumage)*. It was also theorized that student pilots training with RIAC would benefit from the high difficulty of locating eagle nests in cryptic terrain, especially given a mission structure mimicking what they would encounter in theater. Because the Gray Eagle was not always available for monitoring, it was difficult to obtain comparable data.



Figure 3. MQ-1C Gray Eagle

Although not specifically included in the demonstration, helicopters can also be used to monitor nests. This method, as with the other surveying techniques, has its pros and cons. The greatest advantage of using a helicopter as an observation platform is its ability to move quickly from territory to territory. With a trained spotter on board and with the use of optics, nest status can be quickly recorded from an advantageous perspective in hard to reach places. A trade-off of the helicopters speed and mobility is the noise of the aircraft increasing the potential for nest and eagle disturbance.

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These disturbances may skew the data as disruptions of a nesting pair of eagles may result in failure of a nest in a worst-case scenario, especially when monitoring frequently throughout a season as required by DPG's ongoing range activities. The higher perspective and fast movement of the helicopter may also limit the observer's ability to search the area for eagles when first entering a territory, which makes determining early season occupancy difficult. This practice of using optics to search an area when first entering a territory has proven effective in the past of helping an observer's ability to track an eagle to its nest. Furthermore, from a logistical standpoint, the scheduling availability of range airspace for the helicopter to be cleared to fly would be inconsistent at best, as the nesting period of the eagles fall during a typically busy time for range operations. As a final consideration, there is a significant risk to human health and safety when monitoring eagle nests via a helicopter, due to the inherent dangers of flying close to cliff faces and low through rugged terrain. The very high cost of both pilot and helicopter needs to be taken into consideration when contemplating using a helicopter for territory observations and data collection.

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3.0 PERFORMANCE OBJECTIVES

The following performance objectives were developed as the primary criteria by which the DPG Team could assess the success of the sUAS/UAS platforms as nest monitoring tools. The specific benchmarks identified are focused on reduction of time required to monitor nests, increase in number of nests surveyed, and increase in precision of results, all in comparison to the standard ground observer.

Table 2. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative Performance Objectives			
Total amount of time necessary to determine the early season status of all known nests	Amount of time necessary for the method of observation to determine early season status of all known nests	Exact start and ending times of daily survey for each method of observation	sUAS/UAS time to determine early season status < or = in-person time to determine status
Total number of in-use nests identified	Number of in-use nests the method of observation is able to identify	Weekly report of nest activity status for each known territory by each method of observation	Total number of nests identified by sUAS/UAS > or = number of nests identified in-person
In-use nest date of identification	Accuracy of the method of observation in determining nest activity	Dates of territory visits recorded in conjunction with nest status for each method of observation	Date of identification the same or earlier for sUAS/UAS than in-person
Nest failure date of identification	Accuracy of the method of observation in detecting nest failure	Dates of territory visits recorded in conjunction with nest status for each method of observation	Date of identification the same or earlier for sUAS/UAS than in-person
The total amount of time necessary to update the status of in-use nests	Amount of time necessary for the method of observation to update the status of a known in-use nest	Exact start and ending times for territory and nest visits for each method of observation	sUAS/UAS total time spent to update nest status < or = time spent in-person
The number of previously unknown alternate eagle nests found within the 11 territories	Ability of the method of observation to detect new or previously unknown eagle nests	Each new nest observed recorded by each method of observation	Total number of new nests found by sUAS/UAS > or = number of nests found in-person
Differences in hypothetical mission impact *(in days)* and nest protection based on restrictions imposed and lifted due to monitoring	Precision of the method of observation in determining dates of activity and failure/fledge	• Dates of perceived activity and failure/ fledge recorded by each method of observation • True dates of nest activity and failure/ fledge recorded by camera equipment directly observing nest	• sUAS/UAS indicated days of mission impact < or = in-person indicated days of mission impact • sUAS/UAS indicated days of nest protection most similar to days of actual nest activity
Qualitative Performance Objectives			
Quality of video/photos to document occupancy and status	Ability of the method of observation to gather proof of nest activity status	Photo/video documentation of each in-use nest by sUAS/UAS and in-person observers	sUAS/UAS gather higher quality video and photos to document nest activity than in-person observers

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4.0 SITE DESCRIPTION

4.1 SITE LOCATION AND HISTORY

Dugway Proving Ground is located on the southern end of the Great Salt Lake Desert and covers 798,214 acres, serving as a test site for chemical and biological defensive testing, battlefield smokes and obscurants *(Figure 4)*. DPG was activated for military use in 1942 to serve as a proving ground for the testing of chemical weapons. Chemical, biological, and explosives testing have been conducted within DPG. Open air testing of chemical and biological agents was conducted until 1969, after which all chemical and biological warfare testing was confined to sealed chambers. Open-air testing of decontamination methods, contamination avoidance, and evaluation of threat dissemination methods, including the use of biological and chemical simulants in place of biological and chemical agents, has been done at DPG since 1969. In addition, DPG was first opened to Army Reserve Component training in 1969. Ground training on DPG includes a wide variety of activities at DPG, ranging from 12-soldier weekend activities to 3,000- to 4,000-soldier tactical exercises lasting up to several weeks.

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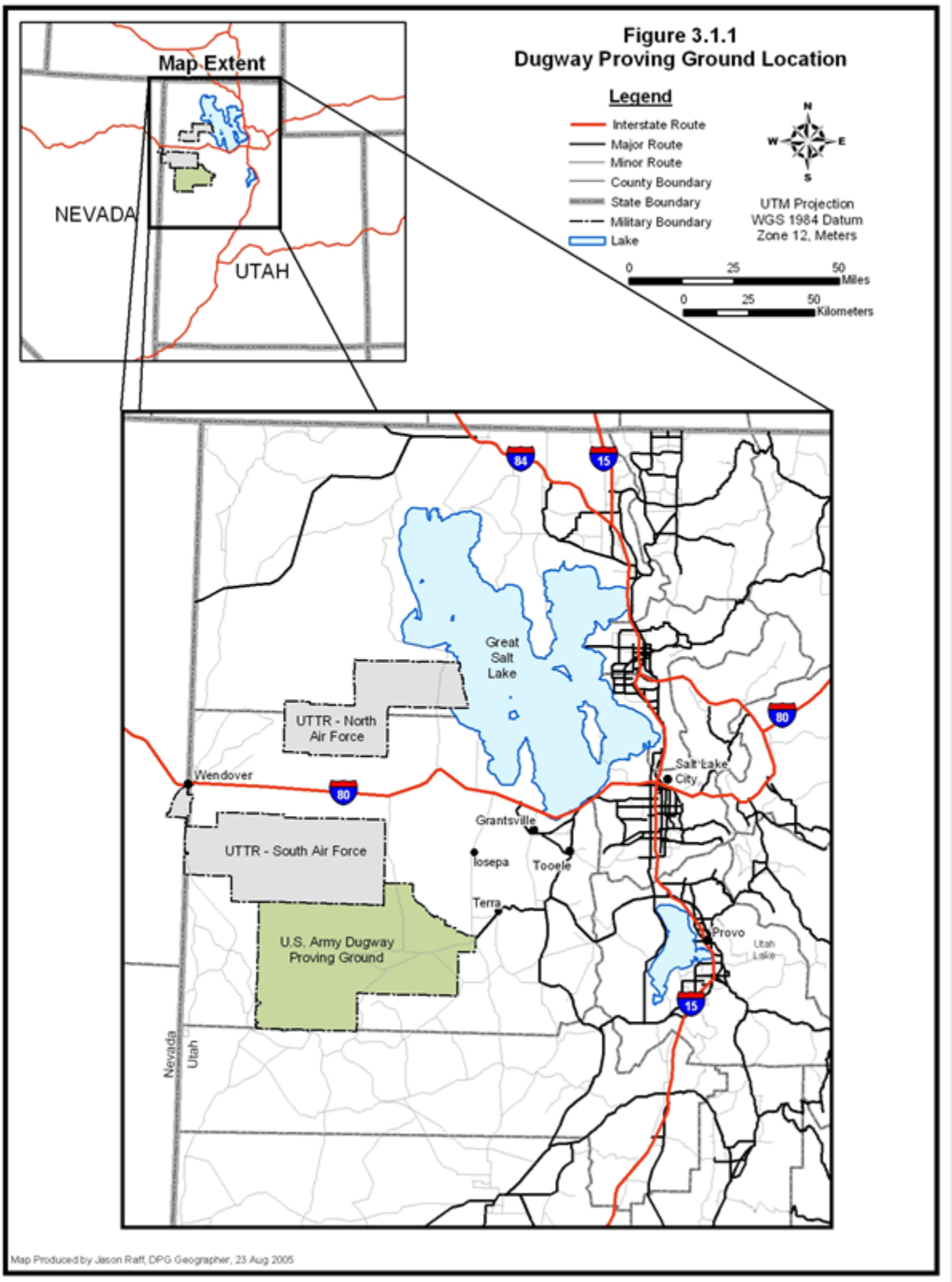


Figure 4. Map of DPG Showing Location Within UT

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4.2 SITE CHARACTERISTICS

DPG is within the Great Basin subdivision of the Basin and Range Physiographic Province. The Basin and Range Physiographic Province includes parts of Idaho, Oregon, Nevada, Utah, California, Arizona, New Mexico, and northern Mexico. This province is characterized by a series of mostly isolated north-south trending mountain ranges that are separated by wide desert plains *(Press and Siever 1982).*

Most of DPG lies within the Great Salt Lake Desert, with mountains and low-lying basin areas covering remaining portions of DPG. DPG is bordered to the northeast by the Cedar Mountains and to the south by a series of ranges and valleys, the closest of which is the Dugway Range. The Onaqui Mountains and Davis Mountain lie to the east of DPG. The Deep Creek Range lies to the west and marks the boundary of the Great Salt Lake Desert. The Stansbury Mountains lie to the northeast of the Cedar Mountains.

Relatively extensive basin areas are broken by the topographic relief of the Cedar Mountains, Little Davis Mountain, Simpson Buttes, Camels Back Ridge, Wig Mountain, Granite Peak, and Sapphire Mountain. There are no large perennial surface water bodies that lie within or border DPG. However, two large playas are located in the western and southern portions of DPG, the DPG Playa, and the Downwind Grid Playa. Vegetated and non-vegetated sand dunes are also located in the eastern and central portions of DPG and along DPG's northern and western boundaries.

DPG is in a semi-arid, continental, steppe region, or high desert known as the Great Basin Desert. This region is often referred to as a cold desert due to its mid-latitude location. Typically, winters are cold; summers are hot and dry with a high evaporation rate; and most precipitation falls in the spring *(Dugway Proving Ground 2003a).*

Other weather characteristics typical of the DPG area include frequent electrical storms and occasional dust storms in summer and temperature inversion conditions in winter. Temperature inversion conditions occur when cold Arctic air spills into the area, wind speed is low, and contrary to the normal pattern, air temperature increases with height above the ground surface. Surface airflow is reduced and any tendency toward reduced air quality is aggravated under these conditions *(Dugway Proving Ground 2003a).*

Weather patterns at DPG are influenced by terrain. Most of DPG is relatively flat because it consists of a former lakebed *(the former Lake Bonneville of which the Great Salt Lake is a small remnant).* Interspersed in the flat terrain are abrupt, often pinnacle-like mountains, which are cooler and receive more precipitation than surrounding flatlands. They influence local weather patterns by channeling winds and promoting up- and down-slope conditions in mornings and evenings, respectively *(Dugway Proving Ground 2003a).*

Local wind patterns are governed by differential heating and cooling of higher elevations relative to flatlands and by regional weather. These patterns usually include the onset of southeasterly or southerly downslope flow at night that persists into morning, which transitions into northwesterly through northerly flow with daytime heating. There are two periods of relative atmospheric stability in early morning and early evening hours. These patterns are marked in summertime but weak or absent in winter, due to differences in the amount of heat in the form of solar radiation received seasonally and the tendency of snow to reflect solar radiation away during winter *(Dugway Proving Ground 2003a).*

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Monthly average temperatures for the Ditto Technical Center for the period 1950 to 1998 range from 77.9° F in July, which is the hottest month, to 27° F in January, which is the coolest. Daily extremes for each month show a substantial range. For example, for July the daily extreme high is 109° F and the extreme low is 37° F. Similarly, the daily extreme range for January is 91° F. Large temperature fluctuations recorded between day and night and seasonally are typical of the area's arid continental climate *(Dugway Proving Ground 2003a).*

Precipitation data for the Ditto Technical Center for the period 1950 to 1998 show that mean annual precipitation is about 8 inches with a low of about 3 inches and a high of about 15 inches. Wettest months are March, April, and May, followed by October. Snowfall occurs November through March; however, snow may persist at mountain elevations for much longer periods than on flatlands *(Dugway Proving Ground 2003a).*

The average warmest month is July, and January is the average coldest month. The highest recorded temperature was 109° F in 1998, and the lowest recorded temperature was -29° F in 1989. May is the average wettest month.

Unusual or severe weather conditions, such as fog and cloud ceilings, which limit visibility, occur most often during winter. Thunderstorms or electrical storms occur during summer *(Dugway Proving Ground 2003a).*

The map below *(Figure 5)* shows the 2018 known eagle nest territories. These territories are significant distances between them and cover a wide range of terrain and are limited by road access.

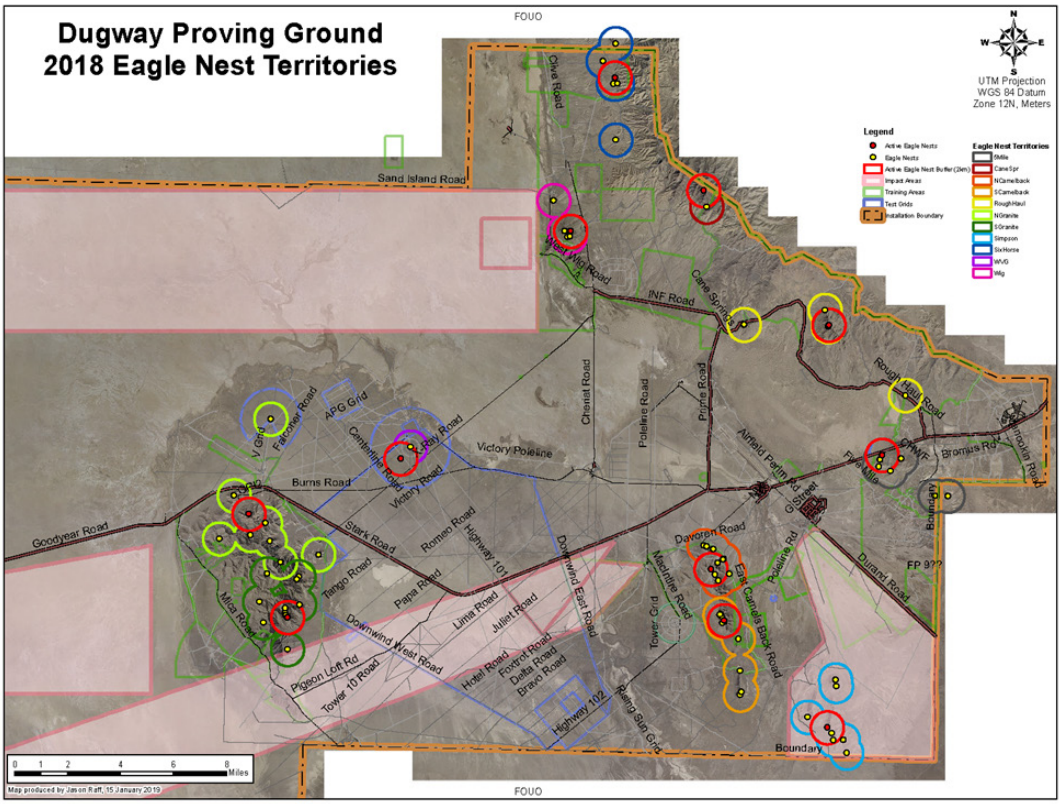


Figure 5. Map of Golden Eagle Nests and Territories at DPG

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5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

The DPG Team conducted weekly golden eagle nest surveys on DPG during the 2019 and 2020 nesting seasons to compare the effectiveness of three "survey systems": 1) a ground-based human observer, 2) a commercially available small sUAS, and 3) one or more military-grade UAS platform(s). The ground-observer was a single vehicle-based biologist; the sUAS system included three personnel *(commercial pilot, observer, and biologist for video monitoring);* and the military UAS required three personnel *(military pilot, military camera operator, and civilian biologist for video monitoring)*. All three biologists associated with each survey approach had comparable familiarity with existing DPG eagle territories and previous eagle nest monitoring experience.

The DPG Team generated territory-specific data sheets that specify known nests within 11 known territories on DPG *(Figure 5),* nest survey order based on historic use patterns, and other detailed survey instructions. The ground observer and the sUAS observation team attempted to survey the same 11 territories relatively close in time, but the biologists associated with each survey system remained blind to each other's findings. The UAS observation team conducted a separate territory and nest survey effort designed to test the platform's capabilities as a precision, on demand survey system for areas with little to no ground access. Two senior DPG environmental staff provided weekly oversight of data collected by all three survey systems and collated survey results to ascertain the weekly "benchmark" status of each territory, and to ensure survey protocols were properly followed. Camera data from a subset of nests were also used to provide retrospective verification and correction of weekly status. Generally, all surveys conducted by the ground and sUAS observation teams occurred on Monday and Tuesday of each week, with Wednesday available as a weather or other make-up day, and Thursday for data review by senior staff. Individual territory surveys by the ground observer and sUAS were staggered to avoid overlap in time. The military UAS observation team conducted surveys as available. Each survey round of co-monitored territories *(i.e., territories "shared" between survey systems, which may vary based on stage of season and performance of individual systems)* were completed by all three platforms within 36 hours of each other, unless weather delays or other unforeseen issues occurred for one or more platform.

Each annual survey was segmented into two time-periods: the "early season", defined as 10 February–14 April *(9–10 weeks)* and the "late season", defined as 15 April–30 June *(12 weeks)*. Survey seasons were selected based on 12 February–19 March "core" egg laying dates *(i.e., 90% of observed values, with 5% tails removed)* back-dated from 1,038 Utah desert nests *(K. Keller, unpublished data)*. The early season end date was set to allow at least two survey rounds after the latest likely lay date based on past data. Similarly, the late season end date was set to encompass 80% fledge age based on the latest likely egg laying date. The primary goal of the early season surveys was to document "Occupied Territories", "In-Use Nests", and "Vacant Territories", while the goal of late season surveys was to track In-Use Nest to "Success" *(at least one nestling surviving to 80% fledge age)* or "Failure" *(terms adapted from Steenhof et al. [2017])*. During the early season, all 11 territories were surveyed every two weeks *(e.g., six one week, five the next)*. In contrast, late season surveys were restricted to In-Use Nests found during the early season surveys, plus any territories with unresolved status.

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For ground and sUAS survey systems, independent teams attempted to survey each nest from outside an 800-meter horizontal protective buffer *(as widely prescribed on public lands and suggested by Romin and Muck [2002])*. If topography prevented clear viewing at that distance, these survey systems were authorized to approach to within 400 meters of a nest, but only as close as necessary to confirm nest status. The "incursion" view distance was recorded. Closer approaches to confirm inactive nests were allowed to facilitate area nest searching. Biologists associated with each survey system recorded eagle response behavior *(i.e., any agitation or flushing observed while conducting nest surveys).*

Surveys conducted for each platform followed specific territory and nest survey protocols to ensure comparable methods were employed and to facilitate the capture of detailed time-keeping records associated with specific survey tasks. Biologists for each survey system recorded total daily "Survey Time", which began upon departure from English Village *(ground and sUAS)* or initiation of take-off from the DPG airfield *(UAS)* and continued until return to same location at the end of the survey effort. For each platform, "Territory Survey Time" was noted, starting when entering into a 2-km buffer around known nests associated with each territory, and continuing until status was confirmed, and the survey was complete, or a 3-hr time limit was reached. Time spent within each territory involved an "Area Search" *(general scanning overall area for adult and nesting evidence),* "Nest Search*" (prescribed order survey of known nests),* and "Extended Search*" (searching for new or uncatalogued nests)* was also recorded. Surveyors used standardized terminology established in this document and photographic guides to age eagle nestlings *(Driscoll 2010, Hoechlin 1976).* The specific protocols associated with each survey period and specific survey tasks are detailed in the following section. These approaches were further reinforced by complementary flow charts *(Appendix 3),* and territory-specific data sheets.

5.2 BASELINE CHARACTERIZATION AND PREPARATION

Three surveyors with high levels of previous experience surveying golden eagle nests for this study were selected. One ground observer had 7 years of golden eagle nest survey experience in the West Desert prior to the start of this study, including 4 years surveying nests on DPG. The sUAS observer had 4 years of golden eagle nest survey experience, all conducted on DPG. The UAS observer possessed 6 years of golden eagle nest survey experience in the West Desert, overlapping with 4 years surveying in other parts of Utah, and 1 year of experience in southern Idaho before this study. Prior to the start of each field season, each observer reviewed the data collection protocols and held a briefing to discuss field procedures and relevant survey details associated with individual territories. Datasheets included territory and nest maps to aid all observers in locating nests *(Table 3).* At the end of year one, a debriefing was held to discuss survey issues encountered by each observer. It was found that high angle, distant views from the UAS platforms and limited UAS observer experience with DPG nests seriously limited nest locations in year one. As a result, "mission packets" were created prior to the start of year two, which included recommended UAS approaches, viewing angle, nest elevation offset, and nest photos, where available.

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Table 3. Status of Golden Eagle Territories on DPG

2015–2018. Nest status was determined by ground observers using binoculars and 60x spotting scopes, equipped with maps showing nest locations and photos of a sub-sample of nests. Territories were considered to contain an "In-Use Nest" if observers detected evidence of a breeding attempt (an adult eagle in incubating posture on a nest, or nestlings), or occupied if a pair of eagles were present in the territory.

Territory Name	# of nests*	2015	2016	2017	2018
Six Horse pass	6	Occupied	**In-Use Nest**	Occupied	Occupied
Cane Springs	2	Occupied	Occupied	Occupied	**In-Use Nest**
North Camelback	12	**In-Use Nest**	**In-Use Nest**	**In-Use Nest**	Occupied
North Granite	8	**In-Use Nest**	**In-Use Nest**	**In-Use Nest**	**In-Use Nest**
Roughhaul Rd	5	**In-Use Nest**	Vacant	Vacant	Occupied
South Camelback	15	Occupied	**In-Use Nest**	Occupied	**In-Use Nest**
South Granite	13	Occupied	Occupied	Vacant	Occupied
Simpson Butte	8	Unknown**	**In-Use Nest**	**In-Use Nest**	Unknown**
West Vertical Grid	4	**In-Use Nest**	**In-Use Nest**	**In-Use Nest**	**In-Use Nest**
Wig Mountain	6	**In-Use Nest**	**In-Use Nest**	**In-Use Nest**	Occupied
Five Mile Hill	7	Vacant	Vacant	Occupied	Occupied

* The number of nest location records is approximate, and includes all documented nest locations, which may include some that have collapsed and no longer exist, or some duplicate nest records.

** Ground observers were not permitted to access Simpson Butte due to unexploded ordnance in the vicinity during 2015 and 2018.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY AND METHODOLOGY COMPONENTS

This project was designed to compare the cost-effectiveness and technical capability of the ground monitor versus the sUAS versus the UAS when monitoring nesting golden eagles. The hypothesis was that sUAS would provide a cost-effective means of monitoring eagles over the traditional ground monitoring due to the amount of area that can be covered in a short amount of time, as well as the use of HD cameras that are able to be positioned at various altitudes and angles to provide the best look into the nest. The sUAS is also a relatively inexpensive, easy to operate platform. Figure 6 below shows the 11 territories that were monitored each season.

The methodology used was based on best practices in the eagle monitoring arena to ensure a blind study with verifiable results. All results were analyzed in conjunction with costs to determine the most cost-effective solution.

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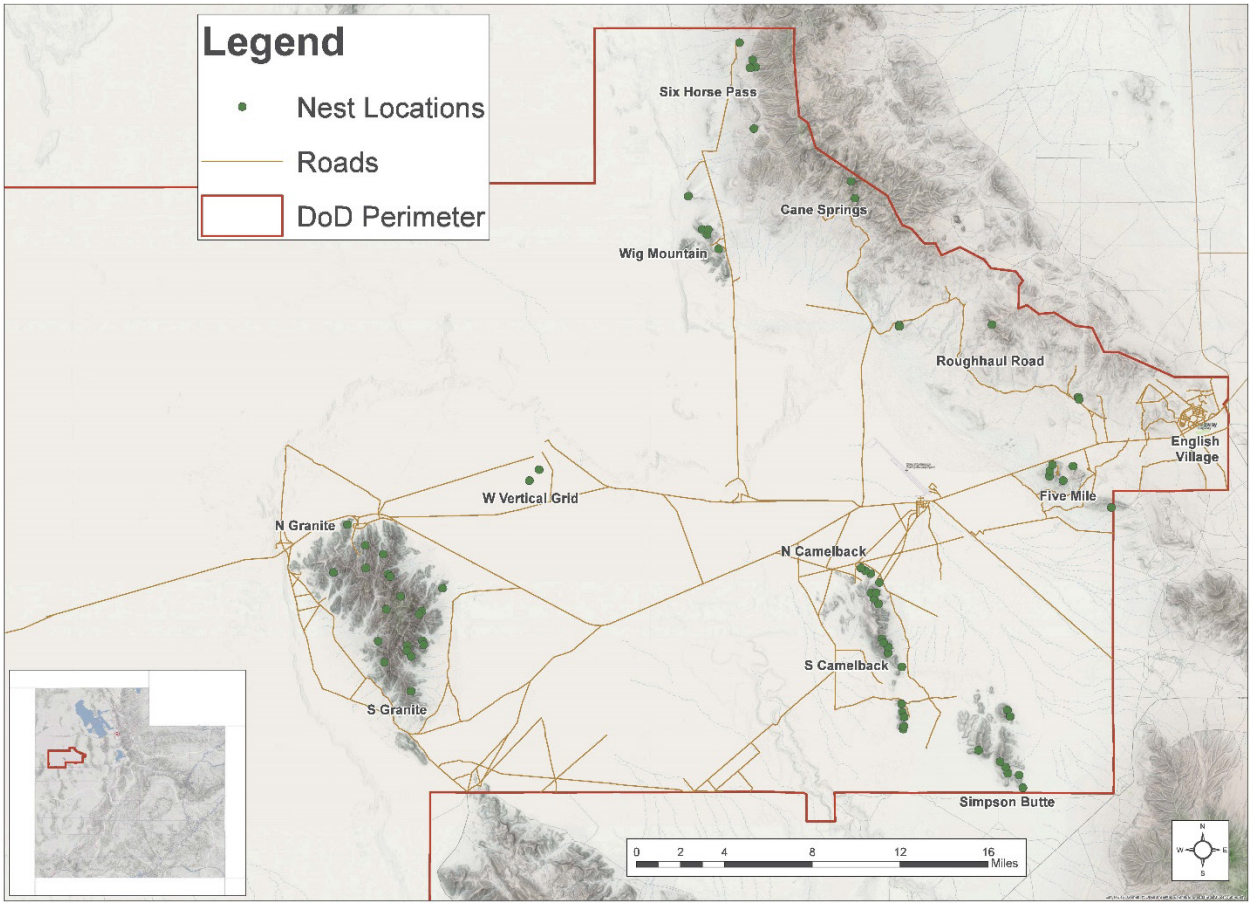


Figure 6. Known Golden Eagle Nest Locations Associated With 11 Territories on DPG

5.4 FIELD TESTING

The following instructions were provided to the observers to guide field observations, in addition to the simplified flow chart of methods provided in Appendix 3.

Early Season: Surveyors will attempt to search all 11 territories every two weeks, with 6 and 5 territories surveyed on alternating weeks, utilizing up to 2 survey days per week, and up to 3 hours search time per territory. Territories will be grouped by location and the ground observer and sUAS team will alternate territory groups between days. Territory survey order within each group will be based upon DPG identified priority areas and optimal time of day viewing conditions. Surveyors will follow strict survey protocols detailed below and visualized by flowcharts in Appendix 3.

Step 1: Determine necessary survey effort level at each territory:

- If first territory survey, or no In-Use Nest found during previous survey(s), attempt complete search below *(Step 2–7)* until territory status is determined or 3-hour time limit is reached for that territory.
- If In-Use Nest present on previous visit, complete Steps 2–4, and then proceed to "In-Use Nest" protocol. This includes nests for which the previous status was "previously In-Use unknown" *(see description in "In-Use Nest" protocol),* until status is resolved.

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- If an In-Use Nest in this territory was previously determined as "failed", do not survey.

Step 2: Record daily "Survey Start Time" when leaving English Village *(Ground/sUAS)* or upon take-off *(UAS).*

Step 3: Record individual "Territory Survey Start Time" when within 2-km buffer around known nests.

Step 4: Navigate to within 800 m+ or adjusted viewing location of first ranked nest(s) *(order prescribed based on survey history).*

Step 5: "Area Search": record stationary time spent searching for free-flying eagles within territory or on ridges *(up to 15 mins).* Time does not include approach drive/fly time to stationary point, but adults observed during approach are noted *(please indicate if observed on approach).*

- No adults seen, proceed to "Nest Survey".
- One adult seen, proceed to "Nest Survey", but adjust nest survey order to begin with known nest(s) within 250 m of adult, survey all other nests in prescribed order.
- Two adults seen off-nest, search any known nest(s) and substrate visible within 250 m of adults for signs of nest tending/eggs. If both eagles remain off-nest for 15 mins, territory survey ends, with times noted, and territory status will be recorded as "Territory Occupied, no In-Use Nest".

Step 6: "Nest Survey": attempt to search all known nests in pre-determined order, with visit-specific modifications as warranted. Each nest is viewed until status is confirmed *(i.e., "In-Use" [adult, egg, or young on nest], "inactive" [not In-Use, based on clearly visible nest bowl/platform, or condition inadequate for nesting], "Unknown" [30 mins viewing viable nest, status unresolved], "Time expired" [territory survey end time reached before status confirmed], or "Not Surveyed").* Evidence of tending/greenery is noted. Record all nest survey time undifferentiated by nest but note if full 30 mins required for individual nests.

- Attempt to survey all known nests in prescribed order (based on nest histories, but adjusted if presence of adult(s) detected during this or previous survey, or recent evidence of tending), until "In-Use Nest" (eggs/nestling/incubating adult) found, two adults seen off-nest, all nests surveyed, or 3 hr time limit reached. If all nests were not surveyed during a previous survey due to time expiration, resume from previous position.
- Up to 5 mins may be spent scanning nearby cliff faces and ridgetops upon arrival at each new viewpoint.
- If an In-Use Nest is found, proceed to "In-Use Nest" protocol (survey ends there, with end times noted). Territory status will be recorded as "Occupied-In-Use Nest".
- If two adults seen off-nest, go to protocol under "Two adults seen", under "Step 5: Area Search" (survey ends there, with end times noted).
- If all nests surveyed without detecting an In-Use Nest, and a single adult has been seen on this or any previous survey, record end of Nest Survey time and proceed to "Extended Search".

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- If all nests surveyed without detecting an In-Use Nest, and no eagles were detected in the territory, record territory status as "Vacant Territory", record end of Nest Survey time and proceed to next territory.

Step 7: "Extended Search": attempt to find new nests when only one adult seen and known nests are not In-Use. Record search time, including time hiking if relevant, and indicate area searched on map.

- Search potential nest substrate and ridges within 250 m of previous adult sightings(s) for potential alternate nests, until an In-Use Nest is found *(go to "In-Use Nest" protocol),* two adults are seen off-nest, the area surrounding the sighting has been adequately searched *(may include hiking for ground observer),* or time expires. Add any new nests found to the end of next territory visit search order unless evidence of tending.
- If an In-Use Nest is found, proceed to "In-Use Nest" protocol *(survey ends there, with times noted).*
- If two adults seen off-nest, go to protocol under "Two adults seen", under "Step 5: Area Search" *(survey ends there, with end times noted).*

Step 8: Record "Territory Survey End Time" when leaving 2-km buffer around each territory (NOTE: 3 hr territory limit begins upon entering 2-km threshold, but may expire during nest survey, extended search, or In-Use Nest monitoring).

Step 9: Repeat Steps 3-8 until all territories allotted for survey in a given day are visited. Ground and sUAS may not survey territories allotted for other survey days to maintain separation of survey platforms.

Step 10: Record daily "Survey End Time" on return to English Village or runway.

Late Season: Surveyors will attempt to visit all In-Use Nests identified in early season every week, plus any carryover territories with ambiguous status until resolution is reached, utilizing up to two survey days per week, and up to a time limit specific to each territory (between 1 and 4 hrs). Territories will be grouped by location and the ground observer and sUAS team will alternate territory groups between days. Territory survey order within each group will be based upon DPG identified priority areas and optimal time of day viewing conditions. Surveyors will follow strict survey protocols, detailed below, and visualized by flowcharts in Appendix 3.

Step 1: Determine necessary survey effort level at each territory:

- If In-Use Nest present on previous visit, complete Steps 2–4, and then proceed to "In-Use Nest" protocol. This includes nests for which the previous status was "previously In-Use unknown" *(see description in "In-Use Nest" protocol),* until status is resolved.
- If an In-Use Nest in this territory was previously determined failed, do not survey.
- If early season surveys found no adults in the territory *(i.e., "Vacant Territory"),* or produced two or more separate sightings of two off-nest adults *(i.e., "Occupied Territory, no In-Use Nest"),* do not survey.

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- If early season surveys found only one adult and no In-Use Nest, additional surveys may or may not be warranted. If all known nests were surveyed definitively on at least two separate visits, and at least one "Extended Search" was conducted of substrate within 250m of any adult sighting(s), no additional survey is necessary. Otherwise, follow Early Season protocol until these criteria are met or In-Use Nest is found.

Step 2: Record daily "Survey Start Time" when leaving English Village *(Ground/sUAS)* or runway *(UAS)*.

Step 3: Record individual "Territory Survey Start Time" when within 2-km buffer around known nests.

Step 4: Approach first nest viewing location of In-Use Nest and proceed to "In-Use Nest" protocol.

Step 5: Record "Territory Survey End Time" when leaving 2-km buffer around each territory, or when time expires *(NOTE: 3-hr territory limit begins upon entering 2km threshold but may expire during survey)*.

Step 6: Repeat Steps 2-5 until all territories allotted for survey in a given day are visited. Ground and sUAS may not survey territories allotted for other survey days to maintain separation of survey platforms.

Step 7: Record daily "Survey End Time" on return to English Village or runway.

"In-Use Nest" Protocol *(to be used with both "Early Season" and "Late Season" surveys)*: Surveyors will determine status of newly or previously found In-Use Nest by watching for up to 60 mins *(but ended sooner if definitive status is reached sooner, or maximum 4-hour territory time expires)*.

- For newly discovered "In-Use Nest", 60-minute clock begins when nest first verified used (e*.g., may exclude up to 30 mins of survey while still "unknown"*); for all others, time begins with arrival at view coordinate.
- If two adults seen on the nest, watch until confirmation of incubation/brooding, eggs, nestlings, fledglings, or *failure (proceed to those statuses below),* or list as "adults on nest-unknown" if status unresolved after 60 mins or when time expires.
- Incubation/brooding: if adult seen in incubating/brooding posture, record status and end nest survey.
- Egg(s): if egg(s) seen, record number, presence of adult(s), other circumstances, and end nest survey.
- Nestling(s): if nestling(s) seen after March 24, spend up to 60 mins attempting to count and age to nearest half-week. Surveys may be ended sooner without a count of nestlings when all-downy eaglet(s) *(<4 weeks)* seen. Note presence of adults, feeding events, etc. List as "unknown" age and/or count if unresolved after 60 mins or time expires *(or note if not attempted due to pre-March 24 date)*. If age is determined to be 7 weeks or older (80% fledge age), proceed to "fledgling" protocol below.

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- Fledgling(s): spend up to 60 mins attempting to determine total number of fledglings reaching at least 80% fledge age *(7 or more weeks).* Annual nest survey effort is complete when fledge age reached and confident fledgling count achieved *(may require subsequent week visit).*
- Failure: nest confirmed as empty of adults, eggs, or nestlings, after previous visit confirmed In-Use *(excluding "adults on nest-unknown"),* or status of previously confirmed In-Use Nest cannot be verified after two consecutive weeks of 60 min survey.
- Previously In-Use-unknown: status cannot be verified after 60 mins of watching, despite activity confirmed during a previous survey. Two consecutive nest surveys with this status results in assigning failure.

5.5 SAMPLING PROTOCOL

Laboratory samples were not collected during this demonstration. Field survey methods are addressed in section 5.4.

5.6 SAMPLING RESULTS

Laboratory samples were not assessed during this demonstration. Field survey results are addressed in section 6.0.

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6.0 PERFORMANCE ASSESSMENT

The demonstration team successfully completed two full seasons of eagle nest monitoring on DPG during 2019 and 2020 *(Table 4)*. However, eagle nesting initiation and success rates were very low across the entire Utah West Desert region during both years *(HawkWatch International 2019)*. Eagle nesting initiation is currently thought to be a function of available food supply, namely black-tailed jackrabbits for the West Desert population of golden eagles *(Steenhof et al. 1997)*. Jackrabbit populations in Utah are currently at a low in their population cycle, resulting in a few years of depressed golden eagle nest initiation and success *(HawkWatch International 2019)*. Eagle nesting success may begin to trend upwards as soon as next year *(2021)* as rabbit populations rebound *(Bedrosian et al. 2017)*. It may be that better eagle nesting success during monitoring would allow for a larger dataset and more robust conclusions regarding the abilities of each monitoring platform.

6.1 STATISTICAL ANALYSIS

As a result of the low nesting initiation and success rates on DPG during both monitoring seasons, the demonstration team was not able to collect enough independent data points to support a robust mixed effect regression model to assess platform success as we had proposed. The large number of variables involved in our proposed model demand a large set of independent nest observations, and a large number of replications of those observations. We only observed two in-use nests in 2019, and 3 in 2020 *(although only one nest in 2020 survived to fledging age)*. Instead, the DPG Team developed a simplified version of the proposed model focusing on general nest observations and status assessment. Survey platform was treated as a fixed effect with the binary response variable being correct or incorrect weekly nest status classification within each territory based on the "true" weekly status. Territory, survey week, and period *(early/late)* were treated as random effects. Mixed effect modeling allowed us to assess whether the survey platform influenced the odds of correctly classifying weekly statuses, outside the random effects of time and territory. In addition, the DPG Team created a logistic regression model to assess the effects of survey platform on the amount of time required to determine nest status. Survey platform was treated as a fixed effect with the number of minutes required to determine each nest status as the response. We included territory, survey week, and nesting period as additional variables. We ran two separate runs of both models for each year, as the differences in sUAS platforms greatly affected the results from year to year.

The initial proposal was to compare military UAS platforms to the sUAS and ground observer teams directly. However, it was determined in the first season of operation *(2019)* that flight schedules for the military UAS platforms were too sporadic to support regular nest monitoring. The military UAS were only able to monitor nests on an as-available basis, and other missions, weather, and maintenance concerns frequently bumped nest observations off the schedule. In addition, the COVID-19 crisis in 2020 resulted in the UAS observer being barred from conducting nest observations within the UAS control box due to health and safety concerns. Due to a lack of repeated observations on the same scale as the ground observer and sUAS, the military UAS platform was not included in the comparison models.

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Table 4. Nest Monitoring Results of Both Survey Years, Broken Out by Year and Platform, and Including "True" Nest Statuses and Dates as Determined by Backdating and Remote Cameras Placed in In-use Nests

Metric	Year	"TRUE"	Ground	sUAS	UAS	Comment
# Territories	2019	11	11	11	6	
	2020	11	10	11	NA	
# Occupied Territories	2019	11	10	11	1	
	2020	6	6	6	NA	
# Nests Surveyed	2019	85	59	63	11	
	2020	85	47	62	NA	
Average Weekly Nests Surveyed	2019	NA	16	27	1	
	2020	NA	15	26	NA	
# In-Use Nests	2019	2	2	2	1	
	2020	3	2	2	0	
# Fledglings	2019	2	2	2	1	
	2020	2	2	0	NA	
% Success	2019	100%	100%	100%	100%	
	2020	33%	50%	0%	NA	
Fledglings/Adult Pair	2019	1	1	1	NA	
	2020	0.33	0.33	0	NA	
Territory Occupancy Sample Units	2019	NA	34	32	1	Total number of early season territory surveys in which definitive territory occupancy *(excluding In-Use Nests)* documented
	2020	NA	33	31	NA	
In-Use Nest Sample Units	2019	NA	21	21	2	Total number of territory surveys in which definitive In-Use Nest documented
	2020	NA	13	6	NA	
% correct closure	2019	100%	81%	89%	25%	% of In-Use Nest survey dates correctly assigned closure
	2020	100%	93%	83%	NA	
% incorrect closure	2019	0%	19%	11%	75%	% of nest survey dates incorrectly assigned closure *(too early/too late)*
	2020	0%	7%	17%	NA	
Field Survey Man-Hours	2019	NA	8:39	18:00	1:22	Average weekly driving/flight and survey hours *("Survey Time" x number of personnel)*
	2020	NA	7:47	20:09	NA	
Territory Survey Man-Hours	2019	NA	1:38	4:09	0:25	Average time within 2-km geofence x number of personnel
	2020	NA	1:47	3:54	NA	
Nest Survey Time	2019	NA	0:17	0:09	0:07	Average weekly time needed to determine nest status
	2020	NA	0:20	0:11	NA	
New Nests Found	2019	NA	1	3	0	Number of previously unknown nests identified
	2020	NA	1	3	NA	

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6.2 TIME TO EARLY SEASON OCCUPANCY STATUS

The ground observer and the sUAS took roughly the same amount of time to determine early season territory occupancy each year, even with the change in sUAS platform in 2020. The ground observer took a mean time of 111 minutes to determine occupancy in 2019 (SD = +-64) and 108 minutes in 2020 (SD = +- 64). The sUAS observer took a mean time of 108 minutes in 2019 (SD = +- 54) and 91 minutes in 2020 (SD = +- 50). The UAS took vastly less time to make a territory determination in 2019, although this is mostly due to the limited available flight time the platform had to work within. The UAS platform was rarely able to make definitive determinations within the given time allowed and was removed from the comparison. Most of the time required by both the sUAS and ground observer was taken by drive time between nests in a territory *(Figure 7).*

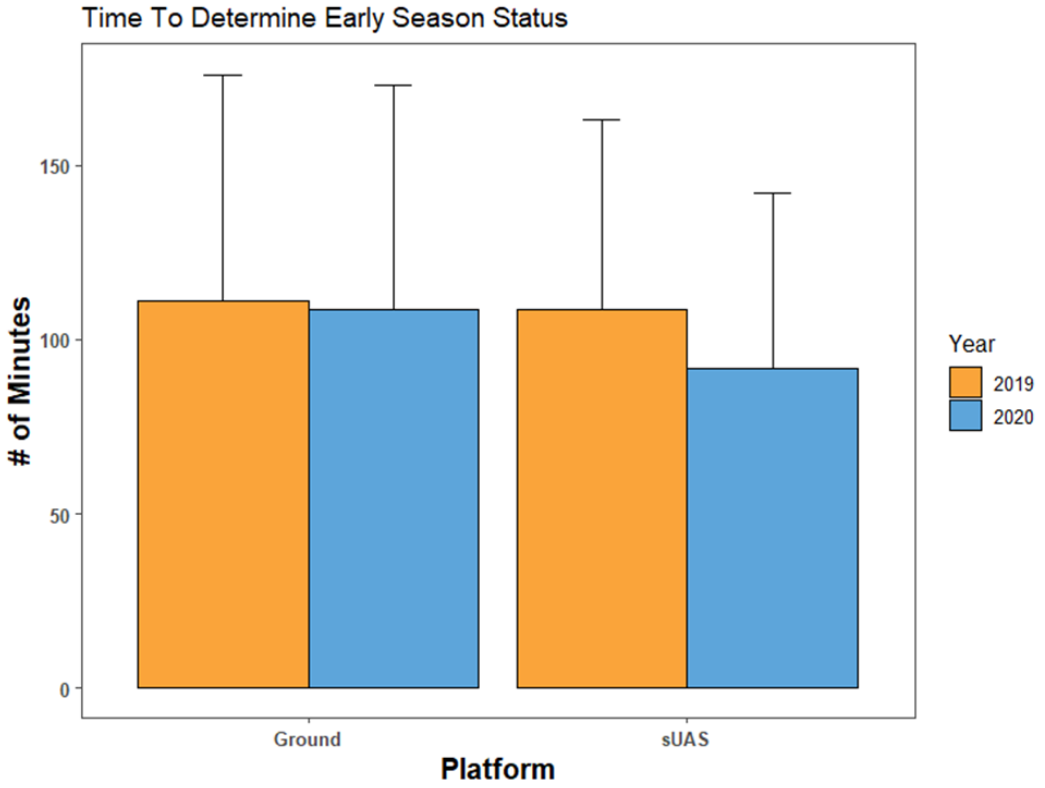


Figure 7. Chart Showing the Mean Time in Minutes (+SD) each Platform Required to Determine the Early Season Occupancy of a Territory.

6.3 NUMBER OF IN-USE NESTS IDENTIFIED

Both the ground observer and the sUAS found the same number of in-use nests each nesting season, while the UAS was unable to locate one of the in-use nests in 2019 *(the UAS was forced to cease operations before in-use nesting in 2020 due to COVID-19).* An interesting point to be considered is that in 2020, there were actually 3 in-use nests. The ground observer located one in-use nest that the sUAS was unable to observe due to territorial aggression against the platform by the eagle pair, while the sUAS located an in-use nest that the ground observer was unable to survey due to lack of ground access in an Impact Area. This illustrates the fact that both survey methods have strengths and weaknesses that the other can supplement *(Figure 8).*

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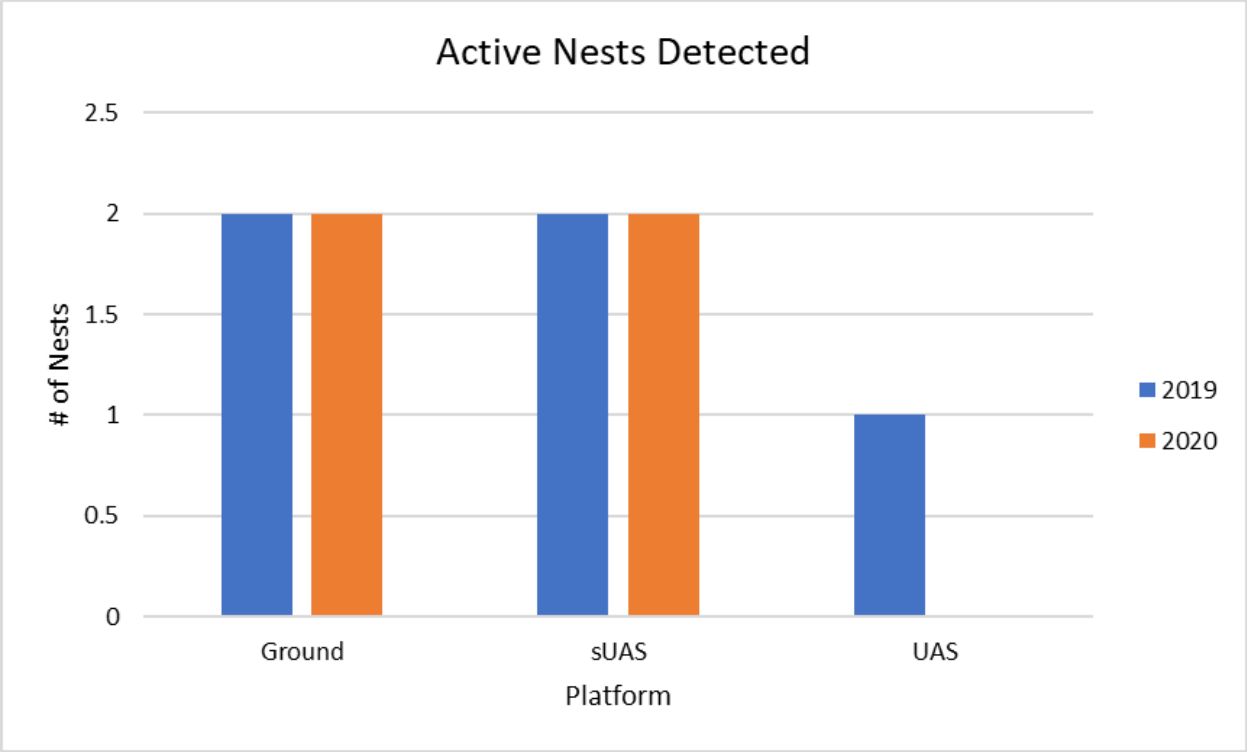


Figure 8. Chart Showing the Number of In-use Nests Each Platform Identified During Each Breeding Season.

6.4 DATE OF IN-USE NEST IDENTIFICATION

The sUAS platform was roughly equal with the ground observer at detecting in-use nests in 2019. The sUAS platform was able to survey almost every known nest in each assigned territory each week, making it more likely for the platform to detect an incubating eagle within a week of nesting initiation. The ground observer, on the other hand, was forced to rotate which nests were surveyed during each visit due to long hikes over rough terrain. The 2019 UAS was typically not able to identify nest activity due to the low resolution of its payload and the lack of precise nest metadata provided to its pilots and was not compared. In 2020 the sUAS was again roughly equal to the gound observer in nest detection time, despite the sUAS's drop in payload resolution. This indicates that the advantage of visiting more nests outweighed the disadvantage of poor payload resolution. In 2020, the UAS platform was forced to cease surveys before nests became in-use, removing it from this comparison *(Figure 9)*.

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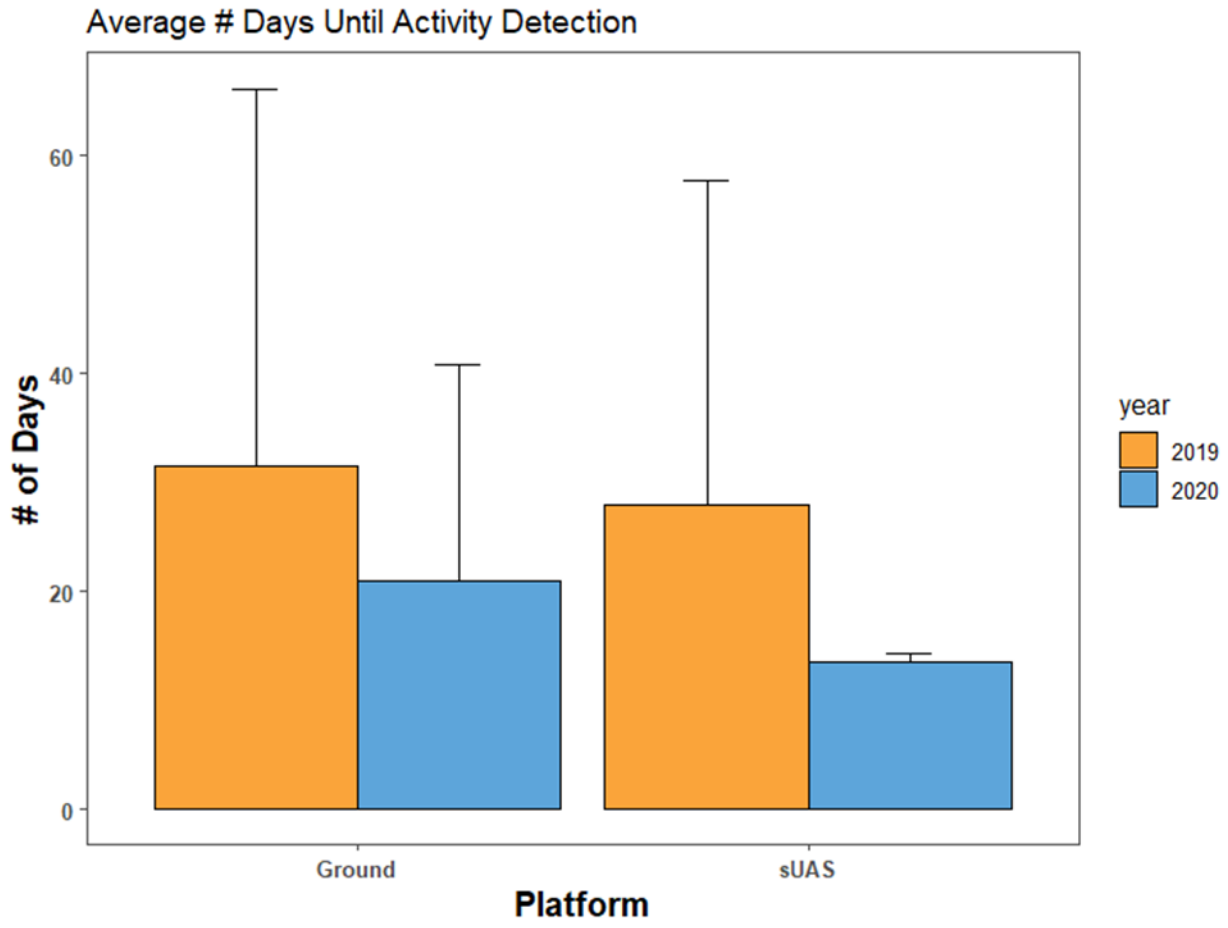


Figure 9. Chart Showing the Mean Number of Days (+SD) from Nest Initiation to Activity Detection by Each Platform.

6.5 DATE OF NEST FAILURE OR FLEDGE IDENTIFICATION

In 2019, the ground observer and sUAS platforms very nearly tied for speed at detecting nest failure or fledge. Both had sufficient quality optics and visitation rates to detect the lack of chicks in a nest almost immediately. The UAS was not compared due to lack of data. By contrast, the ground observer was much faster to detect nest failure or fledge in 2020 than the sUAS. The sUAS's loss of payload resolution made it difficult for the platform to identify the presence or absence of small chicks in a nest. Again, the UAS was forced to cease surveys before nests became in-use, removing it from this comparison *(Figure 10)*.

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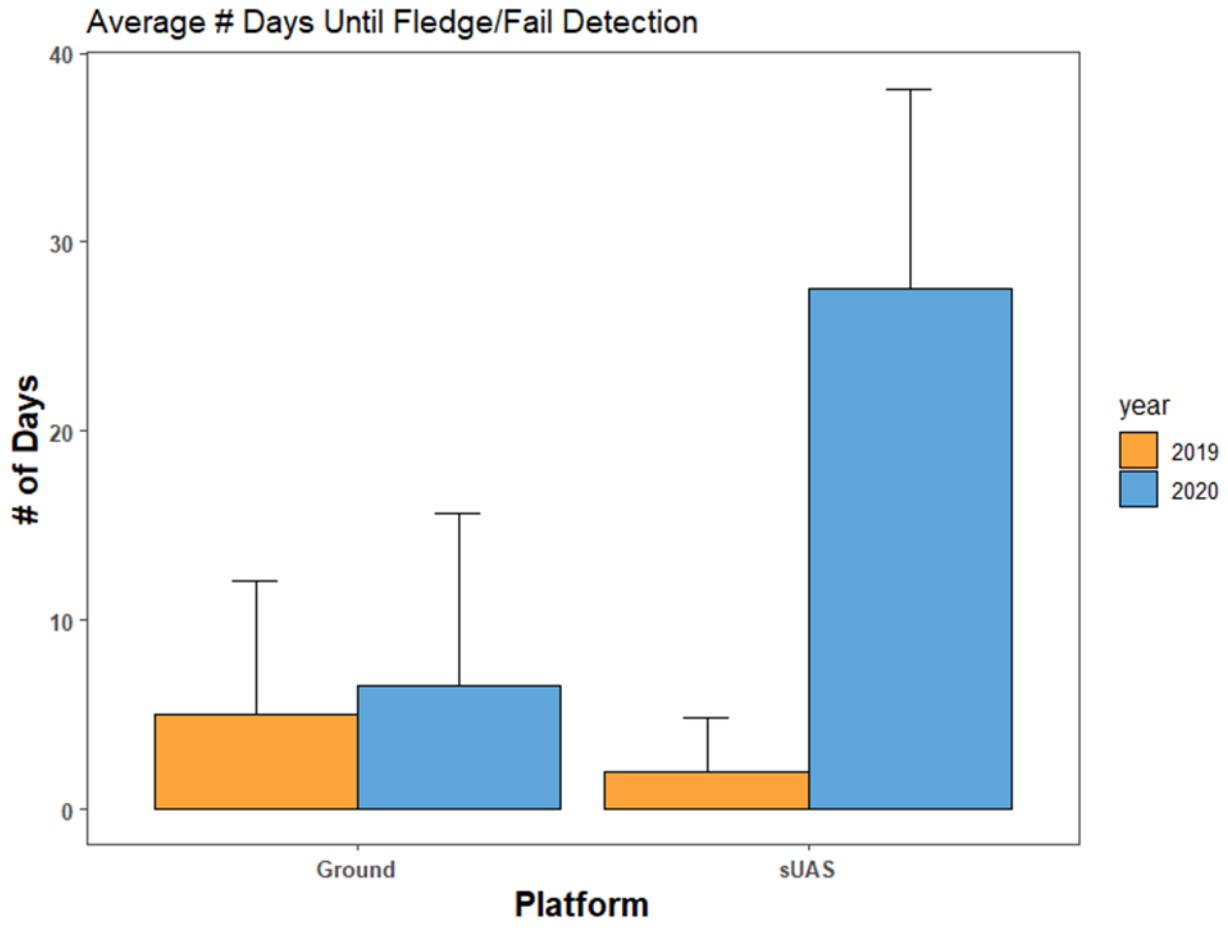


Figure 10. Chart Showing the Mean Number of Days (+SD) from Nest Failure or Fledge to Detection by Each Platform.

Error bars represent standard deviation.

6.6 TIME TO NEST STATUS UPDATE

The following logistic regression models illustrate the differences in nest observation efficiency both between platforms and between years. In 2019, the sUAS displayed a clear efficiency advantage over the ground observer, requiring much less observation time to make a nest status determination, especially in the early nesting season. This is because of the sUAS's ability to view directly into a nest bowl, eliminating the need to wait for a possible incubating eagle to stand or stretch in order to come into view from the ground. As the nesting season went on and chicks got larger, they were easier to see from below, decreasing the advantage of the sUAS. In 2020, the sUAS retained a small advantage over the ground observer, but the poor resolution of the payload meant that the platform had to observe each nest for much longer in order to determine if an object perceived to be in the nest was actually an eagle or if it was simply a pixilation artifact. In addition, the ground observer in 2020 took more time on average as the season went on, mostly due to the fact that one of the in-use nests was located in a high, partially obscured cliff cavity, preventing easy observation at any time.

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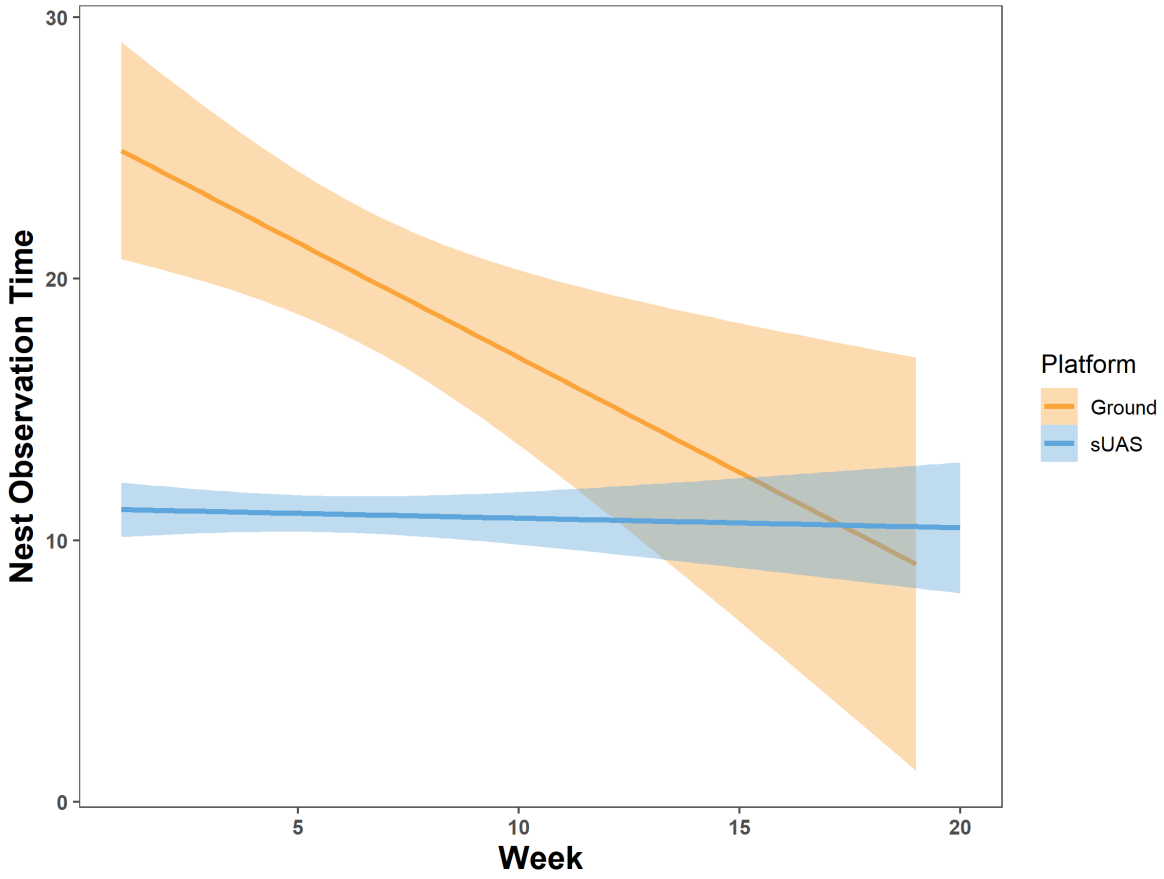


Figure 11. Comparison of the Efficiency of a Ground Observer in Minutes (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2019.
The sUAS took vastly less time to determine status during early season, while the ground observer gained efficiency as unused nests were eliminated from the survey round.

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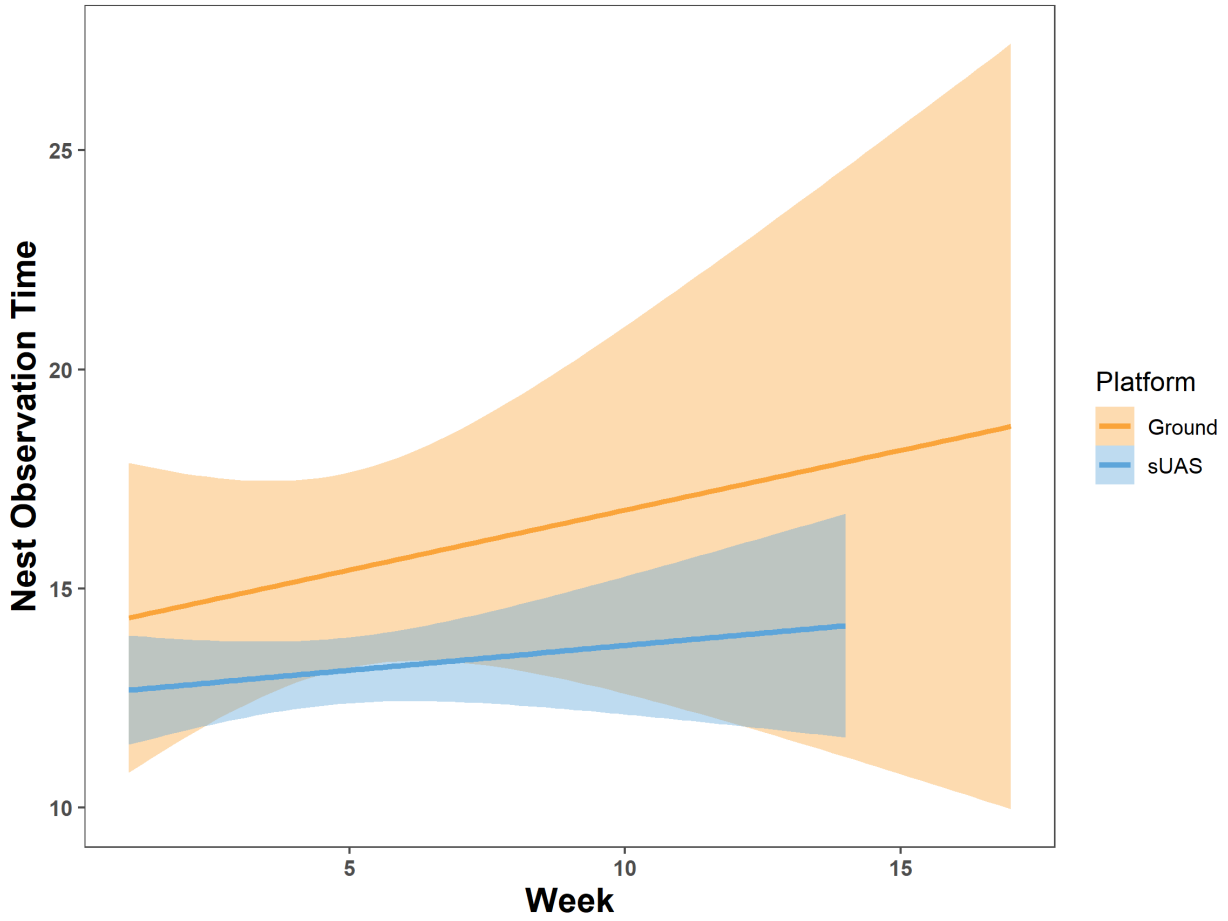


Figure 12. Comparison of the Efficiency of a Ground Observer in Minutes (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2020.
The sUAS took less time to determine status on average. The sUAS's efficiency advantage was much less pronounced than during 2019.

6.7 NUMBER OF NEW NESTS FOUND

In both 2019 and 2020, the sUAS outcompeted the ground observer and the UAS at finding previously undescribed nests. The sUAS had the advantage of covering a great deal of territory quickly, while also taking photos and video of terrain to be later analyzed for potential nests. The ground observer was unable to visit as much of each territory and had to focus on observing already known nests, preventing the observer from spending much time scanning for new nests. The UAS was unsuited to locating new nests due to the complications of approach angle and low payload resolution in 2019 and did not have enough survey time to draw a comparison in 2020 *(Figure 13)*.

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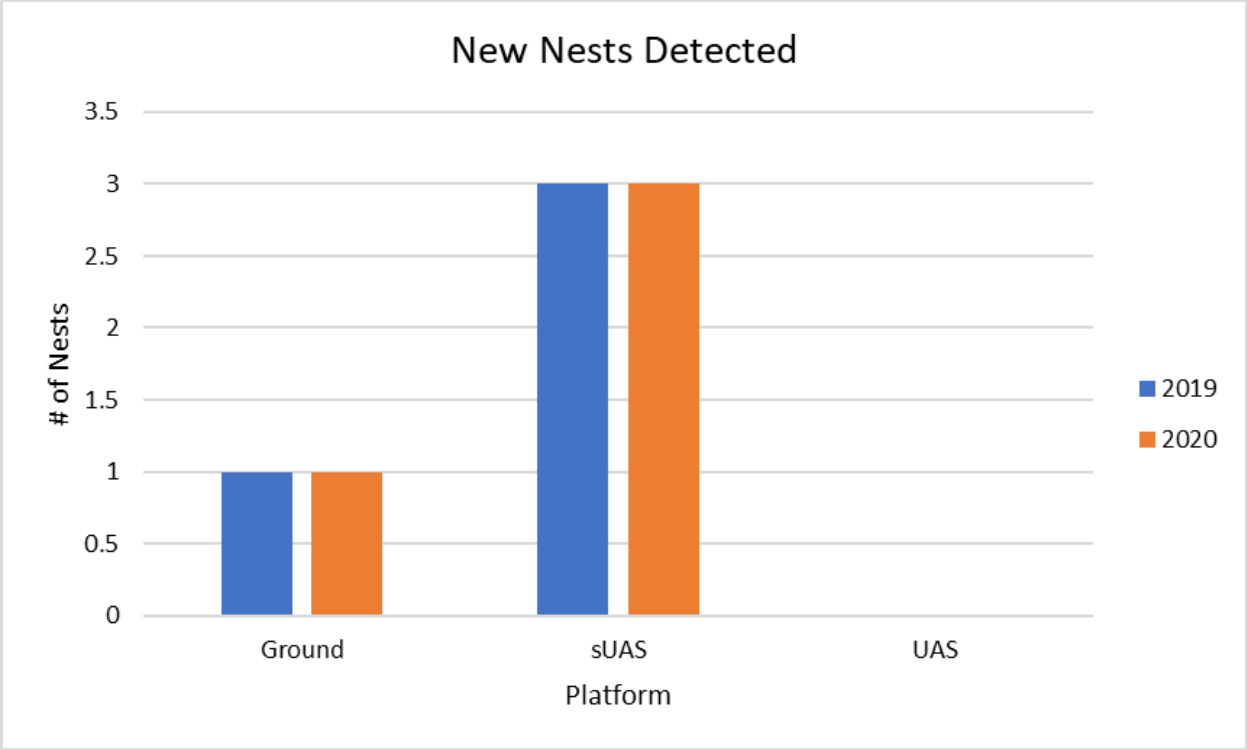


Figure 13. Chart Showing the Number of New Nests Each Platform Located During Each Season.

6.8 HYPOTHETICAL MISSION IMPACT IN DAYS

The hypothetical mission impact of nest area closures and openings is a measure of the precision of each platform in detecting nest status changes. Ideally, an in-use nest will be detected, and an area closure enacted immediately *(within one week or survey period)* upon the start of incubation, and the area opened again immediately upon the failure or fledge of the nest. This minimizes potential mission impacts of unnecessary range closures as well as protecting the nest against potential disturbance *(Figure 14)*.

In 2019, both the ground observer and sUAS platform were slow to detect the activity of RN315, leaving it unprotected for several weeks, although the sUAS was one week quicker in detecting the nest's activity. In addition, the ground observer designated RN315 as fledged prematurely by one week. This resulted in the sUAS being cumulatively more precise in designating range closures in 2019 than the ground observer.

In 2020, the data is complicated by the fact that both the ground observer and the sUAS monitored nests that the other platform was not capable of reaching, leaving only one nest for direct comparison. The ground observer was slow to detect the activity of RN248A by several weeks but caught the fledge of the nest immediately. The rough terrain and lack of road access in RN248A's territory required the ground observer to ration which nests received a survey visit each week, which resulted in the in-use nest going undetected for several weeks. The sUAS detected the activity of RN029 immediately but was slow to confirm the failure of the nest by several weeks.

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The low resolution of the platform payload in 2020 made it much more difficult to identify the presence or absence of young chicks from the nest bowl than the presence or absence of an incubating adult. Both platforms were equally precise at determining the status of RN321.

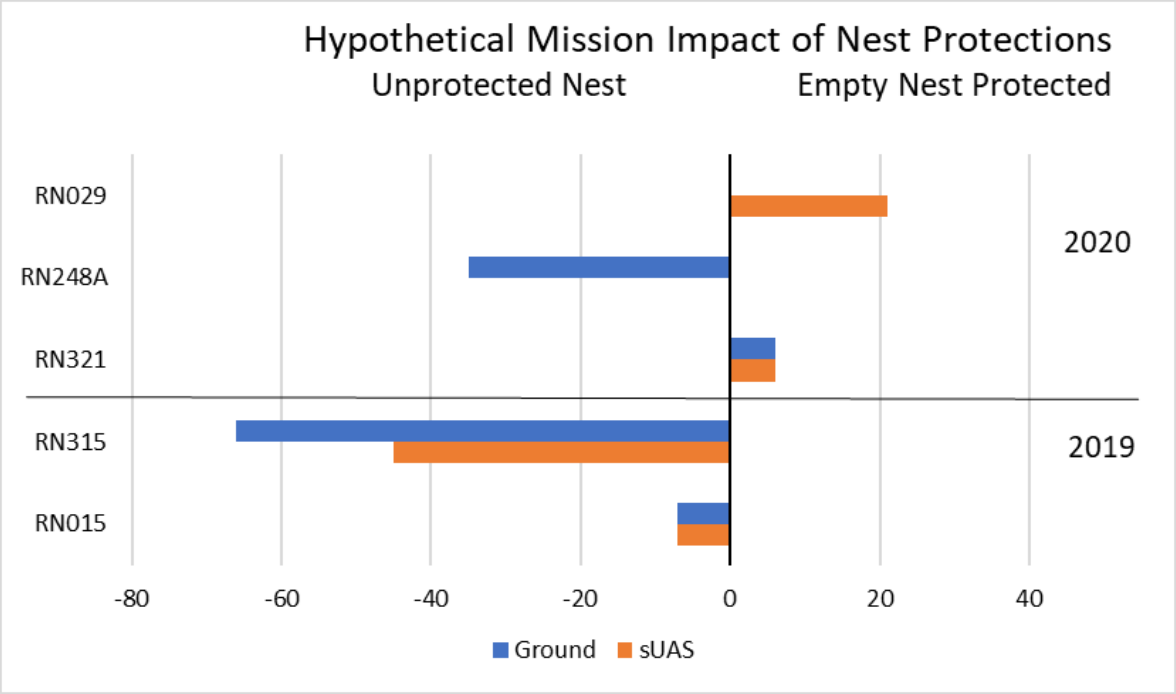


Figure 14. Chart Showing the Hypothetical Impact of Nest Area Closures/Openings by Platform and Year.

The 0 line represents no deviation from actual nest use, i.e., the desired perfect protection.

6.9 QUALITY OF PHOTO/VIDEO DOCUMENTATION

The DPG Team conducted a qualitative evaluation of how well each platform was able to document nest status in both 2019 and 2020. In 2019, the sUAS platform delivered high resolution video and photo documentation of all nests viewed, as well as footage of the surrounding cliffs for the team to search for previously unknown nests. The photo/video documentation allowed the data managers to confirm nest status before putting range closures in place. By contrast, the UAS platform in 2019 was equipped with a low-resolution payload that hampered the observer's ability to identify nests with confidence. The UAS's thermal imaging capability did allow the observer to spot chicks in in-use nests, however. In 2020, the imaging capabilities of the sUAS and UAS platforms were reversed. The replacement sUAS platform had a downgraded payload resolution due to downlink limitations. In addition, it did not have onboard data recording capabilities; the observation team had to record footage from the ground station, and as a result encountered significant issues with poor reception and signal corruption. These limitations resulted in the sUAS team requiring more time on site to determine nest status, and in many cases prevented the team from calling a certain nest status at all. On the other hand, the UAS platform received a significant upgrade to its payload systems, allowing for HD image recording. Unfortunately, the UAS team was forced to cease survey operations after only 2 weeks of monitoring due to the COVID-19 crisis, and the observation team was unable to obtain enough data to present a significant image comparison.

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The photos below show the images taken from the two sUAS and the one UAS *(Figures 15-18).*



Figure 15. A Photo of RN315 as Taken by the sUAS Platform in 2019.

(DJI Matrice 600 Pro with Zenmuse Z30 payload). The photo shows an adult golden eagle sheltering a chick less than a week old.

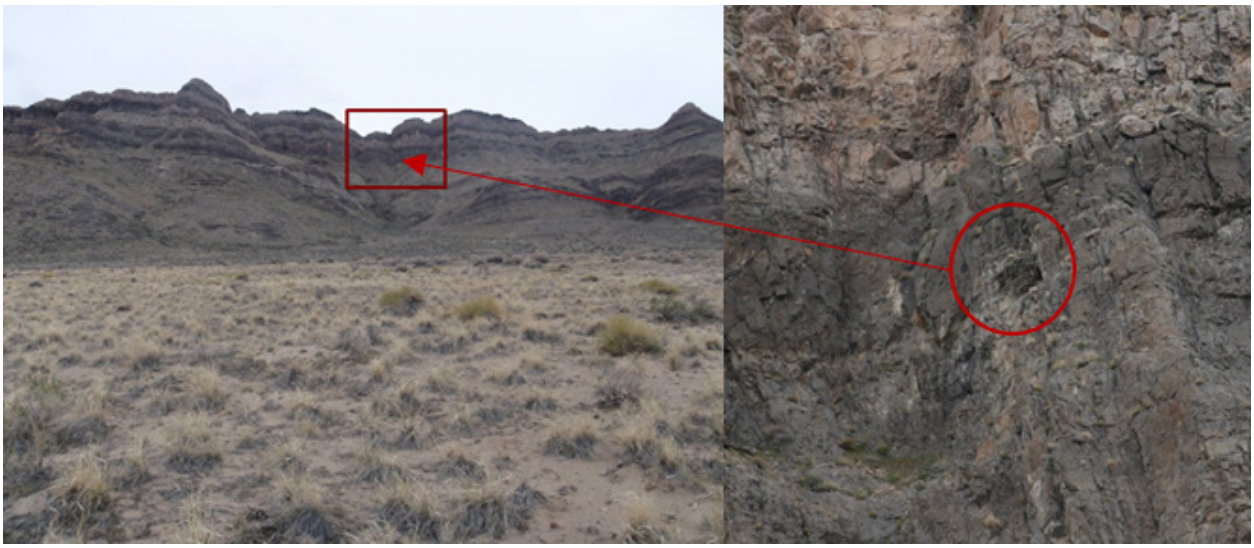


Figure 16. A Series of two photos taken by a ground observer at two different zoom levels of RN046.

The first photo shows the distance the observer must view the nest from, as well as the height of the nest on the cliff face. The second photo shows how the ground observer must view the nest from below, even at high zoom.

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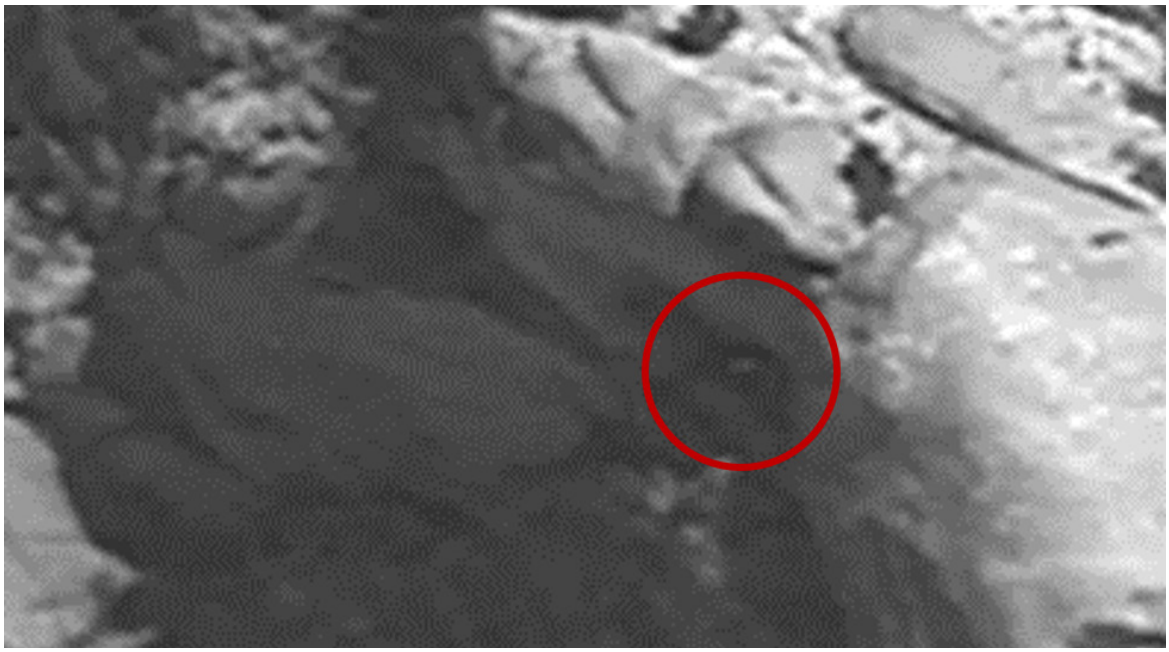


Figure 17. A Video Still Taken from the Footage of the UAS Observer Using Thermal Imaging in 2019, Showing RN315 with a Nearly 9-week-old Chick.

The chick is shown as a pale (warm) shape in the middle of a cool cliff face. This image shows the challenges the UAS observer faced with low resolution imagery, and how thermal imaging was able to partially compensate in the late nesting season.

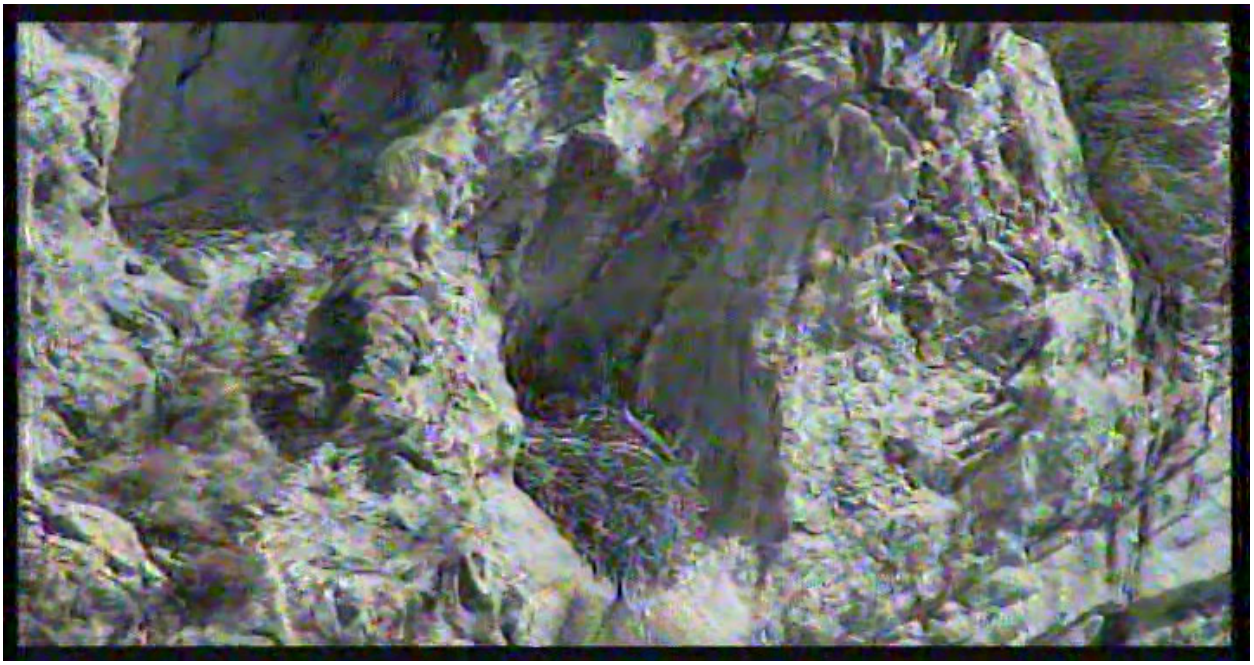


Figure 18. A Video Still Taken from the Footage of the sUAS Observer in 2020 (E900 with Sony FCB-EV7520A), Viewing Nest RN248.

The photo shows the low resolution and video artifacts that inhibited the sUAS's ability to make accurate nest activity identifications in 2020.

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6.10 ADDITIONAL METRICS FOR SUCCESS

The results of the mixed-effect logistic regression models indicate that the ground observer and sUAS platform had essentially equally *(high)* accuracy in determining the status of any given nest in 2019. Both platforms were more than 85% likely to determine nest status accurately and confidently in the early season, growing to more than 95% accurate in the late season. This can be attributed to the experience and skill of the ground observer, as well as the ability of the sUAS platform to take high quality documentation photos and video for review. In 2020, the sUAS platform suffered greatly from the drop in payload resolution. It began strongly and was still confidently able to determine when nests were not in-use. However, it struggled to accurately identify when nests were in-use and to determine the difference between an incubating nest and a nest with chicks. The ground observer, on the other hand, displayed almost the same results as in 2019 *(Figures 19 & 20)*.

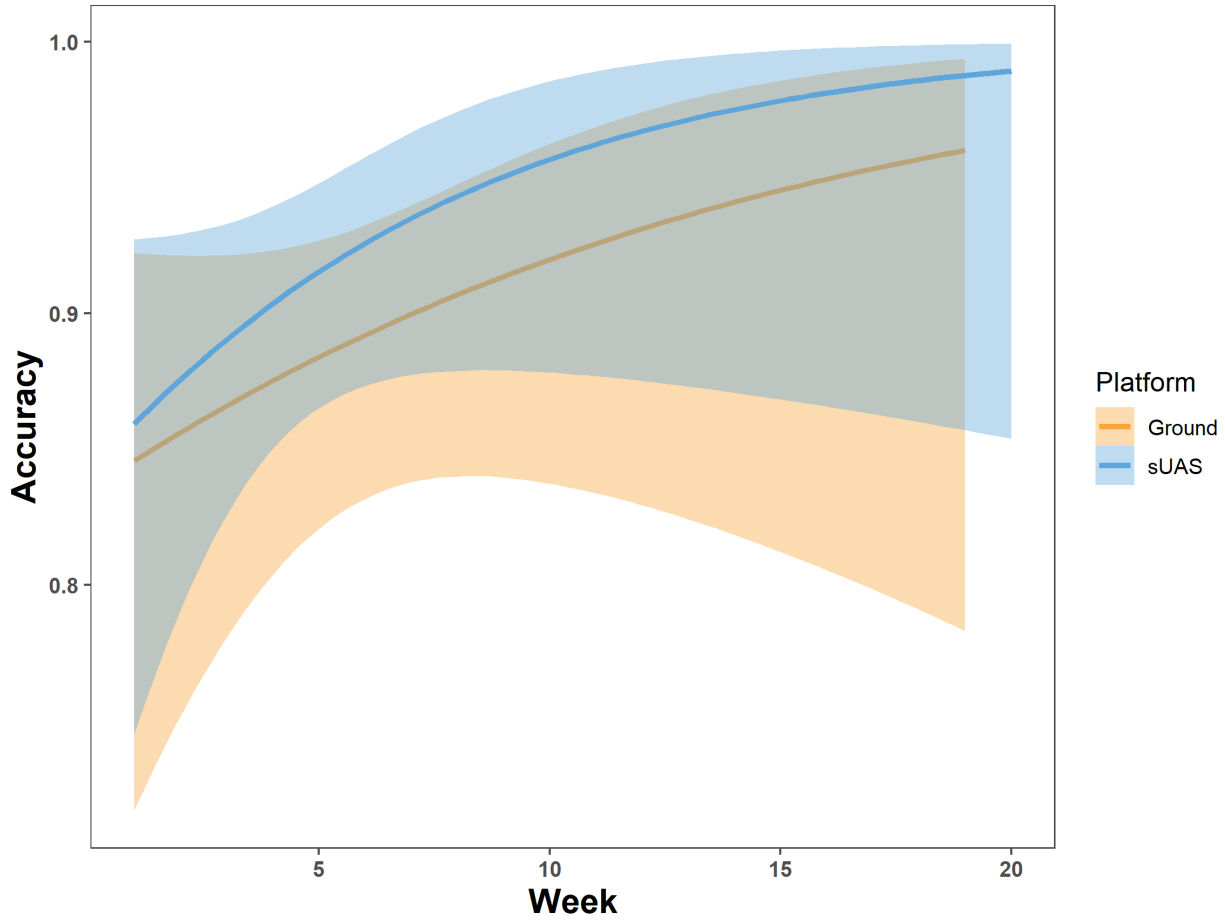


Figure 19. Comparison of the Accuracy of a Ground Observer (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2019

Both platforms gained accuracy as the season went on, roughly equal in accuracy.

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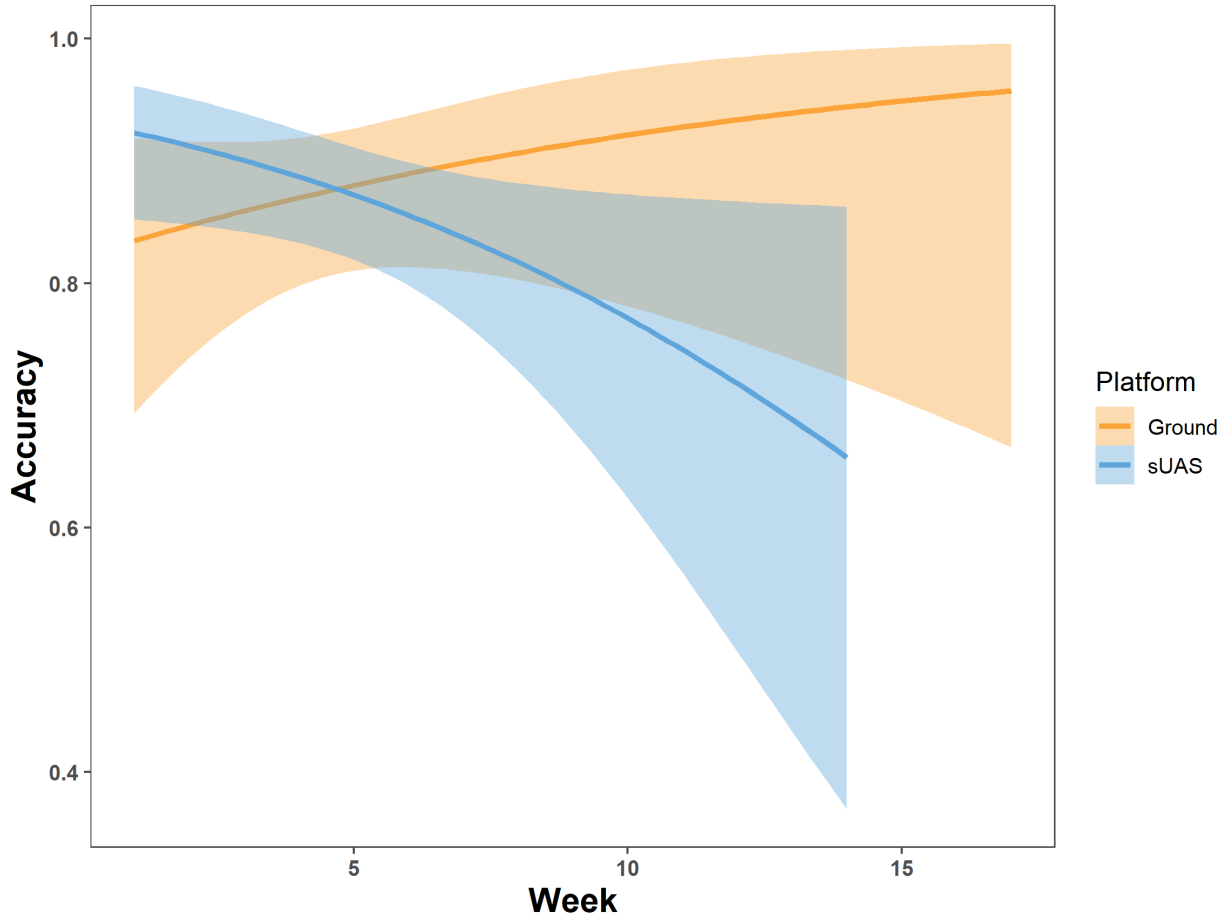


Figure 20. Comparison of the Accuracy of a Ground Observer (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2020.

The ground observer gained accuracy during the season, mirroring 2019, while the sUAS lost accuracy. This represents the challenges of identifying an in-use nest's status with a low-resolution payload.

When determining which platform is most efficient and cost-effective, it is important to take total territory coverage into account, especially in the early nesting season when looking to identify in-use nests. The sUAS platform was able to survey approximately twice as many nests each week than the ground observer in both 2019 and 2020. This grants the sUAS more confidence in accurately calling the occupancy status of early season territories, as well as giving it an advantage in locating in-use nests promptly. This played out in 2019 as the sUAS located one in-use nest a full week before the ground observer. The ground observer had to rotate which nests to observe each week due to time pressure and the lengthy hikes needed to cover some territories. By being unable to cover all known nests each week, the ground observer was slower to identify an in-use nest, leaving it potentially vulnerable to disturbance *(Figure 21)*.

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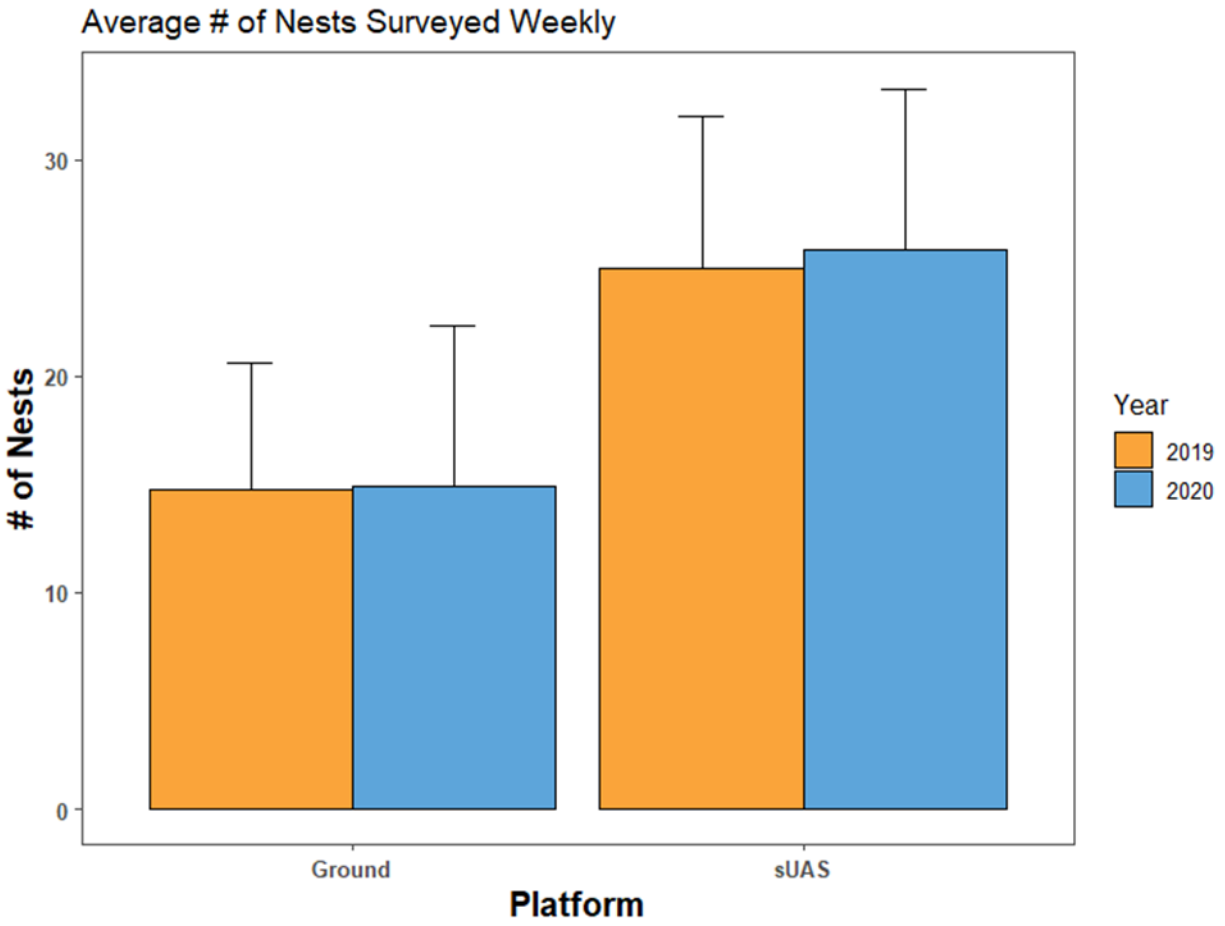


Figure 21. Chart Showing the Mean Number of Nests (+SD) Surveyed Each Week During the Early Season.

There is high variation from week to week depending on which territories were assigned for survey, but the sUAS consistently outperformed the ground observer over the same territory assignments.

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7.0 COST ASSESSMENT

The cost assessment included actual costs of both the sUAS and the on-the-ground observer. However, the actual costs are skewed based on a few circumstances that were out of the ordinary for this project. Just as this demonstration was beginning, the DoD memo was released banning COTS sUAS. The cost of the modified COTS sUAS included non-recurring engineering costs that would not have been included in a COTS sUAS. The changes in policy also required assistance from a Government organization to prepare and obtain a waiver for the project and provide direct oversight of the flights.

7.1 COST MODEL

The tables below break out the costs for each of the monitoring methods for comparison. Due to the significant differences between the two sUAS these were also broken out for comparison. Table 5 provides the costs for year one using the DJI Matrice and Table 6 provides that costs for year two using the E900. Both tables show the cost of Government support for waiver preparation and sponsor/oversight of flights. This cost should not necessarily be considered for future projects.

Table 5. One Year Cost Model for an sUAS.

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Platform	Purchase of sUAS *Modified commercial sUAS *(DJI Matrice)*	$18,139
Payload	Purchase of camera	NA- Integrated into platform
Batteries/Chargers	Purchase of extra batteries/chargers	$1,528
Binoculars/Scope	Not Applicable for sUAS	NA
Transportation	Mileage to-from observation locations	$3,000
Maintenance/Repair	Purchase of repair kit and replacement parts	$256
Monitoring Labor	Team of three	$55,346
Waiver Development *(Contractor)*	Development of waiver request memo and supporting documentation	$7,000
Govt. waiver prep and sponsor/training/oversight of flights	Cost of Govt. support for waiver	$79,557
Total		$164,826

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Table 6. One Year Cost Model for an sUAS

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Platform	Purchase of sUAS *Modified commercial sUAS *(E900)*	$5,500
Payload	Purchase of camera	$5,895
Batteries/Chargers	Purchase of extra batteries/chargers	$1,651
Binoculars/Scope	Not Applicable for sUAS	NA
Transportation	Mileage to-from launch locations	$3,000
Maintenance/Repair	Purchase of repair kit and replacement parts	$893
Monitoring Labor	Team of three	$48,840
Waiver Development *(Contractor)*	Development of waiver request memo and supporting documentation	$7,000
Govt. waiver prep and sponsor/ training/oversight of flights	Cost of Govt. support for waiver	$61,249
Total		$134,028

Table 7 below shows the costs for the military UAS. Because the military UAS was used on an as available basis the costs of the platform/payload were not applicable. Only the cost associated with the biologist that sat with the UAS pilots was calculated. The cost of a military UAS not be cost-effective for natural resource monitoring alone. However, if an installation has a UAS program and the platform can be made available as part of the pilot training program, it is a useful tool to have.

Table 7. One Year Cost Model for an UAS

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Platform	Not Available	NA
Payload	Not Available	NA
Batteries/Chargers	Not Applicable	NA
Binoculars/Scope	Not Applicable	NA
Transportation	Not Applicable	NA
Maintenance/Repair	Not Available	NA
Monitoring Labor	One Biologist	$10,910
Waiver Development *(Contractor)*	Not Applicable	NA
Govt. waiver prep and sponsor/ training/oversight of flights	Not Applicable	NA
Total		$10,910

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Table 8 below provides a detail on the costs for on the ground monitoring. This was performed by one biologist for the two-year study.

Table 8. One Year? Cost Model for On-the-Ground Monitor

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Platform	Not Tracked	NA
Payload	Not Tracked	NA
Batteries/Chargers	Not Tracked	NA
Binoculars/Scope	Approximate Cost	$2,000
Transportation	To and from observation locations	$3,130
Maintenance/Repair	Not Tracked	NA
Monitoring Labor	One Biologist	$14,715
Waiver Development *(Contractor)*	Not Tracked	NA
Govt. waiver prep and sponsor/ training/oversight of flights	Not Tracked	NA
Total		$19,845

Table 9 below shows the cost of using helicopters for monitoring. These costs are based on historical costs since helicopters were not used during the two-year study.

Table 9. One Year? Cost Model for a Helicopter

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Platform	Per hour cost of $1,500 for 36 days (4 hours/ day)	$216,000
Payload	Not Tracked	NA
Batteries/Chargers	Not Tracked	NA
Binoculars/Scope	Approximate Cost	$2,000
Transportation	Not Tracked	NA
Maintenance/Repair	Not Tracked	NA
Monitoring Labor	One Biologist	$8,640
Waiver Development *(Contractor)*	Not Tracked	NA
Govt. waiver prep and sponsor/ training/oversight of flights	Not Tracked	NA
Total		$226,640

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The two tables below provide a side-by-side comparison of the two sUAS, UAS, on-the-ground monitor and helicopter. Table 10 includes the cost of Government support to prepare, obtain a waiver for the sUAS and monitor flights, while Table 11 removes those costs. Due to the unique circumstances faced during this demonstration, it is assumed that the additional cost for Government support for waiver and oversight would not be necessary for future projects.

Table 10. Cost Comparison of Methods with Government Support for Waiver

Cost Elements	sUAS-DJI Matrice	sUAS- E900	UAS	On-The-Ground	Helicopter
Platform	$ 18,139	$ 5,500	NA	NA	$ 216,000
Payload	NA	$ 5,895	NA	NA	NA
Batteries/Chargers	$ 1,528	$ 1,651	NA	NA	NA
Binoculars, scope	$ -	$ -	NA	$ 2,000	$ 2,000
Transportation *(to-from observation locations)*	$ 3,000	$ 3,000	NA	$ 3,130	
Maintenance/Repair	$ 256	$ 893	NA		
Monitoring Labor	$ 55,346	$ 48,840	$ 10,910	$ 14,715	$ 8,640
Waiver Development (*contractor*)	$ 7,000	$ 7,000	NA	NA	
*Govt. waiver prep and sponsor/training/oversight of flights	$ 79,557	$ 61,249	NA	NA	NA
Total	**$ 164,826**	**$ 134,028**	**$ 10,910**	**$ 19,845**	**$ 226,640**

** Cost specific to this project as a result of DoD Memo banning COTS sUAS and FY19 NDAA prohibiting the procurement or operation of Chinese made sUAS.*

Table 11. Cost Comparison of Methods without Government Support for Waiver

Cost Elements	sUAS-DJI Matrice	sUAS- E900	UAS	On-The-Ground	Helicopter
Platform	$ 18,139	$ 5,500	NA	NA	$ 216,000
Payload	NA	$ 5,895	NA	NA	NA
Batteries/Chargers	$ 1,528	$ 1,651	NA	NA	NA
Binoculars, scope	$ -	$ -	NA	$ 2,000	$ 2,000
Transportation *(to-from observation locations)*	$ 3,000	$ 3,000	NA	$ 3,130	
Maintenance/Repair	$ 256	$ 893	NA		
Monitoring Labor	$ 55,346	$ 48,840	$ 10,910	$ 14,715	$ 8,640
Waiver Development (*contractor*)	$ 7,000	$ 7,000	NA	NA	
*Govt. waiver prep and sponsor/training/oversight of flights	$ -	$ -	NA	NA	NA
Total	**$ 85,269**	**$ 72,779**	**$ 10,910**	**$ 19,845**	**$ 226,640**

** Cost specific to this project as a result of DoD Memo banning COTS sUAS and FY19 NDAA prohibiting the procurement or operation of Chinese made sUAS.*

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Cost Elements:

sUAS Platform: The sUAS platform is a primary cost. The platform must be able to meet, in this case, DoD Army cybersecurity and procurement requirements while also being able to accommodate the necessary payload. Performance, durability, and flight time are all important factors when selecting a platform.

Costs for the sUAS DJI Matrice 600: This is based on actual costs of the two DJI Matrice acquired from the Government. The DJI Matrice 600 were COTs that had been modified to use a U.S. developed software for control. This modification increased the cost of the sUAS.

Costs for the sUAS E900: This was an estimated cost provided from the Government. The E900 used in the second year were loaned to the program. The E900s used in this project could be considered developmental. The payload was integrated into the system and was not part of the original system.

sUAS Payload: The sUAS payload includes the camera and/or sensors. The payload can be a significant cost depending upon the requirement and whether or not it has been integrated into the platform. The payload weight will also need to be considered when selecting an sUAS platform.

Batteries/Chargers: Batteries are critical for the operation of the sUAS and are a significant cost. Back up batteries are necessary to ensure flights can continue without downtime. Charging infrastructure for the batteries was also a consideration. Because the sUAS are used in remote locations, it is necessary to have portable charging for the batteries.

Binoculars/Scopes: High quality binoculars and scopes are necessary for on-the-ground and helicopter monitors.

Transportation: Both sUAS and on-the ground monitoring requires transportation from a starting location to the monitoring or launch location.

Maintenance/Repair: Although little maintenance or repair was performed during this demonstration, it is important to consider when implementing a program. Common maintenance/repairs include battery charging, loose bolts/fittings, broken rotors, landing gear, etc. Each platform was only operated for a few months in each year. Industry data suggests the life cycle of the typical sUAS to be approximately 200 flights.

Monitoring Personnel: Personnel for the sUAS consisting of a pilot, an operator, a biologist, and observer. The observer was a person associated with the waiver who ensured that all requirements were being met. However, based on experience, the four people could be reduced to two *(pilot/biologist)*.

Waiver Development *(Contractor):* The Exemption to Policy (ETP) waiver process includes the technical documentation of the sUAS to obtain an Airworthiness Release (AWR). Once the AWR is in place, the development and approval of standard operating procedures, System Safety Management Plan, risk acceptance memos, and the formal ETP memo signed by a senior official may be prepared.

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The preparation of this material, the submission through a SIPR account, discussions/clarifications from the Army CIO, staffing of memos for signature, all take time and have an associated cost. The process to obtain an ETP changed three times from 2018 to 2020.

Access to Installation and Logistics: This cost is associated with obtaining base access and coordination with range control and flight control.

Government Waiver Preparation and Sponsorship/Training/Oversight of Flights: This cost may be eliminated or significantly reduced in the future. During this demonstration, it became necessary to engage with another Government organization to sponsor the waiver and to support its development. In addition, this organization was able to provide a modified sUAS that was capable of meeting DoD cyber requirements. Because they were the sponsor of the waiver, they were on-site to provide training on the sUAS and weekly flights.

7.2 COST DRIVERS

The most significant cost driver is DoD Army sUAS policy. The platform/payload must meet Department of Army cyber security requirements. Each platform must undergo an evaluation and provide an Exemption to Policy (Waiver) to operate in restricted airspace. The cost associated with obtaining an ETP includes labor to develop the ETP application package *(Standard Operating Procedures, System Safety Management Plan, and Memos),* upload through SIPR, and track through the system. The waivers are only for six months. In addition, each sUAS must have an Airworthiness Release.

The prohibition on foreign made sUAS impacts costs because the U.S. market is still developing and has not yet produced a cost competitive commercial sUAS to compete with foreign made sUAS. As the U.S. market matures and purchases increase, this will begin to bring the costs down.

7.3 COST ANALYSIS AND COMPARISON

Costs are based on golden eagle monitoring on a MRTBF with vast distances between nests and rugged terrain. Breeding season begins in February and goes through June, allowing for a range of temperatures and weather conditions.

The cost comparison assumes that both the sUAS and on-the-ground monitoring start and return from the same location. The time to survey nests and return to the starting location was recorded.

Industry data on life expectancy of an sUAS is approximately 200 flights. When first envisioning this project, it was thought that the sUAS would be most cost-effective and could replace the current approach of on-the-ground monitoring. The results from the demonstration show that the use of an sUAS is a good tool to have available but may not be able to cost-effectively replace on-the-ground monitoring. For instances where the nests are too high or distances too long or rugged, sUAS are a good tool. As the cost of the sUAS system is reduced and the policy surrounding flying the sUAS in DoD airspace is streamlined or eliminated, it may become cost-effective compared to on-the-ground monitoring. The sUAS is more expensive than on-the-ground monitoring, however, the sUAS provides benefits over that of the on-the-ground monitor such as photos which can be used to study and accurately age the chicks. The sUAS can also cover more territory than an on-the-ground monitor and access nests that are too high or at a difficult angle to see from the ground.

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In addition, some of the costs associated with this demonstration can be reduced or eliminated. For instance, a three-person team was used to monitor eagles *(the pilot in charge, operator, and observer).* In the future, this team could be reduced to a two-person team. In addition, the Government sponsor of the waiver observed weekly flights which required labor and travel. Due to COVID-19 in the 2020 season, the Government sponsor was able to designate a local Government Point of Contact (POC) to provide oversight which reduced costs. The use of sUAS compared to a helicopter is cost competitive.

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8.0 IMPLEMENTATION ISSUES

8.1 SUAS IMPLEMENTATION

A major implementation issue with the use of sUAS in DoD airspace involves obtaining an Airworthiness Release (AWR) and Exemption to Policy (ETP). This policy seeks to prevent the use of foreign made sUAS based on cybersecurity vulnerabilities. Both approvals take time to develop, review, and obtain approval. Under the 2019 DoD Army policy, a modified DJI Matrice 600 was used to monitor golden eagles after obtaining an ETP. However, because of the FY 2020 NDAA, Section 848 Prohibition on Operation or Procurement of Foreign Made Unmanned Aircraft Systems, the procurement or use of Chinese made sUAS was prohibited. This led to the use of a different sUAS platform. Each change of platform requires a new AWR and ETP. The ETP can only be granted for six months at a time and the time to obtain an approval may take 45-60 days minimum.

To obtain an Airworthiness Release, a Standard Operating Procedure, System Safety Management Plan, Material Risk Acceptance Memo, and Operational Risk Acceptance Memo, must be developed and submitted to the Aviation Engineering Directorate. Once the AWR is provided, it is sent along with the other documents with a memo, signed by a Senior Level memo requesting an ETP. The AWR is valid for three years.

The sUAS platform used for observation and data collection has real potential for becoming a quick, cost-effective way to monitor the progress of nesting birds in hard to reach places. For this platform to work efficiently and in a manner that collects the best data, some points described below have been found over the past two years to help improve the use of this platform.

Good metadata and a member of the team that has experience with eagle behavior and good knowledge of the territory is key to obtaining useful data. A trained eye for these sUAS platforms was able to compensate for finding nests with sometimes less than ideal video streaming quality or lighting situations. A profile containing pictures from multiple angles and distances and GPS coordinates of known nest in the territory was critical to confirming nest locations and to reduce the time that the sUAS team spent locating nests during a flight.

For the legal operation of the sUAS to fly commercially, Federal Aviation Administration (FAA) regulations require one member of the team to be Part 107 rated as a commercial remote pilot. While the Part 107 remote pilot does not need to be on the controls during flight, he/she must be present and is responsible for lawful compliance of the operation; or in other terms, is serving as Pilot in Command (PIC). To comply with Part 107 while also maintaining the ability to collect high quality data, the sUAS must have some certain technological capabilities. For instance, per Part 107 the sUAS must remain in Visual Line-Of-Sight (VLOS) of the PIC, the person manipulating the controls, and a visual observer without the use of any vision aiding device other than corrective lenses. The sUAS must also remain an adequate distance from a nesting site to not "take" the eagles as per BGEPA requirements. Therefore, to comply with both regulations, a long-range transceiver for video transmission, as well as a high optical zoom HD camera, is necessary to record proper data.

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Both platforms have stabilization systems utilizing software that controls a three-axis gimballed camera mount. An HD camera with a gimbal mount was key to obtaining a clear picture for data collection from long distances and in variable wind conditions. The camera for both sUAS platforms had a 30x zoom which allowed the sUAS to maintain legal distance from nesting sites to avoid disturbing nesting eagles. Long distance video transmission capabilities, in this case greater than one mile, also aided in keeping distance from nesting birds. Both cameras on the platforms had auto focus, though the DJI also provided an intuitive touchscreen focus selector to allow operators to quickly refocus on any part of the camera view angle. In addition, DJI had auto and manual exposure, which was very effective in compensating for harsh shadows and high contrast lighting on cliff faces. Both systems offered the ability to record both photo and video data. However, the DJI provided direct on-board data recording while the E900 only allowed for data to be recorded from the receiver, which led to corruption and degradation of the photos and video due to radio interference. Direct on-board data recording capabilities are vastly preferable as a means of retaining high-quality photos and video. On the other hand, because of the E900's modular components and features, it is able to offer the ability to slave two different controllers to the sUAS which proved beneficial. The ornithologist was able to control the camera gimbal and zoom to find nests with one controller, while the operator was able to fly the sUAS into viewing position using a separate controller.

As mentioned in section 4.2, Dugway has a wide range of temperatures and weather conditions during the observation period. It was found during use of the sUAS that cold temperatures adversely affect battery performance and consequentially the amount of time the drone could spend per flight investigating a territory. This led to increased time in a territory as time would be needed for a battery swap and a second flight to obtain the necessary data. Other weather considerations included windy conditions at the surface as well as at observation altitude. These conditions required more finesse from the pilot, as well as requiring the sUAS to expend more battery power as the gimbal and stabilization systems on the platform worked harder to compensate for the windy conditions and maintain a fixed three-dimensional GPS location. The extra battery power required to hold location ended up limiting the loiter time and range of the sUAS. Comparing the two platforms that were used, it was found that the E900 had better battery power duration and a more compact battery system. The downside of this more compact system was a top-heavy design, which made the E900 more unstable and prone to tipping while landing in a crosswind.

8.2 UAS IMPLEMENTATION

The UAS observation method was the most uncertain upon the start of the 2019 nesting season and it proved to be unreliable as a method of weekly nest observations due to scheduling and payload restrictions. The realities of flight scheduling with RIAC students resulted in flight days that were sporadic. RIAC allowed the use of their students and platforms on an as-available basis, and other missions, weather concerns, or maintenance frequently bumped nest observations off the schedule. In addition, the sections of airspace the students were scheduled for were often not over the desired areas of range containing eagle nests to be surveyed. It became clear to the DPG Team that rather than using the UAS as a stand-alone observation method, it would be more useful as a precision tool for obtaining rapid nest observations in areas with no ground access or with critical range use planned within the next two weeks.

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The UAS platform was unique in that it was able to view nests with no ground access within 2 miles. It also possessed a highly useful thermal camera capability, which could identify a chick within a nest in seconds *(given an appropriate time of day, before the cliff face has heated in the sun).* However, the payloads carried by the UAS fleet in 2019 proved to be inadequate to observe most eagle nests due to low resolution imagery. The HD payload upgrade in 2020 improved the nest-monitoring potential of the platform immensely. The DPG Team does not recommend the use of UAS platforms for nest surveys unless equipped with HD payload capabilities.

If the nest location was well known, the UAS was by far the fastest and most efficient observation method due to lack of drive and hiking time between observation points. However, the nature of the platform's flight and approach patterns made detailed nest metadata critical to the success of the survey. UAS platforms must determine an approach angle and loiter point for a territory observation from several kilometers away, requiring the observation team to have precise knowledge of the nest's location reference data, elevation, aspect, bearing from the ideal viewpoint, and topographical inclusion before the nest can be found. The UAS observation team found that landscape level photos combined with detailed descriptions of a nest's location were sufficient to allow for a successful survey. Without this metadata, the UAS platform was nearly incapable of locating a nest in the time allowed.

The DPG Team found that the most important factor influencing the success of the UAS team was the integration of the biological observer into the military framework of the RIAC students. The civilian observer had to learn the correct protocols and language, as well as establish trust and communication pathways with both the students and the instructors. Once the observer was able to work within the RIAC team, the frequency and success of survey flights increased dramatically. The RIAC students and instructors also found the nest surveys to be useful training experiences. Eagle nests are small, cryptic targets for a UAS operator, which presented the students with invaluable practical experience. The nest metadata was also presented in the style of a mission packet, allowing the students to practice working with external intelligence to locate a target. The DPG Team highly recommends nest monitoring as a dual-purpose use of UAS platforms, for both natural resource monitoring and student pilot training exercises.

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APPENDIX B FY 2019 NATIONAL DEFENSE AUTHORIZATION ACT (NDAA)

(C) made available to appropriate government departments or agencies.

SEC. 848. PROHIBITION ON OPERATION OR PROCUREMENT OF FOREIGN-MADE UNMANNED AIRCRAFT SYSTEMS.

(a) PROHIBITION ON AGENCY OPERATION OR PROCUREMENT.—The Secretary of Defense may not operate or enter into or renew a contract for the procurement of—

(1) a covered unmanned aircraft system that—

(A) is manufactured in a covered foreign country or by an entity domiciled in a covered foreign country;

(B) uses flight controllers, radios, data transmission devices, cameras, or gimbals manufactured in a covered foreign country or by an entity domiciled in a covered foreign country;

(C) uses a ground control system or operating software developed in a covered foreign country or by an entity domiciled in a covered foreign country; or

(D) uses network connectivity or data storage located in or administered by an entity domiciled in a covered foreign country; or

(2) a system manufactured in a covered foreign country or by an entity domiciled in a covered for-

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eign country for the detection or identification of covered unmanned aircraft systems.

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(1) Counter-UAS surrogate testing and training; or

(2) intelligence, electronic warfare, and information warfare operations, testing, analysis, and training.

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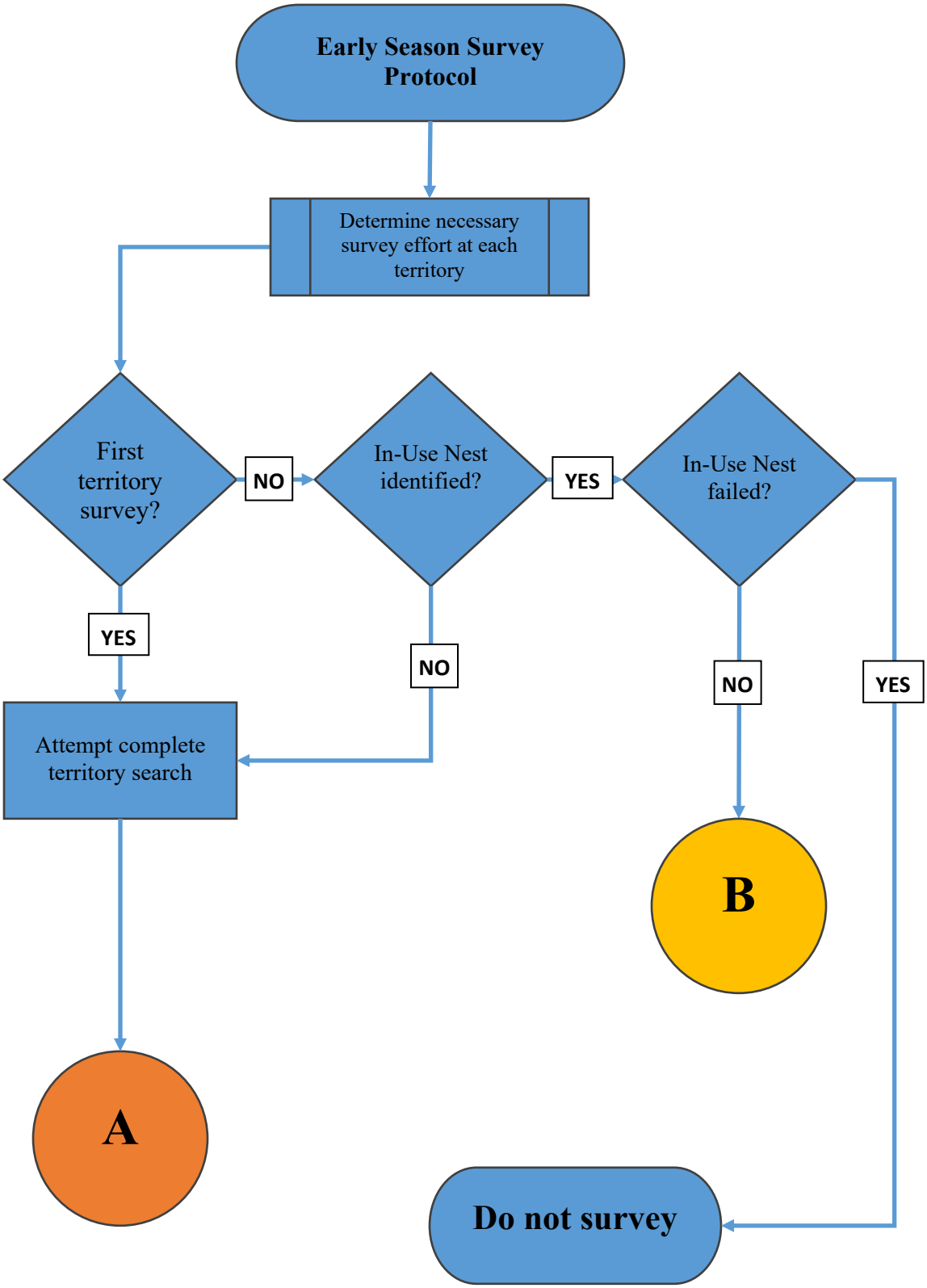
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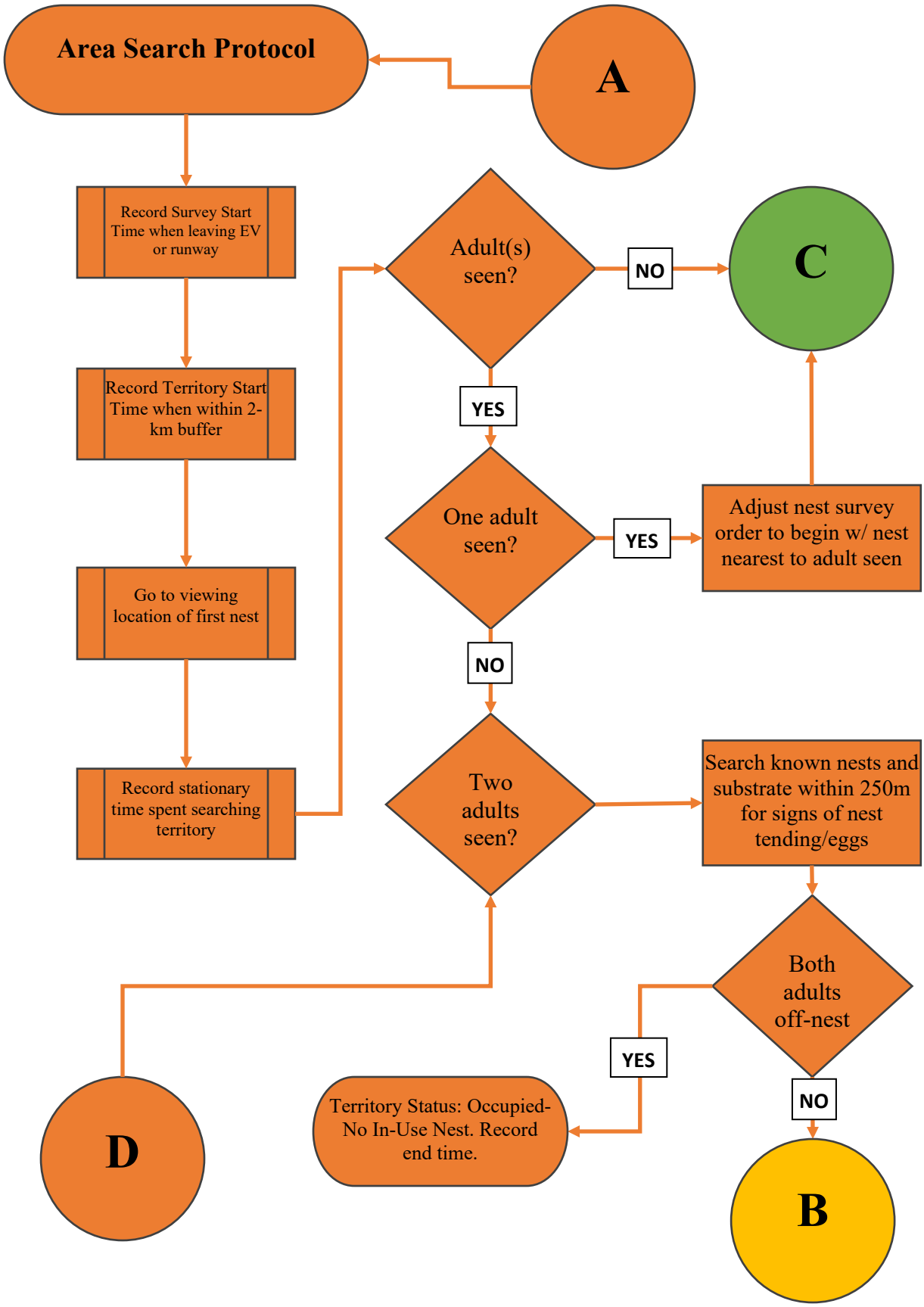
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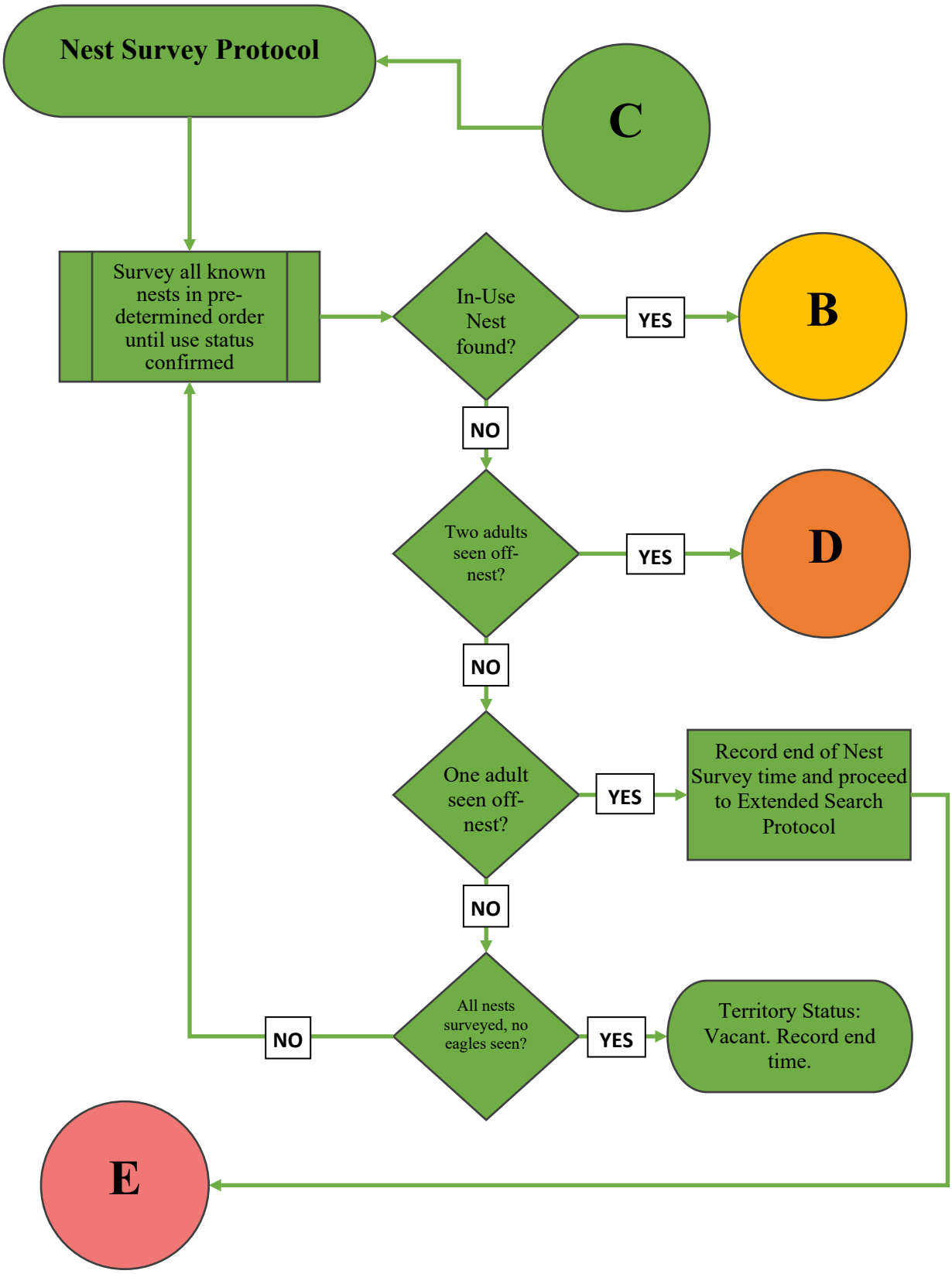
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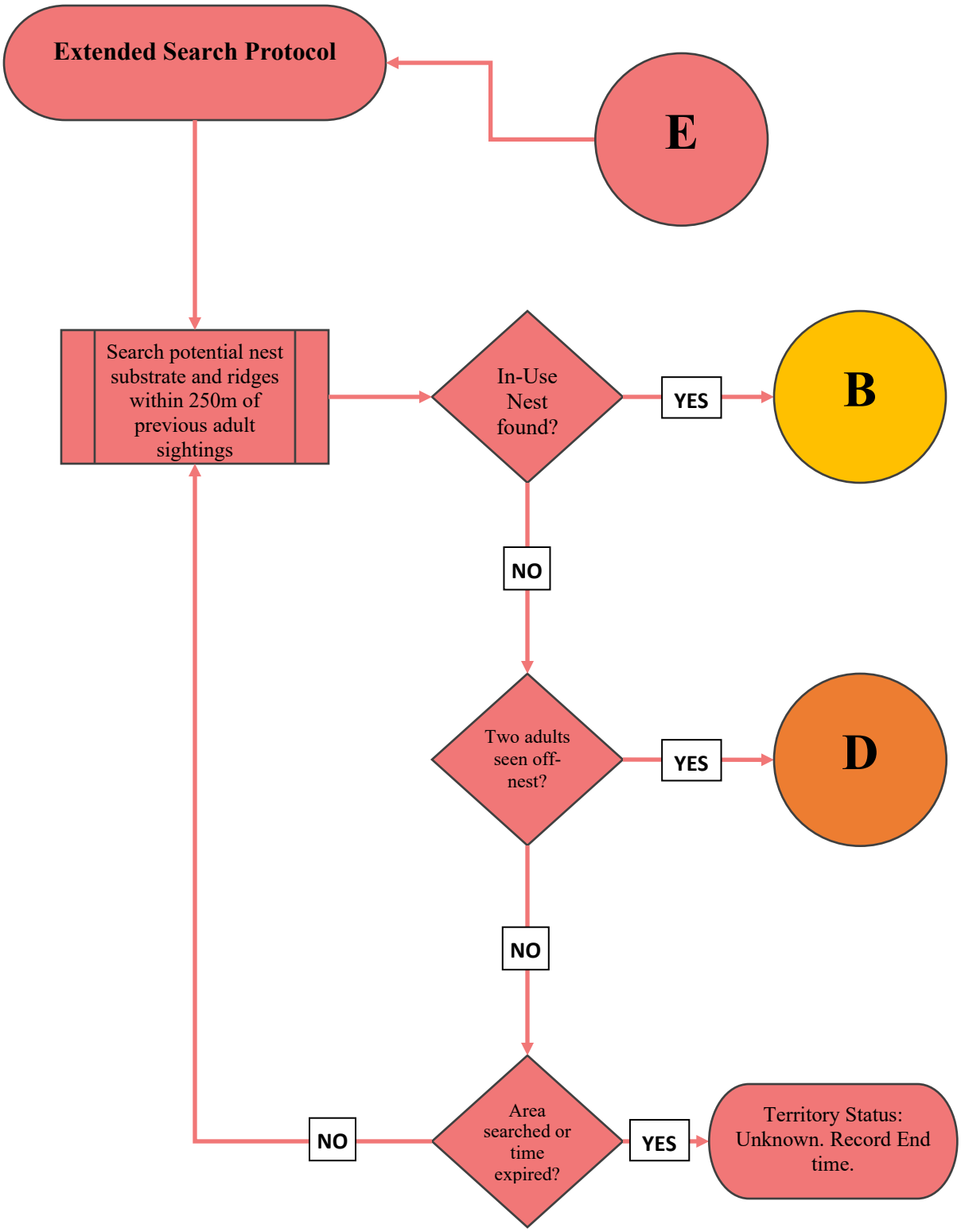
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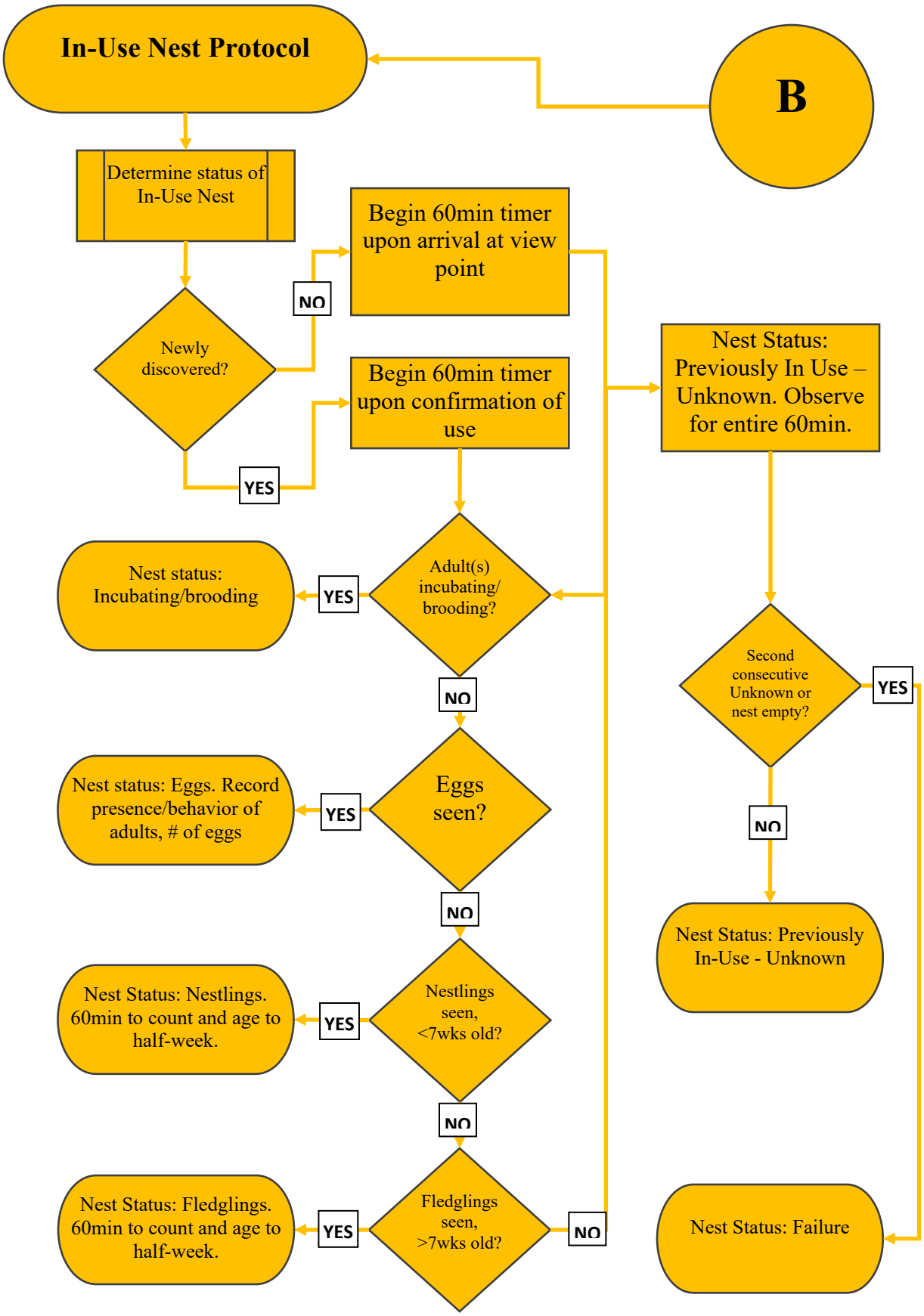
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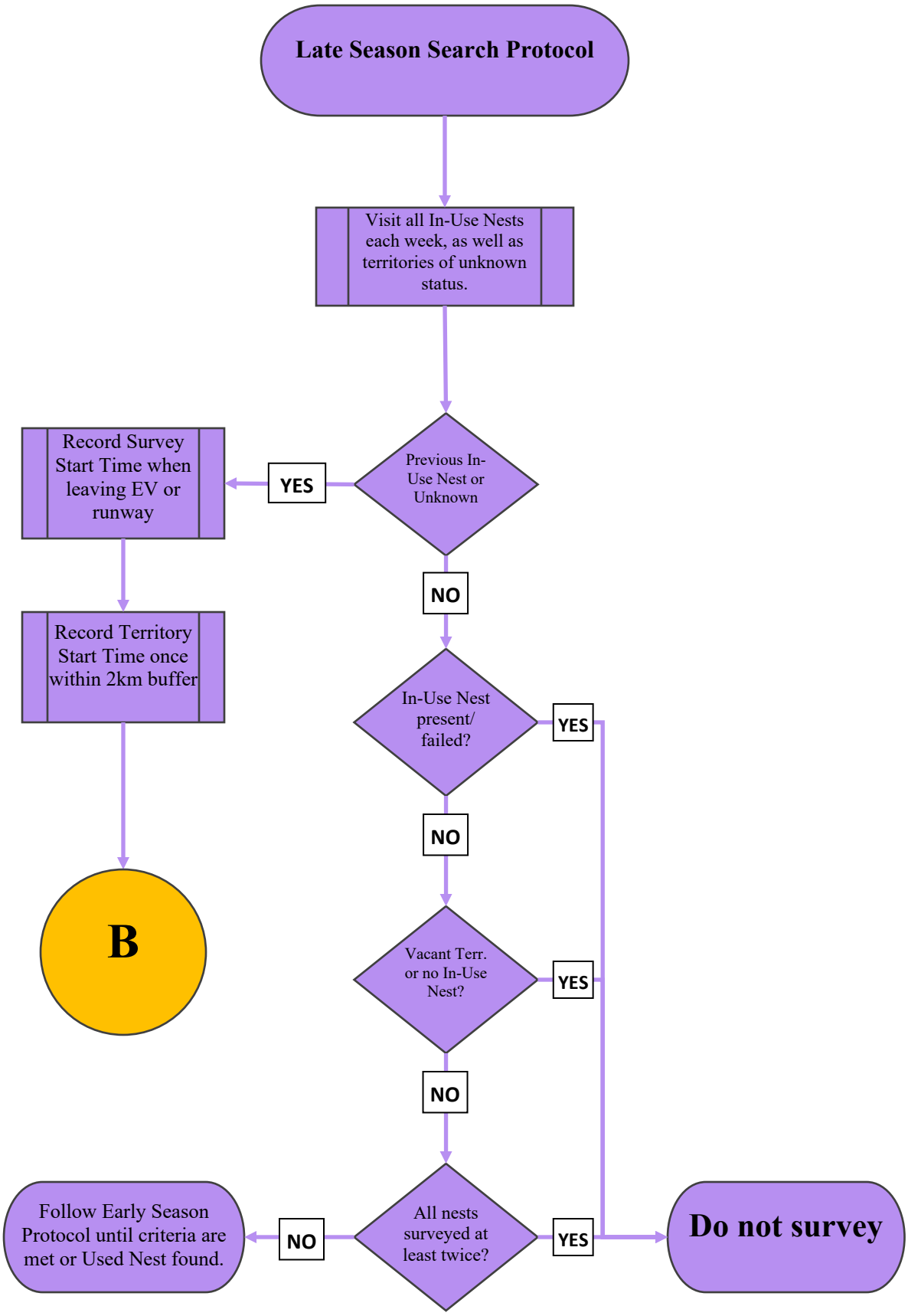
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OFFENSE INVERTED: NON-STANDARD APPLICATIONS OF THE MULTI-DOMAIN TASK FORCE IN THE INDO-PACIFIC

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements for the degree

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Art of War Scholars

by

DAVID E. DEGENHARDT, MAJOR, US ARMY
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14. ABSTRACT

The U.S. Army's Multi-Domain Operations operating concept is meant to solve the problem of anti-access and area-denial (A2/AD) threats posed by peer adversaries. The primary means of defeating these threats is the Multi-Domain Task Force (MDTF), but the MDTF has potential beyond penetrating A2/AD spaces. This is significant amid the ongoing debate about the U.S. Army's role in the Indo-Pacific. This study examines the capabilities of the MDTF and how it can contribute to the Joint Force in the Indo-Pacific by using a reverse version of the Joint Capabilities Integration and Development System process. This process analyzes MDTF's capabilities based on requirements documents, determines the potential gaps those capabilities can fill, examines how the MDTF can fill those gaps at three key locations in the Indo-Pacific.

This study demonstrates that the MDTF has a unique and flexible mix of capabilities that allow it to perform multiple tasks beyond penetrating enemy A2/AD spaces. These include generating its own A2/AD space to serving as a deterrent to enemy escalation and assisting in maintaining operational access for follow-on forces. The MDTF can also isolate enemy forces and delay or disrupt enemy movements and massing of forces, while providing early warning and targeting information. This enables the MDTF to contribute to Joint Force operations in the Indo-Pacific across all phases of competition and conflict if used to its full potential.

15. SUBJECT TERMS

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MASTER OF MILITARY ART AND SCIENCE

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

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ABSTRACT

OFFENSE INVERTED: NON-STANDARD APPLICATIONS OF THE MULTI-DOMAIN TASK FORCE IN THE INDO-PACIFIC, by David E. Degenhardt, 137 pages.

The U.S. Army's Multi-Domain Operations operating concept is meant to solve the problem of anti-access and area-denial (A2/AD) threats posed by peer adversaries. The primary means of defeating these threats is the Multi-Domain Task Force (MDTF), but the MDTF has potential beyond penetrating A2/AD spaces. This is significant amid the ongoing debate about the U.S. Army's role in the Indo-Pacific. This study examines the capabilities of the MDTF and how it can contribute to the Joint Force in the Indo-Pacific by using a reverse version of the Joint Capabilities Integration and Development System process. This process analyzes MDTF's capabilities based on requirements documents, determines the potential gaps those capabilities can fill, examines how the MDTF can fill those gaps at three key locations in the Indo-Pacific.

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ACRONYMS

A2/AD	Anti-Access Area Denial
EW	Electronic Warfare
I2EWCS	Information, Intelligence, Electronic Warfare, Cyber, and Space
IAMDS	Integrated Air and Missile Defense
LRHW	Long-Range Hypersonic Weapon
LRPF	Long-Range Precision Fires
MDO	Multi-Domain Operations
MDTF	Multi-Domain Task Force
MRC	Mid-Range Capability

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CHAPTER 1

INTRODUCTION

Background

Since its inception in late 2016 under the heading of Multi-Domain Battle the Army's most recent operational concept has undergone continuous revision to more clearly articulate the necessary changes required for the Army to remain competitive in great power competition. Doctrinally the concept of Multi-Domain Operations is built around rapidly and continuously integrating all domains of warfare to deter aggression and compete against enemies at a level below armed conflict. If this option fails, goal of Multi-Domain Operations is to use this integration to defeat the enemy and return to a pre-conflict state on more favorable terms for the United States and its allies and partners.[1]

To solve problems with Multi-Domain Operations the Army has identified three central tenets: calibrated force posture to position and maneuver forces on a strategic scale; using "multi-domain formations [that] possess the capacity, capability, and endurance necessary to operate across multiple domains in contested spaces against a near-peer adversary" and convergence or "rapid and continuous integration of capabilities in all domains … that optimizes effects to overmatch the enemy."[2] Despite the flexibility of these tenets, in conflict Multi-Domain Operations is usually described as a solution to

[1] U.S. Army Training and Doctrine Command (TRADOC), TRADOC Pamphlet 525-3-1*: The U.S. Army in Multi-Domain Operations 2028* (Fort Eustis, VA: TRADOC, December 2018), 17.

[2] Ibid., vii.

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anti-access and area denial (A2/AD) threats posed by peer adversaries where forces will penetrate the enemy's A2/AD systems, dis-integrate enemy forces, and then exploit the resulting openings to achieve joint force objectives.[3] This reflects our focus on and preference for offensive maneuver, with shaping and defensive operations taken as a secondary consideration.

One of the methods that has been used to develop Multi-Domain Operation as a concept has been the Multi-Domain Task Force (MDTF), which was directed in 2017 as part of a deliberate process of design and experimentation. The MDTF was conceptualized as a forward-stationed brigade-sized unit combining long-range precision fires, integrated air and missile defense, and special capabilities such as electronic warfare, space, cyber, and information operations before and during conflict.[4] The first MDTF was established at Joint Base Lewis-McChord in 2017, and the Army currently plans to establish five MDTFs with two in the Indo-Pacific, one in Europe, one in the Arctic, and one as a global response force.[5]

Over the last four years the MDTF at Joint Base Lewis-McChord has participated in numerous training exercises including Yama Sakura 75 in 2017, Pacific Sentry in

[3] TRADOC, TRADOC Pamphlet 525-3-1, viii-xi.

[4] Ibid., F-1.

[5] Congressional Research Service (CRS), *The Army's Multi-Domain Task Force (MDTF),* CRS In Focus IF11797, by Andrew Feickert (Washington, DC: Library of Congress, updated 13 April 2021), 2.

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2017, Rim Of The Pacific in 2018, and Valiant Shield in 2020.[6] These exercises have provided valuable insights on integrating the MDTF into the Joint force, particularly in terms of operating across domains while integrating and synchronizing cyber and space effects. Based on the outcome of these exercises the MDTF as a concept has arguably been validated, bringing a much-needed ability for the Army to contribute to conflicts occurring in domains that have historically favored other branches of the United States military. The multinational nature of many of these exercises also demonstrates the role that the MDTF can play in enabling operations alongside our allies and partners.

This is particularly important as TRADOC Pamphlet 525-3-1 takes the unusual approach of specifically naming China and Russia as serious threats and orienting the Multi-Domain concept against them.[7] While both states operate within the Indo-Pacific Theater where the first MDTF is postured, the bulk of Russia's population and forces are concentrated closer to Europe. As a result, China represents the greater threat to U.S. interests in the region and will be treated as the primary adversary within this study.

Despite these benefits the MDTF and Multi-Domain Operations are still in their doctrine development phase, with the latter mostly existing as a conceptual discussion that is slowly percolating through the minds of senior leaders and rising through the ranks carried by field grade officers who have been introduced to the concept through schooling and exercises. The second MDTF was officially activated on 16 September

[6] Brian J. Newill, "Leveling Up: Improving Army Fires and Targeting for Multi-Domain Operations," in *Theater Army in Multi-Domain Operations Integrated Research Project*, ed. Gregory L. Cantwell (Carlisle, PA: Army War College, 2020), 147.

[7] TRADOC, TRADOC Pamphlet 525-3-1, vi.

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2021 and as of yet only has a fraction of its eventual total of about 1,200 Soldiers.[8] A number of the MDTF's required capabilities are still in development, including Mid-Range Capabilities (MRC) and Long-Range Hypersonic Weapons (LRHW) that will not be fully operational until at least 2023.[9]

According to this emerging doctrine the purpose of the MDTF is to use kinetic and non-kinetic capabilities to neutralize an adversary's A2/AD systems to support the Joint Force.[10] This does not account for a basic principle inherent in their design: the same capabilities that allow a force to *penetrate* an A2/AD space can also be utilized to *generate* an A2/AD space. This provides for a number of potential uses for an MDTF that are not captured in the Multi-Domain Operations concept that this study will explore.

The roots of this principle can be found in the 2017 RAND study titled *What Role Can Land-Based, Multi-Domain Anti-Access/Area Denial Forces Play in Deterring or Defeating Aggression?* This study identifies three possible approaches that include attacking enemy A2/AD, mitigating damage from enemy A2/AD, and creating A2/AD challenges for adversaries.[11] Written at approximately the same time that the MDTF was

[8] Todd South, "Army's First Multi-Domain Task Force in Europe Gets to Work," *The Army Times,* 17 September 2021, https://www.armytimes.com/news/your-army/2021/09/17/armys-first-multi-domain-task-force-in-europe-gets-to-work/.

[9] CRS, *The Army's Multi-Domain Task Force,* 1.

[10] Headquarters, Department of the Army (HQDA), "Army Multi-Domain Transformation: Ready to Win in Competition and Conflict," (Chief of Staff Paper #1, Department of the Army, Washington, DC, 2021), 12.

[11] Timothy M. Bonds, Joel B. Predd, Timothy R. Heath, Michael S. Chase, Michael Johnson, Michael J. Lostumbo, James Bonomo, Muharrem Mane, and Paul S. Steinberg, *What Role Can Land-Based, Multi-Domain Anti-Access/Area Denial Forces*

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being developed, this report does not mention the MDTF but forecasts many of the capabilities that the MDTF now possesses. While this report appears to have largely been forgotten as the MDTF has been designed around the first approach, many of the recommendations and conclusions in the report suggest that the MDTF has significant unrealized potential to assist in the third approach. Clarifying and exploring this potential increases the flexibility of MDTF and provides additional options for conducting Multi-Domain Operations that will increase the Army's relevance, capabilities, and relevance in the Pacific Theater.

Without referencing the MDTF, the RAND study also suggests the development of a small and specialized Army unit with longer-range anti-ship capabilities for pre-crisis or rapid deployment. This is described later in the study as a notional A2/AD system that integrates sensors, anti-ship missiles, and antiaircraft batteries within a combined force.[12] This is remarkably like the eventual make-up of the MDTF, although the MDTF and its doctrinal use developed along a different path focused on penetrating A2/AD spaces rather than creating them.

The study goes further by suggesting several locations where such a unit could be useful in scenarios concerning Taiwan, the South China Sea, or the Senkaku Islands.[13] These suggestions are no more than hypothetical cases, however, and do not consider the

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Play in Deterring or Defeating Aggression (Santa Monica, CA: RAND Corporation, 2017), 75-77.

[12] Bonds et al., *What Role Can Land-Based, Multi-Domain Anti-Access/Area Denial Forces Play in Deterring or Defeating Aggression*, xii-xiv, 78-79.

[13] Ibid., 82, 87-88, 104-105.

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capabilities of the MDTF or template possible opposing forces and how the MDTF might fare against them. The purpose of this paper is to build on this earlier research by objectively examining the MDTF's capabilities, determine what tactical tasks it can fulfill outside of its primary use of defeating adversary A2/AD systems, and examine the possible outcomes of using the MDTF in these roles.

Despite the reality that the full operational capabilities of the MDTF as templated will not be available until at least 2023, there is sufficient information available based on the unit's design documents and equipment that is being tested to allow for analysis of the potential uses for a MDTF to fulfill these roles outside of its doctrinal mission. These uses could take advantage of dis-integrating elements of the MDTF to allow portions of the task force to operate independently in several key locations or extending and overlapping coverage from different assets to create a distributed A2/AD bubble.

Maintaining China as the pacing threat in the Indo-Pacific Theater suggests several potential locations where a MDTF could provide a key defensive or deterrent capability. China's increasing naval presence west of the Malacca Strait creates the possibility that denying access to the straits during conflict could effectively split the Chinese Navy and prevent it from massing naval combat power for hours or days. Another example would be deployment of a MDTF to the Philippines, Malaysia, or Vietnam to affect territorial disputes within the Nine Dash Line and potentially intervene in a crisis. In the event of a Chinese attack on Taiwan, its long-range capabilities could also allow a MDTF to influence operations in the Straits of Taiwan from a variety of locations and shield approaching U.S. forces if the United States decided to oppose a forceful reintegration of Taiwan and China. Finally, as referenced in the RAND study the

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MDTF might be able to play a role in support of Japan in the event of a dispute over the Senkaku islands.

Problem Statement

The Army's MDTF is a brigade size element with a mix of unique capabilities which has been primarily designed around a specific offensive role, severely limiting its flexibility and ability to act within a large theater. Failing to account for other tasks that the MDTF might be capable of performing has stifled development of doctrine that could potentially employ it in any other capacity beyond penetrating A2/AD spaces. Overfocus on a single mission has resulted in a general lack of understanding of the precise capabilities that the MDTF was designed to employ, making it difficult for planners to imagine ways that it could potentially be used in shaping or defensive operations that could affect the operational and strategic balance of a theater of war. This is particularly important in the Indo-Pacific, where the United States Army is re-evaluating the role of land component forces and their relevance due to the vast distances between landmasses and limited ground maneuver space.

Purpose of the Study

This intention of this study is to provide a more comprehensive understanding of the doctrinally designed capabilities of the MDTF and how those capabilities can be used in future conflicts beyond the MDTF's planned role of penetrating an A2/AD space. While this study will focus on the Indo-Pacific theater, grounding the study in research on operational capabilities and doctrinal tasks will enable scholars and planners to transfer the resulting conceptual uses of the MDTF into different locations with minor

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modifications based on different operating environments and mission variables. By illustrating the capabilities of the MDTF and potential methods of using those capabilities this paper is intended to generate further discussion on the issues addressed as well as providing a starting point for the development of doctrine that will allow the MDTF to take a greater role in conducting large-scale combat operation and suggest potential roles for Army capabilities in the Indo-Pacific.

Research Questions

The primary research question for this study is how the MDTF can contribute to the Joint Force in the Indo-Pacific outside of its doctrinal mission of penetrating A2/AD spaces. This research question was chosen due to ongoing debate about the role of the Army in the Indo-Pacific theater and because the first and most operationally mature MDTF in the Army's inventory is currently aligned against that region. Providing an answer to this question will provide additional options for joint planners to incorporate a unique mix of capabilities into future conflicts that allows for increased flexibility and methods of shaping the operational and strategic picture using long-range precision fires.

To answer this primary research question, the first secondary research question asks what the planned future capabilities of the MDTF are based on its designed structure. As the analysis in chapter four will demonstrate, the existing MDTF does not match the unit's force structure requirements documents while informational presentations crafted for mass consumption have largely been simplified to top level line and block charts. A large part of this discontinuity has come from the MDTF being designed around capabilities that are only now reaching the point of being tested and

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issued. Envisioning future uses for the MDTF requires a solid understanding of the potential capabilities that the unit is intended to possess.

This ties directly into the second secondary research question, which asks what operational and tactical tasks the MDTF can perform outside of its existing doctrinal mission based on those potential capabilities. The answer to this question requires thorough analysis of the capabilities stipulated in the MDTF's original design documents plus additional capabilities still in development. These should then be measured against doctrinal tasks to ascertain if the MDTF is capable of accomplishing those tasks. Laying a solid foundation of essential basic warfighting tasks and potential tasks that the MDTF can perform sets the stage for applying those tasks against key locations in the Indo-Pacific region and demonstrating the potential impact that a fully realized MDTF could have as a force multiplier if employed as part of a joint strategy supporting national objectives.

The third secondary question addresses this area by asking how the MDTF's capabilities and the associated tasks it can perform can be used to shape the operational and strategic environment in the Indo-Pacific. A definitive answer to this question would constitute a theater campaign plan or a major operational plan, so this study examines a handful of key locations in the Indo-Pacific and use the answers to the first two questions to demonstrate potential uses for the MDTF at those locations. This will allow the question to be answered in terms of strategic and operational military effects that an MDTF can potentially generate, allowing for those effects to be generalized for use in future operations at different locations. This brings us back to the primary research

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question by providing a menu of options showing how an MDTF can allow the Army to contribute to the Joint Force in the Indo-Pacific.

Assumptions

The main assumptions used in this study are based around equipment capabilities, requirements, organizational/doctrinal design documents, and use of the MDTF in hypothetical locations. For the first category, this study will assume that announced ranges and velocities are reasonably accurate for planning purposes. This allows for use of publicly available sources and provides a basis for comparison between various capabilities as well as the possibility of deriving employment concepts based on those capabilities. This includes using the SM-6 and Tomahawk ranges and flight speeds when conjecturing about the possible uses and role of the MDTF's planned mid-range capability. Another example of such an assumption would be quoted speeds and ranges of long-range hypersonic weapons currently in development.

In terms of requirement and design documents, this study assumes that the capabilities described in requirement documents provide an accurate representation of the MDTF's intended design. The most recent active design documents will be considered as authoritative statements of the planned organizational, personnel, and equipment structures of the MDTF, and the listed capabilities will be used to analyze the planned MDTF's suitability for doctrinal tasks. This includes the intended roles for sub-elements of the MDTF and specific capabilities housed within its component battalions. This is particularly necessary when analyzing the I2EWCS battalion since many of the templated capabilities are specifically designed to support a particular aspect of the MDTF's role

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while the exact nature of how those functions would be performed are not publicly available.

The final set of assumptions in this study is concerned with exploring potential uses of the MDTF within the Indo-Pacific. Due to the complex politics of the region and the continuing evolution of relationships among the United States and its allies and partners this study will assume that deployment to strategic locations will be allowed by all participants for the purpose of illustrating the MDTF's capabilities. This enables the study to proceed without an in-depth analysis of the political situation around each potential deployment of the MDTF. As a result, the proposed uses of the MDTF can be applied in the future if conditions change or generalized to apply to locations similar to the ones chosen for this study.

Definition of Terms

Domain – "an area of activity within the operational environment (land, air, maritime, space, and cyberspace) in which operations are organized and conducted."[14] The first four are physical, while cyberspace is "a global domain within the information environment."[15] There is considerable overlap between domains.

Multi-Domain Operations – "Operations conducted across multiple domains and contested spaces to overcome an adversary (or enemy's) strengths by presenting them with several operational and/or tactical dilemmas through the combined application of

[14] TRADOC, TRADOC Pamphlet 525-3-1, GL-4.

[15] Office of the Chairman of the Joint Chiefs of Staff (CJCS), *DOD Dictionary of Military and Associated Terms* (Washington, DC: The Joint Chiefs of Staff, November 2021), 55.

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calibrated posture; employment of multi-domain formations; and convergence of capabilities across domains, environments, and functions in time and spaces to achieve operational and tactical objectives."[16]

Multi-Domain Task Force – "theater-level maneuver elements … [that] synchronizes precision effects and precision fires in all domains against adversary A2AD networks in all domains, enabling joint forces to execute their OPLAN-directed roles." [17]. They are "designed to deliver long-range precision joint strike as well as integrate air and missile defense, electronic warfare, space, cyber, and information operations."[18]

Anti-Access Area Denial (A2/AD) – a combination of "capabilities, usually long-range, designed to prevent an advancing enemy force from entering an operational area" (anti-access) and "capabilities, usually short-range, designed to limit an enemy force's freedom of action within an operational area" (area denial).[19]

Long Range Precision Fires – capabilities designed to "attack, neutralize, suppress, and destroy targets using missile-delivered indirect precision fires."[20] There is no defined maximum range, but the Acquisition Support Center specifies that these fires

[16] TRADOC, TRADOC Pamphlet 525-3-1, GL-7.

[17] HQDA, "Army Multi-Domain Transformation," 12.

[18] Ibid., 32.

[19] Office of the Chairman of the Joint Chiefs of Staff (CJCS), Joint Publication (JP) 3-0, Change 1, *Joint Operations* (Washington, DC: The Joint Chiefs of Staff, October 2018), GL-6.

[20] "Long Range Precision Fires (LRPF)," U.S. Army Acquisition Support Center, accessed 1 January 2022, https://asc.army.mil/web/portfolio-item/long-range-precision-fires-lrpf/.

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will replace the Army Tactical Missile system and have a range in excess of 300 kilometers.[21]

Mid-Range Capabilities – an intermediate capability "designed to hit targets in the range between the Precision Strike Missile and the Long Range Hypersonic Weapons." [22] The current version of this capability is expected to be built around the SM-6 and Tomahawk missile.[23]

Long Range Hypersonic Weapon – a developing capability intended to allow the United States military to launch missiles from a ground platform at a speed of over 3,800 miles per hour with greater ranges than mid-range capabilities.[24]

Scope

This study will focus on the potential uses of the MDTF within the Indo-Pacific theater based on the MDTF's intended capabilities once all included components have been fielded. It will include the MDTF's long range fires capability, I2EWCS battalion, and integrated air and missile defense elements. These capabilities will be analyzed against existing tasks described in Army doctrine and how those tasks can be implemented in select locations within the theater. The selected locations are intended for

[21] "Long Range Precision Fires (LRPF)," U.S. Army Acquisition Support Center.

[22] "Army Awards Mid-Range Capability Other Transaction Agreement," U.S. Army Rapid Capabilities & Critical Technologies office, accessed 1 November 2021, https://rapidcapabilitiesoffice.army.mil/news/mid-range-capability-ota/.

[23] Ibid.

[24] Neil Thurgood, "Hypersonics by 2023," U.S. Army, September 4, 2019, https://www.army.mil/article/226678/hypersonics_by_2023.

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illustrative purposes and do not represent an exhaustive list of all possible locations that the MDTF could be deployed. Finally, the potential uses of the MDTF from this study are intended to be generalizable to similar locations and situations and are not specific to the examples provided.

Limitations and Delimitations

The primary limitation of this study is that it can only use unclassified or open-source weapon system ranges and capability information to prevent classification and foreign disclosure issues. EW, Cyber, and Space capabilities are often highly classified and operational details concerning the precise effects that these systems can generate are not available in open sources. Many of the capabilities listed are at varying stages of development and their final operating parameters have not yet been precisely determined. To proceed, this study will use the most current test results and announced capabilities for research and planning purposes. If this study requires calculations to determine hypothetical factors such as line of sight or detection range of an intelligence gathering capability these calculations will be based on open-source information to preserve classification.

Delimitations applied to this study include the choice to limit the study to assessing potential uses of the MDTF in the Indo-Pacific and the decision to include only fielded weapon systems or weapon systems with prototypes currently being tested This study also only uses the Army's current list of tactical tasks without exploring possible new tasks that could be derived from the capabilities of the MDTF in order to limit the amount of analysis to a manageable level. For a similar reason, the number of example scenarios used to illustrate the potential impact of employing the MDTF will be restricted

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to theoretical potential scenarios based on the results of the literature review in Chapter Two. The primary focus of this study will be on the use of the MDTF in the islands and archipelagos within the Indo-Pacific rather than potential operations on the mainland, as the Army already has sufficient understanding of its role in such a campaign.

Significance of the Study

The significance of this study is that it expands the doctrinal concept of the MDTF outside of its current role as an A2/AD breaching instrument and provides a starting point to consider alternate offensive and defensive uses of the MDTF as part of Multi Domain Operations within the Army Concept Framework. Expanding the MDTF's doctrinal role or describing a multi-purpose role allows for increased flexibility in using these units to generate effects on an operational and strategic level to shape the theater by restricting or denying key movement corridors and strategic locations to enemies. This assists the MDTF in providing freedom of movement for joint forces conducting follow-on operations and demonstrates an additional role for the United States Army in future operations in the Indo-Pacific.

Summary

The concept of Multi-Domain Operations has flown quietly under the radar for much of the Army outside of the Pacific theater, even as the Army prepares to release new versions of ADP 3-0 and FM 3-0 to bring the concept fully into common use. Because of this there has been relatively little intellectual engagement with the doctrinal vision there is considerable work ahead if the United States Army intends to reach the 2028 milestone in the Army Concept Framework. The current operational concept has

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been narrowly focused on offensive operations and does not adequately address the role of international partners in strategic roles. In order to be viable as doctrine, Multi-Domain Operations must be fleshed out and explored through imaginative applications and scenarios.

One of the best methods to accomplish this goal is through engagement of hypothetical case studies, which can serve as a starting point to expand doctrine or serve as the foundation for future exercises and war games. The problem in this case is that the prime experimental laboratory for Multi-Domain Operations, the Multi-Domain Task Force, has been designed around a specific offensive role although some of its components have the potential to be used in other offensive roles or in a defensive situation. This prevents the MDTF from living up to the full potential of its intended capabilities and limits its utility in future conflicts. This problem is particularly exacerbated in the unique operating environment of the Indo-Pacific, which has often been viewed as being dominated by naval forces.

This study is meant to take a fresh look at the MDTF in terms of its intended capabilities and examine the potential gaps that they could be used to fill rather than remaining focused on the specific mission for which it was designed. Comparing these capabilities against the menu of Army tasks allows us to envision additional ways that the MDTF could be useful in the operating environment where it was first developed. Examining these methods of employment through the lens of strategically important locations builds on this concept and provides examples of potential ways that the MDTF could provide a strategically significant capability in support of a joint force before large scale combat operations begin and during the initial phases of conflict. This provides

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additional flexibility to joint planners as well as an additional tool to be used during operational design to affect the movement and deployment of adversary forces.

Before conducting this analysis, it is important to ground the research and further examine the questions that this study is intended to answer by conducting an open source literature review examining previous work that has been completed related to the subject of operational and response forces with multiple organic capabilities. While the concept of Multi-Domain Operations is still in development and the MDTF is a relatively new unit, there has been some initial work written to explain the general concept of Multi-Domain Operations to the force at large and a body of joint doctrine that can be applied to provide insight into how MDO can interface with those force structures and formations.

The Indo-Pacific region and its general security situation has also been the subject of numerous studies as China has continued to develop new capabilities and worked to expand its influence with neighboring countries. Reduced operations in the Middle East have led the Army and joint planners to raise the question of what the Army can contribute to operations in the Indo-Pacific theater, while others have begun engaging in studies on specific applications of MDO as a concept and some limited inquiry into its application within specific sub-fields of Army operations.

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CHAPTER 2

LITERATURE REVIEW

Introduction

As a relatively new operational and strategic concept that has not been fully implemented, literature concerning Multi-Domain Operations and the Multi Domain Task Force is relatively limited. This literature and has undergone a great deal of change over the last few years as these concepts have been developed. This presents a significant challenge when conducting a literature review, especially when examining a novel application of the concept. A great deal of the work that has been completed on this subject resides in prior theses, and monographs written by military officers, professional military education faculty, CGSC students, and students at the School for Advanced Military Studies (SAMS). The remainder can be found in think-tank studies, recent news stories, and journal articles written by national security thinkers on Multi-Domain Operations and the strategic situation in the Indo-Pacific. An additional barrier is that much of the literature on Multi-Domain Operations exists as the classified level and is not available for this study.

The primary research question for this study asks how the MDTF can contribute to the Joint Force in the Indo-Pacific outside of its doctrinal mission of penetrating A2/AD spaces. Because this question is focused on the intended capabilities of the MDTF and what those can contribute, the first secondary research questions is designed to analyze the capabilities of the MDTF based on its design documents and emergent technologies. The second secondary research question compares those capabilities to tactical mission tasks and then applies the valid tasks against joint doctrinal concepts

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based on the range of military operations. The third secondary research question takes the data from the first two secondary research questions and places it in the context of the Indo-Pacific to provide data to determine the potential impacts that the MDTF can generate.

Conducting a literature review concerning these questions is complicated due to the limited body of work that specifically addresses the MDTF in any role outside its designed use of penetrating A2/AD spaces. The idea of a defensive strategic role for the MDTF has been alluded to in some publications and policy documents but has not received the same level of analysis as the MDTF's original and primarily offense-oriented mission. At the same time Army's role in the Indo-Pacific has been a topic of contention over the last few years while there has been an emerging body of work dedicated to China's growing influence in the region as well as the strategies China is likely to use in future conflicts. As a result, the literature review process related to the questions of this study will be largely focused on recent documents in order to provide the most current understanding of the operational environment used in this study.

The process for identifying sources for this literature review began with an examination of doctrinal literature beginning with TRADOC Pamphlet 525-3-1 and expanded to additional relevant Army and Joint documents to provide an overview of the topic. The next step was examining the last four years of CGSC MMAS Theses and SAMS Monographs for topics related to Multi-Domain Battle, Multi-Domain Operations, and the Multi-Domain Task Force. Each document found was assessed for relevance to the topic and analyzed, identifying additional sources that had been referenced in their bibliographies. In addition to this procedure the Defense Technical Information Center

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provided access to some background material and potential sources for analysis. Finally, well known strategy-oriented print journals, online journals, and curated websites provided recent articles related to this study's research questions.

Based on the outcome of this initial research this literature review will primarily examine four major areas of existing research related to the primary and secondary research questions. The first of these areas will be an examination of existing doctrine relating to Multi-Domain Operations, related Joint Doctrine, and other official military documents related to the MDO concept. The second area will examine existing literature on Multi-Domain Operations and the MDTF as well as related tactical concepts. The next area will provide a brief background on recent studies of the Army's role in the Indo-Pacific and current discussion on what that role might entail. Finally, the fourth section will discuss pertinent literature on the security situation in the Indo-Pacific, key strategic locations in the region, and the security posture of countries surrounding these points. There is considerable overlap between these categories, with each reviewed document being placed according to its primary focus.

Doctrinal and Military References

Pending the release of the next version of ADP 3-0 in 2022 the current capstone document for Multi-Domain Operations is TRADOC Pamphlet 525-3-1, *The U.S. Army in Multi-Domain Operations.* The primary purpose of this reference is to introduce the MDO framework to a new audience, define the operational environment, express basic tenets, and present problems facing the new construct for future consideration and development. As a result, it introduces MDO at a broad conceptual level expressed in terms of three tenets: calibrated force posture, multi-domain forces, and convergence.

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The existing MDO framework it describes is overwhelmingly focused on offensive operations, moving from competition directly into penetration, dis-integration, and exploitation. The limited discussion of defense presented focuses on denying an enemy specific objectives and force protection considerations rather than shaping the larger strategic context.[25]

Chief of Staff Paper #1, "Army Multi-Domain Transformation" provides further expansion on the topic of MDO and extends the previous concepts into a more complete operational picture. Relevant to this study the paper discusses contesting adversary movements to provide time to consolidate gains and de-escalate, use of the Army to secure key locations such as the Malacca Strait, and using land-based capabilities to affect other domains.[26] This provides a foundation for use of MDO in strategically significant defensive operations, but does not specify exactly what capabilities would be used in these instances or how they would integrate with multinational forces.

TRADOC Pamphlet 525-3-8 sheds some light on these areas by marrying aspects of Large-Scale Ground Combat Operations with MDO, addressing the need to shape the environment through employing forces and capabilities but only describes key terrain in terms of collapsing enemy air defense and fires capabilities. Employment of partner capabilities is discussed in terms of converging effects and conducting security cooperation activities to set the theater, as well as forming large multinational combined

[25] TRADOC, TRADOC Pamphlet 525-3-1, 17, 26, 34, 36.

[26] HQDA, "Army Multi-Domain Transformation," 5-9.

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arms formations.[27] This formulation includes operations conducted in concert with partners but does not envision or detail close cooperation at brigade level or below. While reflective of how the United States has generally conducted operations in the past, this may not be an ideal model for future high-intensity high-tempo operations.

Congressional Research Service Documents such as *The Army's Modernization Strategy: Congressional Oversight Considerations* and *Defense Primer: Army Multi-Domain Operations* also provide some insight into development of the MDO concept. The first of these addresses MDO challenges and links them to the Army's six major modernization priorities, as well as raising the question of whether modernization will address the military strategies of peer competitors.[28] The *Defense Primer* provides a basic overview of MDO with updated information discussing the Army's Project Convergence Initiative and describes developing MDO concepts with allies and partner nations as well as the potential need to develop a joint warfighting concept for MDO.[29]

Some elements of this joint warfighting concept can be found in other service doctrines, with the most prominent example being Air Force Doctrine Publication

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[27] U.S. Army Training and Doctrine Command (TRADOC), TRADOC Pamphlet 525-3-8, *The U.S. Army Concept for Multi-Domain Combined Arms Operations at Echelons Above Brigade 2025-2045* (Fort Eustis, VA: TRADOC, December 2018), 12-14, 18, 34-36.

[28] Congressional Research Service (CRS), *The Army's Modernization Strategy: Congressional Oversight Considerations,* CRS Report for Congress R46216, by Andrew Feickert and Brendan W. McGarry (Washington, DC: Library of Congress, 7 February 2020), 4-5.

[29] Congressional Research Service (CRS), *Defense Primer: Army Multi-Domain Operations (MDO),* CRS In Focus IF11409, by Andrew Feickert (Washington, DC: Library of Congress, 22 October 2021), 1-2.

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(ADFP) 3-99. Described as emerging doctrine, AFDP 3-99 addresses the Air Force's role in Joint All-Domain Operations (JADO) and includes discussion of competition in that framework as well as the necessity for Joint All-Domain Command and Control (JADC2).[30] In addition, AFDP 3-99 is organized by warfighting function and provides an avenue to consider for future expansion of how the Army describes and explains MDO as the concept becomes operational in the larger force.

This kind of nesting is also applicable when examining the methods of employing U.S. forces alongside partner forces, which is a key consideration within the Indo-Pacific region. While this study focuses on the MDTF operating semi-independently, multinational support and transportation may be required to reach key locations. Joint Publication 3-16, *Multinational Operations* provides guidelines to consider for multinational operations, including organizing and operating parallel command structures as well as coordinating between forces .[31] The Army's Field Manual (FM) 3-16, *The Army in Multinational Operations* provides more detail on these concepts as the operational and tactical level, addressing specifics concerning North Atlantic Treaty Organization and Combined Forces Command Korea operations along with discussions

[30] Headquarters, Department of the Air Force (HQAF), Air Force Doctrine Publication (AFDP) 3-99, *Department of the Air Force Role in Joint All-Domain Operations (JADO)* (Washington, DC: Department of the Air Force, October 2020), 5.

[31] Office of the Chairman of the Joint Chiefs of Staff (CJCS), Joint Publication (JP) 3-16, *Multinational Operations* (Washington, DC: The Joint Chiefs of Staff, March 2019), II-7 – II-9.

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of interoperability and incorporating national capabilities.[32] While not specifically MDO centered, these publications provide some idea of the challenges in supporting and conducting operations in a complex operating environment.

Multi-Domain Operations and MDTF Studies

The concept of Multi-Domain Operations has undergone significant evolution since its inception in 2016. Originally conceived as Multi-Domain Battle, one of the first examples of the concept was Mike Redman and Major Joseph Easterling's Army white paper describing a new concept of combined arms that would utilize cross-domain synergy to fight against peer threats.[33] By the following year General David Perkins was writing about the topic in *Military Review*, focusing on operations in a contested environment and the need to integrate electronic warfare and space capabilities into the battlefield of the future.[34]

As an emerging concept Multi-Domain Battle invited discussion, with junior officers wrestling with the concept as they attempted to reconcile new ideas with existing doctrine. Jonathan Bott and an assemblage of other field grade officers from across all

[32] Headquarters, Department of the Army (HQDA), Field Manual (FM) 3-16, *The Army In Multinational Operations* (Washington, DC: Army Publishing Directorate, April 2014), 2-2:2-17.

[33] Michael Redman and Joseph Easterling, "Multi-Domain Battle: Combined Arms for the 21st Century," (White Paper, Army Capabilities Integration Center, Washington, DC, October 2016), 2-4.

[34] David G. Perkins, "Multi-Domain Battle: Driving Change to Win in the Future," *Military Review* (July-August 2017): 6-12, https://www.armyupress.army.mil/Portals/7/military-review/Archives/English/MilitaryReview_20170831_PERKINS_Multi-domain_Battle.pdf.

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four branches of the Department of Defense examined Multi-Domain Battle in 2017 and identified requirements for a mental shift, education and training, and incorporation of mission orders to drive execution of organizational change.[35] Based on this and other joint collaborations, there were early indications that the MDO concept could evolve into a joint concept as discussed earlier in the doctrinal references. Another example occurred with Shawn Woodford's short article describing Army and Marine Corps collaboration to develop Multi-Domain Battle as a combined arms framework that could be used for tactical application.[36] By 2018 the concept was being used in case studies at SAMS, as demonstrated by Jose Liy's examination of how Multi-Domain Battle had emerged from earlier doctrines.[37]

Multi-Domain Battle officially evolved into Multi-Domain Operations by September 2018, as explained in General Stephen Townsend's article addressing the change in concept. The main factor in this change was the addition of competition and actions below the level of armed conflict, elevating the concept above the tactical level.[38]

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[35] Jonathan W. Bott, John Gallagher, Jake Huber, and Josh Powers. "Multi-Domain Battle: Tactical Implications," *Over the Horizon: Multi-Domain Operations and Strategies*, 28 August 2017, https://othjournal.com/2017/08/28/multi-domain-battle-tactical-implications/.

[36] Shawn Woodford, "Army and Marine Corps Join Forces to Define Multi-Domain Battle Concept," *Mystics & Statistics* (blog), *The Depuy Institute*, 03 February 2017, http://www.dupuyinstitute.org/blog/2017/02/03/army-and-marine-corps-join-forces-to-define-multi-domain-battle-concept/.

[37] Jose L. Liy, "Multi-Domain Battle: A Necessary Adaptation of US Military Doctrine," (Monograph, School of Advanced Military Studies, U.S. Army Command and General Staff College, 28 May 2018), iii.

[38] Stephen J. Townsend, "Accelerating Multi-Domain Operations: Evolution of an Idea," *Military Review Special Edition* (September-October 2018): 4-7.

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Jonathan Bott, now in his capacity as a SAMS student, began exploring this concept as early as 2017 in his monograph arguing for Multi-Domain Operations as an evolution beyond Joint Operations. This represented an early development of the concept, especially factors related to simultaneous operations in multiple domains by one or more departments and how one domain could open vulnerabilities into another.[39]

One of the key developments in the development of MDO theory has been the application of overarching operational design considerations through an MDO framework. Scott Vanoort's 2020 thesis provides one example of this expansion by addressing operational risk in Multi-Domain Operations and updating the risk construct for the modern operating environment. Vanoort concludes that MDO needs to be integrated into joint doctrine while addressing the short timelines of high-tempo operations and pushing authorization authority to lower echelons.[40] These considerations are particularly relevant when addressing an organization like the MDTF that may operate while geographically separated from higher commands in a contested environment.

Current authors have begun to explore applications of MDO in relation to specific military functions and operations. Anthony Clas's article on the challenges of command in multi-domain formation addresses these in terms of emerging technologies, new

[39] Jonathan W. Bott, "What's After Joint? Multi-Domain Operations as the Next Evolution in Warfare," (Monograph, School of Advanced Military Studies, U.S. Army Command and General Staff College, 15 March 2017), 1, 5.

[40] Scott J. VanOort, "Describing Operational Risk in Multi-Domain Operations" (Master's Thesis, U.S. Army Command and General Staff College, June 12, 2020), 11, 76.

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ethical dilemmas in operations, an operational environment that includes dense urban environments, and changes in the roles of leaders and soldiers due to increased complexity in operations.[41] Darren Buss expands on this concept in his participation in an Army War College project, examining the capability of echelons above brigade to command multi-domain operations and control partner units.[42] This addressed the command and control joint warfighting function, a key organizing concept for implementing MDO.

Another example of this concept is the Army's functional concept for fires from 2020-2040. While not specifically addressing MDO, this manual describes many of the fundamental aspects of that concept. This includes leveraging multi-national capabilities, convergence, and cross-domain fires.[43] A third example is Chris Sadoski's thesis, which references Multi-Domain Battle but occurs on the cusp of the transformation between that concept and Multi-Domain Operations. Sadoski examined the requirement for supporting large scale deployment against a peer threat in the context of corps size elements in a rapid response force.[44] These studies and manuals help to align the rest of the force in

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[41] Anthony M. Clas, "Commanding in Multi-Domain Formations," *Military Review* (March-April 2018): 90-100.

[42] Darren W. Buss, "Echelons above Brigades Headquarters in Multi-Domain Operations: Field Army Alternatives," in *Theater Army in Multi-Domain Operations Integrated Research Project,* ed. Gregory L. Cantwell (Carlisle, PA: United States Army War College, 2020), 23-53.

[43] U.S. Army Training and Doctrine Command (TRADOC), TRADOC Pamphlet 525-3-4, *The U.S. Army Functional Concept for Fires 2020-2040* (Fort Eustis, VA: TRADOC, January 2017), v-vi.

[44] Chris J. Sadoski, "Strategic Support to the Multi-Domain Battle Concept," (Master's Thesis, U.S. Army Command and General Staff College, 15 June 2018), 85.

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support of MDO, providing some context for how other parts of the Army relate to the forces that are most heavily involved in conducting operations.

Regarding this study a more relevant consideration is how MDO specifically should be used to counter peer threats. One example of this is Nicholas Stafford's analysis of whether Multi-Domain Operations can be used to counter Russian hybrid warfare in the Baltics. Stafford examined this scenario in terms of a "*fait accompli"* with Russia having already set up A2/AD systems in the Baltics. Stafford assessed that current capabilities cannot enable quick penetration of an A2/AD space and that requirements for synchronizing effects would present difficulties in exercising mission command.[45] Stafford's framework is worthwhile because it contemplates MDO in a conflict against a specific enemy, but less useful in context of this study because it is focused on using conventional forces in an MDO role and does not address the MDTF as a concept.

The complement to addressing how MDO should be used to counter peer threats is how peer threats will seek to counter MDO. Larry Wortzel makes the argument that China is aware of the U.S. MDO concept and is intentionally designing its strategies around defeating it. Wortzel sees China's focus on A2/AD through this lens and then extends the concepts further by addressing China's novel capabilities with possibilities like the use of electromagnetic pulse weapons to disable electronic capabilities or use of ballistic missiles to threaten adversaries.[46] This underscores the importance of developing

[45] Nicholas J. Stafford, "The Alliance Strikes Back: Using Multi Domain Operations to Counter Russian Hybrid Warfare in the Baltics," (Master's Thesis, U.S. Army Command and General Staff College, 14 June 2019), 9, 11, 22, 58.

[46] Larry M. Wortzel, "What the Chinese People's Liberation Army Can Do to Thwart the Army's Multi-Domain Task Force," (Land Warfare Paper 126, The Institute

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a fully fleshed-out MDO concept that uses the MDTF and other units in multiple capacities so that they are not so easily predictable.

The U.S. Army's Role in the Indo-Pacific

In recent years one of the cornerstone issues of the debate over Pacific strategy has revolved around the question of what forces will lead in the area, with naval and air forces generally considered as being dominant while the Army struggles to make a case for its own inclusion. The vast distances between land masses and islands in the region have long been cited as proof that the Army would have little role in conflicts in the area, but this perspective is ahistorical and does not account for the full range of the Army's developing capabilities and demonstrated ability to influence other domains. Even the island-hopping campaigns of World War II saw significant Army participation, and there are few reasons to think that future conflicts would not also be heavily reliant on Army capabilities.

The RAND Corporation's 2014 study, *The U.S. Army in Asia, 2030-2040*, argues for six main roles for the U.S. Army in Asia including defending key facilities from air and missile attacks, projecting combat forces into theater, and contributing to new deterrent options. Although it predates the creation of the Multi-Domain Task Force, the study includes references to many of its elements and suggestions for how they could be useful in Asia. This includes a definition of expeditionary combat power that includes long-range precision fires, defensive cyber operations, and strategies to turn China's

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of Land Warfare at The Association of the United States Army, Arlington, VA, July 2019), 2-7.

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A2/AD strategy against them using shore-based capabilities and threats to blockade and restrict the Chinese military from establishing conditions necessary to initiate hostilities.[47]

These ideas are further developed in the body of the text, based on the concept that time is a major consideration in any potential conflict against China and that any ability to slow down or delay Chinese operations to allow additional forces to intervene works in favor of the U.S. In order to facilitate this, the authors suggest the possibility that the Army should operate in a coastal defense role or gain control of straits to control access through those waters using mobile, shore-based anti-ship missiles. This would serve as a deterrent by undermining Chinese confidence in a successful naval conflict, but the study does note that there is significant risk that this strategy could increase the risk of conflict or drive China toward a more expeditionary posture.[48] While the current MDTF does not incorporate the deterrent or A2/AD concepts this study calls for in its designated mission, the similarity in unit structure to what the study suggests indicates that it could be used in these roles.

Several years later Emily Martin and Samantha Wooley referenced this study and developed the ideas further in "The Army's Role in the Future Pacific Theater." Based on an earlier symposium on land forces in the Pacific Martin and Wooley argue that Army forces should be able to sink a ship, shoot down a missile, and shoot down the aircraft

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[47] Terrence Kelly, James Dobbins, David A. Shlapak, David C. Gompert, Eric Heginbotham, Peter Chalk, and Lloyd Thrall, *The U.S. Army in Asia, 2030-2040* (Santa Monica, CA: RAND Corporation, 2014), xviii-xxiii.

[48] Ibid., 61-62, 97, 109-110.

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that fired the missile within a short window. This article specifically mentions Palawan in the Philippines as a possible site for such actions and discusses the possibility of mobile land-based forces being used to create an A2/AD shield.[49] Without specifically mentioning the MDTF, this article presents another example of a multiple roles that the Army can play in the Pacific that could be within the potential capabilities of the MDTF.

Loren Thompson advanced similar issues the following year in an article in *Forbes Magazine* titled "How the U.S. Army Can Play a Much Bigger Pacific Role Deterring China." Thompson proposes a role for U.S. Army in defeating Chinese naval and air forces trying to traverse the first island chain, suggesting that the Army could establish a major land presence in the archipelago or be based in countries like Vietnam. Thompson references multi-domain operations without bringing up the MDTF, but does discuss long range precision fires, possibly adapting Navy anti-ship missiles for Army use, and the Army's role in providing air and missile defense.[50] Bringing together these functions under a single heading seems to point directly toward the MDTF as a potential method to fulfill these requirements, but Thompson does not make the connection.

More recent discussion in the last year has explicitly tied the MDTF to providing long range precision fires in the Pacific, including Jen Judson's article in October of 2021 on the U.S. Army's desire to carve out a role in the Pacific. Judson initially focuses her

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[49] Emily Martin and Samantha Wooley, "The Army's Role in the Future Pacific Theater," *Military Review* (January-February 2018): 105-108.

[50] Loren Thompson, "How the U.S. Army Can Play a Much Bigger Pacific Role Deterring China," *Forbes Magazine,* 13 August 2019, https://www.forces.com/sites/lorenthompson/2019/08/13/how-the-u-s-army-can-play-a-much-bigger-pacific-role-deterring-china/?sh=2ec8285c58f9.

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attention on establishing relationships and training partners, but also notes that the Army's current priority is developing long-range fires due to the problem of distance in the Pacific and names the MDTF as the primary purveyor of that capability. Judson also brings up criticism of the idea, citing calls for the Army to focus on air and missile defense in the region and arguments that the U.S. Air Force and its bomber force are a better investment than ground-based missile capabilities.[51] The reference to the MDTF here is notable in that it references long-range precision fires but does not specify an anti-A2/AD role, suggesting other uses for the MDTF's capabilities.

The most up-to-date conception of the role of the Army in the Pacific has been based on comments by the Secretary of the Army, Christine Wormuth, on how she sees the Army's mission in the theater. Andrew Eversden from *Breaking Defense* quotes Wormuth as laying out five primary roles including building and defending bases, providing C2, sustaining logistical supply lines, taking an offensive role with long range precision strike capabilities, and counterattacking in the event of enemy incursions.[52] John Grady of the United States Naval Institute digs deeper into the meaning of these comments and notes that many Indo-Pacific nations have cyber, space, and long-range fires in their armies while describing the Army's service role in terms of providing air and missile defense, network security, and the use of long range fires and hypersonic

[51] Jen Judson, "Post-Afghanistan, the US Army Wants to Carve Out Its Role in the Pacific" *Defense News*, 11 October 2021, https://www.defensenews.com/digital-show-dailies/ausa/2021/10/11/post-afghanistan-the-us-army-wants-to-carve-out-its-role-in-the-pacific/.

[52] Andrew Eversden, "Wormuth: Here's the Army's Role in a Pacific Fight," *Breaking Defense,* 1 December 2021, https://breakingdefense.com/2021/12/heres-what-the-army-would-do-in-a-pacific-fight-wormuth/.

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missiles. Crucially, Grady frames these roles in terms of Multi-Domain Operations taking its place as the current doctrine for operations.[53]

The most detailed explanation of these roles and how they would be accomplished comes from Caitlin M. Kenney's article from *Defense One*, which provides an expanded purpose and possible means for each task. Crucial to the discussions in this study is Kenney's explanation of the fourth task of providing ground-based fires, which Kenney indicates includes the ability to interdict fires across sea lines of communications, suppress enemy air defenses, and provide counter-fires against mobile targets. Kenney also references cyber-attacks as a major area of concern and references a need to expand the Army's focus out of northeast Asia and into the southeastern region.[54] These concepts of the Army's use in the Pacific once again leave out the MDTF as a primary executing agent but include many of its components in the Army's projected role and provide some possible tasks that it could execute in a Pacific conflict.

The Indo-Pacific Security Situation

The complexity of the Indo-Pacific security situation is clearly communicated in national security documents, beginning with the *2021 Interim National Security Strategic Guidance* which recognizes that a connection to the Indo-Pacific is vital to our national interests and calls for deepening partnerships with members of the Association of

[53] John Grady, "SECARMY Wormuth Pitches Army's Next Role in the Western Pacific," *USNI News,* 2 December 2021, https://news.usni.org/2021/12/02/secarmy-wormuth-pitches-armys-next-role-in-the-western-pacific.

[54] Caitlin M. Kenney, "Army Would Have 5 'Core Tasks' in a Pacific Conflict," *Defense One,* 1 December 2021, https://www.defenseone.com/policy/2021/12/army-would-have-5-core-tasks-pacific-conflict/187212/.

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Southeast Asian Nations. The guidance also calls for a more robust presence in the Indo-Pacific and places China's assertiveness front and center as a challenge that must be overcome through strong alliances and partnerships.[55] These priorities underwrite the selection of China as the competitor in this study's scenario and show the importance of expanding concepts of defensive partnership.

Although slightly older, the Department of Defense *Indo-Pacific Strategy Report* shares some language with the MDO concept by calling for forward-posturing of combat-credible forces and references interoperable warfighting capability in the region as a force multiplier. This issue is important enough to form the second of the three Lines of Effort in the report, specifically mentioning Singapore, Malaysia, and Indonesia. The report also highlights the importance of the Malacca Strait and addresses the importance of developing the Multi-Domain Task Force and building partner capacity.[56] This suggests some key partners and strategically significant locations, as well and the importance of focusing on their developing capabilities.

Recent testimony and talks by senior Department of Defense leaders have reinforced these ideas, with Secretary of the Army Ryan McCarthy's describing the importance of the Multi-Domain Task Force the possible use of the MDTF as an area denial force in a 2020 statement to the Brookings Institute on the Army's Indo-Pacific

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[55] U.S. President, *Interim National Security Strategic Guidance* (Washington, DC: The White House, March 2021), 10, 15, 20.

[56] Department of Defense (DOD). *The Department of Defense Indo-Pacific Strategy Report: Preparedness, Partnerships, and Promoting a Networked Region* (Washington, DC: DOD, 1 June 2019), 19, 21, 39.

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strategy.[57] More recently, Admiral Philip S. Davidson's testimony before the Senate Armed Services Committee included several MDO related priorities such as Long Range Precision Fires and the importance of establishing a multi-domain command and control node in the region.[58] Taken together these statements help to establish the importance of MDO and the MDTF in the region.

The recent release of the Biden administration's new Indo-Pacific strategy has not significantly altered these conclusions. It retains China as a major threat to the rules-based order in the region and lays out five objectives, specifically prioritizing supporting open societies and preventing coercion along with bolstering Indo-Pacific security and building defense capacity of partners such as Taiwan.[59] The strategy also lays out ten lines of effort, with the third line of "Reinforce Deterrence" including references to the Taiwan Strait and AUKUS partnership.[60] Based on these objectives and lines of effort there is still a continued role in the Indo-Pacific for the MDO and the MDTF.

As a result of this emphasis, recent scholarship has focused on the U.S. strategic situation in the region, specifically in relation to China. Although primarily concerned with the Freely Associated States in the Western Pacific, Christopher Lochridge argues

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[57] Ryan McCarthy and Michael O'Hanlon, "The Army's Strategy in the Indo-Pacific," (Transcript of proceedings at the Brookings Institution, Washington, DC, 10 January 2020; transcribed by Anderson Court Reporting, Alexandria, VA), 7, 17.

[58] "Statement of Admiral Philip S. Davidson, U.S. Navy, Commander, U.S. Indo-Pacific Command Before the Senate Armed Services Committee on U.S. Indo-Pacific Command Posture," (Washington, DC, 09 March 2021), 6-10.

[59] U.S. President, *Indo-Pacific Strategy of the United States* (Washington, DC: The White House, February 2022), 8-13.

[60] Ibid., 15.

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that the United States has a blind spot in the region and addresses China's A2/AD and EW, cyber, and space capabilities as a major concern in the region.[61] George Sotelo describes similar influence tactics by China in the East and South China Sea disputes, arguing that many nations in the region dispute Chinese claims and might welcome U.S. leadership. Sotelo also concludes that China is unlikely to understand or change its behavior for anything short of a military confrontation or a blockade in some situations.[62]

Other authors have examined the possibility of the United States being drawn into a conflict in the region or discussed specific threats China poses to U.S. capabilities. Jacob Rosales imagined two possible categories of scenarios that might lead to U.S. military involvement, with the first being the U.S. acting as a third party on behalf of one or more Southeast Asian nations being threatened by China while the second would be a direct conflict over freedom of navigation operations.[63] Richard Gibson's earlier examination of the region brings the beginnings of MDO into the discussion by addressing China's threat to U.S. space capabilities and potential use of A2/AD systems

[61] Christopher P. Lochridge, "The Pacific's Strategic Blind Spot: US Indo-Pacific Command's Problem of China in the Western Pacific," (Monograph, School of Advanced Military Studies, U.S. Army Command and General Staff College, 21 May 2020), 2. 25.

[62] George D. Sotelo, "The United States Military Strategy and the East China Sea and South China Sea Disputes," (Master's Thesis, U.S. Army Command and General Staff College, 15 June 2018), 20, 77.

[63] Jacob J. Rosales, "The South China Sea: A Strategic Flashpoint," (Monograph, School of Advanced Military Studies, U.S. Army Command and General Staff College, 23 May 2019), 1.

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and electronic warfare.[64] These studies provide some important insights into some of the possible crises that the U.S. could face in the region as well as some of the barriers to activity based on Chinese capabilities.

One of the foremost authorities on anti-access warfare is Samuel Tangredi, whose 2013 book on the subject laid out what he considers the fundamentals of anti-access warfare including the primacy of geography and the predominance of the maritime domain. Tangredi primarily argues from a maritime perspective, but also makes a larger point that technology and tactics alone cannot defeat a well-developed anti-access strategy.[65] Tangredi further details his arguments in his article "Antiaccess Warfare as Strategy" where he differentiates anti-access warfare scenarios from larger anti-access strategies. In this instance Tangredi's chooses to use the South China Sea as an illustrative example, arguing that a conflict between the United States and China in the region would likely involve multiple elements of national power and a whole-of-government approach.[66] Tangredi's analysis provides a good understanding of anti-access warfare, but does not address the Army's role in defeating or enacting similar strategies.

Major Joseph Cangealose's 2020 monograph on A2/AD threats and their impact on future combat operations provides another perspective on the topic, primarily focusing

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[64] Richard W. Gibson, "Extending Operational Reach: A Future Chinese Threat Scenario to the U.S. Space Domain," (Monograph, School of Advanced Military Studies, U.S. Army Command and General Staff College, 23 February 2018), 2, 12, 39-41.

[65] Sam. J. Tangredi, *Anti-Access Warfare: Countering A2/AD Strategies* (Annapolis, MD: Naval Institute Press, 2013), 1-5.

[66] Sam J. Tangredi, "Antiaccess Warfare as Strategy," *Naval War College Review* 71, no. 1, article 4 (2018): 2-10.

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on the impact of integrated air defense systems as a threat to aircraft. Cangealose ties earlier concepts of A2/AD warfare into Multi-Domain Operations, arguing that surface to air missiles are an effective method of inhibiting opponents from conducting effective Multi-Domain Operations. By using a variety of examples from Vietnam, Israel, and Kosovo Cangealose is able to demonstrate how A2/AD strategies can be used to force aircraft into flight corridors, keep them from maneuvering freely, interrupt an offensive operation by diverting efforts to deal with A2/AD forces, and lessen the effectiveness of strike aircraft.[67]

Narrowing the scope to potentially significant locations where the MDTF may be able to create an outsized effect on events within the theater the Malacca Strait has been the focus of a significant amount of analysis as a key strategic location. Peter Rimmer and Paul Lee's exploration of potential consequences identified sea lane closure in the region as catastrophic to the world's economy and identified numerous key locations where the Straits are narrow enough that this could present a significant threat. Their analysis also included the distance and time costs of going around Indonesia to the Lombok Strait as more than 2,500 nautical miles and upwards of 100 hours depending on the speed of the ship at sea.[68] This underscores the strategic importance of the region that

[67] Joseph M. Cangealose, "The Impact of Anti-Access Area Denial Threats on Future Combat Operations" (Monograph, School of Advanced Military Studies, Fort Leavenworth, KS, 28 April 2020), 2-29.

[68] Peter J. Rimmer and Paul T.W. Lee, "Repercussions of Impeding Shipping in the Malacca and Singapore Straits," *Journal of International Logistics and Trade* 5, no. 1 (2007): 7–26, https://doi.org/10.24006/jilt.2007.5.1.001.

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led to it being chosen for this study, as well as demonstrating the possible strategic benefits of denying passage in a time-sensitive military crisis.

Joel Davis's thorough exploration of maritime security in the Strait highlights the potential of the area as a war risk due to the threat of piracy and terrorism. Davis focuses his analysis on Indonesia, Malaysia, and Singapore and examines the military capabilities of each for maritime security but is mostly concerned with anti-piracy measures and cooperation when dealing with criminal organizations. In addition to discussing the relative military capabilities of each country Davis provides valuable insight into the relationships between the actors in the region and concludes that most of the actors in the region have demonstrated the ability to work together and are all nervous about China to one degree or another.[69] With these considerations in mind, it is important to remember that all straits have an entrance and an exit.

Looking at the other end of the Straits of Malacca indicates that India could have a significant role in any action in the region. Ken Moriyasu of *Nikkei Asia* references the Andaman and Nicobar Islands as "strategically situated" locations that overwatch the Malacca Strait and notes that they have been used to refuel U.S. maritime surveillance aircraft.[70] H. I. Sutton of *Forbes Magazine* concludes that India could certainly block the Straits, although China has begun developing alternate routes around the Straits of

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[69] Joel D. Davis, "Maritime Security and the Strait of Malacca: A Strategic Analysis," (Master's Thesis, U.S. Army Command and General Staff College, 16 June 2006), 17-39.

[70] Ken Moriyasu, "Japan Sends First-Ever Aid to Indian Islands at Mouth of Malacca," *Nikkei Asia*, 7 April 2021, https://asia.nikkei.com/Politics/International-relations/Indo-Pacific/Japan-sends-first-ever-aid-to-Indian-islands-at-mouth-of-Malacca.

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Malacca and is increasing its naval strength in the region.[71] With multiple potential avenues for closure the Straits of Malacca are a key chokepoint in the region, but far from the only potential strategic location to employ land-based fires.

Returning to the 2017 RAND study on land based A2/AD, Ishigaki island represents another potential location due to its proximity to the Senkaku islands and Taiwan.[72] The island has made appearances in regional news on several occasions in this role, with Chheang Vannarith of the Khmer Times referring to it as "a strategic gateway to Asia" due to its access to shipping lanes near Miyako islands. The island has also been the site of increasing amounts of defensive infrastructure including Coast Guard and potentially other Japanese Self-Defense Force facilities.[73] In a more recent article Robert Eldridge notes that the Ishigaki City Assembly has called on the central government of Japan to establish a Japan-Taiwan Basic Relations Act and that the Yaeyama Defense Association has requested the establishment of a Maritime Self-Defense Force base to protect the area.[74]

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[71] H. I. Sutton, "Could the Indian Navy Strangle China's Lifeline in the Malacca Strait," *Forbes Magazine,* 8 July 2020, https://www.forbes.com/sites/hisutton/2020/07/08/could-the-indian-navy-strangle-chinas-lifeline-in-the-malacca-strait/.

[72] Bonds et al., *What Role Can Land-Based, Multi-Domain Anti-Access / Area Denial Forces Play in Deterring or Defeating Aggression,* 83-84.

[73] Chheang Vannarith, "Ishigaki Island, a Strategic Gateway to Asia," *Khmer Times*, 6 February 2019, https://www.khmertimeskh.com/50575597/ishigaki-island-a-strategic-gateway-to-asia/.

[74] Robert D. Eldridge, "Ishigaki on Cutting Edge of Japan's Relationship with Taiwan," *Japan Forward*, 17 March 2021, https://japan-forward.com/ishigaki-on-cutting-edge-of-japans-relationship-with-taiwan/.

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Many security concerns in the Indo-Pacific today revolve around the South China Sea, which Marvin Ott described in 2019 as being critical to American interests in terms of critical sea lanes, defense ties with allies and partners, and implications for the global balance of power and influence.[75] Jacob Rosales' monograph from the same year also points out that there are considerable oil and natural gas reserves under the sea floor while pinpointing major Chinese outposts at Fiery Cross, Subi, and Mischief Reef.[76] This builds on and supports earlier work by James Holmes in the *Naval War College Review*, which noted that most of the disputed islands in the region are dependent on outside support and that Chinese vessels moving in or out of the region would most likely transit near the Philippines if not using the Malacca Strait.[77] This indicates that the Philippines should be considered as another location where land-based forces could influence the regional situation.

The 2017 RAND report repeatedly cites the western island of Palawan as a deployment location based on it being within 300 kilometers of the Second Thomas Shoal and within 200 to 300 nautical miles of many other disputed features.[78] The idea of Palawan as a strategic location is a common enough perspective that it has found its way

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[75] Marvin Ott, "The South China Sea in Strategic Terms," *Asia Dispatches* (blog), *The Wilson Center Asia Program,* 14 May 2019, https://www.wilsoncenter.org/blog-post/the-south-china-sea-strategic-terms.

[76] Rosales, "The South China Sea," 3-4, 27.

[77] James R. Holmes, "Strategic Features of the South China Sea: A Tough Neighborhood For Hegemons," *Naval War College Review* 67, no. 2 (Spring 2014): 11-16.

[78] Bonds et al., *What Role Can Land-Based, Multi-Domain Anti-Access / Area Denial Forces Play in Deterring or Defeating Aggression,* 46, 105.

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into nature conservation publications, with a 2021 article describing the island as the country's sentinel in maritime disputes and calling it a jumping off point to the Philippines' Thitu Island base.[79] Based on this information, the MDTF could affect targets within the majority of the South China Sea from this location using its long range fires capabilities. With these three strategic locations identified, the next consideration is the geopolitical climate of the region and how the affected nations view strategic competition between the United States and China.

Broto Wardoyo's examination of Indonesia's perspective on U.S.-China strategic competition argues that Indonesia's concerns in this region are primarily economic in nature. Despite a commitment to reducing tensions in the region Wardoyo highlights the U.S.-Indonesia security relationship and indicates that domestic concerns are the major factor driving these policies.[80] Brian Lenzmeier addressed these factors in his 2019 monograph concerning Indonesian hedging and argues that the U.S. needs to step up its Marine Security Initiatives with Indonesia, strengthen relationships with security assistance and security cooperation, and realign these efforts with other implements of

[79] Crisabela Yabes and Leilani Chavez, "Amid South China Sea Dispute, Philippines' Palawan is Besieged by Political Split," *Mongabay*, 12 March 2021, https://news.mongabay.com/2021/03/amid-south-china-sea-dispute-philippines-palawan-is-besieged-by-political-split/.

[80] Broto Wardoyo, "ASEAN in the United States-China Strategic Competition: An Indonesian Perspective," in *How Can ASEAN Deal with the United States-China Strategic Competition,* NIDS Joint Research Series No. 18 (Tokyo, Japan: National Institute for Defense Studies, 2020), 35-45.

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national power.[81] These studies are based on a relatively stable international situation, and do not anticipate or necessarily apply during a crisis scenario.

Christopher Dibble's 2018 thesis offers a more expansive discussion of these ideas, beginning with describing the history of U.S.-Indonesian relations and then moving on to discuss the principles of Indonesia's maritime framework. One noteworthy portion of Dibble's analysis is that he identifies friction points with China and indications that these might push Indonesia out of its non-aligned status in the face of a severe enough violation. Dibble's thesis primarily focuses on Indonesia's borders, fishing concerns, and piracy.[82] This presents a more nuanced understanding of Indonesia's security and diplomatic considerations, as well as stressing the length and depth of U.S.-Indonesia relations.

The Philippines also has a complicated relationship with the United States and China based on shared history and current security concerns. In 2012 a report from Center for Strategic and Budgetary Assessments described the Philippines as a vital node for U.S. forces in the region, advocating for closer relations with America to check Chinese naval expansion along with assisting the Philippines to develop their own A2/AD capabilities.[83] A more recent report from the Peace Research Institute Oslo shows

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[81] Brian J. Lenzmeier "Indonesian Hedging: Strategies to Counter a Growing Imbalance in Southeast Asia," (Monograph, School of Advanced Military Studies, U.S. Army Command and General Staff College, 23 May 2019), 4-5, 12, 40.

[82] Christopher T. Dibble, "Advancing U.S. Interests in the Indo-Pacific Through Bilateral Maritime Security Cooperation with Indonesia," (Master's Thesis, U.S. Army Command and General Staff College, 15 June 2018), 2, 23-25, 47-48.

[83] Center for Strategic and Budgetary Assessments (CSBA), *The Geostrategic Return of the Philippines* (Washington, DC: CBSA, 18 April 2012), 1-2.

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that this relationship continues to evolve as China has increased its security and economic ties to the Philippines under president Rodrigo Duterte against the advice of members of the Philippine strategy community while still remaining dependent on the United States.[84]

Richard Hedarian addressed this topic at the beginning of Duterte's term, reporting that Duterte expressed an early desire to reduce dependency on the United States and open ties with China. Hedarian notes that Duterte's actual policy has been more restrained than his rhetoric, but has included restrictions on U.S. operations from the Philippines even as the Philippines struggles to find common ground with China over disputes in the South China Sea.[85] Teresita Ang See's recent work on narratives in Philippine-Chinese relationships provides some important historical context to these relationships, citing common experiences in both countries living under imperial and colonial rule and seeking emancipation.[86] These commonalities and recent changes have complicated the security relationship between the Philippines and the United States, but there is still a high level of cooperation between the two countries and shared concern over Chinese actions in the South China Sea.

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[84] Julio Amador III, Deryk Matthew N. Baladjay, Ilaria Carrozza, Marte Nilsen, and Oystein H. Rolandsen, "An Appraisal of Philippines-China Security Relations under the Duterte Administration (2016-2020)," *(*PRIO Paper 2021, Peace Research Institute Oslo, Norway, 2021), 10-21.

[85] Richard Javad Hedarian, "Duterte's Geopolitical Game-Play," in *Line in the Waters: The South China Sea Dispute and its Implications for Asia,* ed. Abhijit Singh (New Delhi: Mohit Enterprises, 2017), 55-63.

[86] Teresita Ang See, "Shared History, Shared Heritage, Shared Destiny: Discovering New Narratives on Philippines-China Relations," *Chinese Studies Journal* 14 (January 2021): 31-32.

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A similar but slightly warmer relationship exists between the United States and India. Alexander Mulling's 2019 monograph on the subject describes the Obama administration as recognizing India as a major partner with the intention of developing bilateral security and defense cooperation even though India is primarily concerned with Pakistan despite being wary of China.[87] Andrew Talone echoes these comments by arguing that China is threatening India's sphere of influence in the Indian Ocean region, suggesting that the U.S. and India could affect China by blocking the Malacca Strait or cutting off energy imports despite military limitations would restrict the amount of assistance that India could provide.[88] As a result of this they are in some ways similar to Japan, as Satoru Nagao observed in his proposal for a Japan-India partnership based on both countries having a shared interest in the South China Sea while being partially dependent on the U.S. to counter China.[89]

Muhammad Prabowo provides a recent look at how Japan perceives China in his article in the *Nation State: Journal of International Studies*, claiming that recent tensions over the Senkaku Islands and increasing clashes in the South China Sea have prompted Japan to increase activities and move troops to support their security concerns in the

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[87] Alexander G. Mulling, "The Army and US-India Alignment," (Monograph, School of Advanced Military Studies, U.S. Army Command and General Staff College, 23 May 2019), 1-27.

[88] Andrew J. Talone, "How the United States Can Reinforce India as a Counterbalance to China in the Indian Ocean Region from a Military Standpoint," (Master's Thesis, U.S. Army Command and General Staff College, 14 June 2019), 4, 63-64.

[89] Satoru Nagao, "A Japan-India Partnership in Maritime Asia," in *Line in the Waters: The South China Sea Dispute and its Implications for Asia,* ed. Abhijit Singh (New Delhi: Mohit Enterprises, 2017), 65-67.

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region.[90] Xuan Tuan Chu contextualizes these views in their 2019 thesis on Japan's engagements in the South China Sea, explaining that Japan views Chinese control over the Spratly Islands as demonstrating their eventual strategy against the Senkaku Islands while at the same time calculating that China being occupied in the South China Sea will prevent such a move.[91] This reinforces the idea that Japan is a key ally for U.S. interests in the region, as well as having an interest in supporting deployment of forces such as the MDTF in pursuit of its own interests.

Sung Keun Hyong's 2018 thesis provides an assessment of Japan's security policy and its impact on U.S. national interests, arguing that Japan is moving toward a more realistic security posture that will see it acting as a more active participant and concluding that Japan's strategy is not detrimental to U.S. interests.[92] In a recent article on Japan's new security posture Taiwan Yamaguchi Noboru refers to bilateral plans to react to Chinese actions toward Taiwan by linking those to the Senkaku Islands, indicating that Japan is working to increase its capabilities for island defenses with long-range stand-off munitions.[93] This is strikingly similar to the concept of using the MDTF

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[90] Muhammad Arif Prabowo, "How Does Japan Perceive China as an Adversary? The Dispute in Diaoyu/Senkaku Islands," *Nation State: Journal of International Study* 4, no. 2 (December 2021): 223-226.

[91] Xuan Tuan Chu, "Japan's Engagements in the South China Sea," (Master's Thesis, U.S. Army Command and General Staff College, 14 June 2019), 5, 31-32.

[92] Sung Keun Hyong, "Impact of Japan's Security Strategy and Policies on U.S. National Security Interests in the Indo-Pacific," (Master's Thesis, U.S. Army Command and General Staff College, 15 June 2018), 1-2, 163-164.

[93] Noboru Yamaguchi, "Japan's New Security Posture and Its Implications for Taiwan," *The ASAN Forum,* 24 September 2021, https://theasanforum.org/japans-new-security-posture-and-its-implications-for-taiwan/.

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in such a role, further validating the concept and the choice of strategic locations in this study.

Summary

The concept of Multi-Domain Operations has continued to evolve over the last five years, expanding from a basic understanding of the need to compete against peer competitors to an offensively oriented doctrine aimed at overcoming a key adversary capability. Multiple scholars have wrestled with this concept and conceptualized operations in terms of the U.S. perspective concerning China, identifying key terrain in the region and international partners who are intricately connected to those features. There is no escaping the importance of the Indo-Pacific region to U.S. National Security priorities, suggesting that national security professionals should retain a comprehensive perspective concerning potential allies, opportunities, and threats in the area.

While the concept of Multi-Domain Operations has involved since it was first developed as Multi-Domain Battle, there are still significant gaps that must be addressed due to limited engagement from allies, partners, and functional components of the U.S. armed forces. Based on this literature review the primary gaps concern analysis of MDO in the Indo-Pacific region and alternate uses of a Multi-Domain Task Force in an offensive or defensive role. This study will address those gaps and demonstrate how the MDTF can contribute to the Joint Force in the Indo-Pacific.

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CHAPTER 3

RESEARCH METHODOLOGY

Introduction

This chapter will discuss the research methodology, data collection, and data analysis that will be used in Chapter Four and Five to analyze the capabilities of the MDTF, determine what tasks those capabilities allow the MDTF perform, and examine the potential effects the MDTF can generate by conducting those tasks in the Indo-Pacific. This study envisions using the MDTF in a non-standard role to create an A2/AD space through the use land-based fires extending into the maritime domain, integrated electronic warfare, cyber, and space capabilities, and air defense systems. Combined with the MDTF's ability to strike distant targets using long range precision fires, this potentially allows the MDTF to play multiple different roles in potential future conflicts based on occupying key strategic locations. This presents multiple dilemmas to adversaries by influencing their ability to deploy and move troops as well as enabling freedom of movement for U.S. forces in the region.

The primary research question for this study asks how the MDTF can contribute to the Joint Force in the Indo-Pacific outside of its doctrinal mission of penetrating A2/AD spaces. While the MDTF may have been designed for that mission, that does not mean that it lacks the capability to perform other tasks if the capabilities required for its primary mission are used in a creative manner. Examining these capabilities and determining how they can be used in the Indo-Pacific increases the utility of the MDTF in scenarios that do not involve supporting an attack into an A2/AD space, expanding its participation within the range of military operations. This in turn addresses a larger

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question within military literature concerning the Army's role in the Indo-Pacific. While this study is focused on a single theater of operations, the general principles derived can be adapted for other operating environments in future studies.

The first secondary research question asks what the MDTF's planned capabilities are based on its design documents. This question is necessary because the MDTF was designed to incorporate emerging technologies and has largely been simplified in explanatory literature based on its primary purpose. Due to the narrow focus on the MDTF's role in penetrating A2/AD spaces there has been little thought put into other methods of employing its capabilities since the gap and solution have been so tightly connected. Answering this question requires examining the capabilities of the MDTF in absolute terms divorced from its specific mission, establishing a baseline of how far it can detect, engage, and effect enemies using the full suite of enablers it is intended to have as well as what self-protection capabilities it possesses with organic equipment.

The next secondary research question addresses what operational and tactical tasks that the MDTF can perform based on those capabilities. This includes an examination of the MDTF's role within a decisive action framework, ability to conduct enabling operations, and ability to perform tactical mission tasks as outlined in Army doctrine. These capabilities in turn contribute to the MDTF's ability to participate in joint operations by providing options that can be exercises across the conflict continuum and the range of military operations.[94]

[94] CJCS, JP 3-0, Ch 1, V-8 – V-10.

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The third secondary question asks how these capabilities and associated tasks can be used to shape the operational and strategic environment in the Indo-Pacific. This question applies the answers to the first two questions against key strategic terrain where the MDTF. This demonstrates how the MDTF could potentially operate to generate effects that would affect the operational or strategic situation within the region. Potential areas to explore while answering this question include the possibility that the MDTF could be used to deny passage through key locations, deter adversary action by the threat of being able to strike at disputed territory, or provide coverage to allow movement of U.S. or allied forces to a more advantageous location or to the location of a conflict.

Method

Based on the variety of secondary research questions this study will use multiple qualitative and quantitative methods for research and analysis. The beginning of Chapter Four will examine the differences between the existing MDTF structure, the rough structure outlined in doctrinal documents, and the structure of the MDTF as defined by its requirement documents that list capabilities and components of the MDTF. The most recent requirement documents available will be used to provide a notional outline of what capabilities the MDTF is intended to possess. From there, this study will answer the first and second questions via a reverse-JCIDS analysis. JCIDS, the Joint Capabilities Integration and Development System, is intended to fulfill military requirements by comparing those requirements with existing solutions to identify gaps and then develop

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solutions to fill those gaps based on the level of risk.[95] Because the solution of the MDTF already exists, reversing the process deconstructs the solution to determine its capabilities and then identifies the gaps that those capabilities can be used to fill.

The first portion of this process is a base level analysis of the doctrinal and organizational requirements for the MDTF, providing a description of the raw capabilities of the MDTF in terms of the systems described within its requirement documents. Once those have been established the second portion of the process examines what gaps those capabilities can potentially fill. To structure this portion of the analysis the MDTF's capabilities will be assessed against the tactical mission tasks listed within ADP 3-90 and further defined in FM 3-90 Volume 1 and 2. The tactical mission tasks that the MDTF is assessed as capable of performing will then be applied against the range of military operations in Joint Publication 3-0.

The results of this analysis will be applied to answer the third secondary question by conducting several small case studies examining the effects of utilizing the MDTF as part of a joint operation in accordance with the tasks it can conduct across the range of military operations. These case studies will begin by overlaying a template based on the range and sensing capabilities of the MDTF over key strategic terrain identified within the literature review to determine the maximum potential area that the MDTF can affect. After defining the area of operations each case study will analyze potential applications of the tasks and capabilities identified in the previous sections to identify how the MDTF

[95] Office of the Chairman of the Joint Chiefs of Staff (CJCS), *Manual for the Operation of the Joint Capabilities Integration and Development System* (JCIDS) (Washington, DC: The Joint Chiefs of Staff, 2018), A-1.

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could be used during different portions of the range of military operations. A graphical depiction of this method is included as Figure 1.

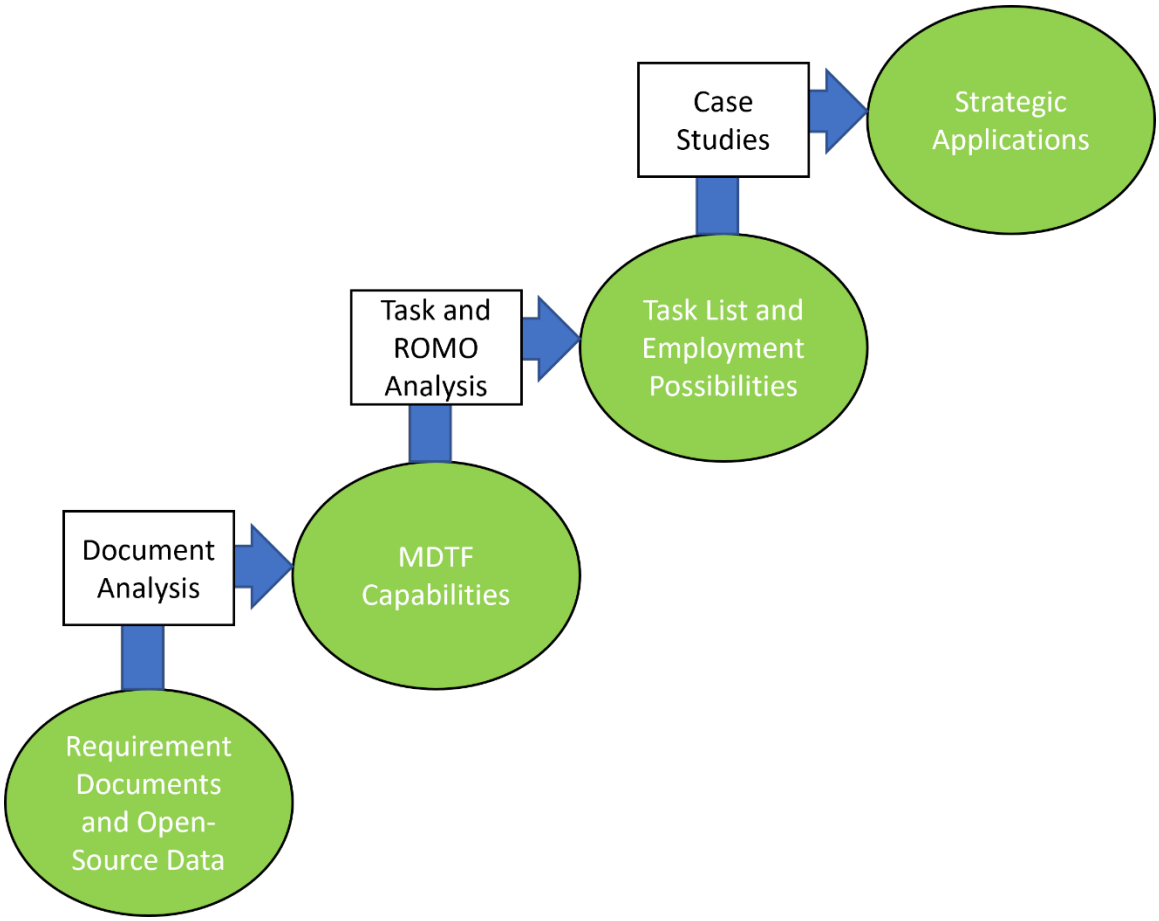


Figure 1. Methodology Diagram

Source: Created by author.

This method is most appropriate because of the requirement for military judgment and non-quantifiable nature of many of the capabilities that will be studied. It would potentially be possible to conduct a mixed methods approach using quantitative methods for the measurable aspects and qualitative descriptions for less concrete data, but the limitation of using non-classified data from publicly available sources and the potential of

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being unable to locate specific data on all required systems would result in an incomplete comparison. The precise disruptive capability of an offensive cyberspace operation or EW attack cannot be easily calculated in an accessible manner, for instance, while the precise accuracy of a long-range fire system requires detailed testing information that is not likely to be publicly available.

Data Collection

The primary method of data collection will be through analysis of open-source press releases, news reports, country and capability assessments from think tanks such as the Center for Strategic and International Studies or U.S. government databases, technical resources on military equipment. Mission task descriptions, joint operation framework concepts, and requirements documents will use publicly available references or be downloaded from unclassified force structure documentation sources such as FMSWeb for the MDTF's organizations, units, and formations. No restricted, classified, or otherwise non-public data will be collected as part of this study. This data will be screened and filtered to ensure that it is relevant, as recent as possible, and reliable before being used to build a develop a capability list for the MDTF.

Data collection will continue until all publicly announced and potentially applicable long-range fires or integrated air and missile defense systems fielded or in testing for the MDTF have been analyzed. Requirements for the MDTF will be analyzed down to at least the company level for all included units and down to the platoon level in the case of special capabilities such as electronic warfare, cyber defense, or intelligence gathering and target location capabilities. After establishing the range of the MDTF's sensing and fires capabilities, these ranges will be plotted on key strategic terrain

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identified in the literature review. This will enable analysis of where the MDTF's capabilities could be leveraged in military operations from those locations.

Data Analysis

Answering the first secondary research question will begin by analyzing the Table of Organization and Equipment (TOE) for the MDTF to determine its intended mission, dependencies, employment, capabilities, and functions. Organizational requirements TOEs provide information on the intended structure of a unit and are arranged in a hierarchical fashion with each subordinate unit's TOE providing expanded information on that aspect of the MDTF. This structure continues down to the detachment or company level, where sections, teams, and platoons are broken out in individual paragraphs that describe what that element is intended to provide to the unit. On some rare occasions individual platoons that provide a highly technical capability are also described in their own TOE, often specifically designed for employment by a unique organization such as the MDTF.

While these requirement documents provide information on structure, manpower, personnel, and equipment about the intended capabilities of the MDTF, they do not provide detailed military effects data concerning weapon capabilities. The second part of answering this question will require analysis of open-source data on existing weapons and systems as well as those that are still in development, particularly long-range precision fires and I2EWCS capabilities. Describing the MDTF's capabilities for fires includes data concerning range, magazine capacity, flight speeds, the kinds of targets it can strike and affect, and the ability to mass effects on a target from different ranges. Air and missile defense systems will be described based on detection range, engagement

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range, and versatility. In terms of this study versatility refers to the ability to engage different types of targets such as cruise missiles, ballistic missiles, and aircraft.

The nature of EW, cyberspace, and space-based capabilities is inherently less measurable and more difficult to compare than long-range fires or air and missile defense systems. Instead, data concerning these capabilities will be assessed for its potential to generate effects on hostile naval and air capabilities or support the use of other systems. Examples of capabilities focused on adversary forces might include the ability to jam, intercept, or interrupt communications, interfering with position-navigation-timing systems, generating false targets or alarms, or remotely shutting down or infiltrating computer systems. Activities in support of friendly activities might include defensive cyber operations to protect partner networks and computer systems, locating targets using overhead imagery or signals intelligence, providing guidance information for weapons systems, or assisting in target identification. These possibilities do not include all possible uses of EW, cyberspace, or space capabilities, and as a result research and analysis may uncover additional possibilities that will be considered during analysis.

To answer the second secondary research question this study will filter the capabilities described in the first research question through the lens of the elements of decisive action and tactical mission tasks described in ADP 3-90. Some elements and tasks will be obviously unsuited for the MDTF and will be identified and discarded at the beginning of this stage of analysis. Detailed information on those tasks is available in FM 3-90 including specific requirements and definitions that allow analysis to determine if a specific unit can conduct the subcomponents of a task. Both actions by friendly forces

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and effects on enemy forces will be addressed, providing a list of potential tasks that can be assessed against the range of military operations.

As described in JP 3-0 the range of military operations comprises three primary categories ranging from military engagement up to large-scale combat operations along a continuum of conflict from peace to war.[96] Further details on typical operations within each category are provided in separate chapters with employment considerations organized based on the joint operation model. Using these concepts as a backdrop makes it possible to integrate the tasks that the MDTF can accomplish into a joint concept that places its capabilities as part of a construct that includes operational and theater level activities in service of national strategic objectives as part of the Chapter Five.

To answer the third secondary research question, this study will graphically depict the information from the first two questions at key strategic locations identified via the literature review to demonstrate the effective reach of the MDTF. Based on the range of the MDTF's capabilities and the terrain within the area of operations, analysis will focus on how the tasks that the MDTF is capable of can be applied to generate different effects on hostile forces across the range of military operations. The end result of the analysis will discuss how the tasks could be used to generate strategic effects.

Following the collection of all required data this study will summarize the results to answer all secondary research questions to provide an analysis of the MDTF's potential to contribute to joint operations in the Indo-Pacific to answer the primary research question. This analysis will lay out the specific capabilities of the MDTF, the

[96] JCS, JP 3-0, Ch 1, V-4 – V-5.

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tasks that it can perform, and consolidate the lessons learned from the case studies. The answers to the secondary questions will be used to describe how the MDTF can be integrated into the Joint Operations Model described in JP 5-0 as well as how this recommended integration differs from the existing mission of the MDTF.

Summary

Based on the literature review in Chapter Two, while the question of what role the United States Army can play in the Indo-Pacific theater has been the subject of discussion for some time much of this discussion occurred before the development of the MDTF or has taken the designated mission of the MDTF at face value. As a result, the full potential the MDTF in a future conflict has not been widely studied and there is a gap in our understanding of its intended capabilities and the effects that they can generate against adversary forces. The concentrated firepower, variety of enablers, and long-range sensing and fires capabilities of the MDTF give the unit a disproportionate impact on an operational and strategic level that cannot be fully exploited without thorough analysis of what the unit might be, what tasks it could conduct, and how those tasks can be used to affect the Indo-Pacific theater.

In order to answer the research questions discussed previously this study will use a blended qualitative approach followed by analysis of the resulting data. The first portion of this approach will use a reverse-JCIDS methodology to analyze the MDTF in its role as an existing solution to determine its raw capabilities and the tactical mission tasks it can conduct to determine the gaps it can fill. The second portion of the approach will apply those capabilities and the associated tasks in small case studies based on employment of the MDTF at key strategic locations in the Indo-Pacific using China as a

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pacing threat. The outcome of those case studies will provide data to answer the primary research question concerning how the MDTF can contribute to the Joint Force in the Indo-Pacific outside of its doctrinally templated mission of penetrating A2/AD spaces.

This method is most appropriate for a variety of reasons, including the non-quantifiable nature of some of the aspects being studied as well as lack of accessible and confirmable numeric data due to classification restrictions. The primary data collection method for this study will be through analysis of open-source documents from a mixture of government, specialist, and media sources. This will include an examination of long-range fires and integrated air and missile defense systems for each country as well as reports on their EW, cyber warfare, and space capabilities. Using publicly available materials does have the drawback of not producing a perfectly accurate representation of the capability being discussed, but the intent of this study is to expand the doctrinal conversation and set the foundation for future development rather than creating a workable operations plan.

While this study focuses on a specific operational environment, the expanded doctrinal role it will support for the MDTF can be adapted to other theaters with appropriate modifications for differences in terrain that create natural barriers to detection and long-range fires. Differences in scale will also affect the role of the MDTF in other theaters, as the widely separated spaces of the Indo-Pacific are in many ways an ideal environment for this unit. Completing those adaptations is a matter of future scholarship, however, and the foundation for that begins now with an examination of what the MDTF is, what it was intended to be, and how it has been described and understood in the past.

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CHAPTER 4

ANALYSIS

The MDTF: Concept, Reality, and Requirements

Before examining the potential roles of the MDTF and how those can be applied in the Indo-Pacific, it is important to first establish what the MDTF is to appropriately evaluate its intended capabilities. This problem is complicated by confusion based on available concept materials, the actual organization as it has been constructed now, and the requirement documents that lay out specific capabilities and equipment sets. No single document can provide an answer to this question, and for the purpose of this study the notional MDTF should include planned future equipment as well as the most current explanations as to what the unit is intended to be capable of accomplishing at is end state as a doctrinal capability. The strongest argument in favor of this approach is that waiting until all required pieces are in places adds a further delay while doctrine catches up to equipment, unit training, exercises, and readiness plans.

Beginning with the depiction of the Multi-Domain Task Force from *Army Multi-Domain Transformation* in Figure 2, we have a broad overview at the battalion and company level. The I2CEWS and Strategic Fires Battalion include breakdowns to the company and battery level but provide no explanation as to what role those companies should play or what terms like "Mid-Range Capability Battery" mean in terms of reach, accuracy, and destructive power. In addition, although this diagram was only published a year ago several of the terms used are out of date and other sources show that all of the MDTF's capabilities are not represented on this diagram.

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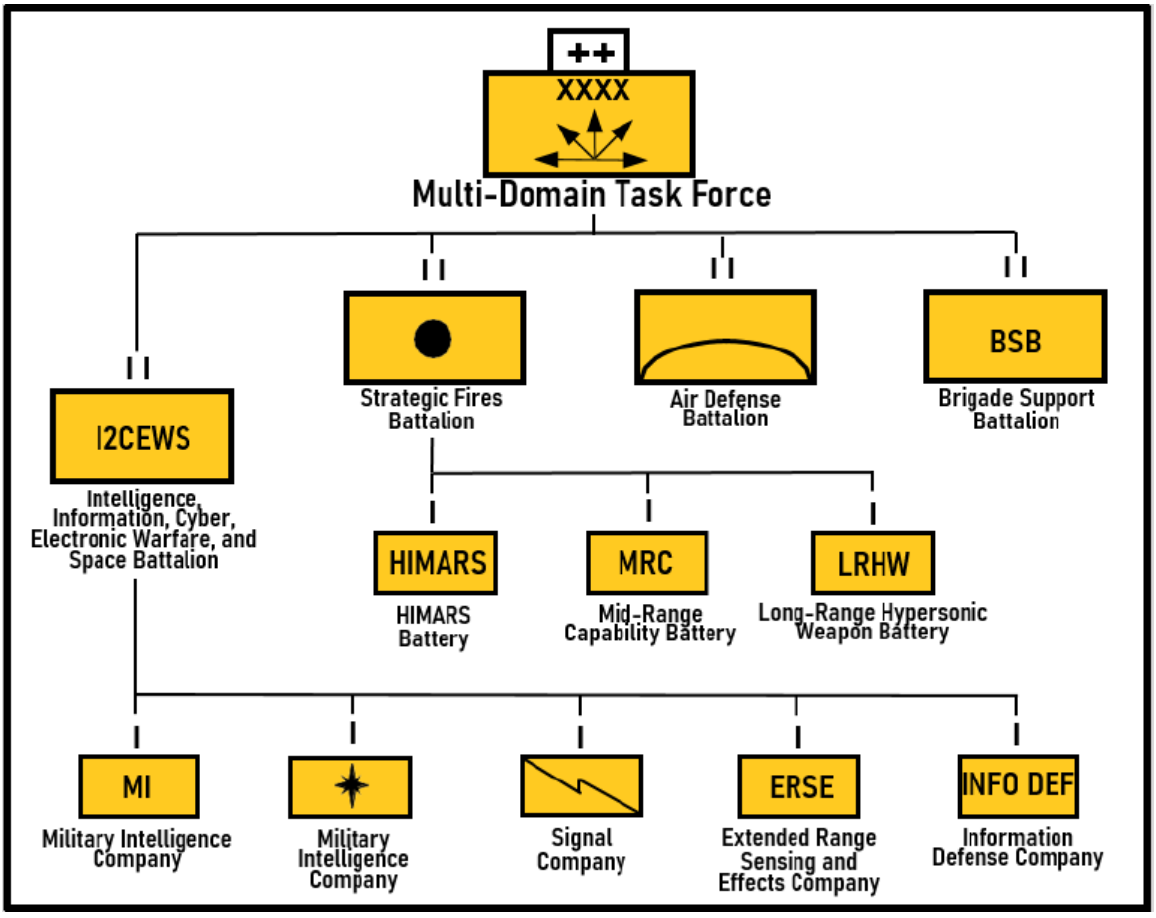


Figure 2. The Multi-Domain Task Force

Source: Headquarters, Department of the Army, "Army Multi-Domain Transformation: Ready to Win in Competition and Conflict," (Chief of Staff Paper #1, Department of the Army, Washington, DC, 2021), 12.

From this starting point it makes sense to examine the actual composition of the Army's most well-established MDTF at Joint-Base Lewis-McChord, but as is so often the case reality does not live up to the vision. Instead, as depicted in Figure 3 below the current MDTF is functioning as a headquarters element that is augmented or has units attached to it for mission or training purposes. The only permanently assigned units are an inactive Indirect Fire Protection Capability (IFPC) Air Defense Artillery battalion, a

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support company, and a cyber detachment. This is a functional concept for current requirements but does not allow for an accurate representation of future uses and strategic impacts. Currently existing units may be aligned with the MDTF headquarters and expected to be associated or later assigned to the unit on a permanent basis, with 5/3 Field Artillery battalion the most likely candidate as the home of the first Long-Range Hypersonic Weapons Battery.[97]

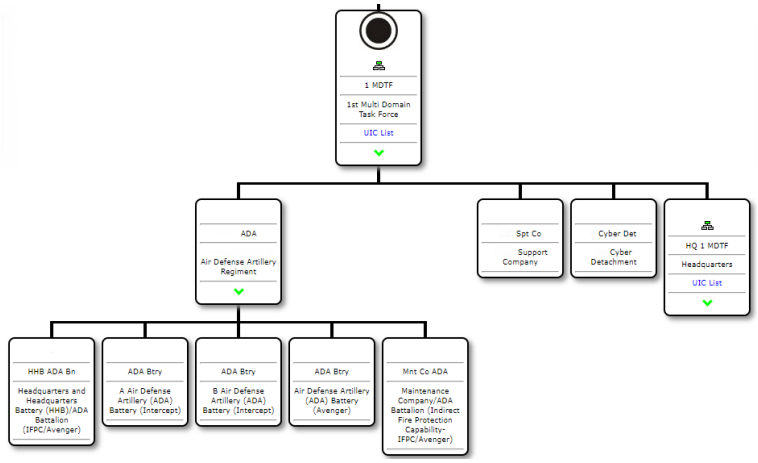


Figure 3. 1st MDTF Line and Block Chart

Source: U.S. Army G3/5/7, "1st Multi Domain Task Force," FMSWeb, accessed 26 February 2022, fmsweb.fms.army.mil.

The next source of information is the most recent Table of Organization and Equipment (TOE) for the MDTF, also drawn from FMSweb. This provides a more complete picture of the intended structure of the MDTF down to the company level, with further detail provided by individual narratives for each assigned unit. This depiction,

[97] Kristen Burroughs, "Dark Eagle is on the Move: Soldiers Complete New Equipment Training," U.S. Army, 14 March 2022, https://www.army.mil/article/254659/dark_eagle_is_on_the_move_soldiers_complete_new_equipment_training.

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seen below in Figure 3, provides the most complete breakdown of what the MDTF is intended to contain but is also not complete on its own merit.

06490K100		MULTI-DOMAIN TASK FORCE (MDTF) (RECAP)
1	06492K000	HQ, MULTI-DOMAIN TASK FORCE (MDTF)
1	71495K100	MULTI-DOMAIN EFFECTS BATTALION (MDEB) MDTF
1	71496K100	HHC, MULTI-DOMAIN EFFECTS BATTALION (MDEB) MDTF
1	11497K100	SIGNAL COMPANY, MULTI-DOMAIN EFFECTS BATTALION (MDEB) MDTF
1	34497K100	MILITARY INTELLIGENCE COMPANY MULTI-DOMAIN EFFECTS BATTALION (MDEB) (MDTF)
1	40843K000	SPACE CONTROL COMPANY, MULTI-DOMAIN EFFECTS BATTALION (MDEB)
1	71490K100	EXTENDED RANGE SENSING AND EFFECTS COMPANY, MULTI-DOMAIN EFFECTS BN (MDEB) MDTF
1	71497KA00	EXTENDED RANGE SENSING AND EFFECTS COMPANY, MULTI-DOMAIN EFFECTS BN (MDEB) MDTF
1	01708KA00	TACTICAL UNMANNED AIRCRAFT SYSTEM (TUAS) PLATOON
1	71498K100	INFORMATION DEFENSE COMPANY, MULTI-DOMAIN EFFECTS BN (MDEB) MDTF
1	06475K200	FIELD ARTILLERY BATTALION, HIMARS (2X9)
1	06476K200	HHB, FIELD ARTILLERY BATTALION, HIMARS (2X9)
2	06477K300	FIELD ARTILLERY BATTERY, FIELD ARTILLERY BATTALION, HIMARS (2X9)
1	63447K200	FORWARD SUPPORT COMPANY, HIMARS BN (2X9)
1	44315K000	ADA BN (M-SHORAD-MANPADS)
1	44316K000	HHB, ADA BN (M-SHORAD-MANPADS)
3	44317K000	ADA BATTERY (M-SHORAD)
1	44318K000	ADA BATTERY (MANPADS)
1	43317K000	MAINTENANCE COMPANY, ADA BN (M-SHORAD/MANPADS)
1	63485K000	BRIGADE SUPPORT BATTALION (MDTF)
1	63466K000	HEADQUARTERS AND HEADQUARTERS COMPANY BSB, MULTI DOMAIN TASK FORCE (MDTF)
1	63468K000	DISTRO CO, BSB, MDTF
1	43497K000	FIELD MAINTENANCE COMPANY, MDTF, BSB
1	08067K000	MEDICAL COMPANY, BRIGADE SUPPORT BATTALION (MDTF)
1	01727K000	GRAY EAGLE UAS COMPANY (MQ-1C)

Figure 4. MDTF Unit Hierarchy

Source: U.S. Army G3/5/7, "MDTF Recap Hierarchy," effective 1 October 2021, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

While certainly more comprehensive than the previous documents, this information is not as clear as a graphic depiction. In addition, it does not include planned capabilities such as the Mid-Range Capability Battery or Long-Range Hypersonic Weapon Battery. Another noteworthy difference is the inclusion of an attached Gray Eagle UAS Company, which carries important implications for target detection and surveillance capability. This version also differs from the existing line and block chart by

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including a short-range air defense artillery battalion instead of an IFPC battalion, which provides different defensive capabilities. Combining the planned future systems with this information results in the structure depicted below, with key capabilities that will be analyzed later broken out to the platoon and section level.

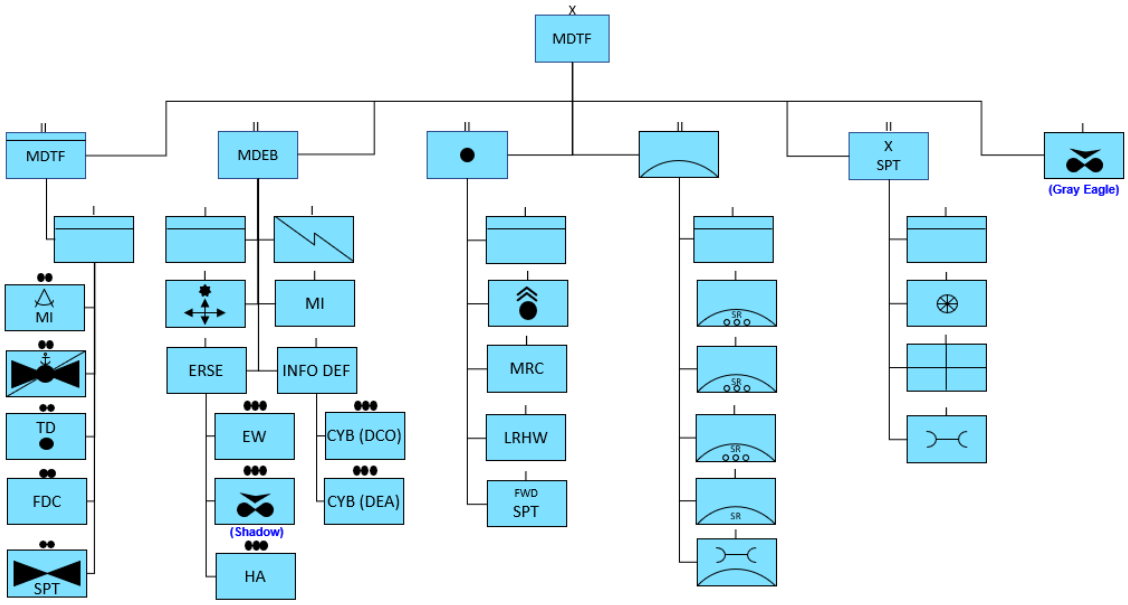


Figure 5. Composite Notional MDTF

Source: Created by author.

Working within this framework it is now possible to begin discussing what these units and capabilities mean in order to build a complete picture of what the MDTF is intended to be and do based on this design. In the next section this study will analyze each battalion and its associated capabilities based on TOE narratives to capture this information. Gaps in information, as in the case of capabilities still in development, will be filled using available sources and publicized results of system tests.

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Intended Capabilities of the MDTF

Headquarters and Overall Purpose

The most recent TOE of the MDTF lays out the formation's purpose in the opening paragraph. Key language for the purpose of this study specifies that the MDTF's mission is "to synchronize and employ fires multi-domain fires (lethal and non-lethal)" to prepare the environment during competition and conduct strikes against enemy A2/AD defenses "to enable joint force freedom of action during conflict."[98] Although this language seems centered around enemy A2/AD defenses, it also specifically says that the MDTF is expected to use both lethal and non-lethal fires during the competition phase of a conflict. This suggests that these fires could be used prior to the establishment of enemy A2/AD defenses. The other important language in this section is that the purpose of the MDTF is to enable joint force freedom of action, which can be read to indicate that while penetration of A2/AD defenses is the primary task of the MDTF that other tasks are acceptable if they meet this overall purpose.

As the rest of the TOE narrative directs the reader to subordinate TOEs for further information, the next source for its capabilities is in the TOE narrative of the MDTF Headquarters Battalion. The capabilities section of the MDTF headquarters TOE claims that it provides twelve capabilities, five of which are relevant to this study: long-range

[98] U.S. Army G3/5/7, "06490K100 Multi-Domain Task Force (MDFT) (Recap) TOE Narrative," effective 1 October 2021, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

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fires, air and missile defense, cyber and electronic warfare, surveillance, and space.[99] Broadly speaking long-range fires, surveillance, and space can be grouped together, with long-range fires allowing the MDTF to target critical enemy assets, surveillance including joint and organic targeting against land, maritime, and air domain forces, and space capabilities for situational awareness and position data.[100] These capabilities allow the MDTF to target and attack enemy forces, with the inclusion of naval and air assets providing support for the idea that the MDTF can be used to attack enemy aircraft and ships with appropriate support.

The MDTF's capability for cyber and electronic warfare supports this structure by providing the ability to conduct surveillance in that domain while also providing protection via jamming and defense of tactical network infrastructure. This protective function also includes elements of the MDTF's space capability, which has the capacity to provide early warning of enemy missile attacks. This would seem to connect to the MDTF's capability to provide air and missile defense against ballistic and cruise missiles, hostile aviation, and surveillance, but there is a problem with this listed capability.[101] As designed the MDTF's air and missile defense assets are all short-range air defense weapons, which are unable to detect or engage ballistic missiles. In order to provide defense against ballistic missiles, including detailed information about their probable

[99] U.S. Army G3/5/7, "06492K000 HQ Multi-Domain Task Force (MDFT) TOE Narrative," effective 1 October 2021, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil

[100] Ibid.

[101] Ibid.

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point of impact, the MDTF would need to be augmented with a longer-range system such as the Patriot missile system.

Examining the functions contained within the MDTF headquarters reveals that it contains many of the elements common to any headquarters, but a few capabilities appear unusual and relevant to its mission. Proceeding in order of appearance within the TOE the MDTF headquarters includes a robust intelligence capability that includes a geospatial intelligence cell to enable use of signals, imagery, electronic signature, and other types of intelligence.[102] The MDTF headquarters also includes capabilities related to controlling fires, including a target development element, fire direction center, and fire control element. Other capabilities are focused on interfacing with attached units and temporary capabilities for air and maritime domain capabilities, including an Air Naval Gunfire Liaison Company element as a liaison for joint fires, an air and missile defense team to integrate air defense assets, and an air support element to control aircraft strikes.[103] While some of these inclusions are expected within a fires-centric organization, the combined capabilities indicate that the MDTF is intended to operate independently and have to control a wider variety of assets than a normal brigade-sized artillery element.

[102] U.S. Army G3/5/7, "06492K000 HQ Multi-Domain Task Force (MDFT) TOE Narrative."

[103] Ibid.

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The Multi-Domain Effects Battalion (I2EWCS)

Known as the I2EWCS Battalion in older documents, the Multi-Domain Effects Battalion (MDEB) houses many of the most critical capabilities within the MDTF. This includes the ability to locate targets, conduct defensive cyber operations, receive and process intelligence support, manage space capabilities, and enable communications when conducting dispersed operations. This unit provides subject matter expertise in these capabilities as well as controlling its subordinate signal, military intelligence, space control, extended range sensing and effects (ERSE), and information defense companies.[104] While the battalion's TOE narrative does provide a general purpose for each company, for detailed information on their capabilities it is necessary to examine their individual TOEs. There is no current TOE for the headquarters company, so this analysis will begin with the MDEB's signal company.

The primary purpose of the MDEB signal company is to provide communications elements to ensure access to the Defense Information Systems Network.[105] To fulfill these functions the signal company includes two types of satellite communications teams for secure communications, network extension teams for network connectivity, and troposcatter teams to provide extended range high-frequency communications.[106] Based

[104] U.S. Army G3/5/7, "71495K100 Multi-Domain Effects Battalion (MDEB) TOE Narrative," effective 1 October 2022, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

[105] U.S. Army G3/5/7, "11497K100 Signal Company, Multi-Domain Effects Battalion (MDEB) MDTF TOE Narrative," effective 1 October 2021, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

[106] Ibid.

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on the structure of the TOE the signal company is organized into platoons, each of which includes teams for each capability.[107] This means that the MDTF can support multiple remote locations with redundant communications on top of the organic equipment and communications capabilities within the brigade headquarters.

To add space as a domain capability, the MDEB's space control company is closely tied to its signal company although there is limited information available about this unit and its role due to classification restrictions. The TOE for the space control company indicates that it uses the Mobile Integrated Ground Suite (MIGS) and operates to support satellite communications, coordinate and control space-based effects on designated targets, and provide information on the capabilities of enemy forces.[108] Much like the MDEB signal company, the space control company operates with identical platoons to enable support in multiple locations.[109] Turning to joint doctrine provides some clarity on the purpose of this unit, with Joint Publication 3-14 defining space control as operations to maintain the capability to act in space and prevent efforts to interfere with friendly space capabilities.[110] These capabilities help to ensure that the

[107] U.S. Army G3/5/7, "11497K100 Signal Company, Multi-Domain Effects Battalion (MDEB) MDTF TOE Narrative."

[108] U.S. Army G3/5/7, "40843K000 Space Control Company, Multi-Domain Effects Battalion (MDEB) TOE Narrative," effective 1 October 2022, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

[109] Ibid.

[110] Office of the Chairman of the Joint Chiefs of Staff (CJCS), Joint Publication (JP) 3-14, Change 1, *Space Operations* (Washington, DC: The Joint Chiefs of Staff, October 2020), ix.

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MDTF can operate in a contested space environment and conduct missions in multiple locations while adversaries are attempting to prevent use of space-based assets.

The ability to provide information and connectivity is carried over into the MDEB's military intelligence company, which is designed to support multiple command and control nodes according to its TOE narrative. In addition to providing analysis and intelligence preparation of the battlefield, the MDTF military intelligence company includes signals intelligence (SIGINT) teams to support electronic warfare and cyberspace operations and to conduct electronics intelligence (ELINT) to detect non-communications devices that emit into the electromagnetic system such as active radars.[111] While such data is often difficult for non-intelligence personnel to understand, this company also includes a Multi-Domain Processing Exploitation and Dissemination (MD-PED) section with the mission of refining data into usable information.[112] These capabilities contribute to the MDTF's overall ability to detect, locate, and target high-tech platforms on the modern battlefield.

These capabilities are further amplified by the MDEB's Extended Range Sensing and Effects (ERSE) company, which provides detection and electronic warfare capabilities in support of the MDTF. According to the doctrinal mission statement from the ERSE's TOE this unit consists of an unmanned aerial system (UAS) platoon, high-altitude balloon platoon, and electronic warfare platoon with associated sections that

[111] U.S. Army G3/5/7, "34497K100 Military Intelligence Company Multi-Domain Effects Battalion (MDEB) (MDTF) TOE Narrative," effective 1 October 2021, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

[112] Ibid.

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provide the capability to detect and attack targets in the electromagnetic spectrum and cyberspace at long ranges.[113] The highly technical nature of these capabilities requires additional exploration, particularly in determining their possible uses and effective ranges. The most straightforward component of the ERSE company is the electronic warfare platoon, which is described across three paragraphs as providing electronic attack, electronic surveillance, and limited cyberspace operations to integrate capabilities and preserve freedom of movement to the MDTF and joint forces.[114]

Two other components of the ERSE company are closely linked: the UAS platoon and the aerial multi-function electronic warfare (MFEW) section. According to the TOE the UAS platoon operates unmanned aircraft for reconnaissance, intelligence, surveillance, and target acquisition (RISTA), communications relay, and persistent surveillance while the MFEW section operates attached systems to support electronic warfare and use electronic attacks to disrupt the enemy.[115]

While the TOE narrative does not specify which unmanned aircraft the platoon operates, doctrinal design and plans for the UAS platoon shows that it is intended to be equipped with the RQ-7B Shadow UAS.[116] The manufacturer's website gives the range of the Shadow as 125 kilometers based on line of sight controls with an endurance of 8 to

[113] U.S. Army G3/5/7, "71490K100 Extended Range Sensing and Effects Company, Multi-Domain Effects Battalion (MDEB) MDTF TOE Narrative," effective 1 October 2022, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

[114] Ibid.

[115] Ibid.

[116] U.S. Army G3/5/7, "01708KA002 UAS Platoon TOE Detail," effective 1 October 2022, FMSWeb, accessed 29 December 2021, fmsweb.fms.army.mil.

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9 hours.[117] A 2020 report on the development of a MFEW system and its use on a RQ-7B Shadow UAS gives a potential detection range of up to 279 kilometers at altitude.[118] Combining these figures gives us a potential detection range of more than 400 kilometers based on a Shadow operating at its maximum potential range.

The ERSE's balloon platoon is less easily defined, with the TOE narrative describing small balloon sections and a large balloon section that are both intended to enable long-range communications, provide RISTA capability, and augment position-navigation-timing data within an area approximately one thousand kilometers across.[119] A 2021 investigation by Adam Kehoe of *The War Zone* provides some insight by identifying recent balloons being tested off the coasts of the United States as derivatives of Raven Aerostar's Thunderhead balloon system.[120]

In his research Kehoe describes two different size variants of the systems operating at altitudes of 60,000 and 92,000 feet, noting that they are designed to act as

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[117] "Shadow Tactical Unmanned Aircraft Systems," Textron Systems, accessed March 10, 2022, https://www.textronsystems.com/products/shadow-tactical-unmanned-aircraft-systems.

[118] Thomas Withington, "Small System, Big Difference," *Armada International*, 5 August 2020, https://www.armadainternational.com/2020/08/small-system-big-difference/.

[119] U.S. Army G3/5/7, "71490K100 Extended Range Sensing and Effects Company, Multi-Domain Effects Battalion (MDEB) MDTF TOE Narrative."

[120] Adam Kehoe, "What We Know About the High-Altitude Balloons Recently Lingering Off America's Coastlines," *The War Zone* (blog), *The Drive*, 17 May 2021, https://www.thedrive.com/the-war-zone/40638/what-we-know-about-the-high-tech-balloons-lingering-off-the-coasts-of-the-u-s-recently.

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surveillance and reconnaissance platforms and as communications relays.[121] This matches the TOE doctrinal description, and using a publicly available line of sight calculator for each altitude gives a line of sight of 482 kilometers for the smaller balloon and 597 kilometers for the larger.[122] Based on these figures and the presence of multiple balloon sections, the ERSE also has the capability of deploying a section forward to provide an extended detection envelope.

The final component of the MDEB is the Information Defense Company, which provides incident detection and response functions to protect the MDTF's network Department of Defense Information Network (DODIN) using its defensive cyber operations (DCO) platoon and defensive electronic attack (DEA) platoon and teams.[123] According to the capabilities section of the TOE narrative the former augments cybersecurity capabilities to protect "MDTF networks and mission command capabilities" while the latter are used to provide early warning and active defense against enemy capabilities that use the electromagnetic spectrum such as artillery fuses, rockets and missiles, and unmanned aerial systems.[124] These capabilities are critical to allowing

[121] Kehoe, "What We Know About the High-Altitude Balloons Recently Lingering Off America's Coastlines."

[122] "Line of Sight Calculator," Southwest Antennas, accessed 10 March 2022, https://www.southwestantennas.com/calculator/line-of-sight.

[123] U.S. Army G3/5/7, "71498K100 Information Defense Company, Multi-Domain Effects Battalion (MDEB) MDTF TOE Narrative," effective 1 October 2021, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil

[124] Ibid.

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the MDTF to function in a contested environment and maintain command and control of detachments and subordinate units.

The Strategic Fires Battalion

Describing the strategic fires battalion of the MDTF represents a challenge as the current TOE and the concept for the MDTF are not remotely similar and the latter employs several capabilities and units that are still under development. Currently the TOE for the MDTF is for a High Mobility Artillery Rocket System (HIMARS) battalion with two subordinate HIMARS batteries[125]. The MDTF concept has a single HIMARS battery along with a mid-range capability (MRC) and long-range hypersonic weapon (LRHW) battery. Both versions retain a headquarters battery and a forward support company, while the TOE for the HIMARS battalion provides a functional mission for either unit: "providing medium range rocket and long-range missile fires … to destroy, neutralize, or suppress" enemy forces.[126] For the purpose of this study the MDTF concept will be used with the current doctrinal mission statement, which is versatile enough to allow the strategic fires battalion to be used for multiple roles.

With neither the headquarters nor the forward support company presenting any novel capabilities, the first subordinate unit of interest is the HIMARS battery. The specified capability of this battery is to provide "rocket and missile fires on preplanned targets and targets of opportunity," which is accomplished through the employment of

[125] U.S. Army G3/5/7, "06475K200 Field Artillery Battalion, HIMARS (2x9) TOE Narrative," effective 1 October 2022, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil

[126] Ibid.

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multiple firing sections divided into platoons.[127] According the United States Army Acquisition Support Center each HIMARS launcher can carry a launch pod with six guided rockets or one Army Tactical Missile System (ATACMS), with the guided rockets having a range of more than 70 kilometers.[128] The latest version of the ATACMS, Block 1A unitary, has a range of 300 kilometers and uses a similar warhead to a Harpoon anti-ship missile.[129] Finally, the Army's new Precision Strike Missile (PrSM) is compatible with the HIMARS launcher and contains two rounds per launch pod with a current range of up to 499 kilometers.[130] These options allow the HIMARS battery for the MDTF to be customized for anti-access and area denial missions, and potentially reloaded with increasingly shorter range options as threats approach.

The only existing TOE for a MRC battery does not provide significant information on the capability as most of it is copied directly from the LRHW battery TOE but does indicate that the unit will likely include two firing platoons.[131] Recent

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[127] U.S. Army G3/5/7, "06477K300 Field Artillery Battery, Field Artillery Battalion, HIMARS (2x9) TOE Narrative," effective 1 October 2022, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

[128] "High Mobility Artillery Rocket System (HIMARS) – M142," U.S. Army Acquisition Support Center, accessed 11 March 2022, https://asc.army.mil/web/portfolio-item/ms-himars-m142/.

[129] "MGM-140 Army Tactical Missile System (ATACMS)," CSIS Missile Threat, accessed 11 March 2022, https://missilethreat.csis.org/missile/atacms/.

[130] "Precision Strike Missile (PrSM)," Lockheed Martin, accessed 11 March 2022, https://www.lockheedmartin.com/en-us/products/precision-strike-missile.html.

[131] U.S. Army G3/5/7, "06489K000 Field Artillery Battery, Mid Range Battery, Long Range Fires Battalion (LRFB) TOE Narrative," effective 1 October 2022, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

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reporting on the battery confirms that it will use a combination of land-based SM-6 and Tomahawk missiles with four trailer mounted launchers, implying that each firing platoon would be responsible for two launchers.[132] Each launcher will carry four rounds, providing a total of sixteen missiles for the battery with the ability to reload by replacing an entire missile cell once all rounds have been expended.[133] The exact ranges of these weapons have not been released, but available open source information suggests a range of at least 1,600 kilometers for both the latest variant being developed for the SM-6 and Tomahawk missile.[134] This provides a flexible, extended range anti-access capability that can be used against surface targets including ships.

The final component of the strategic fires battalion is the Long-Range Hypersonic Weapons Battery, which is divided into two firing platoons according to its TOE with a total of eight firing sections that are each responsible for a single launcher.[135] Having been released in 2020 this document may not account for changes in concept, although it

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[132] Stephen Silver, "The Army's New Mid-Range Capability Revealed," *The Buzz* (blog), *The National Interest*, 15 October 2021, https://nationalinterest.org/blog/buzz/army%E2%80%99s-new-mid-range-capability-revealed-195098.

[133] Joseph Trevithick, "The Army Plans to Fire Its Version of the Navy's SM-6 Missile From This Launcher," *The War Zone* (blog), *The Drive*, 13 October 2021, https://www.thedrive.com/the-war-zone/42712/the-army-plans-to-fire-its-version-of-the-navys-sm-6-missile-from-this-launcher.

[134] Sydney J. Freedberg Jr., "Army picks Tomahawk & SM-6 for Mid-Range Missiles," *Breaking Defense*, 06 November 2020, https://breakingdefense.com/2020/11/army-picks-tomahawk-sm-6-for-mid-range-missiles/. Naval Technology, "Tomahawk Long-Range Cruise Missile," 27 August 2020, https://www.naval-technology.com/projects/tomahawk-long-range-cruise-missile/.

[135] U.S. Army G3/5/7, "06487K000 Field Artillery Battery, Long Range Hypersonic Weapons (LRHW) TOE Narrative," effective 1 October 2020, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

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would be logical for LRHWs to be larger than other munitions. A more recent Congressional Research Report describes a battery as containing four launchers that are each able to carry two missiles, with an expected range of 1,725 miles (2,776 kilometers) traveling between 3,800 and 13,000 miles per hour.[136] This could potentially allow the LRHW to strike a target at maximum range with a flight times between eight and twenty-seven minutes, enabling convergence with other systems within the strategic fires battalion from multiple directions.[137] One potential consideration with employment of a LHRW battery is that it would likely have to operate detached from the rest of the MDTF as positioning this capability forward could be viewed as escalatory due to its potential ability to strike at targets deep within an adversary's borders.

The Integrated Air and Missile Defense Battalion

For defensive purposes the MDTF includes an air defense battalion to provide short-range air defense (SHORAD) against hostile targets. The current TOE for the MDTF's air defense battalion outlines an organization with a headquarters battery, three Stryker mounted Maneuver SHORAD batteries, a man portable air defense (MANPADS)

[136] Congressional Research Service (CRS), *The U.S. Army's Long-Range Hypersonic Weapon,* CRS In Focus IF 11991, by Andrew Feickert (Washington DC: Library of Congress, 8 December 2021), 1.

[137] Calculated by the author based on a maximum speed up to 13,000 miles per hour and maximum range of 1,725 miles. 13,000 miles per hour equals 216.6 miles per minute. 1,725 divided by 216.6 results in a figure of 7.964 minutes (rounded). A lower-bound of 3,800 miles per hour provides a speed of 63.3 miles per minute and a flight time of 27.25 minutes. Acceleration and deceleration would likely result in a flight time between these extremes.

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battery, and a specialized maintenance company.[138] Per the unit's TOE the mission and capabilities for this unit are optimized for defense against cruise missiles, unmanned aircraft systems, and low-altitude aircraft, including the use of the Sentinel Air Defense Radar.[139] This is directly counter to the MDTF's mission of providing ballistic missile defense, but still provides a self-defense capability and can provide limited protection over a given area for installations and units.

Briefly examining the systems included, the manufacturer's information sheet for the original version of the Maneuver SHORAD system uses the Stinger and Longbow Hellfire missiles combined with four onboard radars and a 30 millimeter chain-gun to intercept and destroy aerial threats.[140] The Army has recently begun fielding a directed energy capability provided by Northrop Grumman that replaces the missiles on the platform with a high-energy laser to allow for an increased number of engagements.[141] All variants interface with the Sentinel Air Defense Radar, which is capable of detecting targets over 360 degrees at ranges up to 75 kilometers.[142] For an MDTF operating in an

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[138] U.S. Army G3/5/7, "44315K000 ADA BN (M-SHORAD-MANPADS) TOE Narrative," effective 1 October 2020, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

[139] Ibid.

[140] "M-SHORAD Data Sheet," Leonardo DRS, September 2019, https://www.leonardodrs.com/media/13589/m-shorad_datasheet.pdf.

[141] "SHORAD Capabilities," Northrop Grumman, accessed 11 March 2022, https://www.northropgrumman.com/wp-content/uploads/L-0700-Short-Range-Air-Defense-SHORAD-Infographic.pdf.

[142] "Sentinel Aerial Surveillance Radar – AN/MPQ-64," U.S. Army Acquisition Support Center, accessed 11 March 2022, https://asc.army.mil/web/portfolio-item/anmpq-64-sentinel/.

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isolated location this enables a self-defense capability, but the short range of these systems and limited detection range limits the ability of this battalion to an area-denial role rather than presenting a credible anti-access capability.

One potential change to the structure of the MDTF's air defense battalion would be replacing some or all of its Maneuver SHORAD with the Army's Indirect Fire Protection Capability (IFPC) system. This does not change the role of the air defense battalion for the MDTF, however, as the IFPC system is still designed as a short-range capability system for defeating unmanned aircraft systems and cruise missiles.[143]

Another alternative would be assigning or attaching a Patriot missile battery to operate with the MDTF. The new Lower Tier Air and Missile Defense Sensor (LTAMDS) being provided by Raytheon provides 360 degree detection at ranges above 100 kilometers against ballistic missiles, cruise missiles, and fixed-wing aircraft.[144] With a loadout including the Patriot Advanced Capability-2 (PAC-2), this would also enable interception of aircraft at ranges up to 160 kilometers or at the limit of the detection range for the associated radar.[145] This would allow a small anti-access capability for the MDTF while allowing it to meet its stated mission of providing ballistic missile protection. In

[143] "Indirect Fire Protection Capability (IFPC) Increment 2 – Intercept Block 1," U.S. Army Acquisition Support Center, accessed 11 March 2022, https://asc.army.mil/web/portfolio-item/ms-ifpc_inc_2-i/.

[144] "Lower Tier Air and Missile Defense Sensor (LTAMDS)," Missile Defense Advocacy Alliance, 24 July 2020, https://missiledefenseadvocacy.org/defense-systems/lower-tier-air-and-missile-defense-sensor-ltamds/.

[145] "Patriot PAC-2," Military Today, accessed 11 March 2022, http://www.military-today.com/missiles/patriot_pac2.htm.

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order to demonstrate this as a possibility, this study will include a Patriot capability during case studies later in this chapter.

The Brigade Support Battalion and Attached Units

The original concept of the MDTF proposed in 2019 included a Brigade Support Company with a distribution platoon, maintenance control platoon, and field maintenance section to receive, store, and issue fuel, manage maintenance stocks, and provide a minimal level of on-site maintenance.[146] This has since been replaced with a full Brigade Support Battalion, including a headquarters, distribution, field maintenance, and medical company to provide the capability to deploy within a 96 hour window and establish operations in an austere location.[147] The individual elements within the Brigade Support Battalion are similar to other examples of these units, although one noteworthy capability is the presence of a missile/electronics repair section, armament repair section, and I2CEWS field maintenance section in the field maintenance company.[148] This demonstrates that these units have been customized to support the MDTF's other capabilities in an expeditionary role.

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[146] U.S. Army G3/5/7, "63483K000 Brigade Support Company (Multi-Domain Task Force) TOE Narrative," effective 1 October 2022, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

[147] U.S. Army G3/5/7, "63485K000 Brigade Support Battalion (MDTF) TOE Narrative," effective 1 October 2021, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

[148] U.S. Army G3/5/7, "43497K000 Field Maintenance Company, MDTF, BSB TOE Narrative," effective 1 October 2022, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

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The final unit assigned to the MDTF is a Gray Eagle Company directly assigned at the brigade level. The current associated TOE for the MDTF-specific version of this unit does not have a TOE narrative, but examining the TOE for a similar stand-alone Gray Eagle Company suggests that such an organization would include its own flight operations section, ground control and launch/recovery sections, and organic maintenance capability.[149] The base model of the Gray Eagle has a flight endurance of over 27 hours at an altitude of up to 25,000 feet, can be controlled via satellite communications, and can carry up to four Hellfire missiles.[150] This allows the MDTF the potential for an unmanned deep-strike capability, but given the amount of firepower resident within the MDTF's strategic fires battalion a more productive use would be locating and providing targeting data for those weapons systems.

According to the manufacturer the next generation of the Gray Eagle intended for Multi-Domain operation provides an extended endurance of up to 42 hours operating at 29,000 feet with a larger payload while retaining the capacity to carry Hellfire missiles.[151] This increases the detection footprint of the Gray Eagle, which Armada International calculates at up to 387 kilometers using a larger version of the Multi-

[149] U.S. Army G3/5/7, "01707K000 Gray Eagle UAS Company (MQ-1C) (SEP) TOE Narrative," effective 1 October 2020, FMSWeb, accessed 25 February 2022, fmsweb.fms.army.mil.

[150] "MQ-1C Gray Eagle Unmanned Aircraft System (UAS)," U.S. Army Acquisition Support Center, accessed 13 March 2022, https://asc.army.mil/web/portfolio-item/aviation_gray-eagle-uas/.

[151] "Gray Eagle Extended Range (GE-ER)," General Atomics Aeronautical, accessed 13 March 2022, https://www.ga-asi.com/remotely-piloted-aircraft/gray-eagle-extended-range.

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Function Electronic Warfare capability available to the Shadow UAS platoon discussed earlier.[152] Regardless of which version of the Gray Eagle that the MDTF uses, either platform provides the capability of providing target information out to the limits of the MDTF's MRC battery.

Operating in the Indo-Pacific one useful quality that the Gray Eagle does not currently possess is an anti-submarine capability. This capability is theoretically possible as the Navy has currently fielded a variant of the MQ-9 Reaper that can conduct submarine tracking and detection using a network of sonobuoys dropped by the UAS.[153] Although the MQ-9 Reaper is a significantly larger platform that the Gray Eagle and has a correspondingly higher carrying capacity, a similar system could potentially be developed or modified for use in an MDTF. This would increase the MDTF's ability to conduct intelligence and surveillance operations in the maritime domain and provide early warning for friendly forces.

Doctrinal Requirements and Capabilities Summary

To summarize the overall capabilities based on this analysis, the MDTF's Multi-Domain Effects Battalion provides the ability to locate targets using a variety of methods, conduct defensive cyber operations, receive and process intelligence support, manage space capabilities, and conduct dispersed operations while maintaining communications

[152] Withington, "Small System, Big Difference."

[153] General Atomics Aeronautical Systems, "Versatile Multi-Domain MQ-9B SeaGuardian Has Revolutionized Anti-Submarine Warfare," *Breaking Defense,* 5 April 2022, https://breakingdefense.com/2022/04/versatile-multi-domain-mq-9b-seaguardian-has-revolutionized-anti-submarine-warfare/.

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in a contested environment. It has an organic electronic warfare capability and the ability to locate targets at ranges of at least 400 kilometers using organic UAS, and the potential to detect targets up to almost 600 kilometers using high-altitude balloons.

The MDTF's Strategic Fires Battalion is intended to include a HIMARS battery, a Mid-Range Capability (MRC) battery, and a Long-Range Hypersonic Weapon (LRHW) Battery. The HIMARS battery has three possible weapons systems with maximum ranges of 70 to 499 kilometers, while the MRC battery uses a combination of land-based cruise missiles and ballistic missiles with a range of up to 1,600 kilometers. The LRHW Battery can provide fires at ranges up to nearly 2,800 kilometers with rounds arriving within minutes of being fired. These capabilities are supported by the MDTF's Gray Eagle Company, which can provide targeting information using over the horizon and satellite-based communications.

Finally, the MDTF is intended to include a short-range air defense capability that is optimized to protect the unit from hostile aircraft, unmanned aerial systems, and cruise missiles. The current TOE for this unit is based on a Maneuver Short Range Air Defense battalion but changing to an Integrated Force Protection Capability does not significantly alter this capability. The MDTF cannot provide ballistic missile defense or extended-range defense against aircraft but could do so if assigned or allocated a Patriot missile battery during operations. These assets can also be used to protect other critical locations and systems in addition to protecting the MDTF, with an accompanying risk of reducing their effectiveness due to reduced depth and mass.

While the MDTF is a very capable unit, it also possesses some operational shortcomings that must be considered when deploying it alone or as part of a group. The

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first of these is that it is a relatively small unit with limited capability for self-defense against ground assaults. This is mitigated by deployment to islands in the Indo-Pacific and the ability to interdict incoming forces before they can make landfall. The second major shortcoming is that requires a constant supply of fuel and munitions to conduct operations due to the power requirements of radars, UAS, and sensors. This can be mitigated by pre-positioning bulk fuel and logistical planning but could be a factor in extended operations. Third, the MDTF has a relatively small magazine depth of only 18 Precision Strike Missiles, 16 rounds in the Mid-Range Capability battery, and 8 rounds for the Long Range Hypersonic Weapon battery. This limits the number of targets it can strike before conducting reload operations and requires a substantial ammunition storage facility for extended operations.

It is also important to consider the fact that some of these capabilities are currently in development or in limited rate production. The Army's first Long Range Hypersonic Weapon battery is not expected to reach initial operating capability until fiscal year 2023.[154] The Precision Strike Missile is currently in production, with the Fiscal Year 2022 Army Budget requesting production of 110 rounds for the first year.[155] According to Major General Ken Kamper's speech at the Maneuver Warfighter Conference on 7 March 2022, the next upgrade to the Precision Strike Missile to allow it

[154] Burroughs, "Dark Eagle is on the Move."

[155] Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer, *Program Acquisition Costs by Weapon System,* U.S. Department of Defense Fiscal Year 2022 Budget Request (Washington, DC: Department of Defense, May 2021), 5-15.

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to target moving emitters such as ships is not expected to be complete until 2025.[156] Keeping the current status of these capabilities in mind and planning for future operations, the next step is to examine them with an operational framework.

Capabilities, Gaps, and Applications

Tactical Mission Tasks

Although not an exhaustive list, the Army's list of tactical mission tasks provides a framework that assists in describing the desired action that a force will take and the intended effect that action will have on an enemy. Examining this list considering the established capabilities of the MDTF provides the foundation to conceptualize how the MDTF can be used in operations supporting the joint force. In addition to the table below, tactical shaping tasks including reconnaissance and security operations can also provide clarity on the potential for multiple roles for the MDTF.

[156] Ken Kamper, "Fires Modernization," (Speech, Maneuver Warfighter Conference, Fort Benning, GA, 7 March 2022), https://www.youtube.com/watch?v=RuZxEbWV7s8.

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Actions by friendly forces	*Effects on enemy forces*
Attack by fire	Block
Breach	Canalize
Bypass	Contain
Clear	Defeat
Control	Destroy
Counterreconnaisance	Disrupt
Disengagement	Fix
Exfiltrate	Isolate
Follow and assume	Neutralize
Follow and support	Suppress
Occupy	Turn
Retain	
Secure	
Seize	
Support by fire	

Figure 6. Tactical Mission Tasks

Source: Headquarters, Department of the Army, Field Manual 3-90-1, Change 2, *Offense and Defense,* vol. 1 (Washington, DC: Army Publishing Directorate, March 2013), B-1.

The basic task of the MDTF can be viewed as a combination of attack by fire in support of a larger breaching operation, acting as part of the means to break through an enemy defense for follow-on forces to maneuver as part of Multi-Domain Operations. A number of tasks in the figure above require a degree of movement and direct fires that the MDTF is not constructed to provide, including bypass, clear, disengage, exfiltrate, follow and assume, follow and support, and seize. This leaves seven additional tasks where the capabilities of the MDTF are open to interpretation.

The first of these, control, is defined as "maintaining physical influence over a specific area to prevent its use by the enemy or create conditions necessary for successful friendly operations" by either occupying the area or being able to engage enemy forces

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within the area.[157] In the conventional sense this is usually conducted by ground forces, but given its ability to engage surface targets at extended range using a variety of weapons the MDTF could perform this activity in a maritime environment. The effectiveness of control that the MDTF can provide increases as the volume to be controlled shrinks, allowing the MDTF to apply more weapon systems within the area. This is closely linked to the task of counterreconnaisance, which "encompasses all measures to counter enemy reconnaissance and surveillance efforts" as a fundamental part of security operations.[158] By preventing enemy use of an area the MDTF also prevents enemy forces from effectively locating friendly assets moving through the area.

A similar relationship exists between the tasks of occupy, retain, and secure. Occupy involves "moving a friendly force into an area so that it can control that area" without being opposed by an enemy and is different from control because it requires physical presence at a location.[159] Retain focuses on keeping "a terrain feature controlled by friendly forces from enemy occupation or use" but does not require the unit to occupy the area. Secure requires keeping an enemy from damaging or destroying a unit or location and can also be done without occupying the terrain to be secured as long as the force can keep the enemy from affecting it.[160] The MDTF can occupy terrain to a limited

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[157] Headquarters, Department of the Army (HQDA), Field Manual (FM) 3-90-1, Change 2, *Offense and Defense,* vol. 1 (Washington, DC: Army Publishing Directorate, March 2013), B-5.

[158] Ibid.

[159] Ibid., Ch 2, B-9.

[160] Ibid.

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extent and may be able to retain a location using its long-ranged fires by preventing enemy forces from moving onto a location. The extensive range of the MDTF's capabilities and electronic warfare capabilities may also enable it to secure a location by keeping enemy forces outside of direct or even indirect fire range, but this is limited to air and surface forces within a given radius and does not apply to long-range ballistic missile attacks.

The final two tasks are subject to debate. Reduce is a "the destruction of an encircled or bypassed enemy force,"[161] while support by fire is when a unit "moves to a position where it can engage the enemy by direct fire in support of another maneuvering force" to fix, suppress, or destroy the enemy if they attempt to move.[162] Theoretically an MDTF could be used as the primary instrument to destroy an enemy force using massed fires, but this would likely require a prodigious expenditure of ammunition to accomplish a task that could likely be easily managed by a less specialized capability. The specification of direct fire as the means of accomplishing support by fire makes the MDTF unsuited to the task, although the MDTF could potentially produce the desired effect of suppressing, fixing, or destroying an enemy force trying to reposition.

The second half of the figure at the beginning of this section addresses effects on the enemy, which provides additional utility for discussing employing the MDTF. Effects based language is more general and allows for a freer rein in analysis, with only two of the listed effects appearing immediately unsuited to the capabilities of the MDTF.

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[161] HQDA, FM 3-90-1, B-9.

[162] HQDA, FM 3-90-1, B-10.

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Contain and fix are both tasks that involve controlling the movement enemy forces, with the former requiring a capability to "stop, hold, or surround enemy forces"[163] while the latter requires preventing an enemy "from moving any part of their force from a specific location."[164] Both of these tasks are extremely difficult to accomplish with long-ranged fires and electronic warfare assets, as they typically involve some form of direct contact to control enemy movement.

Other movement controlling tasks are more clearly within the capabilities of the MDTF, especially when operating in a maritime environment. Block and canalize are two examples based on imposing an unacceptable cost for proceeding on an avenue of approach or restricting enemy movement to a confined area using fires or maneuver.[165] Both of these effects can be accomplished by using progressively heavier fires to attrit an enemy force or to force an enemy to stay outside of engagement range and thus limiting their number of available routes. This is closely related to turn, which "involves forcing an enemy element from one avenue of approach or mobility corridor to another."[166] In a maritime dominated environment the MDTF can accomplish this task by using fires to engage an enemy when they attempt to use an undesired avenue of approach and thus force them into using a slower or more dangerous route.

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[163] HQDA, FM 3-90-1, Ch 2, B-11

[164] Ibid., B-13.

[165] Ibid., B-11.

[166] Ibid., B-15.

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Other effects that the MDTF can accomplish are based on their impact on enemy operations. Disrupt involves efforts that "upset an enemy's formation or tempo, [or] interrupt the enemy's timetable"[167] while interdict "prevents, disrupts, or delays the enemy's use of an area or route."[168] Neutralize and suppress prevent an enemy from interfering with friendly activities or accomplishing their own mission and can both be accomplished through lethal and non-lethal effects such as electronic warfare.[169] The ability to detect targets at long ranges and place accurate fires as well as the capability to generate electronic attack within the multi-domain effects battalion make the MDTF uniquely well-suited for generating these effects and degrading or shaping enemy operations.

The final category of effects to consider in relation to the MDTF are effects directly targeted at enemy forces. Defeat includes rendering an enemy unable or unwilling to fight through force or threats of force[170] while destroy "physically renders an enemy force combat ineffective."[171] Isolate requires preventing an enemy from receiving support, denying their ability to move, and preventing them from contacting other forces.[172] The first two are within the MDTF's range of capabilities depending on the

[167] HQDA, FM 3-90-1, Ch 2, B-12.

[168] Ibid., B-13.

[169] Ibid., B-13.

[170] Ibid., B-14.

[171] Ibid., B-11 – B-12.

[172] Ibid., B-14.

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amount of firepower applied, with the task of rendering a naval combat system ineffective particularly well-suited to the MDFT's Mid-Range Capability. Isolation is also theoretically possible since electronic warfare capabilities can be used to prevent contact while fires can target incoming support and deny freedom of movement.

Turning to reconnaissance and security, reconnaissance squadrons and air cavalry forces are doctrinally described as capable of conducting route, zone, or area reconnaissance.[173] The reconnaissance and detection capabilities of the MDTF suggest that it can also conduct these activities, although this is a situational capability as other forces might be better suited to these roles. When operating independently ahead of friendly forces, however, the MDTF could provide initial reconnaissance before other assets are able to arrive.

Combining the tasks and effects that the MDTF can generate also indicates that it could conduct security operations, particularly a screen or advance guard. The doctrinal definition of a screen includes providing early warning while a guard fights to protect the main body, gathers information, and prevents enemies from observing or firing on friendly forces.[174] The advanced reconnaissance and electronic warfare capabilities of the MDTF enable it to provide early warning in a maritime environment while its fires can slow enemy movement to gain time and be used to keep enemy forces out of firing range of other forces as they move through the area it controls.

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[173] Headquarters, Department of the Army (HQDA), Field Manual (FM) 3-90-2, *Reconnaissance, Security, and Tactical Enabling Tasks,* vol. 2 (Washington, DC: Army Publishing Directorate, March 2013), 1-6.

[174] Ibid., 2-1.

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The Range of Military Operations

Armed with the list of potential tasks and effects that the MDTF can employ, the next step is to integrate those within the range of military operations. Most defense professionals are familiar with this construct as depicted below showing notional operations across the conflict continuum. The MDTF and its capabilities, tasks, and the effects that it can generate have a role across the entirety of the conflict continuum.



Figure 7. The Range of Military Operations

Source: Office of the Chairman of the Joint Chiefs of Staff, Joint Publication 3-0, Change 1, *Joint Operations* (Washington, DC: The Joint Chiefs of Staff, October 2018), V-4.

The Department of Defense defines military engagement as "routine contact and interaction" between the United States military and the armed forces and civil authorities of another nation, while security cooperation specifically applies to interactions with foreign defense establishments for purposes such as developing their military capabilities and establishing access.[175] The MDTF has no special capabilities that apply to these

[175] CJCS, JP 3-0, Ch 1, VI-3.

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aspects of the conflict continuum, although it can conduct security cooperation through joint training or exercises and needs established access in order to be effective in situations higher up the continuum. Other units such as Security Force Assistance Brigades or Special Operations Forces are better suited to security cooperation efforts aimed at building capacity, while the MDTF provides a greater deterrent capability.

JP 3-0 describes deterrence as "preventing adversary action through the presentation of a credible threat of unacceptable counteraction" and notes that forces that cannot conduct decisive operations should be prepared to defend themselves while waiting for support.[176] The MDTF's long-range capabilities and ability to locate targets present a credible threat to surface forces attempting to interfere in an area where the MDTF is deployed, either through attacks on facilities or on forces attempting to conduct unwelcome operations. Within joint doctrine these activities can be conceived as a type of show of force or protection of shipping operation. The MDTF's ability to disrupt and interdict forces moving into an area suggest that it would also be able to fulfill the requirement of conducting defensive operations while additional forces move into the region and protect those forces while they are in-route.

The capacity to deter hostile forces is also relevant in crisis response and limited contingency operations further up the conflict continuum. Joint doctrine describes initial response to these situations as deterring aggression and signaling commitment while taking economy of force into consideration.[177] As a relatively small force with an

[176] CJCS, JP 3-0, Ch 1, VI-4.

[177] Ibid., VII-1 – VII-2.

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outsized impact due to the amount of firepower it includes and variety of IC2EWS effects it can generate, the MDTF has considerable potential as an initial response force. This is also supported by its expeditionary capability and ability to quickly establish itself in an austere environment.

Typical examples of contingency and crisis operations include noncombatant evacuation operations, peace operations, foreign humanitarian assistance, recovery operations, strikes, and raids.[178] The MDTF is generally ill-suited for most evacuation, peace, and humanitarian operations, although its signal detection and surveillance activities could prove useful during personnel recovery operations in concert with other forces. The MDTF's long-range fires are ideal for locating targets and launching strikes from a distance, but as a raid requires seizing an area the MDTF would have to operate in a supporting role for such a mission.

At the highest levels of the conflict continuum in large-scale combat operations the MDTF would fulfill its primary function once conflict begins, but there are several relevant areas in setting conditions for theater operations where the MDTF can also play an expanded early role. Joint doctrine for large-scale combat operations stresses the importance of maintaining operational access, isolating the enemy, executing flexible deterrent options (FDOs) or flexible response operations (FROs), control of littoral areas, and the difference between opposed and unopposed deployment operations. [179] Unopposed deployment operations are considered preferable as they provide a more

[178] CJCS, JP 3-0, Ch 1, VII-2 – VII-4.

[179] Ibid., VIII-5 – VIII-12.

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flexible environment, while opposed deployment operations take place in the context of having to deal with enemy A2/AD establishments.[180]

The intended role for the MDTF is in conducting an opposed deployment but based on the capabilities outlined previously early deployment of an MDTF can enable it to contribute to other aspects of setting the theater. This is particularly true in a maritime environment, where an MDTF deployed on key terrain could control enemy access to a space to maintain operational access for friendly forces by controlling littoral areas using shore-based fires. Taking the initiative by deploying the MDTF in this role can turn a potentially opposed entry into an unopposed entry. The MDTF can also be used to isolate potentially hostile forces based on an island by interdicting support using long-range fires or use its electronic warfare capabilities to suppress communication capabilities. Previous discussion on the MDTF as a deterrent show that it can serve as part of a flexible deterrent option with the added capability of acting as a flexible response on command.

Key Terrain and Case Studies

Before launching into individual cases where the MDTF might be utilized in the Indo-Pacific to illustrate its capabilities and the tasks it can conduct overlaid on terrain it is important to set the parameters for the illustrations below. The extreme range of the Long-Range Hypersonic Weapons battery means that in the roles the MDTF will fill in the scenarios below it cannot be collocated with the rest of the unit. There are potentially friendly locations where it can be placed with the ability to range targets within the rest of the MDTF's area of influence for each scenario below. While operational considerations

[180] CJCS, JP 3-0, Ch 1, VIII-12.

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would dictate the actual positioning of this unit during an operation, example locations can be found in the illustrations section at the end of this thesis.

All scenarios included below depict the range of the Mid-Range Capability battery, the maximum range of the HIMARS battery, and the range of a PAC-2 missile depicted as red range rings. The latter is included for illustration purposes even though the MDTF does not have an organic capability to conduct long-range air defense operations. Blue rings illustrate the maximum detection range of the Shadow UAS and the maximum calculated detection range of the high-altitude balloon capability from the Multi-Domain Effects Battalion. The detection range of the Gray Eagle is not included on these diagrams as the system's range, endurance, and over-the-horizon communications capability allow it to range to the full extent of the Mid-Range Capability battery. Selection of a surveillance area would be mission-dependent and focus on surveillance of key avenues of approach detailed in the scenario.

The Senkaku Islands, Taiwan, and Ishigaki

Located west of Okinawa, the Senkaku islands have long been an area of contention between China and Japan as discussed in Chapter Two. The islands are uninhabited but are located near shipping routes, surrounded by fish, and may have reserves of oil and gas.[181] The remote location of the islands has resulted in confrontations over the disputed territory historically involving naval confrontations or air incursions. One of the largest nearby islands that could potentially host a MDTF in the

[181] Center for Preventive Action, "Tensions in the East China Sea," Global Conflict Tracker, Council on Foreign Relations, accessed 15 March 2022, https://www.cfr.org/global-conflict-tracker/conflict/tensions-east-china-sea.

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event that the United States intended to deter activity in the area of deploy forces in a crisis is Ishigaki island, located east of Taiwan. The figure below depicts the range of MDTF weapon and surveillance systems if deployed to Ishigaki.

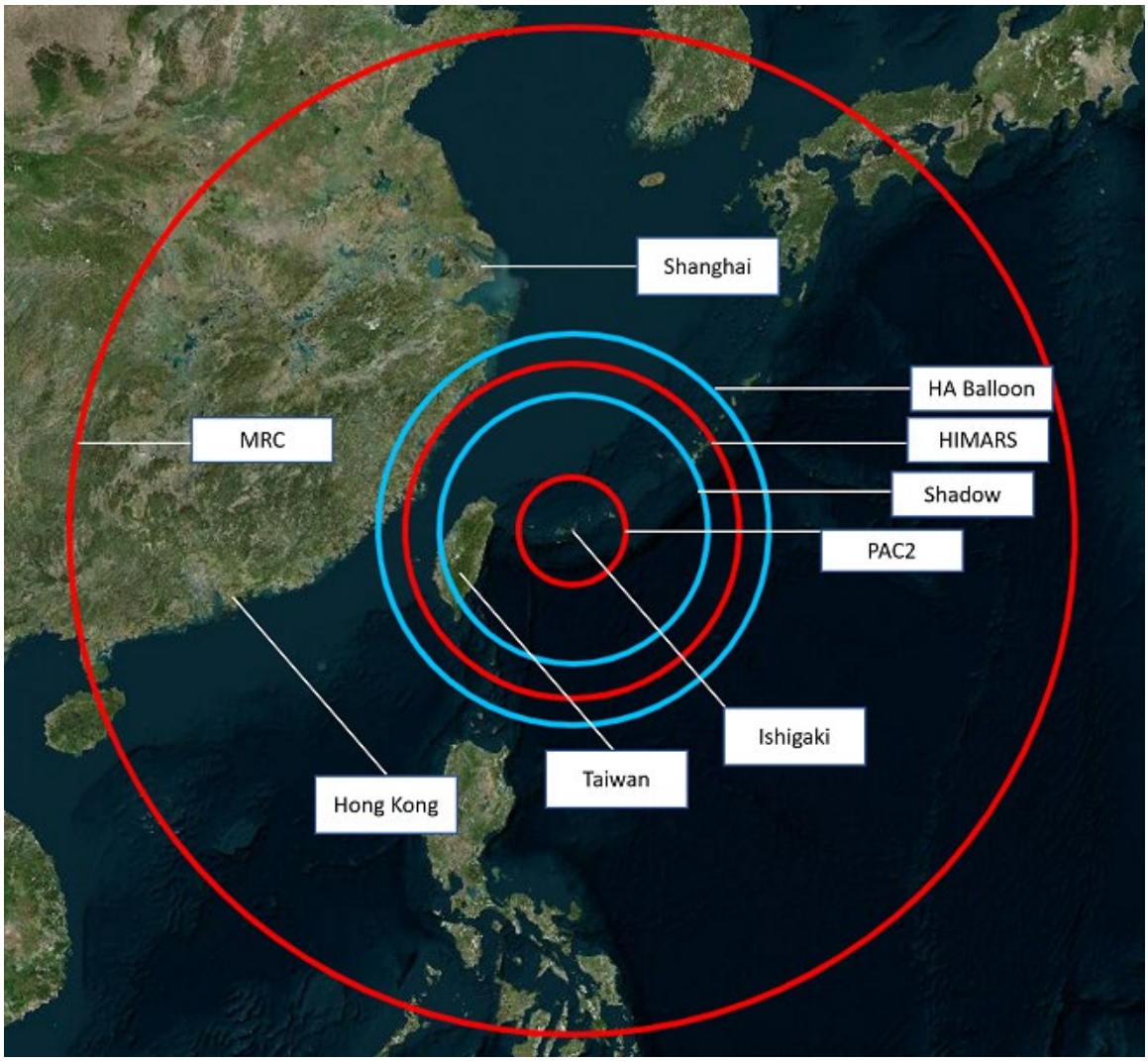


Figure 8. The MDTF on Ishigaki

Source: Created by author using map from DigitalGlobe, "Maxar, Global Enhanced GEOINT Delivery," accessed 15 March 2022, G-EGD Login (digitalglobe.com).

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From this location the MDTF can use its surveillance and detection capabilities to cover the entirety of the disputed region as well as being able to identify and track aircraft and ships departing China's coast adjacent to the Senkaku Islands. The MDTF's Mid-Range Capability battery can provide anti-access capabilities against ships transiting through the South China Sea using the Gray Eagle's surveillance capability. Using the HIMARS to its maximum range also allows the MDTF to conduct area denial operations to deny freedom of movement past the coastline of China and to the south once potential targets pass between Taiwan and the Philippines.

Based on the tasks that the MDTF has been identified as being capable of conducting, this placement allows it to control the region surrounding Ishigaki and retain the Senkaku islands by disrupting naval forces enroute to that location. Deployed as a deterrent, the range of its weapon systems allow it to transition to a response posture and conduct attacks on key port facilities in the region or interdict forces moving into the region. Because the MDTF can control the area between Taiwan and Okinawa from its location on Ishigaki, this also allows it to provide security for naval forces moving south from ports in Japan. This has the potential to allow allied naval forces to proceed much closer to the Chinese coast without coming under direct attack from hostile ships operating in the East China Sea.

In addition to the ability to act in response to a dispute in the Senkaku islands, positioning the MDTF on Ishigaki also places the entirety of Taiwan and most of the Taiwan Strait within the MDTF's area of influence. Although the United States has followed a strategy of deliberate ambiguity on the question of whether it would intervene in the event of a conflict over possession of Taiwan, in such an event an MDTF located

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on Ishigaki could use forward surveillance assets to disrupt or interdict an attack on Taiwan. As a result, the presence of an MDTF on Ishigaki during the leadup to a possible conflict could serve as a formidable deterrent. If the United States were unwilling to intervene directly, the surveillance capabilities of the MDTF could still be used to provide intelligence to Taiwan or to other partners within the region.

Palawan, the Spratlys, and the South China Sea

Another hotly disputed region in the Indo-Pacific is the South China Sea, with almost all surrounding nations submitting competing claims for islands, shoals, and the natural resources surrounding them in the shallow waters of the region. This has been of particular concern with the Spratly Islands, which lie within a disputed area between the Philippines and China, and the Paracel Islands which China has increasingly used as a base of operations. Historically close ties and a mutual defense treaty with the Philippines raise the possibility that the United States could become involved if the dispute escalates.[182] As discussed in Chapter Two of this thesis, in such an event the island of Palawan southwest of Luzon could serve as an important strategic location for deployment of an MDTF as depicted in the figure below.

[182] Center for Preventive Action, "Territorial Disputes in the South China Sea," Global Conflict Tracker, Council on Foreign Relations, accessed 15 March 2022, https://www.cfr.org/global-conflict-tracker/conflict/territorial-disputes-south-china-sea.

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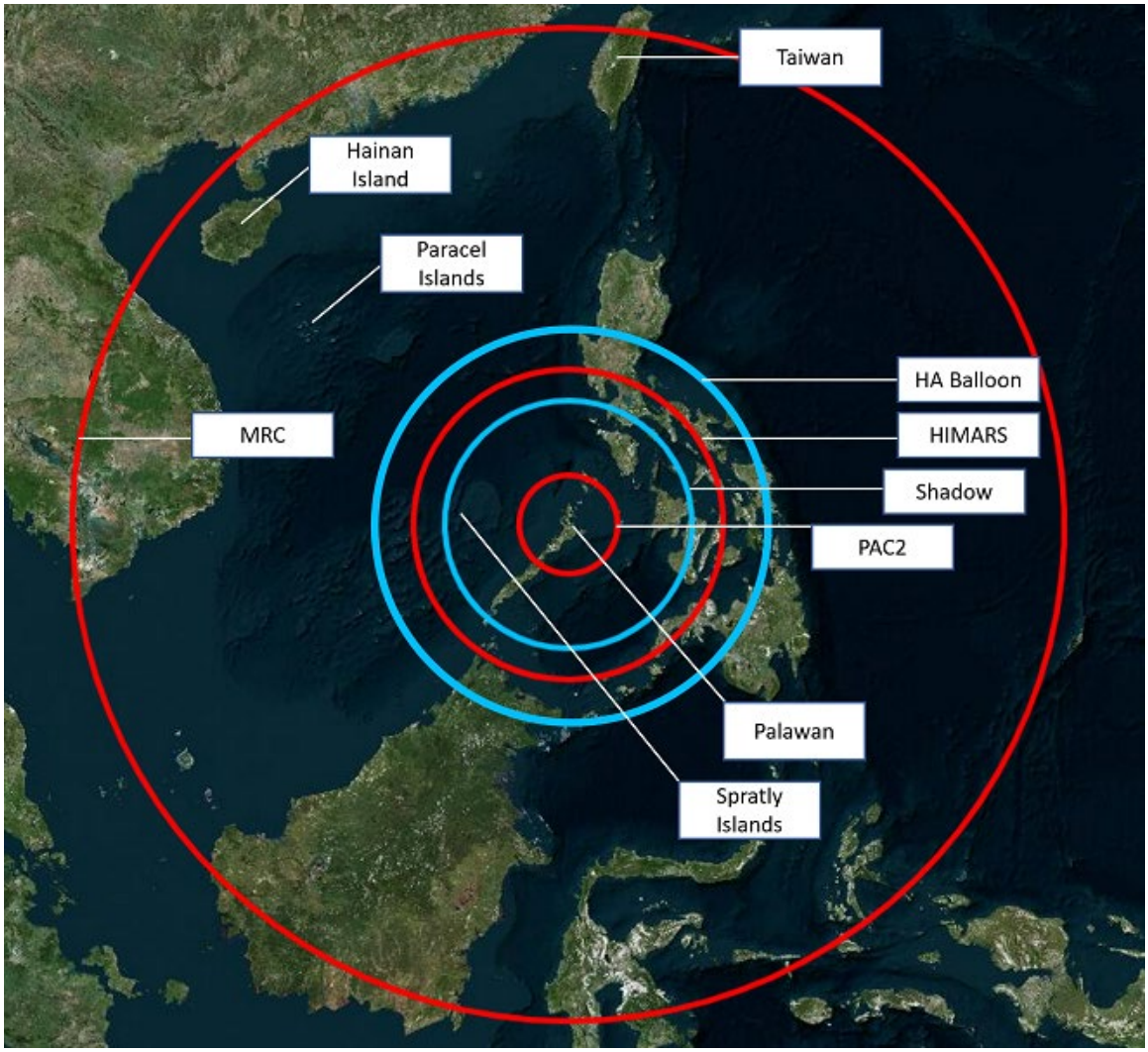


Figure 9. The MDTF on Palawan

Source: Created by author using map from DigitalGlobe, "Maxar, Global Enhanced GEOINT Delivery," accessed 15 March 2022, G-EGD Login (digitalglobe.com).

From a position on northern Palawan, the MDTF has the ability to detect and target forces moving throughout the majority of the Spratly Islands. The bulk of the islands are within range of the MDTF's HIMARS fires, enabling area denial activities to restrict enemy movement in the waters around the islands. The Mid-Range Capability battery can deny access from the south and around both sides of Taiwan to the north. It

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can also range the Paracel Islands to the northwest and reach ports on the coast of China. The number of potential avenues of approach and potential targets has the potential to stretch the MDTF's Gray Eagle company to its limits, requiring careful selection of surveillance locations to enable continuous operations.

From a task-based perspective, the MDTF has multiple potential roles to play from this location. Its proximity to the Spratly Islands enables it to control the space around them, as well as being able to secure Palawan and the nearby islands by preventing enemy forces from approaching within firing range. The MDTF also has the capability to interdict movements into the South China Sea from either direction or disrupt operations originating from the Paracels or the coast to the north. This enables it to potentially isolate forward bases such as Woody Island in the Paracels through long-range fires and electronic warfare. Finally, the MDTF's control of the southeastern approach through the Philippines protects an avenue of approach for U.S. and allied forces as well as a protected location to stage for follow-on operations.

The Malacca Strait

The previous two examples have focused on the MDTF's potential roles in controlling access and movement within a designated area. The final example examines the capability of the MDTF to interdict movement through a key waterway: the Malacca Strait. As the most direct route between the Indian Ocean and the South China Sea the Malacca Strait is one of the busiest waterways in the world while at the same time being extremely narrow and shallow throughout most of its length.

This makes it particularly susceptible to land or sea-based control, with the long-range fires of the MDTF allowing it to subject incoming forces to an increasing volume

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of fire as they continue onward. This can serve to either block enemy forces or turn them and force them into a more distant passage, substantially delaying China's ability to mass forces by moving ships from the Indian Ocean to the South China Sea and vice-versa. The geography of the Malacca Strait allows for several options to deny passage, with the first depicted in the figure below.

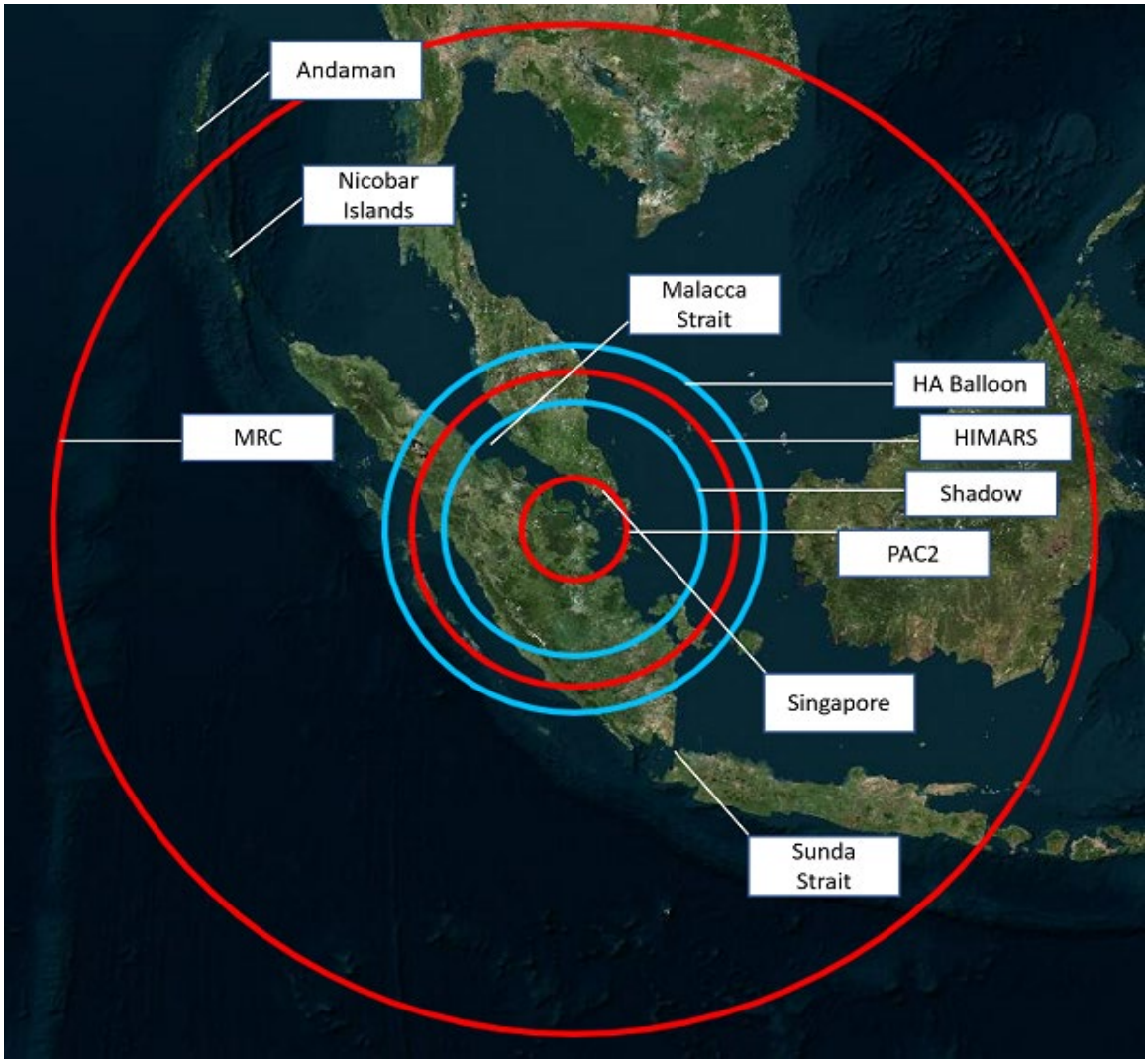


Figure 10. The MDTF in the Malacca Strait

Source: Created by author using map from DigitalGlobe, "Maxar, Global Enhanced GEOINT Delivery," accessed 15 March 2022, G-EGD Login (digitalglobe.com).

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In this example the MDTF is positioned in Sumatra, although the confined terrain within the Malacca Strait would allow a similar effect operating from Malaysia or Singapore. This increases the flexibility of this option by allowing for multiple deployment locations dependent on the currents of international relations. Regardless of the location used, this position provides superior area denial within the Strait while retaining the ability to deny access from either direction through the South China Sea or the Indian Ocean. In addition to denying access to the Malacca Strait, an MDTF positioned near this location can also deny access to the Sunda Strait between Java and Sumatra. This compounds the delay created by denying access to the Malacca Strait, effectively preventing China from combining its naval forces across the region in response to a crisis on either side of the Strait and enabling the U.S. and allied forces to obtain local superiority.

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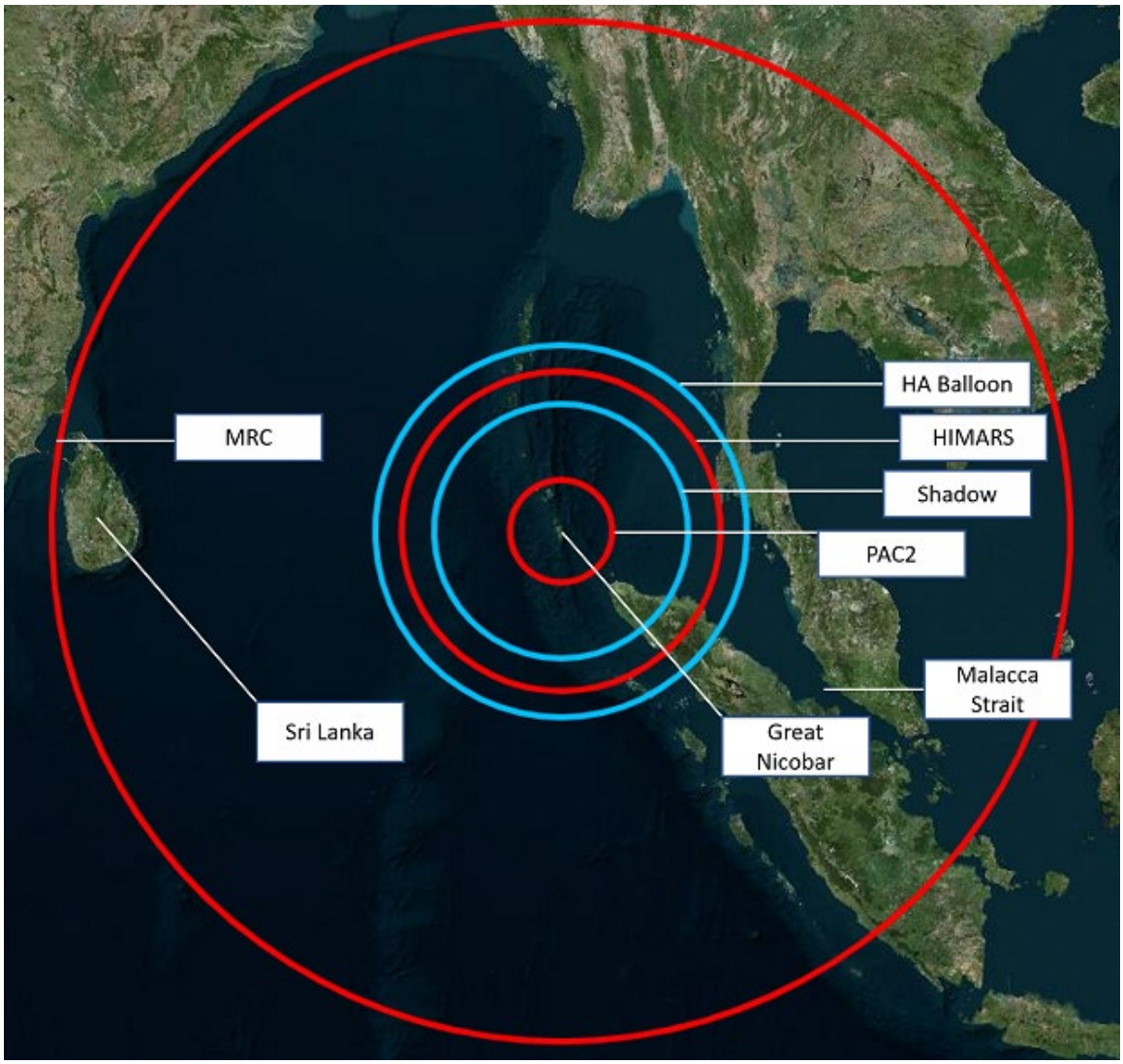


Figure 11. The MDTF on Nicobar

Source: Created by author using map from DigitalGlobe, "Maxar, Global Enhanced GEOINT Delivery," accessed 15 March 2022, G-EGD Login (digitalglobe.com).

The second alternative depicted in the figure above places the MDTF on Great Nicobar Island. This extends the anti-access capability to the east at the expense of losing the ability to block routes through the South China Sea and Sunda Strait. It retains the ability to deny access throughout the Malacca Strait while providing increased area denial

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capability at the mouth of the Strait to strengthen the ability to turn naval forces and drive them to another route. By limiting the number of avenues of approach that the MDTF must cover this positioning also conserves reconnaissance and surveillance assets, increasing their endurance. In this case the duration of the delay imposed by controlling the Malacca Strait from this end is reduced in exchange for a greater probability of success. This deployment is more suited for an attempt to delay Chinese forces in the Indian Ocean from reaching the South China Sea than the reverse, which may be a more effective response based on the level of emphasis placed on the respective regions.

This chapter has analyzed the MDTF based on the requirement documents establishing the capabilities defined for each subordinate element by using open-source information to define the exact ranges and roles of each significant section. After defining the MDTF based on its capabilities the analysis proceeded to put these capabilities against the Army's menu of tasks and effects to show how the MDTF can support the joint force beyond its intended role in penetrating A2/AD spaces. Finally, by templating the MDTF against terrain in the Indo-Pacific this chapter demonstrates how the MDTF can be used in a variety of situations to provide examples of situations where the MDTF could fulfill these new roles. In the concluding chapter, this study will summarize the conclusions from this research and provide recommendations to the force and areas for further study.

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CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusion: How the MDTF Can Contribute to the Joint Force

To frame the conclusion of this study, the most efficient method is to return to the secondary and primary research questions established in the first chapter beginning with the secondary questions and concluding with the primary question. The first secondary research question asked what the planned future capabilities of the MDTF are based on its design structure. The second secondary research question asks what tasks the MDTF can accomplish outside of its existing doctrinal mission as an A2/AD piercing formation based on those capabilities. The third secondary research question asks how the MDTF's capabilities and the tasks it can perform can be used to shape the operational and strategic environment in the Indo-Pacific. This ties directly into the primary research question, which asks how the MDTF can contribute to the Joint Force in the Indo-Pacific beyond penetrating A2/AD spaces.

Beginning with the first secondary research question, based on the analysis in Chapter Four the MDTF's planned capabilities include the ability to deploy and operate in an austere environment and operate dispersed in at least three locations. The MDTF's organic components provide the capability to detect targets at ranges up to approximately 600 kilometers using signal and electronic intelligence, as well as two types of UAS that can operate on a line-of-sight basis with a detection capability of over 400 kilometers and an over the horizon capability that is only limited by the endurance of the UAS platform. These UAS have a detection footprint of 279 kilometers and 387 kilometers from the

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location of the platform itself, allowing the two types of UAS to cover more than 240,000 and 470,000 square kilometers of surface area for each operating platform.

The MDTF is also equipped to maintain satellite and network communications in a contested operational environment and to answer with its own electronic warfare capability. The layered fires capabilities within the MDTF allow it to engage targets simultaneously with three weapons systems at ranges of up to 500 kilometers, two weapons systems out to 1600 kilometers, and up to 2750 kilometers with its Long Range Hypersonic Weapon battery. It does not possess an organic capability to defend against ballistic missiles but has a self-defense capability against Class 1 or 2 UAS, low-flying aircraft, and cruise missiles and can use these assets to protect other forces or locations. This capability is augmented by a defensive electronic attack capability to interfere with enemy UAVs and guided munitions.

Turning to the second secondary research question, the MDTF's capabilities as documented above enable it to control a maritime area and prevent its use by an enemy. This is referred to in other service doctrinal literature as sea denial. It can also perform counterreconnaisance activities in these areas against enemy ships and some types of aircraft. The MDTF has an extremely limited ability to occupy terrain but has a greater ability to meet the doctrinal requirements of retaining or securing terrain by preventing enemies from occupying them or being able to effectively attack them through a combination of long-range fires and defensive capabilities. These long-range fires also allow it to block, canalize, or turn enemy forces from key lines of advance in a maritime environment through an increasing density of fire as enemy ships move closer to the MDTF.

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These tasks are accomplished by using the MDTF's fires to disrupt or interdict enemy forces while they are moving, and the MDTF has a limited ability to neutralize or suppress enemy fires and other tactical activities. The MDTF can defeat or destroy small ground forces or larger naval forces and has the capability of isolating enemy forces using a combination of electronic warfare and fires to prevent reinforcement or resupply of enemy forces that are forward of or isolated from the main body. This is particularly true in the maritime environment of the Indo-Pacific, where enemy forces may be operating on small islands. Finally, the MDTF's surveillance capabilities allow it to conduct initial reconnaissance of the area where it is deployed and to conduct limited security operations such as a screen or an advance guard by providing early warning of enemy forces or using long range fires to prevent enemy forces from approaching to within range of friendly forces.

For the third secondary research question, the MDTF can shape the operational and strategic environment in the Indo-Pacific by deploying to key terrain in the region where it can control key seaways and littoral areas. This enables the MDTF to provide security for U.S. and partner naval forces as they enter the region and provide intelligence to those forces as they move into positions. In the event that conflict breaks out during this process the MDTF can strike targets within its area of influence in order to delay, disrupt, or possibly defeat enemy attempts to prevent friendly forces from moving into theater. This can be viewed as an extension of the MDTF's doctrinal mission to defeat enemy A2/AD efforts carried out by establishing its own A2/AD space and establishing local fire superiority ahead of friendly forces.

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While not an exhaustive list, this study examined three locations where the MDTF could be deployed in such a role and the function it would perform in that location. The first of these locations was Ishigaki Island, which would allow the MDTF to influence the region around the disputed Senkaku islands or support operations with the Taiwan Straits. A second possible location off the coast of the Philippines offered the ability to influence the South China Sea by exerting control over the Spratly and Paracel islands as well as the sea routes entering the region. Finally, the MDTF can be positioned within the Malacca Strait or at its western end to delay or deny passage of hostile forces and force them onto a longer route that would add multiple days in comparison to a normal transit. This capability is particularly important in the event of a future conflict with China, as it could serve to isolate a portion of China's naval strength from a contested location and allow the U.S. and partner nations to obtain local superiority.

Based on this analysis the answer to the question of how the MDTF can contribute to the Joint Force in the Indo-Pacific stretches across multiple phases of the Joint Combat Operations Model. The presence of the MDTF with its long-range fires and surveillance capabilities can serve as a deterrent to enemy escalation and assist in maintaining operational access for follow-on forces. In the initial stages of a conflict the MDTF can isolate enemy forces and prevent an adversary such as China from massing forces by delaying or disrupting movement of enemy forces. This places the MDTF in line with joint concepts of flexible deterrent and flexible response operations, combined in a single package that can swiftly shift from one type of operation to another. Integrating the MDTF into the Joint Combat Operation Model requires careful consideration of what this expanded role means in that context.

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Although there is no one-size-fits-all operational model, JP 3-0 provides an example of how a joint combat operation can be described as a group of interrelated actions divided among operation shaping, deter, seize initiative, dominate, stabilize, and enable activities. The figure below depicts one such operation from beginning to end, with each activity scaled based on the amount of emphasis placed on each type of activity.

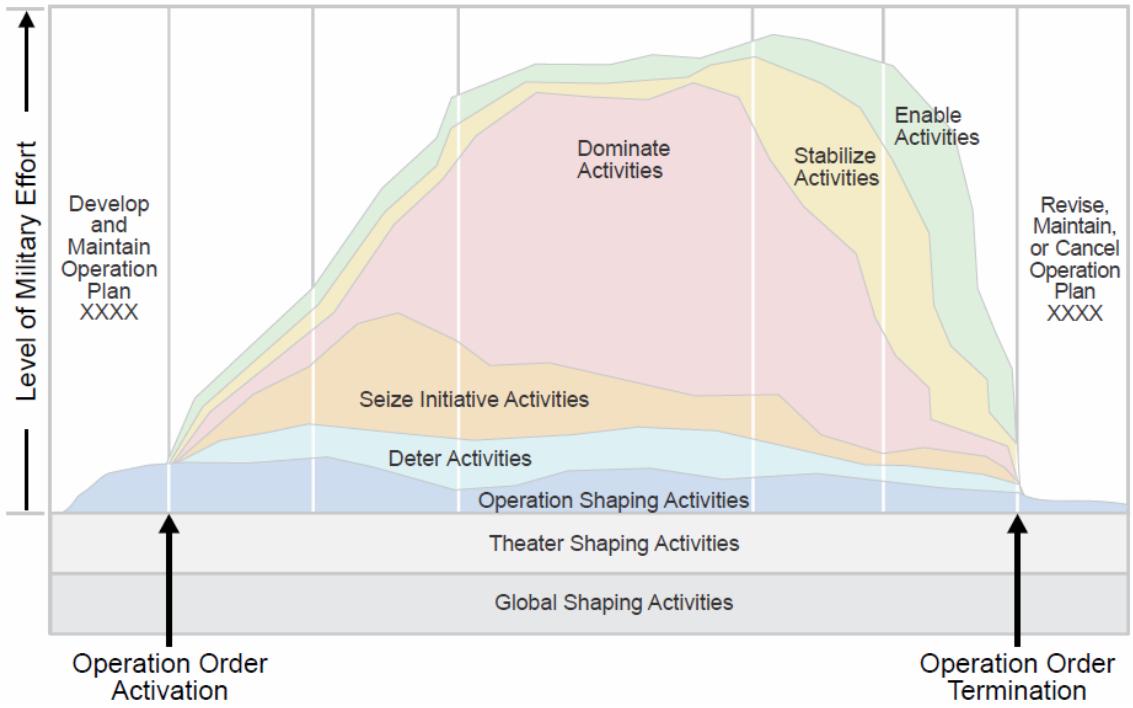


Figure 12. Notional Joint Combat Operation Model

Source: Office of the Chairman of the Joint Chiefs of Staff, Joint Publication 3-0, Change 1, *Joint Operations* (Washington, DC: The Joint Chiefs of Staff, October 2018), V-8.

The figure above depicts a five-phase operation that proceeds from activation of an order to end of mission. The standard use of the MDTF in this figure would most likely occur near the middle of the second phase in support of increases in dominate and

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seize initiative activities by penetrating enemy A2/AD spaces in support of an opposed entry. The full range of the MDTF's capabilities and application across the range of military operations indicates that it can be used earlier in the operation during the first phase. This provides several benefits supported by the MDTF's ability to swiftly deploy to a strategically significant location as part of a flexible deterrent option.

As the operation continues the MDTF can act in an operational shaping role by isolating enemy forces and conducting long-range strikes as a flexible response option. In a maritime environment it can use fires to restrict access to the site of a crisis and maintain freedom of movement and operational access for follow-on forces. This serves to protect those forces and increase the flexibility of the operational environment as the combat operation shifts into a phase that is more characterized by dominate activities. At this point the MDTF's role transitions to its normal mission of penetrating A2/AD spaces to enable other operations, although the variety of systems that it employs could also be used against other critical targets and facilities that are unrelated to A2/AD missions as part of conducting long-range precision fires.

Recommendations for the Force

In order to fully realize the potential of the MDTF as described in the answer to the primary and secondary research questions above, there are a total of five recommendations that this study makes to the joint force:

1. Exercise and test the MDTF in an A2/AD capacity to validate the concepts outlined in this study. If they are validated, modify the MDTF's purpose and operational concept accordingly and train to this mission.

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2. Develop a concept for deploying the MDTF as a flexible deterrence/flexible response option with a pre-developed movement concept. Train and exercise this concept according to the Brigade Support Battalion's requirement to be able to manage a 96-hour rapid deployment. In order to enhance the capability of the MDTF to conduct deterrence in time sensitive situations this should include an initial operating capability that can execute fires with the first turn of cargo aircraft.
3. Equip and train the MDTF in the Indo-Pacific for reconnaissance and security tasks in the maritime domain and other associated domains by ensuring that multi-function electronic warfare (MFEW) capabilities are available for all UAVs in the MDTF. Develop a version of the Sea Guardian package used on the MQ-9B for the MDTF's Gray Eagle or replace a portion of the Gray Eagle platforms with MQ-9B platforms with that package.
4. To mitigate the MDTF's inability to defend against ballistic missiles the MDTF should either have a Patriot battery added to its Air Defense Artillery battalion or be apportioned a Patriot battery in preparation for future operations. This relationship should be formalized, and the MDTF should then conduct training with the identified unit.
5. To enhance the MDTF's ability to control an airspace in a geographically isolated region where Navy or Air Force may not be able to provide air coverage the U.S. military should develop an extended range anti-aircraft capability. This extended range anti-aircraft capability should have a greater

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range than the Patriot PAC-2 and be designed from its inception to receive terminal guidance from forward sensors.

Possibilities for Future Studies

After 20 years of focusing on counterinsurgency operations the United States Army is going through a conceptual reorganization that can be compared to the changes that took place in the 1980s or the interwar period between World War I and World War II. This includes both doctrinal and technological changes, with the MDTF and similar specialized organizations on the leading edge of this movement. Victory in future conflicts will go to the side that makes the most accurate judgments concerning national and international security interests, national defense strategies, offensive-defensive concepts, and requirements and plans for the future of warfare. Making these judgments requires the development of a body of intellectual work that extrapolates from current trends and our best understanding of developing systems.

One of the strengths of the MDTF is that each doctrinal MDTF is expected to be modified for actual capabilities and missions based on the region it will operate while still retaining the same core concept and requirements regarding force structure capabilities and capacities. This allows for future studies similar to this one to be conducted for other MDTFs that consider the unique requirements of each theater. The second MDTF operating in the European theater has to contend with significantly different terrain but may be able to provide unexpected advantages if placed on key terrain in the Baltic Sea or Mediterranean. An MDTF operating in the Arctic will have different requirements and different force structure considerations as well. This provides a unique opportunity to

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study those considerations and make recommendations while those units are being designed.

Another possible avenue of study would be examining the MDTF in a multinational construct operating either as part of a multinational joint task force or incorporating similar capabilities from partner nations. The first of these possibilities allows for an expanded appreciation of how the MDTF can operate in concert with other forces as well as how it fits in with a larger military operational concept. A study on similar capabilities existing within partner militaries within a given region could provide a potential framework for using different parts of the MDTF as the core of several task forces to conduct operations in multiple critical locations for an enhanced effect.

The sensitive political climate in the Indo-Pacific means that many nations in the region may be hesitant to directly oppose China also suggests that in some future conflicts a MDTF may be required to operate only from U.S. or Australian territory. Further study in this direction could examine the implications of a MDTF on American Samoa, Guam, or the Northern Mariana Islands. The vast distances of the Pacific Ocean would limit the ability of some components of the MDTF to directly affect China or adjacent waterways but could affect the ability of U.S. forces to access the theater, move within the umbrella of the MDTF, and build combat power in a larger conflict. This placement might also provide an increased role for the MDTF's Long Range Hypersonic Weapon battery.

Finally, a critical assessment of the MDTF's strengths and weaknesses could also be applied against areas where international partners have capabilities that could mitigate those weaknesses. Based on the results of this study, this could include investigating how

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allies and partners could assist the MDTF with long range air defense systems. Another promising area would include how other forces could assist in providing defense against ballistic missiles. Additional research could include examining the capabilities of other branches of the Department of the Defense in these areas to create templates for joint force packages that could operate as a quick reaction or rapid deployment force while reinforcing the multidomain capabilities of the MDTF.

The outcome of this research and future research into these areas should be published and widely read to influence the development of doctrine, strategies, requirements, technologies, and operational concepts for future use. Serious mistakes in establishing assumptions, threats, and conditions for designing future forces and understanding their potential can be corrected after the fact, but extract a price in blood, time, and resources when those failures come to light during combat. Study and research supporting mission analysis, threat assessment, and measured responses can help to forestall such a cost or provide a starting point for mitigation efforts once future leaders recognize that an error has been made in the past. The purpose of this study and others like it is to ensure that the MDTF and the rest of the Army's Multi-Domain Operations concept realize their full potential when they are called upon to go into battle.

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Figure 13. The Long-Range Hypersonic Weapon Battery at Ogasawara

Source: Created by author using map from DigitalGlobe, "Maxar, Global Enhanced GEOINT Delivery," accessed 15 March 2022, G-EGD Login (digitalglobe.com).

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Figure 14. The Long-Range Hypersonic Weapon Battery at General Santos City

Source: Created by author using map from DigitalGlobe, "Maxar, Global Enhanced GEOINT Delivery," accessed 15 March 2022, G-EGD Login (digitalglobe.com).

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Figure 15. The Long-Range Hypersonic Weapon Battery at Christmas Island

Source: Created by author using map from DigitalGlobe, "Maxar, Global Enhanced GEOINT Delivery," accessed 15 March 2022, G-EGD Login (digitalglobe.com).

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Unmanned Aircraft Systems Sensors

Dyke D. Weatherington
OUSD(AT&L)/Defense Systems
Air Warfare

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Outline

- Background
  - UA in Operation IRAQI FREEDOM
    - Small UA
    - Tactical UA
    - Operational
    - Theater UA
- Electro-optical and Infrared Sensors
  - Small UA
  - Tactical UA
  - Operational & Theater UA
- Radar Sensors
  - Small UA
  - Tactical UA
  - Operational & Theater UA
- Sensor Fusion
- Summary

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Small UA in Operation IRAQI FREEDOM

	User / Mission	Size		Payload	Endurance
	Army, Air Force & SOCOM				
		Weight	4 lbs		
	Over the Hill	**Length**	3 ft		
	Reconnaissance	**Wing Span**	4.4 ft		
		Payload Weight	1 lb	EO or IR	80 min
Raven					
	Marine Corps	**Weight**	4 lbs		
		Length	2.4 ft		
	Over the Hill	**Wing Span**	3.75 ft		
	Reconnaissance	**Payload Weight**	1 lb	EO or IR	40-60 min
Dragon Eye					
	Air Force	**Weight**	4.5 lbs		
		Length	3 ft		
		Wing Span	4 ft		
	Force Protection	**Payload Weight**	1 lb	EO or IR	60-90 min
FPASS					
	SOCOM	**Weight**	8 lbs		
		Length	6 ft		
		Wing Span	9 ft		
	Special Operations	**Payload Weight**	2 lbs	EO or IR	60 min
Pointer					
	SOCOM/USMC	**Weight**	14 lbs		
		Length	4.2 ft		
		Wing Span	7.7ft		
	Special Operations	**Payload Weight**	4 lbs	EO or IR	3-5 hr
Silver Fox					
	USMC	**Weight**	40 lbs		
		Length	4 ft		
		Wing Span	10 ft		
	Force Protection	**Payload Weight**	6 lbs	EO or IR	15 hr
Scan Eagle					

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Tactical UA in Operation IRAQI FREEDOM

	Army	**Weight**	327 lb	EO/IR	5 hrs
		Length	11.2 ft		
	Brigade Level	**Wing Span**	12.8 ft		
	Recce	**Payload Weight**	60 lbs		
Shadow (RQ-7)					
	Marine Corps	**Weight**	452 lbs	EO/IR	5 hrs
		Length	14 ft		
	Suveillance/Recce	**Wing Span**	17 ft		
		Payload Weight	75 lbs		
Pioneer (RQ-2B)					
	Army	**Weight**	1600 lbs	EO/IR	11.6 hrs
		Length	23 ft		
	Division/Corps Level	**Wing Span**	29.2 ft		
	Recce	**Payload Weight**	200 lbs		
Hunter (RQ-5)					

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Operational UA in Operation IRAQI FREEDOM

		User / Mission	Size		Payload	Endurance
		Air Force	**Weight**	2250 lbs		24 hrs
			Length	28.7 ft		
		Armed Recce	**Wing Span**	49 ft		
			Payload Weight	**Internal:** 450 lbs	EO/IR & SAR	
				Wings: 100 lbs each	Hellfire	
Predator (MQ-1)						
		Army				
			Weight	2250 lbs		24+ hrs
		Division/Corps Level	**Length**	27 ft		
		Recce	**Wing Span**	49 ft		
			Payload Weight	450 lbs	EO/IR & SAR	
I-Gnat						

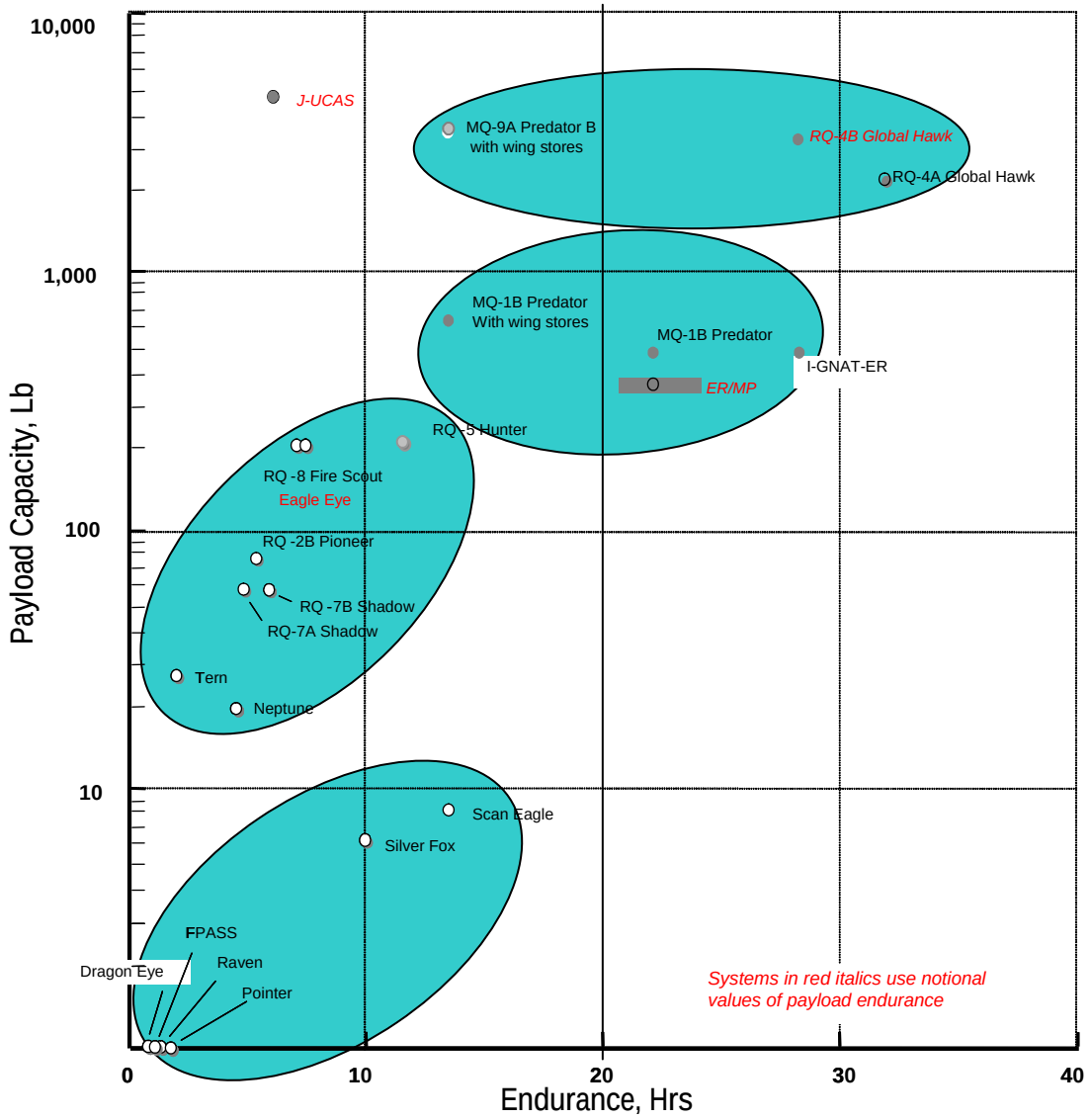
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Prototype Theater UA in Operation IRAQI FREEDOM

		Service / Mission	Size		Payload	Endurance
		Air Force	**Weight**	10,000 lbs		
			Length	36.2 ft		
		Armed Recce	**Wing Span**	64 ft		
			Payload Weight	**Internal:** 750 lbs	EO/IR & SAR	24+
Predator B (MQ-9)				**Each Wing:**	GBU-12	
Prototype				Inboard: 1500 lbs		
				Middle: 350 lbs		
				Outboard: 150 lbs		
				Maximum: 3750 lbs		
		Air Force	**Weight**	26,700 lbs		
			Length	44.4 ft		
		Persistent High	**Wing Span**	116.2 ft		
		Altitude Surveillance	**Payload Weight**	1950 lbs	EO/IR & SAR	24+
Global Hawk (RQ-4A)		& Reconnaissance				
Prototype						

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UA Payload Weight vs. Endurance



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UA Sensor Summary

- All UA have an Electro-Optic (EO) and Infrared (IR) capability
- Small UA sensors
  - EO/IR is primary sensor
  - Fixed vs Gimbaled
- Tactical UA sensors (in order of priority)
  - EO/IR
  - SIGINT
  - Radar
  - Comm relay
- Operational & Theater UA sensors (in order of priority)
  - EO/IR
  - Radar
  - SIGINT
  - Comm relay
- Sensor specifications drive UAS costs and capabilities
  - Cost control is critical to development of UAS and UA sensor capabilities

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Small UA EO/IR Sensors

- **EO** – Requirement for a facial recognition capability while remaining undetected (NIIRS 8+)
- **IR** – Requirement for identification and tracking while remaining undetected
- **Small UA (SUA)**
  - ***SUA*** are ***expendable*** and ***numerous***
  - Sensors must be
    - Reliable
    - Low Cost
    - Supportable
    - Commercially available
- **Goal for Industry**
  - Gimbaled sensor with EDTV capability (480P)

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Raven









System Components:

- 3 Air Vehicles (AV) per system
- 3 Payloads
- One (1) Ground Control Unit
- Remote Video Terminal (RVT)
- Batteries: Mission & Rechargeable
- Carry / Protective Cases
- Battery Charger / Power Supply
- Field Maintenance Kit
- Spares and Repair Parts

Mission:

Army tactical level reconnaissance, surveillance, target acquisition, and battle damage assessment

Capabilities:

- Hand Launched / AutoLand Recovery
- Military P(y)-Code GPS
- AutoNavigation
- Quick Assembly (< 3 min)
- Man Portable / Backpackable
- Quiet
- Reusable (100+ flights)
- Typical Operational Altitude 150-500 ft AGL
- Climb to Operational Altitude in 1-2 mins

Characteristics / Description:

- **Power:** Batteries
  - Mission: Lithium ($LiSO_2$)
  - Rechargeable: Lithium Ion
- **Wing Span:** 4.5 feet
- **Weight:** 4 lbs (w/carrying case, 12 lbs)
- **GCU Weight:** 17 lbs
- **Range:** 8-12 km
- **Endurance (Mins):** 90 (Lithium) / 60 (Lithium Ion)
- **Speed:** 27-60 mph, Cruise 40 mph
- **Payload(s):** High Resolution, Day / Night Camera & Thermal Imager
- **Crew / Manpower:** 2 Soldiers

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Raven Image – OEF

"Altitude Hold" Mode (Commanded Altitude)

DTG

GPS Satellites



Aircraft MH Battery Voltage Reading

AGL Altitude Range from GCU

Raven video and image capture from food distribution convoy mission.

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ScanEagle



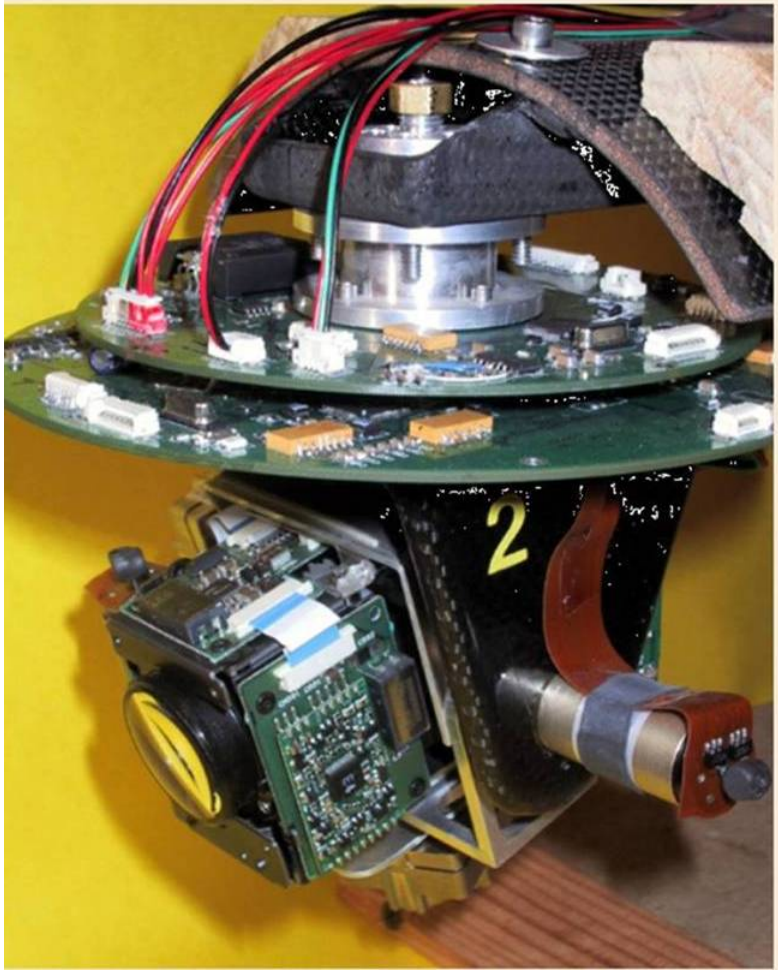


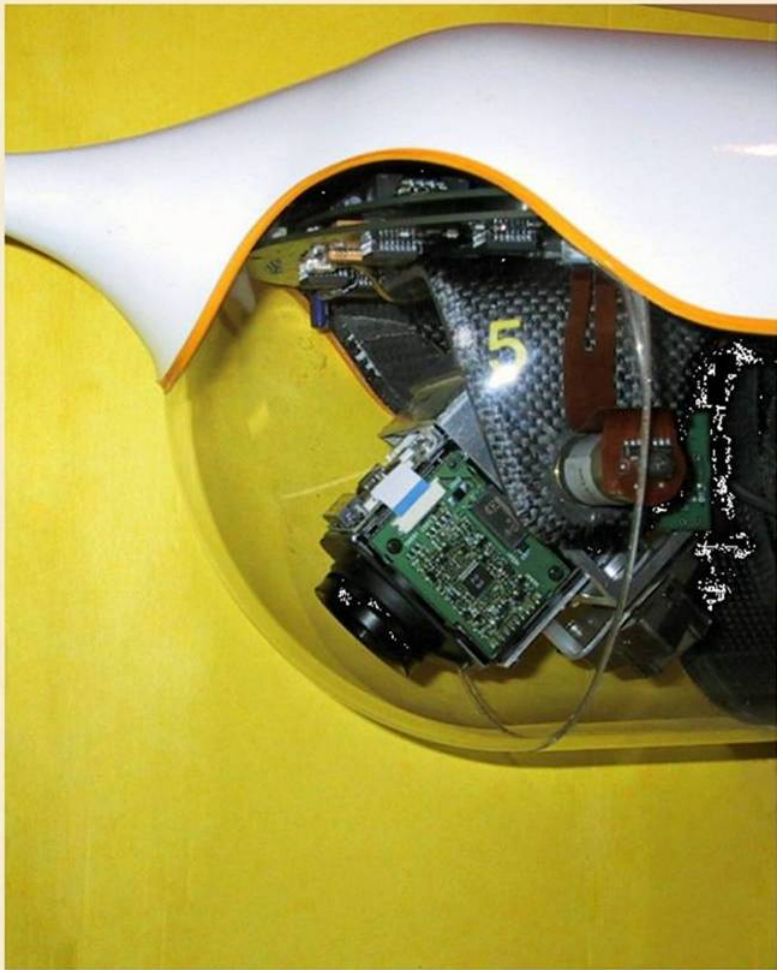
Wing span	10.0 ft
Fuselage diameter	7.0 inches
Overall length	4.0 ft
Folded length	6.5 ft
Folded width	1.5 ft
Folded height	1.3 ft
Max. Gross Wt.	40.0 lbs

- Max level speed — 68 knots
- Cruise spd @ max wt. — 48 knots
- Loiter spd @ max wt. — 42 knots
- Service ceiling @ max wt. — 16,000 ft
- Endurance, no reserves — Current : 15+ hrs
  Planned:
  B: 30+ hrs
  C: 40+ hrs
- Launch — Pneumatic catapult
- Recovery — "Skyhook" wingtip snag/ land in 600 x 100 ft field or skid landing
- Navigation — D-GPS
- Surveillance — 25:1 zoom daylight color video camera (or IR) in inertially stabilized nose turret

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Stabilized EO Turret System





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Stabilized Camera System





Video Camera System Stabilized on Mobile Flight Test Center and Zoomed to 11:1 at 2000’.

Full Motion Video Camera System Stabilized on Mobile Flight Test Center at Wide Angle FoV at 2000’.

Tactical UA EO/IR Sensors

- EO – Requirement for a facial recognition capability while remaining undetected. (NIIRS 8+)
- IR – Requirement for identification and tracking while remaining undetected
- Laser Designator Range Finder – Requirement for integration with EO/IR sensor
- Tactical UA (TUA)
  - ***TUA*** are ***attritable,*** fewer in number than SUA
  - Sensors must be
    - Gimbaled turret providing weapons quality precise coordinates
    - Reliable
    - Supportable
    - Commercially available
- Goal for Industry
  - Gimbaled sensor with HDTV capability (720P)
  - Challenge is low cost gimbaled turret
  - Ability to upgrade easily (FPA)

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Shadow RQ-7B



Characteristics / Description:

Wing Span	14 feet
Weight	380 lbs
Range	~ 125 km
Airspeed	(60 kt loiter, 105 kt dash)
Altitude	14,000 Ft
Endurance	> 5 Hours @ 50 km
Primary Payload (s)	EO / IR (up to 60 lb)
Launch / Recovery	100m x 50m Area

Capabilities :

- Automatic Landing and Takeoff
- System and Maintenance Section transportable on 3 C-130s
- Early entry capability with 1 C-130
- Compatible with ABCS
- EO / IR Sensor
- TCDL Ready

Unit Composition

- Platoon Set = a System:
  - 22 Soldiers (2 Officers, 20 Enlisted)
  - 4 - Air Vehicles
  - 6 - HMMWVs (Ground Control Station, air vehicle transport, troop transports, maintenance shelter)
  - 3 - Trailers (equipment, launcher)
  - 4 - Remote Video Terminals

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POP 300 Sensor Characteristics



Detector	640 x 480 InSb
Narrow Field-of-View	2.3 x 1.7 Deg
Medium Field-of-View	9.2 x 6.9 Deg
Wide Field-of-View	28.9 x 21.6 Deg
Instantaneous Field-of-View	0.062 mrad

FLIR

CCD Type	1/6”, 768 x 494 Pixels
Optical Zoom	1.00° - 22.5° Continuous optical zoom
Digital Zoom	0.5° - 0.37° Digital Zoom
Resolution	480 TV Lines

Electro-Optical

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POP 300



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Operational & Theater UA EO/IR Sensors

- EO – Requirement for a facial recognition capability while remaining undetected. (NIIRS 8+)
- IR – Requirement for identification and tracking while remaining undetected
- Laser Designator Range Finder – Requirement for integration with EO/IR sensor
- Operational and Theater UA
  - Global War on Terrorism requires precision and facial recognition capability
  - Stand-off range is important
- Goal for Industry
  - Multi-spectral Capability with Fusion Onboard
  - HDTV resolution (720P) in Full Color
  - Weapons quality precise coordinates

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MQ-1 Predator / AGM-114 Hellfire



- Testing began in Feb 2001
- Operationally employed in Afghanistan and Iraq
- IOC declared 2005

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Predator / Hellfire Launch



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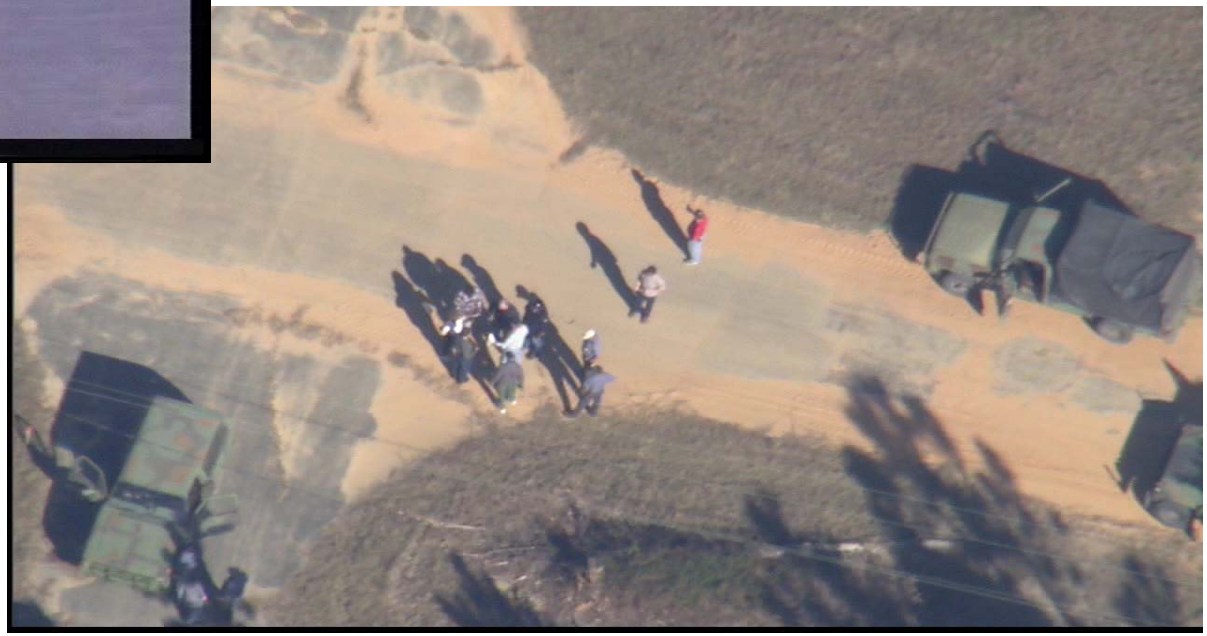
Human Activity

Predator vs HDTV – 3 mile slant range



Predator, 955 mm focal length

HDTV, 1200 mm focal length



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Global Hawk

High-altitude, long-endurance capability providing intelligence, surveillance and reconnaissance information

Unique Capabilities

- Persistence
- Responsive
- Multi-INT Collection



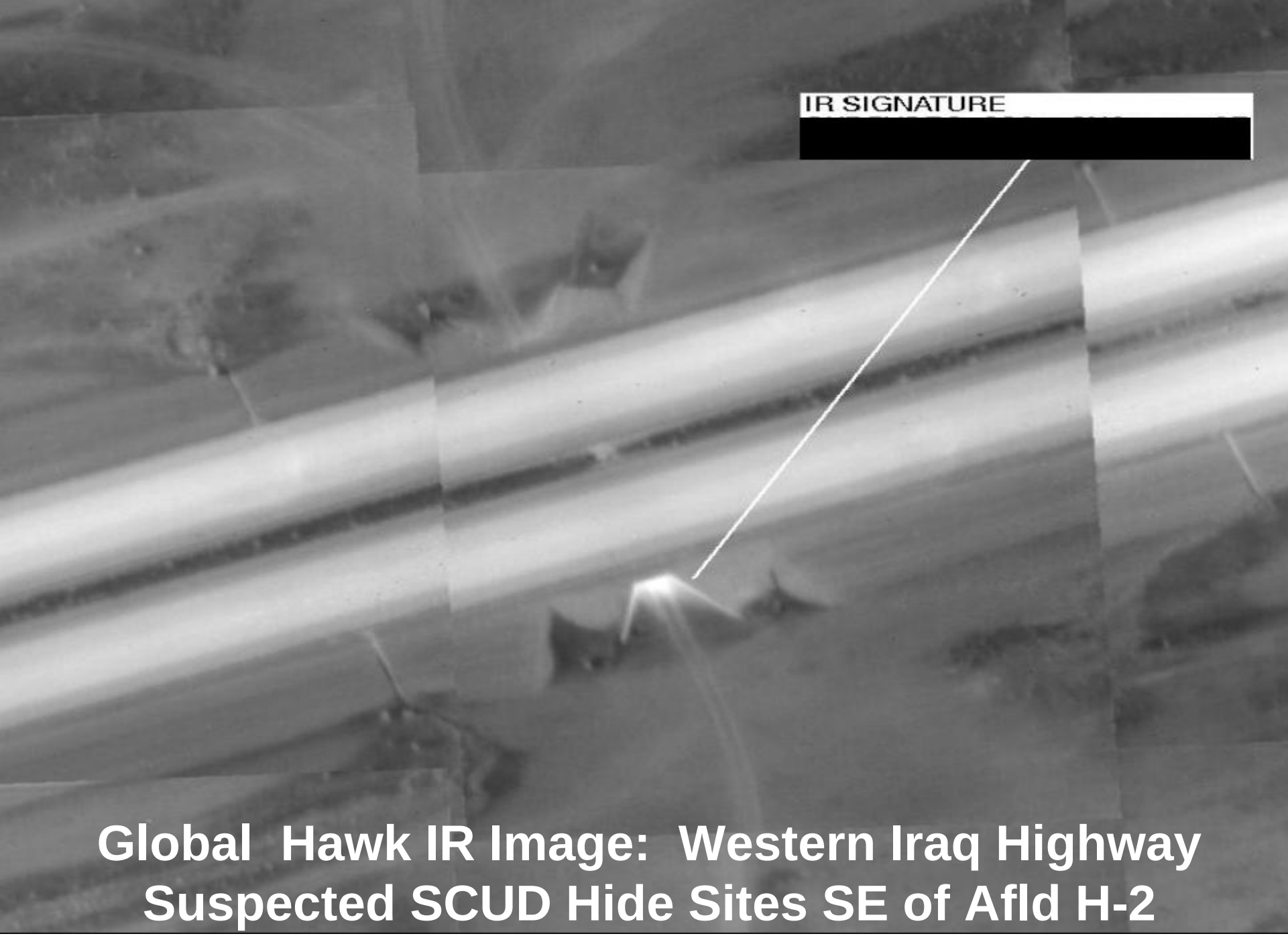




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Global Hawk EO Image: Ad Hoc Suspected SA-2 Battery 20NM N of Baghdad



Global Hawk IR Image: Western Iraq Highway Suspected SCUD Hide Sites SE of Afld H-2

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UA Radar Sensors

- Most UA will not have radar as the only system
- Goals for Industry
  - Literal radar image with same level of fidelity as low end monochromatic or high end IR image
  - Multi-band
    - Low frequencies for foliage penetration
    - High frequencies for detail
    - Sub-foot resolution
  - GMTI
  - Radar Video – Full motion video representation
  - Radar to EO/IR cueing

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Army I-GNAT System



Characteristics / Description:

Wing Span	48.7 feet
Length	27 feet
Max Gross Weight	2,250 lbs
Fuel Weight	500 lbs
Speed Range	70-125 KIAS
Ceiling	25,000 feet
Endurance	40 hours
Payload (Internal)	450 lbs
Data Link	C-Band

Army I-GNAT UAV Characteristics

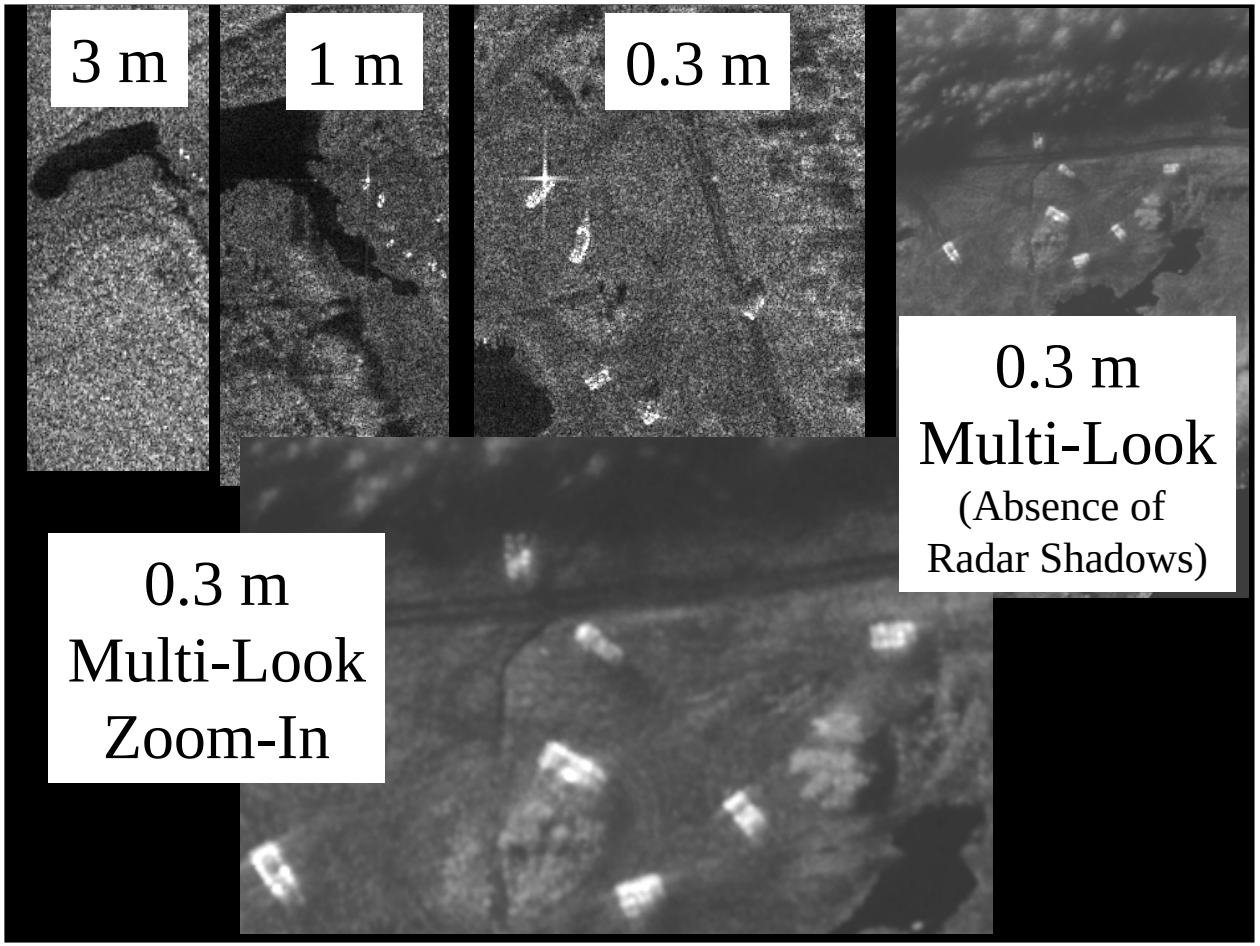
- Multi-Payload / Mission Capable / Hellfire Capable
- Numerous combat area deployments
- C-130 Transportable
  - In-Place Logistics
- Current IRAD Programs:
  - TUAV GCS
  - Differential GPS Auto Launch & Recovery
  - Point-n-Click Operation (No sticks/pedals)

One System

- Three (3) Air Vehicles
- One (1) Ground Control Station
- Two (2) Antennas
- Repair and Spare Parts
- Ground Support Equipment
- OIF since May 2004

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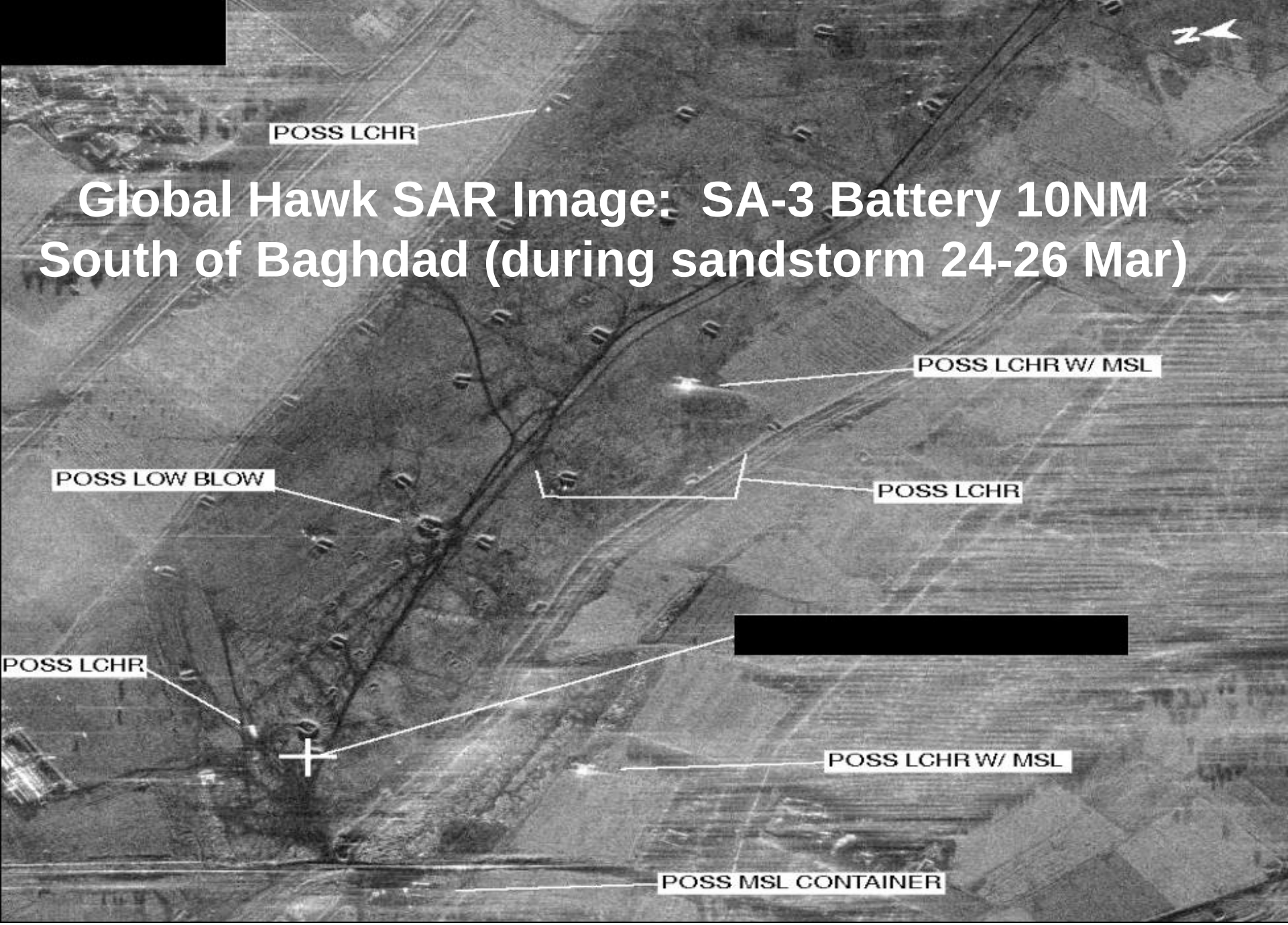
LYNX SAR



Convoy Search Ft Dix: 2 x Cargo Trucks / 6 x Hummers

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Global Hawk SAR Image: SA-3 Battery 10NM South of Baghdad (during sandstorm 24-26 Mar)



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Sensor Standards

- Time sensitive operations currently hampered by
  - Lack of sensor metadata
  - Use of multiple, non-standard formats for sensor data

- Requirement for standard metadata for time sensitive operations
  - NGA Motion Video Metadata (KLV) allows derivation of Precision Guided Munitions-quality coordinates in near real-time from video
    - GRIDLOCK Advanced Concept Technology Demonstration
  - Critical component of Global Information Grid integration
    - Makes integration and fusion of products, and use by others, easier

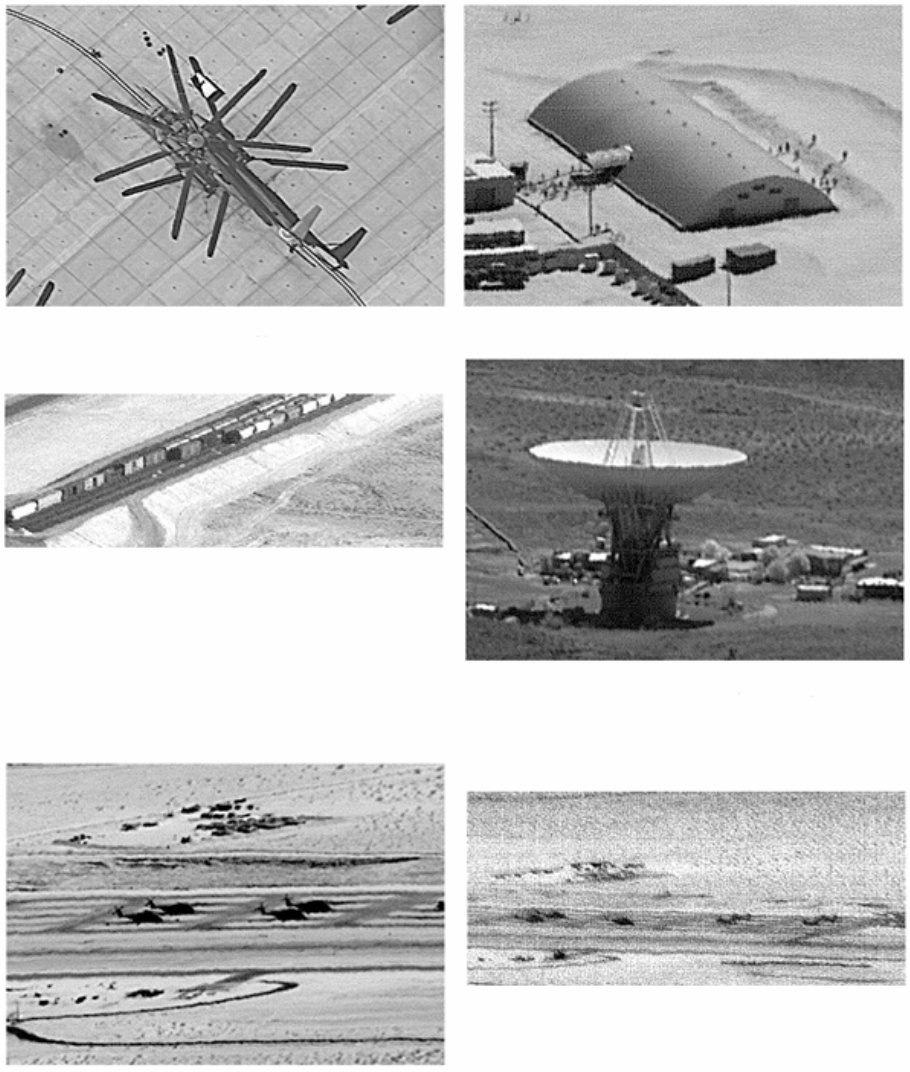
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Sensor Fusion

- Fusion enhances visible image
  - Hyperspectral has potential, but not robust
  - No single frequency provides best solution
  - Hyperspectral + EO/IR = Image with highlights
  - Need to be able to select the frequency, or combination thereof, that best fits the situation/environment

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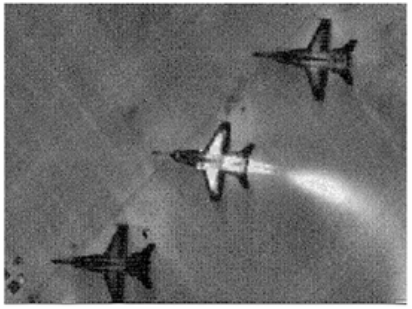
High Altitude ISR System Performance



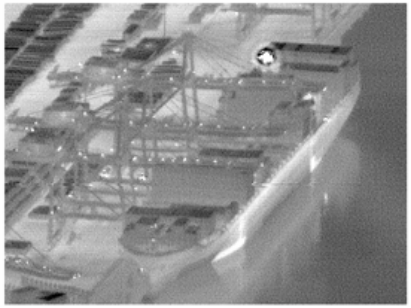
Detail Image Chip examples from the *Pan/NIR band* at various ranges.

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High Altitude ISR System Performance









MWIR Band

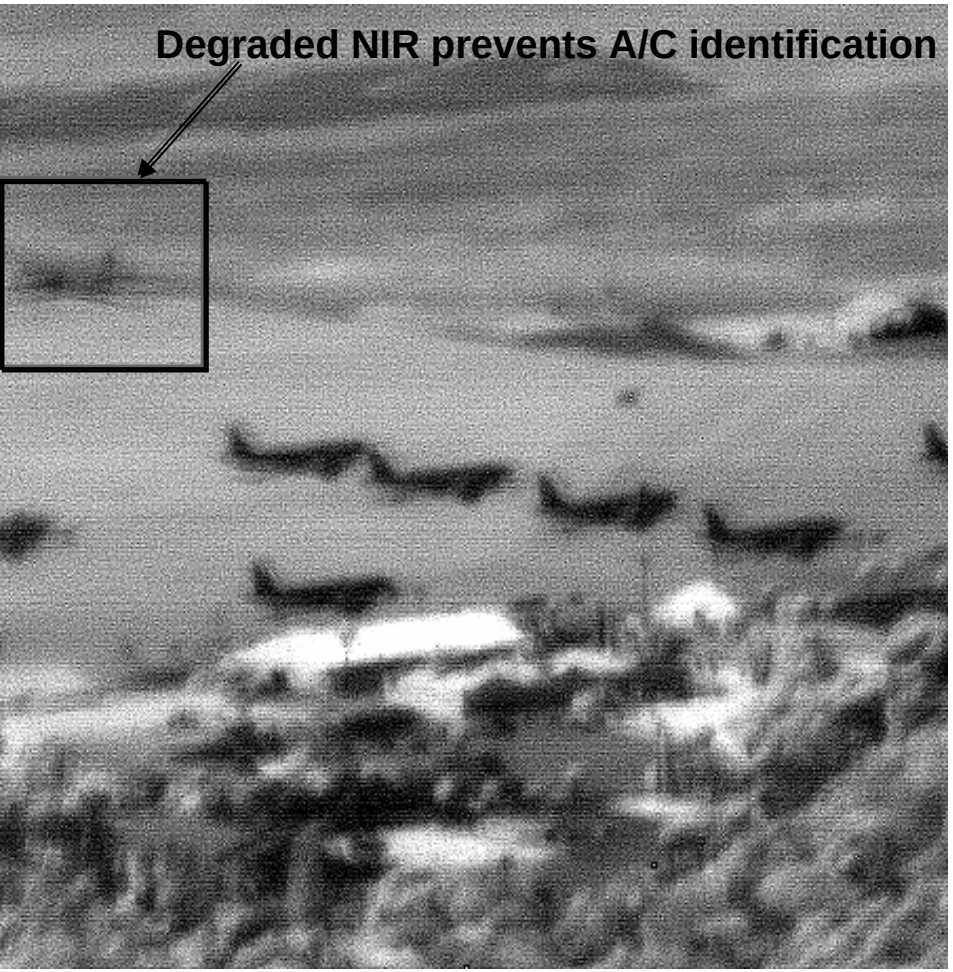
Night time Detail Imagery examples collected over various ranges.

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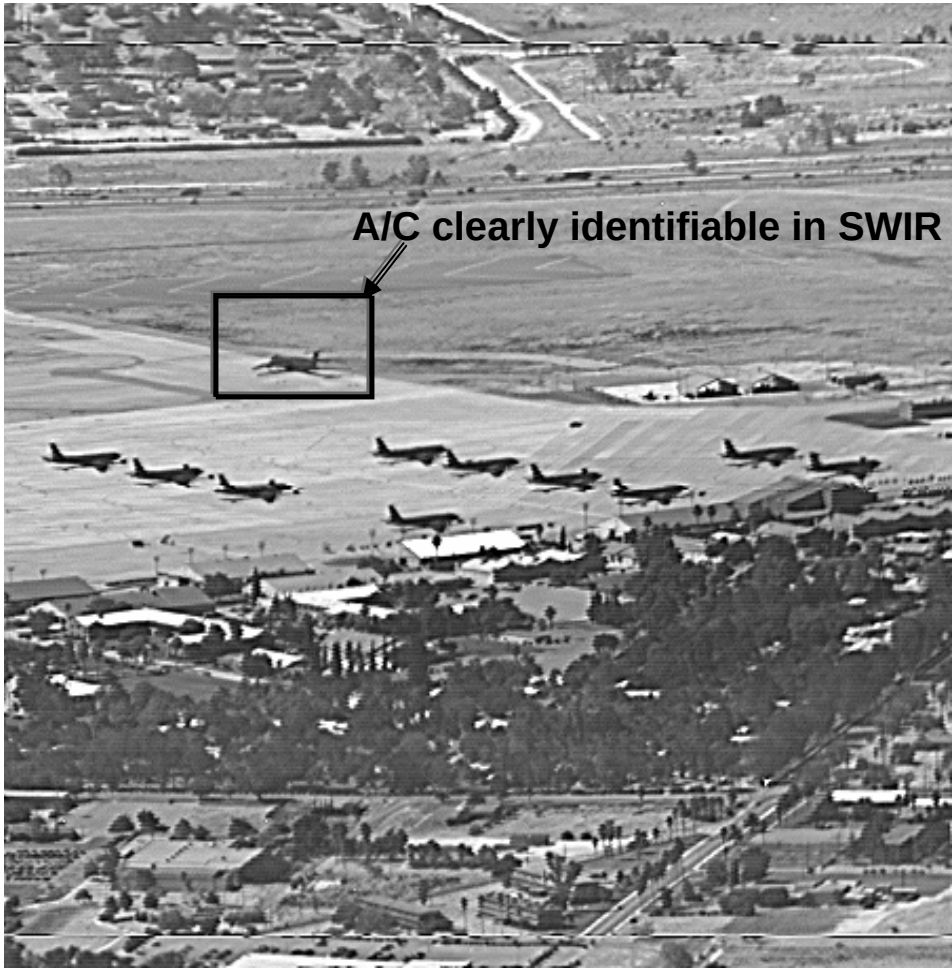
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Poor Visibility Enhancement (Pan vs. SWIR)

AOB: Identify/Detect Aircraft Activity



NIR



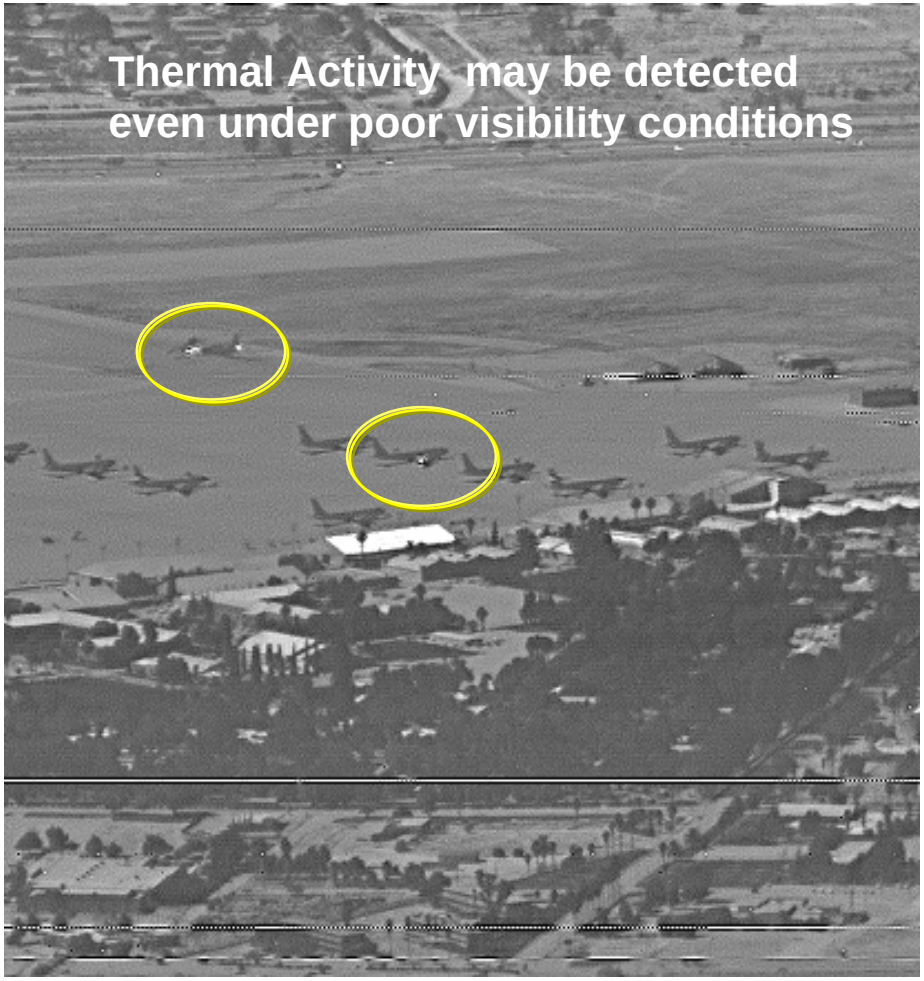
SWIR2

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Poor Visibility Enhancement (SWIR & MWIR)

AOB Identify/Detect Aircraft Activity





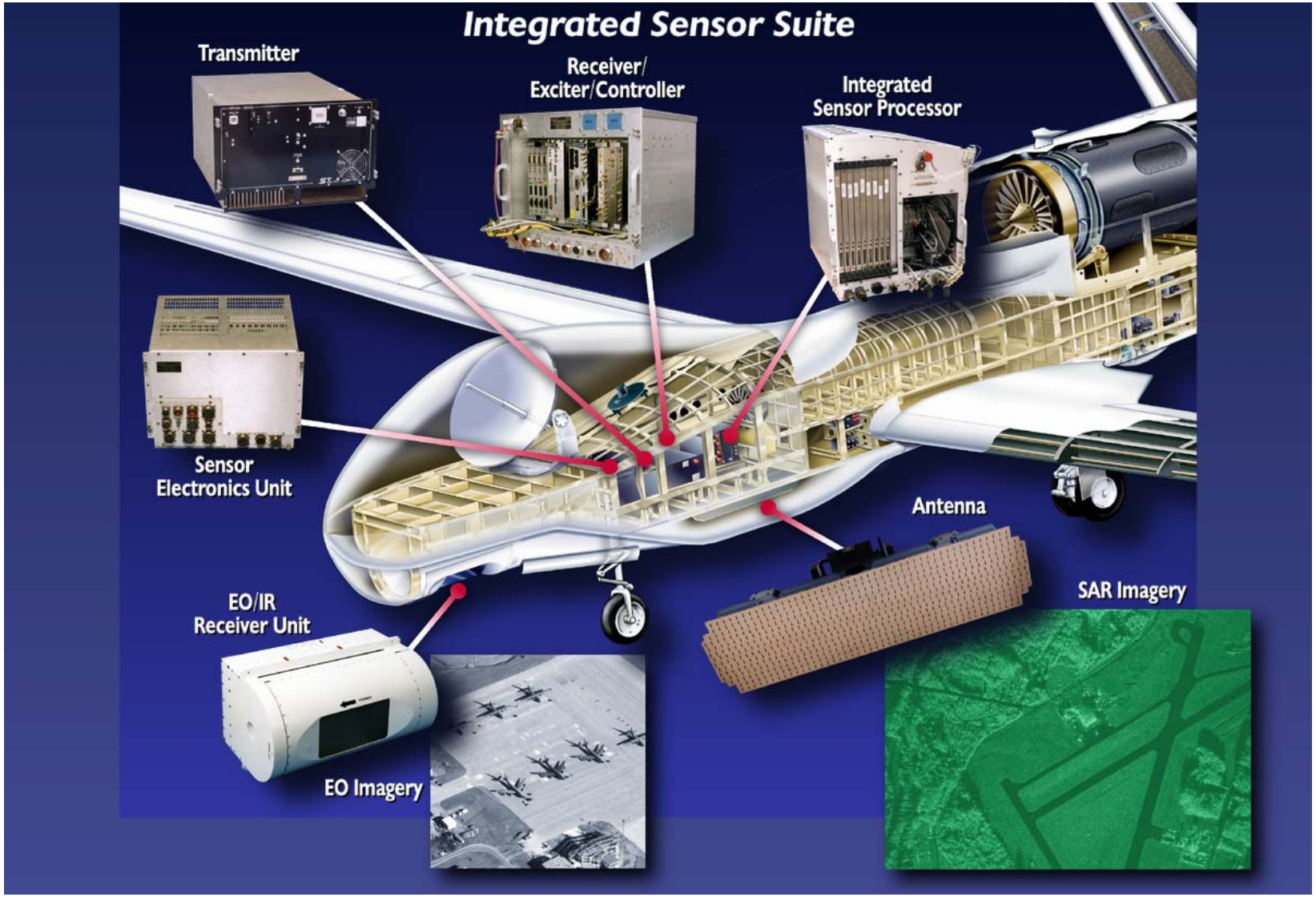
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Summary

- Cost control is critical to development of UAS and UA sensors
- Standard metadata and standard data formats are:
  - Essential for time sensitive operations
  - Critical component of Global Information Grid integration
- Fusion enhances visual image
- Different sensor capabilities required to combat full range of asymmetrical threats:
  - Small
  - Tactical
  - Operational
  - Theater

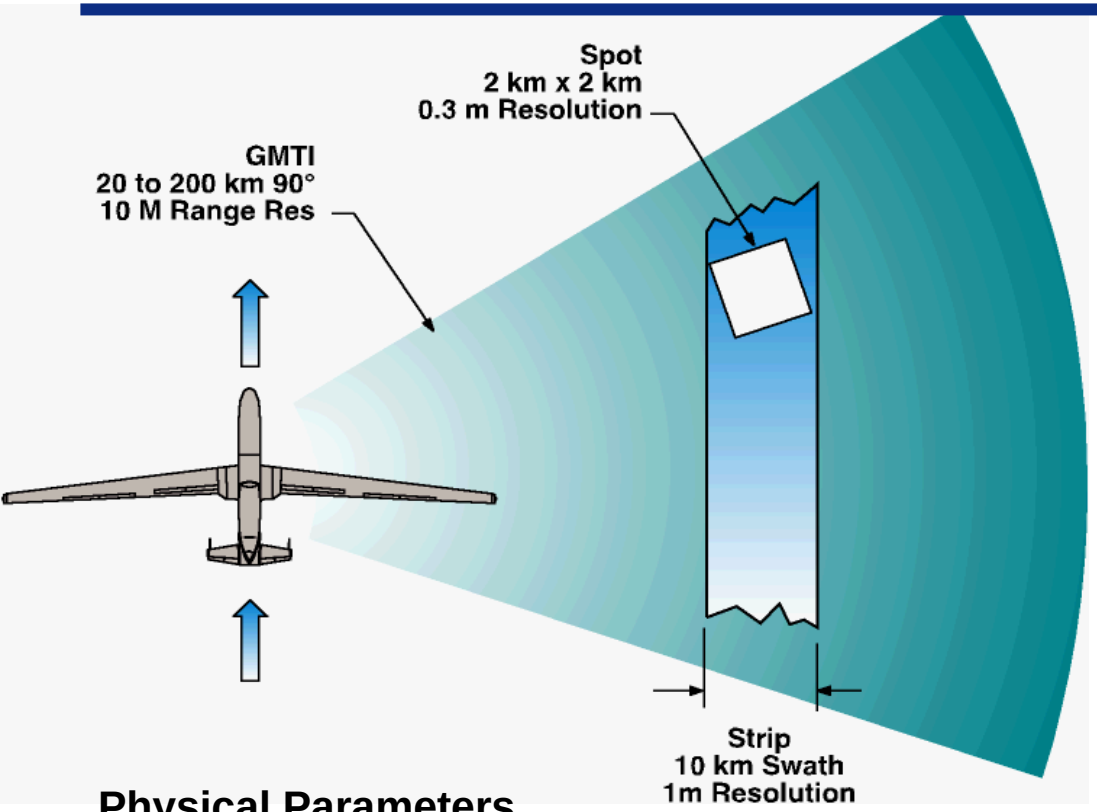
Back Up Slides

Global Hawk
Integrated Sensor Suite



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SAR/MTI Sensor



Radar Characteristics

X-Band Frequency
480 MHz Bandwidth
3.5 kW Peak Power
±45° Antenna Field of Regard
Either Side of Aircraft

Performance Parameters

Spot Mode:	**1900 images/day**
	200 km Range
	Squint to ±45°
Search Mode:	**138,000 sq km/day**
	200 km Range
GMTI Mode:	**15,000 sq. km/min**
	Search Rate
	4 knots Minimum
	Detectable
	Velocity @ 100 km

Physical Parameters

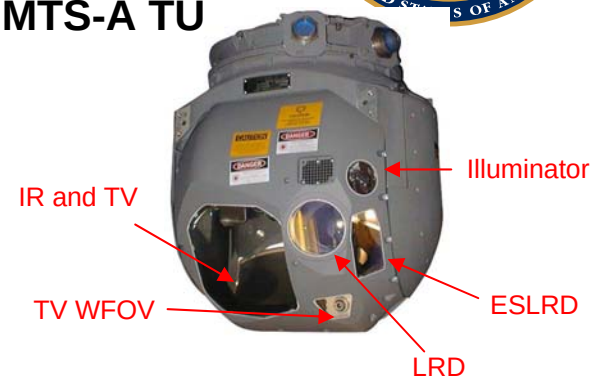
7 LRUs
15 cu. ft. (excluding antenna)
640 lb
Power Required: 4700 W 400 Hz 3ø
1300 W 28 Vdc

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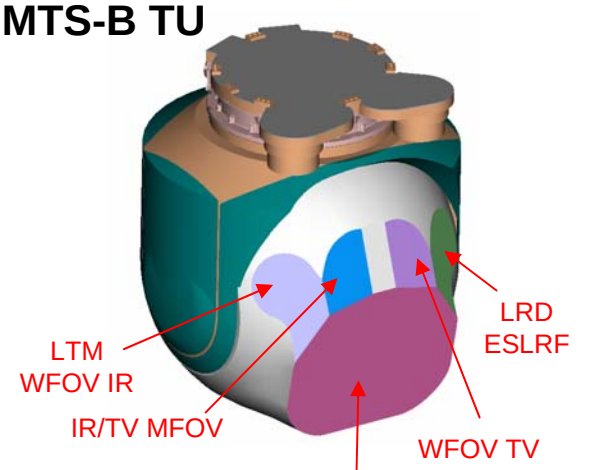
MTS System Overview

		MTS-A			MTS-B		
Physical Characteristics							
Diameter		17.43"			22.0"		
Height		18.70"			26.0"		
Weight							
Turret		124 lbs			230 lbs		
Electronics Box		30 lbs			30 lbs		
Power (nominal)		28Vdc, 30 Amps			28Vdc, 30 Amps		
Video Interfaces		RS-170, NTSC, Firewire, DVI			RS-170, NTSC, Firewire, DVI		
System Interface		MIL-STD-1553, RS-422, Ethernet			MIL-STD-1553, RS-422, Ethernet		
Temp		-54C to +55C			-54C to +55C		
Altitude		30,000 ASL			50,000 ASL		
Imaging Sensor							
Fields of View (FOV)		TV	IR	IITV	TV	IR	IITV
Wide	W-1 45°	33 X 44	33 X 44	--	34 X 45	34 X 45	--
Medium-Wide	W-2 22°	15X 20	15X 20	--	17 X 22	17 X 22	--
Medium	M-1 7.6°	5.7 X 7.6	5.7 X 7.6	5.7 X 7.6	5.7 X 7.6	5.7 X 7.6	5.7 X 7.6
	M-2 2.6°	--	--	--	2.2 X 2.6	--	--
Narrow	M-2 3.7°	1.2 X 1.6	1.2 X 1.6	1.2 X 1.6	--	2.8 X 3.7	2.8 X 3.7
	M-3 1.3°	--	--	--	0.96 X 1.3	--	--
Ultra-Narrow	N-1 0.63°	0.21 X 0.28	0.6 X 0.8	0.6 X 0.8	0.47 X 0.63	0.47 X 0.63	0.47 X 0.63
	N-2 0.22°	--	--	--	0.16 X 0.22	--	--
	N-2 0.31°	--	--	--	--	0.23 X 0.31	0.23 X 0.31
	N-3 0.011°	--	--	--	0.08 X 0.11	--	--
Spectral Band (microns)		0.4 to 0.7	3 to 5	0.6 to 0.89	0.4 to 0.7	3 to 5	0.6 to 0.89
Focal Plane Array Size		640 X 480 InSb			640 X 480 InSb		
Autotracker		Yes			Yes		
Laser Rangefinder Designator		Yes			Yes		
Eyesafe Laser Rangefinder		Not Installed			Yes		
Laser Illuminator		Yes			Yes		
Laser Spot Detection		Yes			Yes		
Inertial Measurement Unit		Yes			Yes		
Target Location Error		Weapons Quality			Weapons Quality		

MTS-A TU



MTS-B TU



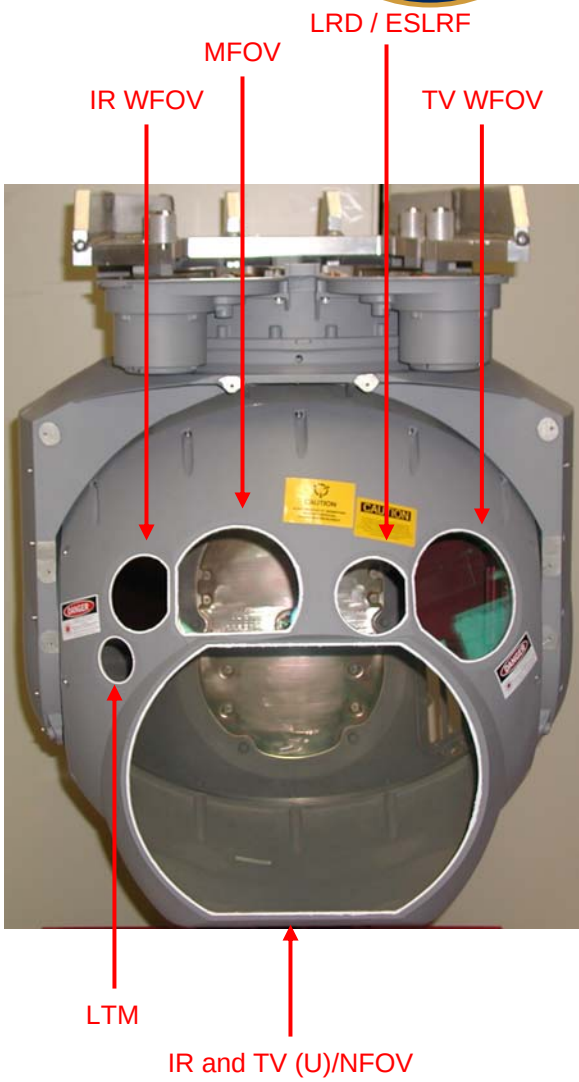
Common EU



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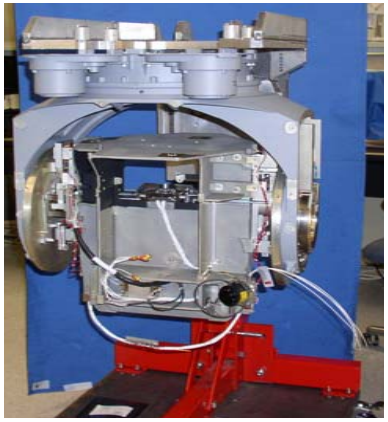
MTS-B Prototype

		MTS-A			MTS-B		
Physical Characteristics							
Diameter		17.43"			22.0"		
Height		18.70"			26.0"		
Weight							
Turret		124 lbs			230 lbs		
Electronics Box		30 lbs			30 lbs		
Power (nominal)		28Vdc, 30 Amps			28Vdc, 30 Amps		
Video Interfaces		RS-170, NTSC, Firewire, DVI			RS-170, NTSC, Firewire, DVI		
System Interface		MIL-STD-1553, RS-422, Ethernet			MIL-STD-1553, RS-422, Ethernet		
Temp		-54C to +55C			-54C to +55C		
Altitude		30,000 ASL			50,000 ASL		
Imaging Sensor							
Fields of View (FOV)		TV	IR	IITV	TV	IR	IITV
Wide	W-1 45°	33 X 44	33 X 44	--	34 X 45	34 X 45	--
Medium-Wide	W-2 22°	15X 20	15X 20	--	17 X 22	17 X 22	--
Medium	M-1 7.6°	5.7 X 7.6	5.7 X 7.6	5.7 X 7.6	5.7 X 7.6	5.7 X 7.6	5.7 X 7.6
	M-2 2.6°	--	--	--	2.2 X 2.6	--	--
Narrow	M-2 3.7°	1.2 X 1.6	1.2 X 1.6	1.2 X 1.6	--	2.8 X 3.7	2.8 X 3.7
	M-3 1.3°	--	--	--	0.96 X 1.3	--	--
Ultra-Narrow	N-1 0.63°	0.21 X 0.28	0.6 X 0.8	0.6 X 0.8	0.47 X 0.63	0.47 X 0.63	0.47 X 0.63
	N-2 0.22°	--	--	--	0.16 X 0.22	--	--
	N-2 0.31°	--	--	--	--	0.23 X 0.31	0.23 X 0.31
	N-3 0.011°	--	--	--	0.08 X 0.11	--	--
Spectral Band (microns)		0.4 to 0.7	3 to 5	0.6 to 0.89	0.4 to 0.7	3 to 5	0.6 to 0.89
Focal Plane Array Size		640 X 480 InSb			640 X 480 InSb		
Autotracker		Yes			Yes		
Laser Rangefinder Designator		Yes			Yes		
Eyesafe Laser Rangefinder		Not Installed			Yes		
Laser Illuminator		Yes			Yes		
Laser Spot Detection		Yes			Yes		
Inertial Measurement Unit		Yes			Yes		
Target Location Error		Weapons Quality			Weapons Quality		



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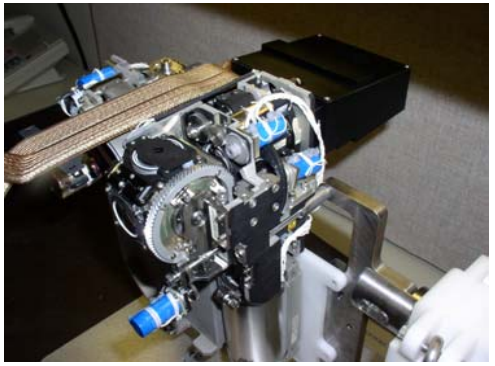
MTS-B Hardware



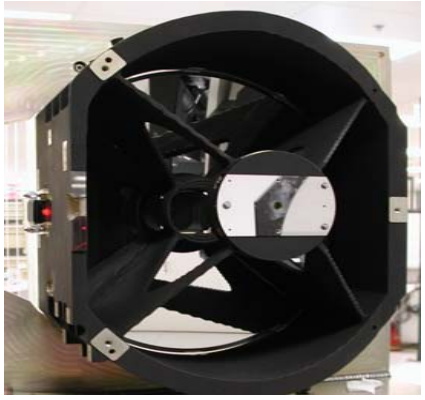
MTS-B Gimbal



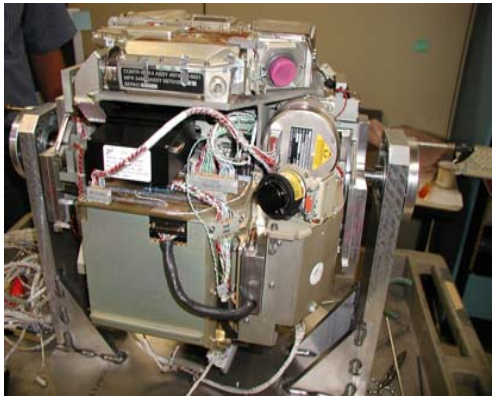
MTS-B Turret Unit



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Unmanned Aircraft Systems Sensors

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THE VULNERABILITIES OF UNMANNED AIRCRAFT SYSTEM COMMON DATA LINKS TO ELECTRONIC ATTACK

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements for the degree

MASTER OF MILITARY ART AND SCIENCE
General Studies

by

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B.S., Weber State University, Ogden, Utah, 1998

Fort Leavenworth, Kansas
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Unmanned aircraft are fulfilling critical roles in Iraq and Afghanistan. They are integral in base defense plans and the protection of key infrastructure. They enable commanders to monitor activity throughout their area of responsibility and direct action, when required. Many policymakers see Unmanned Aircraft Systems as a cost effective alternative to manned aircraft and a way to prevent risking a pilot's life. These systems have a number of advantages over manned aircraft. They are unbound by human limitations. They can remain airborne for long durations, do not require life support systems, do not need to eat or sleep, and they will never say no to a mission. They may minimize friendly loss of life by conducting missions that have a minimal chance of survival. However, unmanned systems also have some disadvantages when compared to manned aircraft. They are still prone to human error due to their being flown by ground-based operators. Their development and procurement cost has grown exponentially as capabilities increase. Current systems are not autonomous and their control is contingent on uninterrupted communications. Their dependence on a constant control signal has contributed to a UAS accident rate 100 times greater than manned aircraft A threat could exploit this need for an uninterrupted data feed by using Electronic Warfare to disrupt this signal, potentially crippling unmanned systems.

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

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ABSTRACT

THE VULNERABILITIES OF UNMANNED AIRCRAFT SYSTEM COMMON DATA LINKS TO ELECTRONIC ATTACK, by Major Jaysen A. Yochim, 118 pages.

Unmanned Aircraft are fulfilling critical roles in Iraq and Afghanistan. They are integral in base defense plans and the protection of key infrastructure. They enable commanders to monitor activity throughout their area of responsibility and direct action, when required. Many policymakers see Unmanned Aircraft Systems as a cost effective alternative to manned aircraft and a way to prevent risking a pilot's life. These systems have a number of advantages over manned aircraft. They are unbound by human limitations. They can remain airborne for long durations, do not require life support systems, do not need to eat or sleep, and they will never say no to a mission. They may minimize friendly loss of life by conducting missions that have a minimal chance of survival. However, unmanned systems also have some disadvantages when compared to manned aircraft. They are still prone to human error due to their being flown by ground-based operators. Their development and procurement cost has grown exponentially as capabilities increase. Current systems are not autonomous and their control is contingent on uninterrupted communications. Their dependence on a constant control signal has contributed to a UAS accident rate 100 times greater than manned aircraft A threat could exploit this need for an uninterrupted data feed by using Electronic Warfare to disrupt this signal, potentially crippling unmanned systems.

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ACRONYMS

AC2	Airspace Command and Control
ADAM	Air Defense Airspace Management
AE	All Environment
AGL	Above Ground Level
AMPS	Aviation Mission Planning System
ANCOC	Advanced Non-Commissioned Officer Course
AO	Area of Operations
APART	Annual Proficiency and Readiness Test
AR	Army Regulation
ASI	Additional Skills Identifier
ATM	Aircrew Training Manual
ATO	Air Tasking Order
AVGAS	Aviation Gas
BAE	Brigade Aviation Element
BAMS	Broad Area Maritime Surveillance
BCT	Brigade Combat Teams
BLOS	Beyond Line of Sight
BNCOC	Basic Non-Commissioned Officer Course
C2	Command and Control
C4ISR	Command, Control, Communication, Computer, Intelligence, Surveillance and Reconnaissance
CA	Coordinating Altitude
CAB	Combat Aviation Brigades

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CAB	Combined Arms Battalion
CBO	Congressional Budget Office
CDL	Common Data Link
C-IED	Counter-Improvised Explosive Device
CJCS	Chairman Joint Chiefs of Staff
COCOM	Combatant Command
COMSEC	Communications Security
COP	Common Operational Picture
CRP	Communications Relay Package
CTC	Combat Training Center
DARO	Defense Airborne Reconnaissance Organization
DOD	Department of Defense
DOTMLPF	Doctrine, Organization, Training, Material, Leadership, Personnel, and Facilities
EA	Electronic Attack
ECCM	Electronic Counter-Countermeasures
ECM	Electronic Countermeasures
EHF	Extremely High Frequency
EM	Electromagnetic Jamming
EO	Electro Optical
EP	Electronic Protection
ERMP	Extended Range/Multi-Purpose
EW	Electronic Warfare
EWS	Electronic Warfare Support
FAA	Federal Aviation Administration

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FCS	Future Combat System
FM	Field Manual
FMV	Full Motion Video
FYDP	Future Years Defense Plan
GAO	Government Accountability Office
GCS	Ground Control Station
GMTI	Ground Moving Target Indication
GPS	Global Positioning System
HIMEZ	High Altitude Missile Engagement Zone
HMMWV	High Mobility Multi-purpose Wheeled Vehicles
IFF	Identification Friend or Foe
IR	Infra-Red
ISR	Intelligence, Surveillance, and Reconnaissance
JCIGCS	Joint Common Interoperable Ground Control Station
JDDC	Joint Doctrine Development Community
JDPC	Joint Doctrine Planning Conference
JFACC	Joint Forces Air Component Commander
JFC	Joint Force Commander
JP	Joint Publication
LOS	Line of Sight
LRFD	Laser Range Finder Designator
LRS	Long Range Surveillance
MOI	Memorandum of Instruction
MPH	Miles per Hour
MSL	Mean Sea Level

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MTT	Mobile Training Teams
NATO	North Atlantic Treaty Organization
NRL	Naval Research Laboratory
NTC	National Training Center
OC	Observer/Controller
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OSGCS	One System Ground Control Station
OSRVT	One System Remote Viewing Terminal
PEO AVN	Program Executive Office Aviation
RDT&E	Research, Development, Test and Evaluation
RL	Readiness Level
ROE	Rules of Engagement
RSTA	Reconnaissance, Surveillance, and Target Acquisition
RVT	Remote Viewing Terminal
S-APART	Semi-Annual Proficiency and Readiness Test
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
SECDEF	Secretary of Defense
SHF	Super High Frequency
SIP	Standardization Instructor Pilot
SIP	Standardization Instructor Pilot
SME	Subject Matter Expert
SOCOM	Special Operations Command
SUAS	Small Unmanned Aircraft System

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SUAV	Small Unit Unmanned Aerial Vehicle
TACS	Theater Air Control System
TC	Training Circular
TF	Task Force
TUAS	Tactical Unmanned Aircraft System
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
US	United States
USA	United States Army
USAF	United States Air Force
USJFCOM	United States Joint Forces Command
USN	United States Navy
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
VDL	Video Data Link

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CHAPTER 1

INTRODUCTION

> We're at a real time of transition, here, in terms of the future of aviation, and the whole issue of what's going to be manned, and what's going to be unmanned, and what's going to be stealth and what isn't. How do we address these threats? . . . . I think we're at the beginning of this change. I mean, there are those that see JSF as the last manned fighter--fighter-bomber--or jet. And I'm one that is inclined to believe that.
>
> — Admiral Michael G. Mullen, USN, Chairman, Joint Chiefs of Staff

Unmanned Aircraft (UA) are fulfilling critical roles in Iraq and Afghanistan. They are integral in base defense plans and the protection of key infrastructure. They enable commanders to monitor activity throughout their area of responsibility and direct action, when required. Many policymakers see Unmanned Aircraft Systems (UAS) as a cost effective alternative to manned aircraft and a way to prevent risking a pilot's life.

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Research Service 2005, 2). A threat could exploit this need for an uninterrupted data feed by using Electronic Warfare (EW) to disrupt this signal, potentially crippling unmanned systems.

Military aviation is in a transitional phase. Determining the future force structure and the required equipment is a complex proposition, and this transformation demands extensive research and development. The research and development effort will be expensive and time-consuming. US military aviation stands to remain the dominant global airpower force if their vision of the future force is correct, but if their vision is incorrect, it will be fighting to regain airpower relevancy.

Background

The history of unmanned aerial flight is long and diverse, reaching back to the early years of military aviation. Military aviation, as a distinct organization, was first established in 1912 with the formation of the British Royal Flying Corps (Royal Air Force Organization 2009). Military aviation innovation continued to progress and soon military forces began using aircraft to spot for artillery and limited reconnaissance. The combat effectiveness of aircraft supporting ground warfare resulted in the birth of anti-aircraft artillery, but early anti-aircraft gunners were ineffective, due to inadequate training. In 1917, the British Army requested a system that would improve training for anti-aircraft gunners. The government assigned Archibald Montgomery Low, a pre-war physicist, engineer, and inventor who some consider the father of radio guidance, with the task of developing such a system. On 21 March 1917, he designed and tested the first Unmanned Aerial Vehicle (UAV) known as the Ruston Proctor Aerial Target (Bloom 1958, 142).

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In World War II, the remotely operated aircraft experienced its next evolution. The most famous unmanned systems of World War II were the German V1 and V2 guided munitions. These systems were pre-programmed with an area target, guided by simple autopilots, and were completely autonomous once launched. While impressive and a critical concern for the British, the German Henschel Hs 293 and Ruhrstahl Fritz-X were the most successful unmanned systems of the war. Both were air launched, radio guided, anti-ship bombs and are credited with damaging or destroying 32 allied vessels (Bogart 1976, 62). The German military also used remotely operated Surface-to-Air and Air-to-Air Missiles (AAM) with minimal success. During this period, remotely operated systems were limited by their inability to reliably maintain communication links.

Throughout the Korean and Vietnam War Eras, the use of unmanned target drones, cruise missiles, and reconnaissance drones expanded. However, similar to the German V-1 and V-2, these systems were auto-piloted, and not remotely guided. In 1986, the UAV entered the modern era with the development of the British Phoenix and United States/Israeli Pioneer. For the first time, these systems integrated remote guidance, range, endurance, payload, and cost into a reliable platform. Since 1986, unmanned system design, procurement, and utilization exploded globally (Goebel 2009). Most modern militaries are or have developed UAS programs and numerous countries are producing UASs. Asymmetric threats are also seeking UASs. In 2006, Israel acquired and shot down an Iranian produced UAS operated by Hezbollah, a non-state actor (Eshel 2006).

The use of unmanned systems is becoming a mainstay on the modern battlefield. Unmanned systems gather intelligence, observe key terrain, disable explosives, clear underwater mines, and perform a myriad of other missions. Future plans call for

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unmanned systems capable of ground combat, medical evacuation, troop transport, logistical support, and innumerable other functions limited only by the human imagination. UAS have become so integrated in modern military operations that some contest that unmanned systems have spurn an emerging Revolution in Military Affairs (RMA) (Edwards 2009, 4). Undeniably, the use of unmanned systems has spread beyond their original design concept.

Military leaders originally intended to utilize remote platforms on dirty, dangerous, and dull missions (Braybrook 2004). The logic was simple; when military leaders determined a mission profile caused undue risk to personnel, unmanned systems provide expendable options. However, the performance of unmanned systems in combat and the information they provide commanders, has transformed the view of these systems. Once a dispensable tool, they are now an invaluable asset. Military forces have become information dependent organizations were command centers serve as the information hub.

The design and layout of Tactical Operations Centers (TOC) support the gathering, processing, and redistribution of information. The geographic center of most TOCs consists of a digital map, a computerized significant event tracker, and a display showing UAS Full Motion Video (FMV). The real-time information provided by these airborne systems is processed and analyzed within the TOC resulting in the development of intelligence. In essence, the UAS has become the commander's window to the battlefield. If required, commanders can rapidly redeploy these systems throughout the battle space ensuring the ability to see the operational environment. While these systems have proven important to combatant commanders, has the United States military become

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over reliant on UAS? If the answer to this question is yes, then protection of the electromagnetic spectrum must be a mission priority.

Remotely operated UASs require two separate radio communications links to operate: one communications link feeds FMV to a Remote Viewing Terminal (RVT) through a Video Data Link (VDL), the other communication link controls the UAS through a Common Data Link (CDL). The VDL uses an omnidirectional antenna to broadcast its communication feed in all directions, allowing any RVT tuned into the UASs VDL frequency to observe the UASs FMV. Video quality and consistency of reception is dependent on the VDL signal strength. The CDL can use either an omnidirectional antenna or a directional antenna that broadcasts only in the direction of the Ground Control Station (GCS) (Hill 2010).

If a CDL experiences frequency interference, the UA executes a self-recovery program known as a "lost link procedure" and attempts to reacquire the CDL from the GCS. If smaller UA, such as the RQ-11 Raven, fails to reacquire the CDL, it continues its self-recovery program and returns to a preprogrammed recovery point. When some larger UA, such as the RQ-7 Shadow, fail to reacquire the CDL, the operators may identify the UA as rogue and deploy a recovery parachute to avoid endangering manned aircraft (Hill 2010).

The scope of this research is limited to Man-Portable and Tactical UAS as defined in Field Manual (FM) 3-04.15, *Multi-Service Tactics, Techniques, and Procedures for the Tactical Employment of Unmanned Aerial Systems,* dated 3 August 2006. These UAS operate in support of tactical commanders and at altitudes less than 10,000 feet. The systems referenced will primarily be US Army systems. This study presumes design

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philosophies and technologies are common throughout this class of UAS. However, if systems emerge that demonstrate minimal weaknesses, those systems will be identified as recommendations for future development.

The US military has conducted little research on counter Tactical UAS operations. The UAS field is scientifically complex and this researcher is not a scientist. Rather, the focus of this research is on the operational application of scientifically informed theory. Continuing, this research does not address the science of UAS vulnerabilities. Further scientific research is required to adapt UAS to counter threats once identified.

The primary question of this study is: Are UAS CDLs vulnerable to Electronic Attack (EA)? To address this question, the following secondary questions are relevant:

1. What are the ramifications of an EA on UAS CDL systems?
2. What countermeasures can mitigate EAs?
3. Using DOTMLPF, how has the Army prepared for EW?
4. What UAS are most susceptible to EW?

Significance

Today's commanders are using UASs throughout the battlefield. They have become indispensable to combat commanders and their ability to command and control forces. The Joint force has revised doctrine to account for their abilities to shape the battlefield environment. If threat forces develop a technique to deter UAS operations, it could drastically effect how the US, as well as other militaries, operates. Additionally, the design and procurement of UAS has expanded due to the relative reliability of UAS in an uncontested environment. Consequently, due to budgetary constraints the US military has favored increased funding to the research and development of unmanned systems over

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manned vehicles. Some military analysts have professed an UA might ultimately replace existing and recently developed observation and attack aviation assets as well as fighter platforms. The aircraft affected would include the OH-58, AH-1, AH-64, A-10, F-16, F-22, and F-35 (Allexperts 2005). Thus, innovative research and development of advanced manned aircraft, specifically attack rotary wing, has been limited in the United States. Instead, the United States has favored modernization of current manned aircraft with minimal planning for replacements. While effective in the current environment, if unmanned systems are susceptible to EA, the future force might not receive the vital services manned aircraft currently provide.

Assumptions

The US military is an expeditionary force that projects its power globally. As such, its equipment tends to be mobile, hardened, and durable. If the equipment requires power, it is often vehicle mounted or tied into a power generation grid. Due to this specialization, US equipment tends to be large and expensive. As an expeditionary force, they tend to fight wars on foreign soil.

Mobility requirements do not bind current or future adversarial forces when planning their internal defenses. Equipment designers do not need to account for mobility or durability in their designs. Their equipment will utilize existing infrastructure and thus have an unlimited power potential. These designs may be technologically advanced, but simple to produce. The simplicity allows for indigenous production. Compiled, these advantages reduce the equipment cost and allow for higher equipment inventories.

Further, an adversary's mission may not depend on shooting down an UAS. As mentioned earlier, commanders utilize the information provided by UAS to plan,

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synchronize and execute combat operations. They rely upon UASs to increase their situational awareness and expand their command and control (C2) capabilities to assess effects and direct forces as required to achieve mission objectives. But for the adversary, denying commanders the ability to effectively use a UAS may represent a tactical victory.

Throughout history, warfare has driven the adaptation and production of new equipment. Complex equipment, such as aircraft, requires an expensive and lengthy procurement process. The time required to design effective countermeasures is lengthy if an adversary is able to design an effective counter UAS weapon.

Further, historically adversaries have used the US forces Rules of Engagement (ROE) to their advantage. Future adversaries will continue to use the US ROE to their advantage. Their counter-UAS weaponry will be intermixed with their civilian populace. These tactics mitigate the US military's ability to target such weaponry by conventional means.

Definitions of Key Terms

Listed below is a brief glossary of key terms relevant to this study. Based on Joint and Army Publications, these definitions will aid the reader in understanding the concepts and analysis presented in this paper.

Common Data Link (CDL). The means of connecting an UA to a GCS for the purpose of transmitting and receiving flight command data inputs necessary to control UAS while in flight (US Joint Forces Command 2009b, 111).

Countermeasures. That form of military science that, by the employment of devices and/or techniques, has as its objective the impairment of the operational effectiveness of enemy activity (US Joint Forces Command 2009b, 101).

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Electronic Countermeasures (ECM). A subsection of EW, ECMs defend against forms of EA or surveillance including communication jamming, radar acquisition, and radar tracking (US Joint Forces Command 2009b, 101).

Electromagnetic Interference (EMI). Any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades or limits the effective performance of electronics and electrical equipment. It can be induced intentionally, as in some forms of EW, or unintentionally, as a result of spurious emissions and responses, intermodulation products, and the like (US Joint Forces Command 2009b, 135).

Electromagnetic Jamming. The deliberate radiation, reradiation, or reflection of electromagnetic energy for the purpose of preventing or reducing an enemy's effective use of the electromagnetic spectrum, and with the intent of degrading or neutralizing the enemy's combat capability (US Joint Forces Command 2009b, 135).

Electromagnetic Spectrum. The range of frequencies of electromagnetic radiation from zero to infinity. It is divided into 26 alphabetically designated bands (US Joint Forces Command 2009b, 47).

Electronic Attack (EA). Division of EW involving the use of electromagnetic energy, directed energy, or antiradiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability and is considered a form of fires (US Joint Forces Command 2009b, 47).

Electronic Warfare (EW). Military action involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or to attack the enemy. EW consists of three divisions: EA, Electronic Protection (EP), and Electronic Warfare Support (EWS) (US Joint Forces Command 2009b, 137).

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Line of Sight (LOS). The unobstructed path from a soldier, weapon, weapon sight, electronic-sending and -receiving antennas, or piece of reconnaissance equipment to another point (Headquarters, Department of the Army 2004, 125).

Man-portable UAS. These UAS are small, self-contained, and portable. They usually operate below the coordinating altitude. Their use supports the small ground combat teams/elements in the field. They are self-contained and controlled at the combat team level. Data is usually direct FMV constrained to LOS to the operator only (Headquarters, Department of the Army 2006a, 14).

Remote Video Terminal (RVT). An RVT enables a user to receive UAS video away from a GCS. RVTs are designed to be portable and compatible for operations in battlefield command vehicles and some aircraft (Headquarters, Department of the Army 2006a, 18).

Tactical UAS. Tactical UAS are larger systems that support maneuver commanders at various tactical levels of command and can also support the small combat teams when so employed. They are deployable among the tactical command levels and are operated by specialized UAS units, locally controlled and operated. Data products can expand beyond FMV depending on UAS payload configuration and can be disseminated to combat teams in real time using an RVT (Headquarters, Department of the Army 2006a, 14).

Theater UAS. Theater UAS are generally deployed to support theater-wide requirements. Theater UAS permit varied support to combat team and subordinate tactical command levels depending on the type of UAS. The theater UAS design and robust C2 architecture permit split site operations. Specifically, the UA can be deployed

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to theater with mission C2 and data collection, processing and dissemination being conducted locally or outside of theater of operations under reachback conduits (Headquarters, Department of the Army 2006a, 15).

Unmanned Aerial Vehicle (UAV). A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semiballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles (US Joint Forces Command 2009b, 419).

Unmanned Aircraft (UA). An aircraft or balloon that does not carry a human operator and is capable of flight under remote control or autonomous programming (US Joint Forces Command 2009b, 419).

Unmanned Aircraft System (UAS). That system whose components include the necessary equipment, network, and personnel to control an unmanned aircraft (US Joint Forces Command 2009b, 419).

Video Data Link (VDL). The means of connecting an UA to a RVT for the purpose of transmitting and receiving FMV (US Joint Forces Command 2009b, 111).

Limitations

This study is limited to the Man-Portable and Tactical UAS classes, the most commonly used systems by tactical units. The US military has conducted limited research on counter UAS operations against these classes and this research is beyond the classification of this study. This study will examine the Army Readiness Center research on UAS reliability but these records are incomplete due to inconsistencies in reporting of Man-Portable UAS accidents. Man-Portable and Tactical UAS are untested in an active

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EA environment due to the relative age of these technologies. Therefore, no combat findings are available to add to this study. This qualitative study may identify operational theories that require further scientific research. However, it will not present scientifically tested solutions to a known problem, though it may identify an unknown problem that requires a scientific solution. In order to maximize distribution, this study remains unclassified.

Delimitations

The focus of this study is external threats to the UAS CDLs. This study will not cover fully autonomous UAS or their internal navigation control systems. The focus is on UA intended to complete an entire mission sortie through a successful recovery. Therefore, this research does not include remotely guided munitions such as cruise missiles, wire guided missiles, radio guided munitions, or precision guided bombs.

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CHAPTER 2

LITERATURE REVIEW

> Technology is not the limitation . . . it's the ability of people to conceive of ways to use the technology.
>
> — Rich O'Lear, VP for Unmanned Aircraft Systems, Lockheed Martin

Six types of literature are relevant to this study. The first is Joint and service doctrine including Joint Publications (JP), Army FMs, and Multi-Service Manuals that concentrate on the training, operation, and command and control of UAS. Second, government white papers, congressional reports, and service studies contain a vast amount of information. Third, professional journals such as Jane's, Armada International, and Journal of Electronic Defense contain information from analysts, researchers, and manufactures. Fourth, books including institutional textbooks, reference books, and history books detail research and experiences involving UAS. Fifth, to the dynamic nature of this studies subject, this study will review numerous blogs as well as print, video, and web based news reports. Lastly, the UAS industry has published numerous fact sheets, brochures, and information papers to advertise their products.

This chapter will first review the types of literature this study may use to answer the primary research question. Next, this chapter analyzes the existing literature in order to identify the gaps in the record and identify pertinent military trends. Lastly, this chapter describes the significance of the thesis in relation to existing literature.

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Doctrine

Joint Doctrine

The Joint doctrine regarding UAS is not current and does not reflect lessons learned during combat operations in Iraq and Afghanistan. Consequently, Joint Publications (JP) offer little new information regarding UAS training, employment, or command and control. There are also inconsistencies in UAS terminology.

There are four noteworthy Joint or multi-service publications relevant to this UAS discussion. The base JP for UAS is JP 3-55.1, *Joint Tactics, Techniques, and Procedures for Unmanned Aerial Vehicles,* dated 27 August 1993. The focus of this publication is the Reconnaissance, Surveillance, and Target Acquisition (RSTA) capabilities UAS deliver to the battlefield. It attempts to establish basic terminology, determine UAS classifications, identify airspace considerations, and recommend methods of employment. However, most of the Joint doctrine contained in JP 3-55.1 is outdated and does not incorporate lessons learned in Iraq and Afghanistan, or account for UAS innovation over the last decade. This JP does not address employment or considerations of armed UAS. In addition, the publications doctrine uses inconsistent UAS terminology and individual service doctrine terminology often differs from Joint doctrine.

The most current multi-service UAS publication is FM 3-04.15, *Multi-Service Tactics, Techniques, and Procedures for the Tactical Employment of Unmanned Aerial Systems,* dated 3 August 2006. This publication adds fidelity to the tactics, techniques, and procedures introduced in JP 3-55.1. It discusses planning considerations, employment tactics, and communications procedures for armed and RSTA UAS platforms. However, the classification of UAS platforms in FM 3-04.15 differs from the

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UAS classifications in JP 3-55.1. To establish common terminology, this study uses the UAS platform classifications identified in FM 3-04.15.

The primary procedural control publication for UAS is, JP 3-52 *Doctrine for Joint Airspace Control in the Combat Zone, dated*, 22 July 1995. This literature concentrates on procedural control of UAS in congested airspace to mitigate risk. It discusses considerations requiring attention to integrate UAS into manned airspace, such as difficulties using radar to acquiring and tracking UAS due to their unique design, construction and design profile.

The Joint community's primary Electronic Warfare (EW) doctrine is, JP 3-51 *Joint Doctrine for Electronic Warfare*, 7 April 2000. This publication does not specifically address UAS employment, considerations, or vulnerabilities. Rather, the focus of JP 3-51 is the fundamentals and principles of EW. The Joint environment breaks EW into EA, EP, and EWS. This study draws on the EA and EP aspects of this publication. This information allows for determining what type of EW can affect UAS CDL and what protection designs are possible.

Army Doctrine

There are four Army Field Manuals (FM), Training Circulars (TC), or Army Regulations (AR) pertinent to this study. The capstone Army publication is, FM 3-04-155, *Army Unmanned Aircraft System Operations*, dated 29 July 2009. FM 3-04-155 informs commanders, staff, and soldiers on the operation and employment of UAS. It is the foundation for the further refinement of tactic, techniques, and procedures. In addition to the traditional ISR considerations, this manual accounts for lessons learned during operations in Iraq and Afghanistan and employment of armed UAS. Due to its recent

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update, FM 3-04-155 is relevant in the current operational environment and lays out the Army's vision for future UAS operations.

The Army's primary training publication for Tactical UAS is, TC 1-600, *Unmanned Aircraft Systems Commander's Guide and Aircrew Training Manual*, dated 23 August 2007. As with all Aircrew Training Manuals (ATMs), TC 1-600 standardizes aircrew training and determines flight evaluation procedures. It also establishes crewmember qualification, refresher, and mission readiness training standards for Tactical UAS, such as the MQ-5 Hunter and RQ-7 Shadow. Tactical UAS crewmembers are school trained and are Military Occupational Specialty (MOS) qualified. They must maintain a higher standard of training than operators of Man-Portable UAS and complete an annual flight physical similar to rated aviators.

The primary Man-Portable UAS training publication is, TC 1-611, *Small Unmanned Aircraft Systems and Aircrew Training Manual*, dated 2 August 2006. This ATM standardizes operator training for Man-Portable UAS. The guidelines and standards identified in TC 1-611 are not as strenuous as TC 1-600. Man-Portable UAS operators do not receive the same extensive training as Tactical UAS crewmembers and do not have an MOS qualification. This publication focuses on operators being proficient in the integration of their UAS in combined arms operations.

The AR mandating UAS operations is, AR 95-23, *Unmanned Aerial Systems Flight Regulations*, dated 7 August 2006. This regulation covers UAS operations, UA crewmember training, crewmember currency requirements, and flight rules. In contrast to the ATMs, AR 95-23 focuses on procedural control of planning, training, and execution

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to ensure safety of operation. This publication is applicable to all Army UAS classifications.

US Governmental Reports

The US government has published four white papers that discuss UAS operations. The most comprehensive of these papers is, *FY2009–2034 Unmanned Systems Integrated Roadmap*, dated April 2009. This paper details the importance of current UAS in the combat environment and lays out the military's future UAS strategy. This paper targets a wide audience including military leaders, academic institutions, UAS industries, and government officials. The purpose of the roadmap is to explain UAS capabilities in the current operational environment and identify potential combat applications on tomorrow's battlefield. This paper culminates with a projection of future UAS technologies, missions, and implications on the 2034 battlefield.

In contrast, the *Defense Science Board Study on Unmanned Aerial Vehicles and Uninhabited Combat Aerial Vehicles*, dated February 2004, focuses on current operations, not future operations. The report details current UAS tactics and technologies found in Iraq and Afghanistan. Unlike the roadmap, this report is a critical review of the current UAS structure and issues recommendations for improvement. One of the issues identified is UAS CDL communications failures (Defense Science Board 2004, 43).

Next, *Unmanned Aerial Vehicles: Background and Issues for Congress*, dated 21 November 2005, is a comprehensive information paper written for members of congress. This article also explains the advantages UAS present on the modern battlefield. This paper includes the implications of UAS production on the American industrial base, and presents considerations for UAS export and possible implications of UAS proliferation.

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In considering export potential, this paper details various UAS types including obsolete systems no longer found in the US inventory.

Lastly, the *Unmanned Aerial Vehicle Reliability Study*, dated February 2003, examines current Defense Department UAS to determine the risk posed by unmanned aviation to persons and property due to accidents. The DOD commissioned this study under its campaign to influence the FAA to allow UAS utilization in national airspace. This study attempts to identify issues of reliability and recommend solutions to improve reliability. Pertinent to this research, the study details UAS mishaps related to communication interference.

Professional Journals

Three noteworthy journals contribute to this study. The most important of these is *Jane's Unmanned Aerial Vehicles and Targets*, a non-governmental journal, not subject to UAS industry influence. It details UAS produced in the US and those produced globally. Jane's explains UAS technology with greater fidelity than any other publication and identifies foreign states with active UAS industries. It also details states that actively export UAS technology. This journal allows for examination of commonalities found in UAS globally and threats related to forces being able to obtain similar systems and develop UAS countermeasures.

Armada International is monthly publication focused on the defense industry and issues a comprehensive annual report on UAS. This annual report details current and future UAS globally, although it is not as detailed as *Jane's Unmanned Aerial Vehicles and Targets.* However, where Jane's tends to focus only on current military systems,

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Armada examines military and prominent civilian systems still in the developmental phase.

The final publication is the *Journal of Electronic Defense* produced by the Association of Old Crows, a nonprofit international professional organization specializing in EW. This journal reports on trends, industry news, and other developments in the EW field. Concerning this study, the journal's EW coverage includes electronic countermeasures (ECM), airborne EA, and command and control warfare.

Books

Four books provide texture to this study. The first of these books is *Advances in Unmanned Aerial Vehicles,* edited by Kimon P. Valaavanis. The book does not focus on military UAS. Rather, it is a compilation of articles written by civilian researchers across the world. It is written and edited by civilians and allows them to share information. The book gives a detailed history of civilian UAS theory and research, and discusses control fundamentals, aspects of navigation, and application of these principles in current projects. Of greatest interest to this study, *Advances in Unmanned Aerial Vehicles* discusses numerous control designs that could provide direction for military UAS CDLs.

In *Modern Communications Jamming Principles and Techniques,* author Richard Poisel explains the science of disrupting modern communications. Dr. Poisel does not write for a military audience. However, the information provided is applicable to military operations. The book discusses the operational use and vulnerabilities of modern communications systems. It identifies forms of jamming including active, passive, structural, and environmental. The book provides examples of jamming techniques and

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explains their advantages and disadvantages. It also indentifies principles of anti-jamming technology and tactics.

In contrast, *Fundamentals of Electronic Warfare*, by Sergei Vakin, Lev Shustov, and Robert Dunwell is intended for a military audience. The book is a detailed description of EW in modern warfare, and provides a short history of EW and its application in historical context. *Fundamentals of Electronic Warfare* is both a scientific text, which details the mathematical models of EW and an operational text that explains EW tactics. Further, it explains active and passive jamming of electromagnetic energy. Unlike *Modern Communications Jamming Principles and Techniques*, this text concentrates on EW directed against or produced by aircraft.

The final book, *Wired for War*, by P. W. Singer is not a science-based text. Singer conducted an exhaustive study on the science of UAS, current application of UAS technology, and the potential UAS future. Singer believes there is an ongoing UAS RMA and that the proliferation of robotics has changed the face of warfare. This book also identifies robotics limitations and exposes the myth of computer infallibility. Singer discusses the global proliferation of robotics in military and paramilitary organizations, and contends the global proliferation of robotic systems could undermine America's perceived dominance.

Media

This study intends to use two real time sources of information. The first of these is news coverage from print, video, and web based media. On a regular basis, these outlets detail UAS combat operations. However, these sources do have limitations. They report high profile events such as UAS attacks and UAS crashes yet lack many of the relevant

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facts surrounding these events. Despite these drawbacks, some of these reports may contribute to the depth of this study.

This study also uses a number of professional blogs. The first blog is the Congressional Unmanned Aerial Vehicle Caucus co-chaired by Rep. Howard "Buck" McKeon and Rep. Alan Mollohan of the US House of Representatives. This caucus' mission is to educate members of Congress and the public on the strategic, tactical, and scientific value of UAVs. Another potential blog for review is UAVforum.org, an online working group that discusses global UAS research and advances. Many of the systems discussed on UAVforum are non-US designs and generally not reported on in US sources.

UAS Industry Releases

This study used fact sheets, brochures, and information papers from UAS manufactures. AeroVironment, Inc. and AAI Corporation produced the most important products due to their share of the UAS market. General Atomics Aeronautical Systems, Inc, Honeywell, and Northrop Grumman information was also reviewed to determine their systems capabilities.

These documents are industry advertizements that tend to espouse capabilites and ignore limitations. This study used these products to develop an understanding of system specifications and capabilites.

Review of Current UAS

To call a UAS a remote control airplane is simplistic. An UAS is a complex integration of various technologies designed to operate in austere environments. They

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consist of three separate major components an UA, a GCS, and a RVT. Multi-echelon military leaders depend on UAS to increase their situational awareness and enable decision-making. The CDL structure of UAS varies based on the size, mission, and capabilities of the UA.

The differing service components have had their own UAS classifications. To prevent confusion, this research utilize the broad multi-service UAS classification as defined in FM 3-04.15, *Multi-Service Tactics, Techniques, and Procedures for the Tactical Employment of Unmanned Aerial Systems,* dated 3 August 2006 (see table 1). This multi-service manual categorizes UAS into three main classes: Man-Portable, Tactical, and Theater UAS. The employment philosophies of differing classes are similar, but the limitations of some airframes require tactical adaptations. UAS within these classifications have similar CDL structure due to common manufactures, similar operational environments, and DOD mandated interoperability directives.

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Table 1. UAS Capabilities

	Speed (knots)		Maximum Altitude	Maximum Endurance[1]	Maximum Range
	Cruise	Dash			
Man-portable					
Desert Hawk	50	50	1,000 AGL	1 hr	10 km^2
Dragon Eye	45	45	500 AGL	1 hr	10 km^2
Pointer	45	45	985 AGL	1 hr	5 km^2
Raven	34	60	1,000 AGL	1 hr	10 km^2
Silver Fox	50	50	1,000 AGL	10 hrs	32 km^2
Tactical					
Hunter	70	100	15,000 MSL	8-9 hrs	125 $km^{2\,\&\,4}$
IGNAT	70	120	25,000 MSL	30 hrs	500 nm^2
Pioneer	65	110	15,000 MSL	5 hrs	185 km^2
Scan Eagle	70	70	19,000 MSL	15 hrs	110 km^2
Shadow	70	105	15,000 MSL	5 hrs	50 km^2
Fire Scout	80	125	20,000 MSL	6 hrs	280 km^2
ERMP	70	150	29,000 MSL	36 hrs	1200 km^2
Theater					
Global Hawk	310	340	60,000 MSL	28 hrs	5,400 nm^3
Predator	70	117	26,000 MSL	20 hrs	500 nm^3
Predator B	90	220	45,000 MSL	16 hrs	500 nm^3

[1] Endurance equals total time from takeoff to landing.
[2] Range equals range from GCS.
[3] Range equals total mechanical range of UA.
[4] With retransmission, range equals 200 km.

Source: Headquarters, Department of the Army, FM 3-04.15, *Multi-Service Tactics, Techniques, and Procedures for the Tactical Employment of Unmanned Aircraft Systems* (Washington, DC: Government Printing Office, 2006), 21.

Man-Portable UAS

Man-Portable UAS are small, self-contained, portable systems often employed at the lowest levels of command. This class of UAS operates at lower altitudes and often shares airspace with manned rotary-wing aircraft. Most tactical organizations that employ these systems have a single operator, selected from within the unit, who has attended a qualification course. Man-Portable UAS operators are required to attend a certification course, but do not receive an Additional Skills Identifier (ASI).

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Current Man-Portable UAS are either hand-launched, bungee launched, or take-off vertically. The operator commands the UAS by maintaining a CDL between the UA and the GCS. The UAS broadcasts its FMV to any RVT within range of the system, which is monitoring the correct VDL. Man-Portable UAS have shorter ranges than other systems due to their dependence on LOS communications and lower operating altitudes (Headquarters, Department of the Army 2006a, 14).

These UAS use omnidirectional antennas for both their CDL and VDL. In theory, the simplicity of the antenna design improves CDL reliability and maximizes VDL distribution. Additionally, the omnidirectional antenna configuration and interoperability allows any GCS broadcasting the appropriate CDL frequency to command the UA. This flexibility enables multiple operators to command a single UA by transferring command using a CDL "*handshake*", effectively extending the range of a single UAS. However, an incorrectly performed handshake can result in a disruption of the CDL and cause a crash. Man-Portable UAS rarely utilize this function to avoid risk of an accident (Hill 2010).

Current Man-Portable UAS in include the RQ-16 Tarantula Hawk (T-Hawk), RQ-11 Raven, RQ-14 Dragon Eye, Puma AE, and Wasp. The following is a review of the design characteristics of these current UAS designs (Headquarters, Department of the Army 2006a, 21).

RQ-16 Tarantula Hawk

The RQ-16 T-Hawk, produced by Honeywell Aerospace, is the newest Man-Portable UAS in the US Army inventory. The original Army designation for the system was the XM156 Class 1 UAS and was a subsystem of the Army's Future Combat System (FCS) (Department of Defense 2009, 86). The DODs review of the Army's FCS left the

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T-Hawk's future in doubt, but seeing the systems potential, the Navy adopted the XM156. In January 2008, the Navy surprised many by placing a surprise order for 186 XM156s and re-designated the system as the RQ-16 Tarantula Hawk (Trimble 2008). In Iraq, the Navy led Multi-Service Explosive Ordnance Disposal Group is currently using 20 T-Hawks to combat roadside bombs.

The T-Hawk is gasoline operated, has a range of up to 10 kilometers, and can remain airborne for 50 minutes (see figure 1). The system includes a GCS, a ground support package, and two UAs. The UA takes off vertically, flies to 100 waypoints at up to 46 Miles per Hour (MPH), can establish a stationary hover over a desired location, and communicates on L-band Ultra High Frequency (UHF). The UAS has a gimbaled sensor capable of recording Electro Optical (EO) and Infra-Red (IR) images. The GCS is capable of recording up to 240 minutes of FMV imagery. The T-Hawk is limited to LOS communications and cannot operate in moderate rain, heavy wind, or high temperatures (Honeywell Aerospace 2008).

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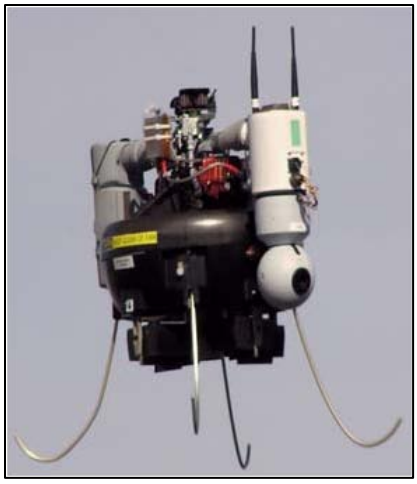


Figure 1. RQ-16 Tarantula Hawk
Source: FY2009–2034 Unmanned Systems Integrated Roadmap, DOD (Photo, FY2009–2034 Unmanned Systems Integrated Roadmap, DOD, 6 April 2009).

RQ-11 Raven

The RQ-11 Raven, produced by AeroVironment, Inc., is the most common Man-Portable UAS in the US military. In 2002, AeroVironment's Flashlight UAS won the Army's small UAV competition and was redesignated the RQ-11 Raven (Net Resources International 2010). The Raven is one of the world's most popular UAS with over 9,000 UAs produced for international clients, including all US military service branches and eight other international partners.

The Raven uses an electrical engine, has a range of up to 10 kilometers, and can remain airborne for up to 110 minutes (AeroVironment Inc. 2009c) (see figure 2). The system includes the Joint Common Interoperable Ground Control Station (JCIGCS), six individual sensor payloads, and three UAs (AeroVironment Inc. 2009e). The RQ-11 is hand-launched, flown either manually or on a preprogrammed route, flies up to 50MPH at 500 feet AGL, and performs a conventional belly landing. The Raven UAS has two

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sensor payloads; a dual forward and side-look EO nose camera with a stabilized electronic pan-tilt-zoom feature for daytime operations, and a forward and side-look IR nose camera for night operations. The JCIGCS is an AeroVironment designed interoperable GCS that provides FMV, captures screen images, stores data for playback during target assessment, communicates on L-band UHF frequencies, and is compatible with all other AeroVironment UAS. The Raven is limited to LOS communications and cannot operate in moderate rain or high winds (AeroVironment Inc. 2009c).



Figure 2. RQ-11 Raven
Source: Courtesy AeroVironment, Inc., Media Gallary, www.avinc.com (accessed 10 January 2010).

RQ-14 Dragon Eye/Swift

The RQ-14 Dragon Eye is an original Naval Research Laboratory (NRL) project, but AeroVironment designed the latest version of the UAS (AeroVironment Inc. 2009a). Production has been limited with the Navy, Marines, and Special Operations Command

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(SOCOM) being the primary users. The RQ-14s production run is complete with approximately 630 systems produced (Department of Defense 2009, 84). The RQ-14 is being phased out and replaced by the RQ-11 Raven.

The RQ-14 is a dual engine UAS, which uses electric engines (see figure 3). The system has a range of up to 10 kilometers and can remain airborne for up to 60 minutes. The RQ-14s UA is bungee launched, flown using an autopilot or on a preprogrammed Global Positioning Satellite (GPS) route, flies up to 40MPH at 500 feet AGL, and performs a conventional belly landing. The RQ-14 uses an EO payload for daytime operations and an IR payload for night operations. The Dragon Eye includes three interchangeable payloads: a GCS, three UAs, and two RVTs (AeroVironment Inc. 2009a). The improved Swift variant includes four interchangeable payloads, an AeroVironment JCIGCS, four UAs, and two RVTs. The JCIGCS provides FMV, captures screen images, stores data for playback during target assessment, and communicates on L-band UHF frequencies. The RQ-14 is limited to LOS communications and cannot operate in moderate rain or high winds (AeroVironment Inc. 2009e).

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Figure 3. RQ-14 Dragon Eye / Swift
Source: Courtesy AeroVironment, Inc., Media Gallary, www.avinc.com (accessed 10 January 2010).

Puma AE

The Puma AE, produced by AeroVironment, is an All Environment (AE) UAS intended for land or maritime operations but is still in the developmental phase (AeroVironment Inc. 2009b). The primary proponent for the Puma AE is SOCOM, but no orders have yet been placed. The Puma AE is comparable to the RQ-11 Raven but the Puma AE is waterproof and can land in water (Department of Defense 2009, 67).

The Puma AE has an electric engine, a range of up to 15 kilometers, and can remain airborne for up to 120 minutes (see figure 4). The Puma AE is hand launched, flown on a pre-programmed GPS route, flies up to 45MPH at 500 feet AGL, and performs a conventional belly landing on land or water. The Puma AE utilizes a gimbaled payload that pans plus or minus 180 degrees, tilts plus 10 to minus 90 degrees, uses both an EO and IR sensor, and contains an IR illuminator. The Puma AE uses the AeroVironment JCIGCS, which provides FMV, captures screen images, stores data for

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playback during target assessment, and communicates on L-band UHF frequencies (AeroVironment Inc. 2009e).



Figure 4. Puma
Source: Courtesy AeroVironment, Inc., Media Gallary, www.avinc.com (accessed 10 January 2010).

WASP III

The WASP III, produced by AeroVironment, is the smallest UAS in the US inventory. Its primary users are the Air Force, Navy, and Marine Corps (AeroVironment Inc. 2009d). The WASP III is a Micro-UAV but the DOD has not established a separate classification for micro systems. The DOD procurement plan does not detail the systems anticipated end strength, but AeroVironment has completed hundreds of systems with production continuing until 2012 (Department of Defense 2009, 68).

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The WASP III uses an ultra-quiet electrically powered engine, has a range of up to 5 kilometers, and can remain airborne for up to 45 minutes (see figure 5). The WASP III is hand launched, flown manually or on a preprogrammed route, flies up to 40MPH at 1000 feet AGL, and performs a conventional belly landing. Three payloads are available for the WASP III: a forward and side-look EO camera, a high-resolution EO camera with electronic pan/tilt/zoom, and an IR imager. It uses the AeroVironment JCIGCS, which provides FMV, captures screen images, stores data for playback during target assessment, and communicates on L-band UHF frequencies (AeroVironment Inc. 2009e). The WASP III is limited to LOS communications and cannot operate in moderate rain or high winds. AeroVironment is also upgrading the WASP III and in the near future plans to offer a waterproof version (AeroVironment Inc. 2009d).

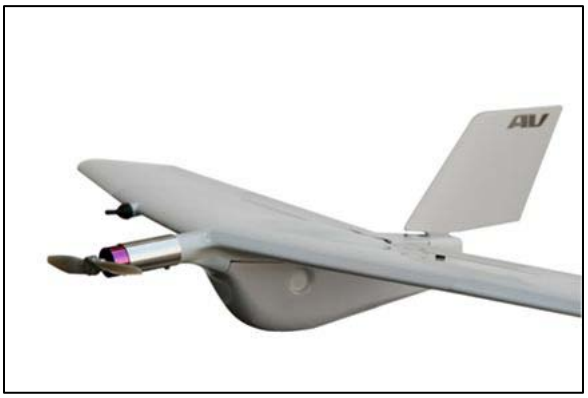


Figure 5. Wasp
Source: Courtesy AeroVironment, Inc., Media Gallary, www.avinc.com (accessed 10 January 2010).

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Other Man-Portable UAS

This review of Man-Portable UAS is not exhaustive but represents a cross section of the current US military fleet. The Silver Fox UAS is another UAS program of record produced by BAE Systems. This study did not review the Silver Fox due to its low production, lack of a procurement plan, and limited DOD interest in future development. The Desert Hawk III is a Lockheed Martin design and is primarily used by the Air Force and allied military forces. This study did not review the Desert Hawk III due to limited US procurement. Other UAS may be in the design phase of procurement but due to lack of information, these systems are included in this review (Department of Defense 2009).

Tactical UAS

Tactical UAS are larger than Man-Portable UAS and operates in support of maneuver commanders. These systems operate under restrictions similar to manned aircraft and require a more robust support structure than Man-Portable UAS. Tactical UAS belong to ground brigades, but Combat Aviation Brigades (CAB) often provide oversight as aviation safety experts (Hill 2010). CABs have a limited number of Tactical UAS but plans call for an expansion in CAB systems (Ford 2010). Brigades C2 these systems but they can operate in support of any organization with access to a RVT.

Tactical UASs may be launched using external power, such as a pneumatic catapult, or take off under its own power. In the US inventory, UASs in this class all land by conventional means, but some foreign made Tactical UAS land by parachute (Armada International 2009). These systems require extensive training to operate and pilots must maintain standards similar to rated-aviators. Tactical UAS require high-power mobile GCS to maintain control and are often dependant on maintaining constant LOS

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communications. These systems have more sophisticated sensors than Man-Portable UAS and use a single sensor payload for all mission profiles. The current fleet of Tactical UAS includes the RQ-7 Shadow, RQ-5 Hunter, I-GNAT, and MQ-1C Sky Warrior/Gray Eagle (Headquarters, Department of the Army 2006a, 21).

RQ-7 Shadow 200

The RQ-7 Shadow, produced by AAI Corporation, is the most common Tactical UAS in the US inventory and is in use by both the Army and Marine Corps (Department of Defense 2009, 89). The RQ-7 Shadow 200 is the flagship airframe of AAI's Shadow family of UAS. The Shadow family includes the Shadow 400 and Shadow 600 (AAI Corporation 2009a). These other Shadow UAS are larger than the RQ-7 and the US military has not shown interest in them. The US Army currently has 63 RQ-7 UAS in its inventory and procurement plans call for 115 systems in total (Department of Defense 2009, 89). In 2006, the Marine Corps selected the RQ-7 as a replacement for the aging RQ-2 Pioneer UAS, but the Marines have not determined their final system strength (Department of Defense 2009, 89).

The RQ-7B uses an Aviation Gas (AVGAS) fueled pusher prop engine, has a range of up to 125 kilometers, and can remain airborne for up to 6 hours (see figure 6). The Shadow 200 is launched using a trailer mounted pneumatic catapult rail system, flown manually, flies up to 140MPH at 14,000 feet MSL, and uses an automated Take Off and Landing System (TALS) to land conventionally on fixed landing gear (Department of Defense 2009, 89). The RQ-7B is equipped with plug-in optical payload (POP) 300, an Israeli made payload that includes a thermal imager, an EO sensor, a laser range finder (LRF), and an IR illumination for target identification (Tamam Division

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2010). The Shadow 200 uses the Army One System Ground Control Station (OSGCS) which can simultaneously operate numerous UA. This is housed in a climate-controlled shelter, provides UA health and fault monitoring, conducts video coding and decoding, and can archive up to 30 days of ISR data (AAI Corporation 2009b). The Shadow is limited to LOS communications and operates using S-band UHF/SHF frequencies for its CDL and C-band SHF frequencies for its VDL (Hill 2010). The Shadow 200 cannot operate in moderate-rain, extreme-winds, or turbulence (AAI Corporation 2009a).



Figure 6. RQ-7 Shadow 200
Source: FY2009–2034 Unmanned Systems Integrated Roadmap, DOD (Photo, FY2009–2034 Unmanned Systems Integrated Roadmap, DOD, 6 April 2009).

MQ-5 Hunter

The MQ-5 Hunter, produced by Northrop Grumman Corporation, is the latest variant of the RQ-5 medium-range Tactical UAS first introduced in 1996 (Department of Defense 2009, 79). The Army is only user of the Hunter and its service life is yet to be determined. The Army has cancelled and recalled the Hunter on numerous occasions out

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of operational necessity. The Hunter's first operational deployment was in support of NATO operations in the Balkans and it is currently operating in Afghanistan and Iraq (Department of Defense 2009, 79).

The MQ-5 operates using a heavy fuel engine, which incorporates a conventional and pusher prop in combination (see figure 7). The Hunter has a range of up to 200 kilometers, can remain airborne for up to 18 hours, and flies up to 125MPH at altitudes up to 18,000 feet MSL. The Hunter takes off conventionally, is manually flown, and lands using fixed landing gear (Department of Defense 2009, 79). The MQ-8 is equipped with an advanced payload that includes an EO/IR sensor, an IR illuminator, a laser range finder designator (LRFD), and a communications relay package (CRP). The MQ-5 can use the GBU-44/B, Viper Strike, a glide bomb that uses the Hunter's LRFD to attack targets. The Hunter uses the same OSGCS as the Shadow 200 allowing for simultaneous operation of numerous UA, is housed in a climate-controlled shelter, provides UA health and fault monitoring, conducts video coding and decoding, and can archive up to 30 days of ISR data (AAI Corporation 2009b). The Hunter is limited to LOS communications and uses a C-band SHF frequency for both its CDL and VDL (Northrop Grumman 2010).

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Figure 7. MQ-5 Hunter
Source: FY2009–2034 Unmanned Systems Integrated Roadmap, DOD (Photo, FY2009–2034 Unmanned Systems Integrated Roadmap, DOD, 6 April 2009).

I-GNAT

The I-GNAT, produced by General Atomics Aeronautical Systems, is an improved version of the GNAT 750 first introduced in 1989 (Department of Defense 2009, 75). The Army procured the I-GNAT in response to a congressional request for additional UAS to support operations in Afghanistan and Iraq. General Atomics Aeronautical Systems produced 25 I-GNATs in numerous variants, but its production run is complete. I-GNATs support operations until their service life expires. The MQ-1C is replacing these systems (Department of Defense 2009, 75).

Depending on the variant, the I-GNAT operates using either an AVGAS or a heavy fuel pusher prop engine with a LOS range of up to 250 kilometers or a BLOS range of 2500 kilometers, can remain airborne for up to 40 hours, and flies up to 140MPH at altitudes up to 25,000 feet MSL (see figure 8). The I-GNAT takes off conventionally, is manually flown, and lands using retractable landing gear. The system is equipped with an advanced payload that includes an EO/IR sensor, a LRFD, and a CRP

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(General Atomics Aeronautical Systems 2009b). The I-GNAT uses the OSGCS allowing for simultaneous operation of numerous UA, is housed in a climate-controlled shelter, provides UA health and fault monitoring, conducts video coding and decoding, and can archive up to 30 days of ISR data (AAI Corporation 2009b). Most of the I-GNAT variants are limited to LOS communications operating on C-band SHF frequencies. However, some I-GNATs are equipped to use a BLOS satellite communications (SATCOM) radio operating on Ku-band EHF frequencies (General Atomics Aeronautical Systems 2009b).

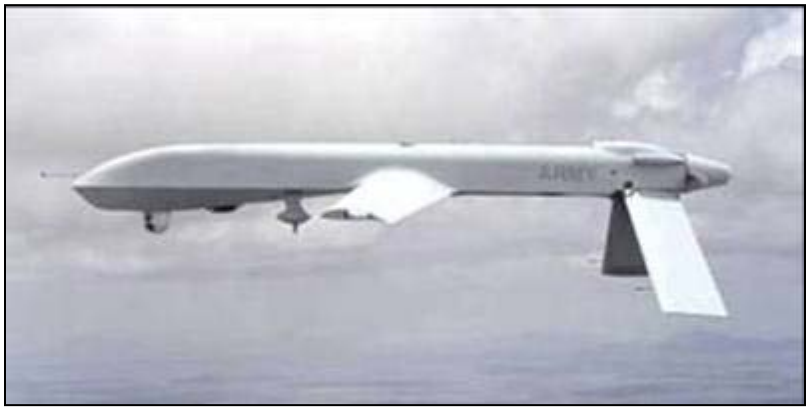


Figure 8. I-GNAT
Source: FY2009–2034 Unmanned Systems Integrated Roadmap, DOD (Photo, FY2009–2034 Unmanned Systems Integrated Roadmap, DOD, 6 April 2009).

MQ-1C Sky Warrior/Gray Eagle

The MQ-1C Gray Eagle, produced by General Atomics Aeronautical Systems, is an upgrade of the MQ-1 armed Predator UAS produced specifically for the Army. The MQ-1C is the end product of the Army's Extended Range/Multi-Purpose (ERMP)

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development program. It was original designation was the Sky Warrior, but the Army has recently re-designated the UAS as the Gray Eagle (Jensen 2010). Production of the MQ-1C is ongoing and systems are operating in Iraq and Afghanistan in support of the War on Terror. The Army plans to procure 11 complete systems with a total production of 132 airframes (Department of Defense 2009, 78).

The MQ-1C operates using a heavy fuel pusher prop engine with a LOS range of up to 500 kilometers or a BLOS range of up to 1200 kilometers, can remain airborne for over 30 hours, and flies up to 170MPH at altitudes up to 29,000 feet MSL (General Atomics Aeronautical Systems 2009a) (see figure 9). The MQ-1C takes off conventionally, is manually flown, and lands using retractable landing gear. The system is equipped with a payload that includes an EO/IR sensor, a Synthetic Aperture Radar/Ground Moving Target Indication (SAR/GMTI) sensor, a LRFD, and a CRP. The MQ-1C can use up to four laser guided AGM-114, Hellfire missiles, which use the systems LRFD to attack targets. The MQ-1C uses the OSGCS allowing for simultaneous operate numerous UA, is housed in a climate-controlled shelter, provides UA health and fault monitoring, conducts video coding and decoding, and can archive up to 30 days of ISR data (AAI Corporation 2009b). The Gray Eagle is capable of either LOS or BLOS communications using Ku-band EHF frequencies (General Atomics Aeronautical Systems 2009a).

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Figure 9. MQ-1C Sky Warrior / Gray Eagle
Source: FY2009–2034 Unmanned Systems Integrated Roadmap, DOD (Photo, FY2009–2034 Unmanned Systems Integrated Roadmap, DOD, 6 April 2009).

Analysis of Literature

Current doctrine focuses on the employment of UAS. The doctrine does address considerations when operating an UAS in vicinity of other friendly activity and cites concerns with UAS control in vicinity of Counter-Improvised Explosive Device (C-IED) jammers. The doctrine recommends avoiding flight within a set distance of active jammers, turning jammers off when using UAS, or programming jammers to not broadcast against the UAS designated frequency. The doctrine also states that operation of multiple UAS in a concentrated area could cause CDL interference.

The government reports recognize the occurrence of CDL communication jamming. One report claims that 11 percent of UAS accidents are a result of

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communications failures (Office of the Secretary of Defense 2003, 53). Unlike the doctrine that identifies the likely sources, government reports do not reference possible sources of signal interference. The reports recommend technological development to mitigate CDL interference.

Only one book, *Wired for War*, by P. W. Singer, directly addresses incidents of military UAS CDL interference. In addition, this book identifies sources of natural interference not addressed in any of the governmental publications. Like other military tactics, EW is a continuously adapting field of countermeasures. The books do offer civilian applications, which could be altered for military UAS operations.

Gaps in the Record

Doctrine openly acknowledges that US equipment can interfere with UAS data links. CDL communications appear to be susceptible to both jamming and mimicking. The government reports identify improvements required in CDL technology. The books suggest that any radio frequency can be jammed.

There is limited literature addressing enemy counter-UAS attacks. However, doctrine does acknowledge the possibility that enemy forces may attack UAS. It does not identify possible vulnerabilities the enemy may exploit, nor does it provide recommendations to counter an enemy attack against UAS.

Trends

The ongoing trend in the military is to increase and expand unmanned operations. Most of the government publications stress the integration of UAS throughout the operational environment and detail the advantages UAS provide to the combat leader.

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Generally, current doctrine focuses solely on UAS employment. The military has not acknowledged or addressed contingencies when operating in a non-permissive UAS environment. The most troubling trend is a sense of ignorance regarding UAS limitations.

Significance of Thesis in Relation to Existing Literature

Existing literature focuses on the advantages of UAS employment. In comparison, this study focuses on vulnerabilities in a non-permissive UAS environment. Literature has identified the CDLs susceptibility to communications failure. However, these failures are attributed to specific scenarios involving operations in the vicinity of C-IED jammers or multiple UAS. Civilian literature attests such failures could occur from numerous manmade or natural sources. Therefore, to determine these vulnerabilities, this study will identify occurrences of UAS failure during training and execution of combat operations.

As seen in this review, these six types of literature provide a comprehensive view of UAS CDL and possible vulnerabilities to these control structures. The Joint doctrine establishes some common terminology between services but is limited by the age of the documents. Army doctrine is tactically based and draws on lessons learned during combat operations. It details considerations for the employment of UAS in the operational environment. Books explain the science of UAS communications and the possibility of interference with UAS data links. Professional journals provide information by subject matter experts (SME) in the field of UAS, communications, and EW. Finally, media sources are the most dynamic literature and provide near real time information on current UAS operations. This review has also identified gaps in the record and trends in existing literature.

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CHAPTER 3

RESEARCH METHODOLOGY

> Discovery is to see what everybody else has seen, and to think what nobody else has thought.
>
> — Albert von Szent-Gyorgyi

While some literature is available on UAS CDLs, the current information does not provide sufficient detail to identify the scope of the problem. To answer the research questions presented in chapter 1, this qualitative study of UAS CDL structures analyzes the current record and conducts interviews to add to the record. In order to achieve a comprehensive answer, this process includes an evaluation of current and developmental military and civilian UAS CDLs. This study will propose recommendations to change military UAS planning to account for operations in a non-permissive UAS environment.

This chapter explains the steps taken previously to gather available information. This study identifies information that necessitates interviews with experts and those with experience in the field pertaining to this study. Lastly, this chapter describes the research methodology and the advantages and disadvantages to the methodology.

Information Gathering

To identify relevant doctrine, regulations, and unclassified publications, this study extensively reviewed Joint, Army, Navy, Marine, and Air Force electronic publications. Due to the dynamic nature of UAS technology, numerous web-based resources have been reviewed, including Association for Unmanned Aircraft Systems International, Congressional Unmanned Aerial Vehicle Caucus, The Association of Old Crows, Space Media Network, and the Air Force Research Institute. The US Army Combined Arms

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Research Library in Fort Leavenworth, Kansas, provided access to UAS development and procurement plans. Combined Arms Research Library research librarians provided government reports, journals, and other relevant literature.

Interview Selection

Limited information is available in current literature regarding vulnerabilities to UAS CDLs. Consequently, this study necessitated conducting interviews to gather relevant institutional knowledge. Either the military or the civilian UAS community may help answer the research question. This study interviews experts from both communities in order to conduct a comprehensive study. Additionally, numerous variables have been identified that could affect the results of this study. The interviews must address these variables to minimize information gaps relevant to the primary question.

The initial interviews were conducted with experts in UAS development. The US Army UAS Project Managers at Redstone Arsenal, Huntsville, Alabama were the primary target of these interviews. These project managers are experts on the operational design of current and future Army UAS. These interviews were intended to identify known limitations to UAS CDLs and the Army's attempts to mitigate these risks in current and future UAS.

This study also interviewed civilian UAS engineers and designers currently conducting research and development. The purpose of this interview was to compare and contrast the differing design characteristics. This study determines if civilian and military designs suffer from similar limitations. Where design differences exist, what civilian applications have potential military applications?

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In addition, this study interviewed Observer/Controllers (OCs) from the National Training Center (NTC), Fort Irwin, California, to determine the frequency of UAS CDL failures in a permissive peacetime environment. This was intended to help determine how often CDL interference occurs and what systems are most vulnerable. However, not all incidents of UAS CDL interference amount to an accident that requires an official accident investigation. Due to this, the official accident statistics may only account for UAS accidents requiring an investigation, thus limiting the validity of accident data.

Lastly, this study interviewed experts in the EW community. These experts assist in understanding the science of EW. Understanding the science of EW helps determine if UAS CDLs are vulnerable to UAS attacks. Additionally, if the study finds that UAS CDLs are susceptible to EW attacks, the EW expert may recommend changes to improve UAS communications security.

These interviews were conducted using 20 base questions and additional secondary interview questions determined during the course of the interview. Interview participants provided answers based on individual knowledge when possible. Some interviewees were not capable of answering certain questions. A digital recorder was used to capture information and ensure obtained data is not lost. The basic interview questions were:

1. On what radio bands do UAS CDL and VDL communicate? Please explain communication bands used for current and future Man-Portable and Tactical UAS.

2. Do current UAS CDLs experience interference? What conditions contribute to possible interference?

3. Are certain UAS or classes of UAS more likely to experience interference?

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4. What is shadow jamming or self-jamming? How common is this phenomenon?

5. FM 3-04.15, *Multi-Service Tactics, Techniques, and Procedures for the Tactical Employment of Unmanned Aerial Systems*, dated 3 August 2006, states, "Users must be aware of enemy actions and environmental factors that can limit the effectiveness of UAS communications." What enemy actions or environmental conditions affect UAS communications?

6. How often do incidents of UAS CDL interference occur in Iraq or Afghanistan?

7. Do C-IED systems employed in Iraq and Afghanistan interfere with UAS CDLs? What classes of UAS are more susceptible to C-IED interference?

8. Are beyond line of sight (BLOS) communications more or less likely to encounter interference?

9. What are the lost link procedures for current and future UAS?

10. How can commanders or UAS operators mitigate CDL interference risks?

11. The *Unmanned Aerial Vehicles: Background and Issues for Congress*, dated 21 November 2005, reported that UAS have 100 times greater accident rate than manned aircraft. Is this still a valid statistic or has UAS reliability improved?

12. On 17 December 2009, *The Wall Street Journal*, reported that insurgents had compromised UAS VDL communications. Have insurgents successfully compromised UAS CDL communications?

13. On 31 December 2008, *CBS News*, reported that Palestinian militants issued an open request on an extremist blog seeking assistance in developing technology with the capability to "detect, intercept and jam UAV signals". Have similar additional threats been issued? Does such requests factor into UAS design considerations?

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14. Do current UAS possess adequate electronic countermeasure (ECM) protection? What ECM modifications will current UAS receive?

15. What size issues must Program Executive Office Aviation (PEO AVN) consider when developing ECM devices? What size concerns are most difficult to overcome?

16. What redundancy is built into current UAS CDLs? What redundancy is being designed into future UAS CDLs?

17. Do current UAS Doctrine, Organization, Training, Material, Leadership, Personnel, and Facilities (DOTMLPF) accurately account for UAS shortcomings or vulnerabilities? What adjustments are required in the UAS DOTMLPF to account for UAS shortcomings or vulnerabilities?

18. Does PEO AVN research civilian UAS CDLs for possible military applications?

19. Does PEO AVN participate in the Navy's annual Black Dart counter-UAS exercise at Naval Air Weapons Station, China Lake? Should PEO AVN participate in this exercise?

20. What additional publications can advance this study?

Research Methodology

This study used the DOTMLPF construct to address the primary and secondary questions posed in chapter 1. It focused mainly on the adequacy of Joint and Army doctrine to prepare for EW, structure of UAS organizations to provide oversight of EW preparations, the training operators receive to identify EW, and materials that affect a

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CDLs ability to cope with interference. This use of the doctrine, organization, training, and material portions of DOTMLPF will continue throughout chapters 4 and 5.

Advantages and Disadvantages of Methodology

The advantage to this methodology is the inclusion of interviews with the US Army's experts in UAS design and EW fields. This technique directly addressed the gaps identified during the literature review. Additionally, including the civilian UAS community brought a fresh perspective and potential alterations to military UAS designs.

The disadvantage to this methodology is that identified issues may not have near term solutions. It may not be possible to incorporate ECM on some UAS classifications due to size and weight limitations. The field of EW research and development is also very dynamic and ECM devices effectiveness may be short lived. While this study may find that UAS CDLs are vulnerable, those vulnerabilities may be acceptable due to a number of other considerations.

As seen in this chapter, this study relied heavily upon interviews to address gaps identified in the available record. Interviews with both military and civilian UAS researchers allowed the researcher to compare and contrast differing design philosophies. This study used interviews, doctrine, and government reports to recommend changes to the UAS DOTMLPF construct. Experts across the UAS spectrum were interviewed to ensure this study is comprehensive. However, technological limitations may not allow an adequate recommendation for all UAS classifications.

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CHAPTER 4

ANALYSIS

> I am concerned about the continued decline in research-and-development funding. From 1980 through today, our investment in basic defense research as a percentage of gross domestic product has declined by 50 percent. . . . choosing to win in Iraq and Afghanistan should not mean our country must also choose to assume additional risk. . . . Who is thinking about the war in 2015? Or the war in 2030?
>
> — Rep. Howard "Buck" McKeon, US House of Representatives

This chapter focuses on the doctrine, organization, training, and material portions of the DOTMLPF construct. This study analyzes the UAs identified as Man-Portable and Tactical UAS in FM 3-04.15, *Multi-Service Tactics, Techniques, and Procedures for the Tactical Employment of Unmanned Aerial Systems,* dated 3 August 2006. First, this chapter defines criteria for Man-Portable UAS classification and reviews the design, capabilities, and employment of the major systems. The study then examines the criteria for Tactical UAS and conducts a similar review of major Tactical UASs. Lastly, the analysis focuses on the doctrine, organization, training, and material considerations that influence UAS CDLs.

Doctrine

Doctrine is composed of the fundamental principles and codified briefs direct action or motive to a common philosophy. Historically, the armed services have struggled to nest their individual service doctrines in a manner that supports mutual operations. To force cooperation, The Chairman of the Joint Chiefs of Staff (CJCS) issues guidance known as Chairman of the Joint Chiefs of Staff Instruction (CJCSI). This directive dictates the procedure for the development of collaborative Joint doctrine. In CJCSI

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5120.02B, *Joint Doctrine Development System*, dated 4 December 2009, the CJCS charges the Commander, United States Joint Forces Command Commander (CDRUSJFCOM), to oversee Joint doctrine production. This qualitative study examines both Army and Joint doctrine to determine the adequacies of their considerations for UAS operations in an EW threat environment.

This section reviews Army and Joint doctrine to determine planning considerations, recommendations, or mitigations for operating Man-Portable and Tactical UAS in an EW rich environment. The RQ-11 Raven is the primary example of Man-Portable UAS due to its extensive use throughout the Joint forces. The RQ-7 Shadow is the primary example of Tactical UAS due to its use by both the Army and Marines. Findings for these systems are transferable within their classifications due to system commonalities and interoperability.

Joint and Multi-Service

The first mission of Joint operations is to establish a common language, but dissimilar terminology has posed a problem for Joint UAS operations. UAS technology is dynamic and defining language today might not account for systems in development. The services might have differing logic behind their language structure. Some UAS classifications are based by system specifications and capabilities, and some describe the environment in which the system operates. A consistent naming convention allows for universal understanding by system operators and non-operators. Clear classification becomes critical if this study determines certain system criteria, such as their operational environment, increases susceptible to CDL disruption and EA.

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In recent years, UAS have held numerous classifications depending on the source and age of the defining publication. For example, the RQ-11 Raven has held numerous classifications including a Close Range-UAV (CR-UAV), Small-UAS (SUAS), Man-Portable UAS, Tier-1 UAV, Tactical-1 UAS, and Group-1 UAS. This study reviewed various publications including JP-55.1, *Joint Tactics, Techniques, and Procedures for Unmanned Aerial Vehicles,* dated 27 August 1993, FM 3-04.15, DODs UAS strategic planning document, *FY2009–2034 Unmanned Systems Integrated Roadmap,* dated April 2009, and FM 3-04.15, *Multi-Service Tactics, Techniques, and Procedures for the Tactical Employment of Unmanned Aerial Systems,* dated 3 August 2006 to determine classifications.

JP 3-55.1, *Joint Tactics, Techniques, and Procedures for Unmanned Aerial Vehicles,* dated 27 August 1993, is the capstone Joint UAS manual. The validity of this publication in the current operational environment is limited due to its age. The JP 3-55.1 identifies smaller systems, such as the RQ-11 Raven, as CR-UAVs and larger systems, such as the RQ-7 Shadow, as Medium Range-Unmanned Aerial Vehicle (MR-UAV). This classification is not in any other service publication but these are common system descriptions in the civilian UAV community (Blyenburgh 2008, 5)(see table 2). The UAVs capabilities determine the identification, not the environment in which the system operates (US Joint Forces Command 1993, 14).

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Table 2. Civilian UAS Classes					
Classification	Description	Weight	Range	Altitude	Endurance
Mini-UAV	Miniature	Less than 25 kilograms	Less than 10 kilometers	Less than 500 feet	Less than 2 hours
CR-UAV	Close-Range	25 – 150 kilograms	10-30 kilometers	Less than 10,000 feet	2-4 hours
SR-UAV	Short-Range	50 – 250 kilograms	30-70 kilometers	Less than 10,000 feet	3-6 hours
MR-UAV	Medium-Range	150 – 500 kilograms	70-200 kilometers	Less than 16,500 feet	6-10 hours
MALE	Medium-Altitude Long-Endurance	1000 – 1500 kilograms	Over 500 kilometers	16,500-25,000 feet	24-48 hours
HALE	High-Altitude Long-Endurance	Over 2000 kilograms	Over 2000 kilometers	Less than 65,000 feet	24-48 hours
STRATO-UAV	Stratospheric	Over2500 kilograms	Over 2000 kilometers	Over 65,000 feet	24-48 hours

Source: Created by author using data from *EASA UAS Workshop*, European Aviation Safety Agency, Blyenburgh, 2008.

The *FY2009–2034 Unmanned Systems Integrated Roadmap*, dated April 2009, is the DODs strategic planning guidance for all current and forecasted unmanned systems. The roadmap identifies smaller UAS, such as the RQ-11 Raven, as a Group 1 UAS and larger UAS, such as the RQ-7 Shadow, as a Group 3 UAS. The specifications and performance of the UAS determines its classification, not the UASs operational environment. The group identification is broad and does not account for the growing micro-UAS field (see table 3). Additionally, this group identification is of little value to a non-operator who does not know the specifications and performance parameters of a specific UAS (Department of Defense 2009, 110).

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Table 3. Joint UAS Groups			
UAS Category	Weight	Altitude	Speed
Group 1	Less than 20 pounds	Less than 1,200 feet AGL	Less than 100 knots
Group 2	21-55 pounds	Less than 3,500 feet AGL	Less than 250 knots
Group 3	Less than 1320 pounds	Less than 18,000 feet AGL	Less than 250 knots
Group 4	Over 1320 pounds	Less than 18,000 feet AGL	Any speed
Group 5	Over 1320 pounds	Over 18,000 feet AGL	Any speed

Source: Created by author using data from *FY2009–2034 Unmanned Systems Integrated Roadmap*, Department of Defense, 2009.

The FM 3-04.15, *Multi-Service Tactics, Techniques, and Procedures for the Tactical Employment of Unmanned Aerial Systems,* dated 3 August 2006, is the most relevant UAS publication with Joint considerations. It identifies smaller UAS, such as the RQ-11 Raven, as a Man-Portable UAS, and larger UAS, such as the RQ-7 Shadow, as a Tactical UAS. The operational environment of the UAS and general system capabilities determine this classification (see table 4). This operational environment class identification means a similar system may fall into multiple categories dependant on utilization. For example, the FM 3-04.15 calls the MQ-1B Predator a Theater UAS and the MQ-1C Sky Warrior a Tactical UAS due to the MQ-1Cs planned employment (Headquarters, Department of the Army 2006a, 21).

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Table 4. Multi-Service UAS Classifications			
Classification	Size	Altitude	Characteristics
Man-Portable UAS	Small, self-contained	Below coordinating altitude	-controlled at the combat team level. -Data is usually FMV constrained by LOS. -Data may be disseminated to brigade/battalion TOCs. -Imagery processing/interpretation is limited to the combat team.
Tactical UAS	Larger systems with more robust requirements	Above coordinating altitude	-Operated by specialized UAS units. -Products can expand beyond FMV depending on payload. -Imagery processing/interpretation may be conducted by intelligence units. -Communication may be LOS dependant.
Theater UAS	Large systems	Above coordinating altitude	-Operated by specialized UAS units. -Numerous products available depending on payload. -Imagery processing/interpretation may be conducted by local intelligence units or reach back intelligence organizations. -BLOS Communications.

Source: Created by author using data from *Multi-Service Tactics, Techniques, and Procedures for the Tactical Employment of Unmanned Aerial Systems*, Headquarters, Department of the Army, 2006.

UAS terminology is continuing to evolve as new systems are developed and fielded. The current Joint community classification is the group identification associated with the *FY2009–2034 Unmanned Systems Integrated Roadmap*. The roadmap includes five UAS groups separated by gross weight, operating altitude, and airframe speed (Department of Defense 2009, 110). The group system in the roadmap requires knowledge of a specific UAS, but the class system in the FM 3-04.15 requires general knowledge of the UAS (Headquarters, Department of the Army 2006a, 21). This study is using the class system identified in FM 3-04.15, *Multi-Service Tactics, Techniques, and*

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Procedures for the Tactical Employment of Unmanned Aerial Systems, due to its ease of use for a general audience.

This study defines threats to UASs and evaluates doctrinal mitigation of these threats. The focus of research is EW threats directed against Man-Portable and Tactical UAS but minimal information was available due to their limited employment. Information was available for attacks against larger Tactical and Theater UAS but these systems experienced conventional attacks, not EAs. There are three verifiable accounts of attacks against UAS conducting operations and these incidents provide direction for this study.

The first incident occurred in Israel during the 2006 Israel-Hezbollah War in southern Lebanon. On 7 August 2006, an Israeli F-16 shot down an Iranian built Ababil-T UAS using an AAM (Weiss 2006). Israel reported shooting down two additional Iranian UAVs less than a week later, but these claims are in dispute. These attacks each used fighter aircraft employing conventional air superiority tactics.

The next incident occurred in Georgia during the 2008 build up to the South Ossetia War. On 21 April 2008, the Georgian government operated an Israeli built Hermes UAS over their disputed Abkhazian region. The Georgian government accused the Russians of shooting down their aircraft, a claim the Russian government denied. The Georgian government released a video it claims shows a Russian MIG-29 attacking their UAV using an AAM (BBC News 2008).

The last confirmed incident occurred in 2009 during Operation Iraqi Freedom. Coalition forces did not confirm the incident for a month, but coalition forces reportedly tracked the Iranian UAV over Iraq for 70 minutes before shooting it down. A coalition

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fighter shot down the UAV but the report did not state how the aircraft downed the UAV. The Iranian system was an Ababil-3, similar in size to the MQ-1B Predator (Reid 2009).

These incidents all involved fighter aircraft attacking Theater UAS using conventional air superiority tactics. The value of these attacks in identifying threats to Man-Portable and Tactical UAS is limited. Such tactics could be effective against larger Tactical UAS but would be impractical against Man-Portable UAS. Countering smaller Tactical and Man-Portable UAS requires unconventional methods either not yet produced or not yet released to the public.

In 2008, the effective Israeli airstrikes of Operation Cast Lead resulted in a more realistic and plausible threat against these smaller systems. These airstrikes decimated the Hamas terror network leadership within the Gaza Strip and prompted militants to request external technological support (Ronen 2008). On 31 December 2008, a militant group identified as "The Sons of Palestine" used a jihadist Blog, m3ark forum, to request assistance from "anybody who could suggest a way to detect, intercept and jam the electronic signals transmitted by Israeli reconnaissance UAVs" (CBS News Investigates 2008). This insurgent group had somehow identified the ability to EA UAS but it is unknown how they came to this determination. There is no evidence that this group received the assistance they sought, but this request demonstrates the technological networking capability of asymmetric threats.

This study reviewed the Joint and service publications to identify perceived UAS threats and examine the adequacy of threat mitigation. The focus of this study is threats to UAS CDLs, but this study reviewed all forms of counter-UAS to be comprehensive.

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JP 3-55.1, *Joint Tactics, Techniques, and Procedures for Unmanned Aerial Vehicles*, dated 27 August 1993, the capstone Joint UAS publication is woefully inadequate in its counter-UAS planning guidance. It identifies UAS employment opportunities, but fails to address any threat to UAS operations.

JP 3-30, *Command and Control for Joint Air Operations*, dated 12 January 2010, is the newest JP that addresses UAS operations and does a better job in identifying the potential implications of disrupting CDL communications. It explains that UAS and manned aircraft operate similarly, but that operating UAS requires special considerations. JP 3-30 states, "In the event of lost communications, a manned aircraft will typically press with the mission . . . (UAS) rely on a nearly continuous stream of communications to successfully complete a mission . . . communications security, and specifically bandwidth protection (from both friendly interference and adversary action) is imperative" (US Joint Forces Command 2010, 83). Despite the publication not being a UAS manual, JP 3-30 is the best Joint planning tool for UAS operations.

Lastly, this study reviewed FM 3-04.15, the multi-service publication that fills the void in Joint UAS doctrine. FM 3-04.15 addresses conventional threats to UAS operations once and its mitigation guidance is only applicable to Theater UAS. It states, "Cloud decks may make it desirable to station the UAS in a low-altitude environment, but minimum altitude limitations and/or enemy threat systems may restrict this option. Against an overcast cloud background, the UA may be highlighted, aiding AAM, antiaircraft artillery (AAA), and surface-to-air missile (SAM) threat operators." The counter-UAS threats identified are not practical means for use against Tactical or Man-

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Portable UAS and it makes no mention of EW threats. This guidance is of little value to these lower altitude systems.

US Army

This study took a different approach reviewing Army publications and split its focus into two areas. First, this study examined Army maneuver doctrine to determine the adequacy of employment planning and considerations when integrating UAS into operations. Second, the study examined how well Army doctrine addresses EW threats to UAS operations.

The tactically focused review of maneuver doctrine included FM 3-90.6, *The Brigade Combat Team*, August 2006, FM 3-90.5, *The Combined Arms Battalion*, dated April 2008, FM 3-20.96, *Reconnaissance Squadron,* dated September 2006, and FM 3-21.10, *The Infantry Rifle Company*, dated July 2006. These publications all do an outstanding job integrating UAS in to all aspects of operations including all types of offensive, defensive, security, and reconnaissance operations. However, these manuals do not address threats to UAS operations or contingency planning when operating a non-permissive UAS environment. The only Army publication that addresses limitations to UAS operations is FM 3-20.971, *Reconnaissance and Cavalry Troop*, dated August 2009. FM 3-20.971 identifies issues such as vulnerability to enemy fire, acoustic signature, and LOS communications that may limit UAS operations. Most of these publications discuss EW, but none offer planning considerations for UAS operations on an electronic battlefield.

The capstone Army UAS publication is, FM 3-04.115, *Army Unmanned Aircraft Systems Operations*, dated July 2009. This study extracts two major contributions from

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this publication. First, *Army Unmanned Aircraft Systems Operations* identifies the susceptibility of UAS CDLs to disruption by EMI and friendly EW jamming systems. Second, FM 3-04.115 is the only publication that addresses counter-UAS threats and how enemy forces may attack all classes of UAS. It addresses multiple conventional counter-air threats but it is also identifies the potential for an EA (Headquarters, Department of the Army 2009a, 34).

UAS CDL susceptibility to EMI, coupled with the militant request for EW assistance, presents a reasonable direction for counter-UAS development. This study was unable to find any evidence of EA against UAS. The relative age of Man-Portable and Tactical UAS technology has limited their use on an electronic battlefield and these systems are largely untested against EW threats. Reason dictates that if UAS CDLs are susceptible to passive EMI, they are also vulnerable to an active EA.

In discussing disruption due to EMI, FM 3-04.115 states, "UAS operations are susceptible to interference from military and civilian communications systems. Terrestrial microwave systems using high energy directional antennas (MSE and tropospheric systems employed by Army and Marine units) may cause significant frequency interference problems and should be avoided (Department of the Army 2009a, 43)." These high-energy communications systems are common in major population centers and on an increasingly technologically dependant battlefield. This study continues to examine EMI on UAS CDLs and implications of such interference throughout this chapter.

Army Unmanned Aircraft Systems Operations discussed EW threats against UAS in general terms. Although it identifies the potential threat of EW systems, it fails to identify possible means to conduct an EA against UAS. It states, "UAS may be subjected

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to offensive EW, computer network attacks, computer network exploitation, and signal intelligence exploitation (Department of the Army 2009a, 43)."

This study examined Joint, multi-service, and Army publications to identify perceived threats, threat mitigations, and employment considerations for all classes of UAS. Multiple manuals contribute to the discussion of these aspects, but no single publication adequately examines each of these topics. Tactically focused maneuver manuals such as FM 3-20.971, *Reconnaissance and Cavalry Troop,* dated August 2009, explains how UAS are effective combat multipliers and provides the ground commander with some UAS considerations. An aviation centric manual such as FM 3-04.115, *Army Unmanned Aircraft Systems Operations,* dated July 2009, identifies possible threats to UAS but it does not adequately support counter EW planning for UAS.

Organization

This study conducted an organizational review of Tactical and Man-Portable UAS units to assess their ability to plan for EW against UAS. This examination was conducted separately due to the differing command and control structure of these UAS. Units that employ Man-Portable UAS range from as large as Combined Arms Battalion (CAB) to as small as a Long Range Surveillance (LRS) teams. Man-Portable UAS operate below Joint airspace coordinating altitudes and do not require the same airspace control and control (AC2) considerations as larger platforms. Tactical UAS are Brigade level systems that may operate in support of subordinate unit operations. These systems operate above Joint airspace coordinating altitudes and require stringent AC2 measures to ensure de-confliction with manned aircraft.

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Man-Portable UAS

TC 1-611, *Small Unmanned Aircraft System Aircrew Training Manual*, dated August 2006, is the primary training publication for Man-Portable UAS. This training circular standardizes Man-Portable UAS training and is a byproduct of Army Aviation adoption of UAS prepotency. Army aviation attempted to standardize Man-Portable UAS organizations and used manned aviation units as a design template. The organization built mirrors manned aviation units, but the Man-Portable UAS units lack the expertise of their manned counterparts (Headquarters, Department of the Army 2006c, 7). This lack of SMEs limits their ability to conduct detailed UAS planning.

In accordance with TC 1-611, the commander of an organization equipped with Man-Portable UAS is responsible for the training, planning, and mission execution of their combat system. The commander identifies an experienced operator to serve as the unit UAS Master Trainer and act as the technical and tactical expert in Man-Portable UAS operations. Man-Portable UAS operators must obtain and maintain a set level of proficiency by completing mission preparation training, compulsory training requirements, and a Semi-Annual Proficiency and Readiness Tests (Headquarters, Department of the Army 2006c, 10).

Similarly, commanders of manned Army Aviation units are responsible for the training, planning, and mission execution their pilots. An experienced warrant officer serves as the units Standardization Instructor Pilot (SIP), who is the technical and tactical expert in the employment of their airframe. Rated aviators must obtain and maintain a set level of proficiency by completing Readiness Level (RL) progression training,

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compulsory semi-annual training requirements, and an Annual Proficiency and Readiness Tests (APART) (Headquarters, Department of the Army 2006g).

The Man-Portable UAS organizational structure looks similar, but it fails to meet the intent of TC 1-611 due to a lack of expertise for three reasons.

First, the commander of a manned aviation unit is a rated aviator who maintains the same standards as the pilots they lead and is proficient in the employment of their combat system. Commanders of units equipped with Man-Portable UAS are unlikely operators and they receive no specific Man-Portable UAS training. They may not recognize the implications of CDL disruption or what can be done to mitigate interference.

Second, the SIP of a manned aviation unit is not only an experienced pilot. They have also received advanced training to assist their service as a standardization authority. An SIP receives additional training on techniques for training and evaluating individuals, designing comprehensive training programs, and maintaining aviation-training records. Conversely, Man-Portable UAS Master Trainers may themselves be inexperienced operators (Hicks 2008). The ability of a UAS Master Trainer to train operators on EW considerations is dependent on their individual experiences.

Lastly, rated aviators are board selected and undergo a ridged evaluation process. These professional pilots, especially warrant officers, are in career fields that ensure continuous growth throughout their service and this constant progression ensures a healthy talent pool. Man-Portable UAS operators are unit commander selections and there is no minimal requirement to become an operator. They do not receive a Military Occupation Specialties (MOS) career code and may only serve as an operator once in

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their career. Without ensuring Man-Portable UAS operators remain in the community, it is impossible to develop a healthy talent pool. This lack of collective knowledge limits the intellectual growth potential of the Man-Portable UAS organizations. This stagnant knowledge pool hampers their ability to cope with contingences, such as an EA, against their aircraft.

Tactical UAS

TC 1-600, *Unmanned Aircraft Systems Commander's Guide and Aircrew Training Manual*, dated August 2007, is the primary training publication for Tactical UAS. This TC standardizes Tactical UAS training and is a byproduct of Army Aviation adoption of UAS prepotency. Army aviation standardized Tactical UAS organizations and using manned aviation units as a design template (Headquarters, Department of the Army 2007, 7).

In accordance with TC 1-600, the commander of an organization equipped with a Tactical UAS is responsible for the training, planning, and mission execution the systems. A UAS Standardization Officer/NCO, who is often a warrant officer, assists the commander and serves as the technical and tactical expert for Tactical UAS operations. The commander may assign additional experienced Tactical UAS pilots to serve as Evaluator/Unit Trainers. The remaining pilots are either Mission Commanders or Unmanned Aircraft Crewmembers depending on their level of experience. Tactical UAS operators and rated aviators maintain similar standards. Tactical UAS pilots must complete RL progression training, compulsory semi-annual training, an Annual Proficiency and Readiness Tests (APART), and be medically cleared for flight duties (Headquarters, Department of the Army 2007, 21).

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The Tactical UAS organizational structure looks similar and the expertise of its members allows for its successful operation.

First, the commander of a manned aviation unit is a rated aviator who maintains the same standards as the pilots they lead and is proficient in the employment of the combat system. Commanders of Tactical UAS units are not qualified to operate the systems, but the inclusion of a Standardization Officer/NCO mitigates their lack of experience.

Second, the SIP of a manned aviation unit is not only an experienced pilot, he/she has also received advanced training to assist their service as a standardization authority. An SIP receives additional training on techniques for training and evaluating individuals, designing comprehensive training programs, and maintaining aviation-training records. Tactical UAS Standardization Officer/NCO is either an experienced Tactical UAS operator or often a permanently grounded rated aviator. There is no additional training for a Standardization Officer/NCO. They rely upon their individual or collective experience to varying degrees of success (Hill 2010).

Lastly, rated aviators are board selected and undergo a ridged evaluation process. These professional pilots, especially warrant officers, are in career fields that ensure continuous growth throughout their service and this constant progression ensures a healthy talent pool. Tactical UAS operators enlist into the career field and must satisfactorily complete an extensive entry level training program that includes Federal Aviation Administration (FAA) ground school. Tactical UAS pilots are in the MOS 15W career field and will continue to progress throughout their service (Thomas 2006). This progression ensures the development of a healthy Tactical UAS talent pool. This pool of

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talent allows organizations to constantly grow and mature. This growth enables such organizations to cope with unplanned contingences, such as an EA, against their aircraft.

Training

This study reviewed training required to become a Tactical or Man-Portable UAS operator. The training plans have been examined separately due to the stark differences between the training programs. A Man-Portable UAS operator is not a unique MOS and the operators do not receive an ASI after qualification. Tactical UAS operators enlist into a career field they will remain in throughout their career.

Man-Portable UAS

There are no prerequisites for becoming Man-Portable UAS operators, but they should be technically savvy individuals. Man-Portable UAS operators in this study included infantrymen, fire supporters, mechanics, engineers, and cooks. In 2007, all RQ-11 Raven operators received their training during a 10-day course of instruction at Redstone Army Arsenal, Alabama. However, various alternate Raven qualification courses are now available due to an expansion of Man-Portable UAS utilization and constrained home-station training timelines (Hicks 2008).

In 2009, Man-Portable UAS operators received training at Redstone Army Arsenal, Alabama, Fort Benning, Georgia, Mobile Training Teams (MTTs), and Combat Training Centers (CTCs). The RQ-11 qualification course Memorandum of Instruction (MOI) includes UA familiarization, flight controls and EMI indicators, basic aerodynamics, mission planning, and UAS emergency procedures. RQ-11 operators

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receive a certificate of completion and an operator's qualification card once they complete the training (Hicks 2008).

The RQ-11 qualification course discusses EMI indicators and some common sources of this interference. This EMI discussion focuses on passive environmental sources such as radio towers, high-frequency antennas, meteorological interference, and self-imposed interference. The qualification course does not cover enemy threats to UAS or contingency planning for operations in an active EW environment (Hicks 2008).

Tactical UAS

Tactical UAS operators attend a 23-week qualification course at Fort Huachuca, Arizona. This Aviation Professional Training program includes a fully certified FAA ground school, aerodynamics, and meteorology is the first phase of training (Thomas 2006). They next receive training on image analysis, aviation maintenance management, use of the Aviation Mission Planning System (AMPS), and aviation safety considerations. Students transition to field operations once they complete classroom instruction. Field instruction includes establishment of a Tactical UAS operating base, UAS mission preparation, operating a Tactical UAS, and displacement of a Tactical UAS operating base (Thomas 2006).

Tactical UAS is a professional career field that offers advancement and career enhancement opportunities as operators gain experience. These operators attend military schools such as Basic Non-Commissioned Officer Course (BNCOC) and Advanced Non-Commissioned Officer Course (ANCOC) as they advance (Thomas 2006). They are competitive for leadership opportunities including Platoon Sergeant and First Sergeant positions. Senior operators may choose to become Warrant Officers as MOS 150U,

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Tactical Unmanned Aerial Vehicle (TUAV) Operations Technician (Ayers 2008). This independent career field supports retention and encourages operators to remain in the UAS community.

The Tactical UAS qualification course focuses on UAS employment in support of maneuver operations and students do not study threats to UAS. The course MOI does not discuss either environmental EMI on UAS CDLs or EW threats to UAS CDLs. Interviews conducted with OCs at the NTC, Fort Irwin, California, confirmed a lack of EW education within the Tactical UAS community (Hill 2010). The NTC has identified this lack of EW education and aviation trainers will soon implement scenarios that train EW planning considerations (Hill 2010).

Material

This study examines vulnerabilities of UAS CDLs to an EA but these systems have not served on an active EW battlefield. However, publications such as FM 3-04.115, *Army Unmanned Aircraft Systems Operations,* dated July 2009, explain UAS susceptibility to EMI. Signal interference is the root cause behind both EMI on an UAS CDL and an EA against an UAS CDL, therefore the symptoms of both these events are similar. This section will review how such interference occurs and what material measures may be taken to mitigate this interference.

The primary subjects of this UAS CDL security review are *Unmanned Aerial Vehicle Study*, dated February 2003, the *Unmanned Aerial Vehicles: Background and Issues for Congress*, dated 21 November 2005, *Airspace Integration Plan for Unmanned Aviation*, dated November 2004, and *Unmanned Aircraft Systems FY05-FY09 Class A-C Accident Analysis,* dated 4 December 2009. Despite a wide variation in their production

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dates, the information in these reports is consistent and lends credence to the reliability of these reports.

UAS CDL Reliability

The intent of UAS is to be a cost effective alternative to manned aircraft and a way to prevent risking a pilot's life. Human needs and emotions such as fatigue, hunger, ambition, and fear do not bind unmanned systems. They dutifully carry out any assigned task, without regard to their survival or need for reward. Some believe they are incapable of committing human errors that often contribute to aviation accidents and there is a common perception that UAS never fail (Singer 2010, 63).

However, reports indicate that UAS are 100 times more likely to succumb to failure than their manned counterparts (Congressional Research Service 2005, 2). The most common causes for these failures are malfunctioning power plant or props, flight control malfunctions, human error, and communications failures (Office of the Secretary of Defense 2003, 39). According to those interviewed, determining the cause of communication failure or disruption is difficult but accident investigators often suspect EMI (Hill 2010).

A September 2009 report found that the MQ-1B Predators, an Air Force Theater UAS, experienced an estimated accident ration of 40 aircraft for 100,000 hours of flight time, an increase over the 30 aircraft for 100,000 hours of flight time ratio the previous year (Dunnigan 2009). The Air Force had anticipated a reduction in the MQ-1B accident rate to ratio of 15/20 aircraft for 100,000 hours of flight time as the technology matured (Office of the Secretary of Defense 2003, 34). Communications failure is the primary

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cause of 11 percent of these accidents and this rate has been consistent over time (Office of the Secretary of Defense 2003, 39).

The Army's Tactical UAS losses are even higher with the US Army Combat Readiness/Safety Center reporting 246 RQ-7 Shadow accidents during 421,071 flight hours over a four period. This equates to a Tactical UAS loss ratio of approximately 60 aircraft for 100,000 of flight time (Air Task Force 2009, 5).

It is impossible to estimate an accident to flight hour loss ratio for Man-Portable UAS due the Army not tracking these systems by flight hours. The Army tracks Man-Portable UAS by the number of missions an airframe completes, but information is available that allows us to examine their reliability. The US Army Combat Readiness/Safety Center reported 128 Class C accidents over a four-year period, 125 involving the RQ-11 and 3 involving the RQ-16 (Air Task Force 2009, 11).

However, this number is misleading due to many accidents causing less than $20,000 in damage, below the Class C accident threshold that requires an official report (Headquarters, Department of the Army 2009e, 32). Interviews conducted with a former NTC OC found that Man-Portable UAS operators experience CDL failure 5 to 10 times per week. Most of these crashed systems experience minimal damage and no accident report is required (Gaub 2010). NTC safety trends indicate that one Tactical UAS is damaged for every 90 hours of flight and one Man-Portable UAS is damaged for every 20 hours of flight (Key 2010, 16).

Communications failure was the primary cause for 15 percent of Army UAS reportable accidents (Air Task Force 2009, 6). The Army's higher communication failure

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ratio is due in part to the operational environment in which Tactical and Man-Portable UAS operate.

Man-Portable UAS operators in Iraq and Afghanistan have lost airframes due to EMI causing CDLs communications failure. Units use traditional and unique methods to ensure the recovery of their UAS. One unusual technique stated, “Another thing we put on there is a bilingual label in Arabic and English that says, ‘If found, return to the nearest coalition forces base for a reward,’ We’ve had several turned in that way.” (Army Magazine 2005) Commanders consider the recovery of lost UAS a priority mission due to security and strategic message concerns. If enemy forces delve into the inner workings of a captured UAS, they may be able to exploit this information and develop countermeasures. In addition, an insurgent force may score a strategic communications victory by displaying a captured UAS in their propaganda.

The accident rate of manned aircraft is marginal in comparison to unmanned systems and even innovative immature aircraft, such as the F-22, is much more reliable than unmanned systems. An operational F-22 Raptor has an estimated loss ratio of six aircraft for 100,000 hours of flight time and the Air Force estimates two aircraft for every 100,000 hours of flight time its technology matures (Dunnigan 2009). The F-16 Fighting Falcon has a loss ratio of four aircraft for 100,000 hours of flight time but some have advocated its replacement by an armed UAS (Dunnigan 2009). The Army helicopter accident rate ranged from the loss of five aircraft for 100,000 hours of flight for the AH-64, to two aircraft for 100,000 hours of flight for the UH-60 (Lucas, Thompson, and Davis 2007, 1).

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EW Threats

The more dependent on technology a military force, the more vulnerable the force is to EW. The Army has lagged behind the rest of the services in the development of EW, but they are now building a comprehensive EW program. In March 2009, the Army established EW career fields that will develop Soldiers whose expertise is fighting in the electromagnetic spectrum.

EW is a set of measures and actions performed by conflicting sides to detect and attack enemy electronic systems for the control of forces and weapons, including high precision weapons, as well as to electronically defend one's own electronic systems and other targets from technical intelligence, jamming and non-deliberate interference (Vakin, Shustov, and Dunwell 2001, 1).

The symptoms of an EA on a UASs CDL and the results of EMI on a UAS CDL are similar. An EA against a UAS CDL is a likely threat scenario due to the CDLs susceptibility to EMI being public knowledge. This attack would come in the form of an active jammer designed to drown out the CDLs communications.

Jamming is a form of EA using an electronic device, known as a jammer, to transmit high power signal at receiver to disrupt signal quality (Vakin, Shustov, and Dunwell 2001, 1). The three forms of jamming this study reviewed is broadband noise, tone, and swept jamming (Poisel 2003, 213). These jammers each have advantages and disadvantages on the modern EW battlefield but their limiting factor is the power available to apply to the jamming signal.

The goal of noise jamming is to send a threat signal sufficient strength to "out shout" the transmitter sending the attacked frequency (Schlesinger 1961, 13). Noise

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jamming disrupts the communication waveform by inserting noise onto the receiver. The bandwidth of the signal may be as wide as the entire spectrum used by the communications system or it may occupy only a single channel (Poisel 2003, 216).

Broadband jamming is also known as full band or barrage jamming. This type of jamming can be effective against all forms of anti-jamming (AJ) communication systems (Poisel 2003, 216). This type of jamming raises the background noise level at the receiver, creating a higher noise environment for an AJ system. If the noise is increased, it makes it difficult for a communications system to operate. Effective noise jamming may reduce the range of the communications or if the noise is sufficient, the jammer may deny communication (Poisel 2003, 216). An effective noise jamming attack can disrupt UAS CDL communications and cause the UAS to execute its lost link programming.

The greatest advantage of broadband noise jamming is the simplicity of the system. A jammer operator selects a frequency band and creates as much noise as possible to degrade an entire frequency spectrum. It does not require a smart means to acquire the specific transmitting frequency or the need to chase a frequency hopping system. The greatest disadvantage of broadband noise jamming is the strength of the jamming signal. The larger the spectrum being jammed, the less power is available to create noise.

Sweep jamming, or swept jamming, occurs when narrowband noise is swept across a frequency band of interest (Poisel 2003, 235). The jammer focuses on a specific frequency and a small portion of the band around the single frequency. This sweep can jam a selected band in rapid succession and have effects similar to a barrage jammer. However, a swept jammer concentrates its full power against specific frequencies on the

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band of interest and this allows swept jammers to have greater range than broadband jammers.

The greatest advantage of swept jamming is the ability to jam a broadband while maintaining adequate power to project its signal (Vakin, Shustov, and Dunwell 2001). Timing is the key to effective sweep jamming and if timing is correct, the jammer can hop around a spectrum with sufficient power to degrade communications. Timing is also the greatest disadvantage to swept jamming. If the jammer hops the spectrum too quickly, it may not loiter on a selected frequency long enough to achieve the degradation desired (Poisel 2003, 235).

Spot jamming, or single tone jamming, occurs when a jammer concentrates all of its power on a single frequency (Poisel 2003, 229). These jammers are effective against communications systems that do not hop and are in use by the opposition. Spot jamming does not move along the frequency spectrum and this limits the utility of such jammers against modern military equipment.

The greatest advantage of spot jamming is the power available to project on its disrupting power at a target. These jammers may have greater range than systems that attack a broad frequency spectrum (Vakin, Shustov, and Dunwell 2001). The greatest disadvantage of spot jamming is its inability to target modern frequency hopping communications and the intelligence requirement of identifying the specific target frequency (Poisel 2003, 230).

Man-Portable UAS are the systems most likely to experience an EA against their CDLs. These systems operate at low altitudes and in close proximity to threat forces. Their flight profile allows enemy forces to visually or acoustically acquire and track the

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system throughout their mission. Man-Portable UAS CDLs communicate on an L-band UHF frequency that is easy to jam (Poisel 2003, 213). The CDL does not use any electronic protection (EP) such as a frequency hopping radio or a coded receiver. Lastly, the UAS uses an omnidirectional that can receive commands from any direction throughout its flight profile. The C-IED devices in Iraq and Afghanistan use this type of jammer and their tendency to jam UAS CDLs is a testament to the vulnerabilities of these systems (Gaub 2010).

Tactical UAS are less likely to experience an EA against their CDLs but it is still at greater risk than Theater UAS. These systems operational altitudes are higher than Man-Portable UAS but are often within audio or visual range of threat forces (Hill 2010). Directing a jamming signal able to disrupt Tactical UAS CDLs would likely require an advanced directional antenna in order to project and focus its signal (Wilson 2010). Tactical UAS Man-Portable UAS CDLs operates using S-band UHF/SHF frequency and although more jam resistant than the L-band, it is still vulnerable to jamming (Poisel 2003, 214). Lastly, the UA uses an omnidirectional that can receive commands from any direction throughout its flight profile but the GCS transmits its signal using a directional antenna (Hill 2010)

If a CDL experiences frequency interference, the system executes a self-recovery program known as a “lost link procedure” and attempts to reacquire the CDL from the GCS. If a Man-Portable UAS fails to reacquire its CDL, it continues its self-recovery program and attempts to return to a preprogrammed recovery point. If a Tactical UAS fails to reacquire its CDL, the operators may identify the UA as rogue and deploy the systems recovery parachute to avoid endangering manned aircraft.

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Electronic Protection

EP is the subdivision of EW where military forces take action to protect personnel, facilities, and equipment from any effects of friendly or enemy use of the electromagnetic spectrum that degrade, neutralize, or destroy friendly combat capability (US Joint Forces Command 2007a, 8). Some experts refer to EP as the fixes to the faults exploited by ECM (Schlesinger 1961, 2). EP three subcategories are spectrum management, Electromagnetic (EM) hardening, and emission control. This study will focus on EM hardening of UAS as the only subcategory that is a defense measure against EA. It will also review self-protective measures such as counter-jammers (Headquarters, Department of the Army 2009c, 13) and Communications Security (COMSEC) measures (Headquarters, Department of the Army 2009b, 13).

In an unconstrained environment, vulnerabilities or flaws in military systems would be quickly repaired, but in reality, modifications take time. An aerospace engineer interviewed discussed a constant struggle to balance considerations of weight, size, form, and technological capabilities into component design (Macdonald 2010). A component designed for one system might not work for another system due to variation in design parameters and space available on a given airframe. EP components designed for use in Tactical UAS might be too large or heavy for use in a Man-Portable UAS. EP requirements for Man-Portable UAS might not be required for a Tactical UAS due to its higher operational altitude. Designers must consider the compromise of all these parameters and cost when developing new systems (Macdonald 2010).

Designing equipment that protects personnel, facilities, and equipment by filtering, attenuating, grounding, bonding, and shielding against undesirable effects of

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EM energy is hardening(US Joint Forces Command 2007a, 24). EM hardening is a design consideration for all UAS and hardening is one of the key differences between civilian and military UAS (Macdonald 2010). All military electronic equipment receives some hardening such as filtering, attenuating, grounding, and bonding during the production process (Wilson 2010). Most military systems receive some degree of shielding but the amount varies depending on the system. EM shielding can drastically increase the weight of a system and weight is a major concern for aircraft designers (Macdonald 2010).

Systems at risk from EW may execute a preemptive attack against a threat using defensive EA. These measures use the electromagnetic spectrum to protect personnel, facilities, capabilities, and equipment. A vulnerable system conducts a defensive EA to deny an enemy the use of the electromagnetic spectrum to attack the system (Headquarters, Department of the Army 2009c, 13). This fix to system vulnerability is referred to as electronic counter-countermeasures (ECCM) (Schlesinger 1961, 55). A common defensive EA component designed for aircraft is a counter-jammer.

An airborne counter-jammer jams in the same manner as a ground based system. They detect a jamming signal directed against an aircrafts communications system and transmit a counter-jamming signal toward the threat jammer (Puttre 2004, 57). Various self-protection electronic systems are currently available and some larger UAS have tested systems such as the AN/ULQ-21 (Puttre 2004, 67). It is very difficult to develop a completely effective ECCM system due to the dynamic nature of EW. Military forces may invest millions of dollars and an incredible amount of time to develop an ECCM that is obsolete soon after fielding. ECCM equipment often countered by electronic counter-

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counter countermeasures (ECCCM) and countering portion of the ECCM term can be carried to the ridiculous extreme (Schlesinger 1961, 55).

An overarching EW philosophy is that designers cannot make a communications system jam-proof but they can make a communications system jam-resistant. The ability to jam communications or the ability to resist jamming is a question of power. If sufficient power is available, any frequency within the electromagnetic spectrum can be jammed (Wilson 2010).

It would be difficult for a Man-Portable or Tactical UAS to produce sufficient power to resist an EA. Most Man-Portable UAS are battery powered and do not have the capability to produce their own power. Any power diverted for electronic self-protection would drastically affect their mission (Hill 2010). A Tactical UAS generates the power required to operate its systems but its ability to support additional power requirements is questionable (Hill 2010). The power production capability of a UAS is limited and the power potential of a UAS counter-jammer will be equally limited.

Denying unauthorized forces information of value that might be derived from the possession and study of telecommunications is COMSEC. These protective measures mislead or deny unauthorized persons attempting to interdict friendly communication (Headquarters, Department of the Army 2009b, 253). UAS program offices are working to improve COMSEC by applying cryptographic measures (Jensen 2010). The emphasis of these COMSEC improvements is UAS VDLs due to the publicized security breach of UAS video security by insurgents in Iraq (Gorman, Dreazen, and Cole 2009). The development of some of this COMSEC equipment is complete and fielding is ongoing (Hill 2010).

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These COMSEC systems encrypt a communications signal with a code prior to transmission and the receiver must decrypt the signal with a key to interpret the information. Coding communications does provide some EP to the transmitted signal. A smart jammer attempting to hop over a specific signal will fail unless it has the correct timing and frequencies (Poisel 2003, 237). This does not mean that a coded signal is jam-proof but it is more jam resistant. Some forms of jamming, such as broadband jamming, are not dependant on timing or frequency specificity. If enough power is available, a jammer can jam any frequency along the spectrum it is targeting (Poisel 2003, 214).

This chapter began with an extensive review of the primary Man-Portable and Tactical UAS. It analyzed existing Joint and Army doctrine, UAS organizational structure, UAS operator training, and materials that influence UAS CDL security. Each of these components play a part in UAS CDL vulnerabilities but the material aspect has the greatest degree of influence. This study has shown that UAS CDLs are susceptible to EMI and that threat technology is available to attack these flaws making the UAS vulnerable. Measures are available that provide some EP to improve the security of these systems and electronic self-protective devices could be incorporated. These modifications must account for factors such as weight, size, form, technological capabilities, and cost into any modification design. Lastly, this study found that no communications signal is jam-proof weight but designers can develop a system that is resistant to jamming.

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

> [Y]ou may fly over a land forever; you may bomb it, atomize it, pulverize it and wipe it clean of life--but if you desire to defend it, protect it, and keep it for civilization, you must do this on the ground, the way the Roman legions did, by putting your young men into the mud.
>
> — T. R. Fehrenbach

Conclusions

The procurement and utilization of UAS has exploded globally and these systems have changed the face of 21st century warfare. They are a mainstay on the modern battlefield gathering intelligence, observing key terrain, and targeting threat forces. Time will tell if the world is experiencing an UAS RMA or if these weapons are products of simple innovation. What is clear is the faith the US government has placed in UAS and their intent to lead the global development of this technology.

Reliability of the UAS communications structure is a major concern and failure of CDL communications due to EMI has resulted in numerous UAS accidents. The omnidirectional antennas the aircraft uses to establish the CDL leaves the system open to interference. Environmental EMI from communications systems produce sufficient energy to disrupt CDLs and are responsible for 15 percent of Army UAS accidents (Air Task Force 2009, 6). Man-Portable UAS CDL experience communications failure more frequently but accurate statistics are not available due to lack of reporting (Gaub 2010).

An adversary can exploit this susceptibility to EMI by conducting an EA against the CDL. The indicators of an EA and the symptoms of EMI disrupting UAS CDLs are similar. Jammers capable of disrupting CDLs may be simple range omnidirectional

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systems or smart systems that can project a signal far away from the transmitter. Interviews conducted confirmed that any communications signal can be jammed if the appropriate technique is used and sufficient power is available (Wilson 2010). Simple jammers are easy to make and these improvised jammers can attack UAS CDLs.

This chapter presents the findings and recommendations of this study using the doctrine, organization, training, and material portions of the DOTMLPF construct. These findings and recommendations are not all inclusive, but they do present the key issues that require attention to shape the future force.

Doctrine

This study's review focused the adequacy of Joint and Army doctrine to prepare for EW. The Joint doctrine review examined the establishment of a common operational language, Joint UAS employment planning, and considerations for UAS CDL protection. This study took a different approach reviewing Army publications and split its focus into two areas. First, this study examined Army maneuver doctrine to determine the adequacy of employment planning and considerations when integrating UAS into operations. Second, the study examined how well Army doctrine addresses EW threats to UAS operations.

The Joint community has failed to establish a language. Development of Joint terminology is the responsibility of US Joint Forces Command (USJFCOM) but this process is complicated due to the dynamic nature of UAS innovation. Operators and non-operators alike should clearly understand Joint terminology. The language must be ridged enough to minimize ambiguity but retain the flexibility that allows for system innovation

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and growth. Clearly defining classes is critical, especially if findings demonstrate that some classes are more susceptible to EW.

The failure to establish flexible Joint terminology has resulted in continuous changes in UAS classifications. There has been at least five different UAS naming conventions, and at one time the Air Force, Army, and Marines all used service-specific terminology. The *FY2009–2034 Unmanned Systems Integrated Roadmap,* dated April 2009, contains the most recent UAS categories. It specifies groupings based on aircraft specifications and performance. This group identification is of little value to a non-operator who does not know the specifications and performance parameters of a specific UAS (Department of Defense 2009, 110). It also lacks flexibility and the fielding of new micro UASs will require a revised terminology.

This study used the UAS classifications found FM 3-04.15, *Multi-Service Tactics, Techniques, and Procedures for the Tactical Employment of Unmanned Aerial Systems,* dated 3 August 2006, which establishes three classes based on a systems operational environment and general system capabilities. It classifies systems as Man-Portable UAS, Tactical UAS, and Theater UAS. These general groupings allow non-operators to understand system capabilities but their general description may lack the specificity some desire.

Joint planning considerations for UAS employment and considerations for CDL protection within the JPs is acceptable. There is room for improvement but the newest manual, JP 3-30, *Command and Control for Joint Air Operations,* dated 12 January 2010, is excellent.

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This study then conducted a review Army maneuver publications to determine their understanding of UAS capabilities and limitations. Maneuver forces have embraced UAS and they have a good understanding of its capabilities. They integrate unmanned systems in all operations: offensive, defensive, and tactical enabling. However, these forces lack a general understanding of UAS limitations and survivability planning considerations. They do not stress UAS dependence on uninterrupted communications, their susceptibility to EMI, or their vulnerability to EW. The only maneuver publication that addresses UAS limitations is FM 3-20.971, *Reconnaissance and Cavalry Troop*, dated August 2009. *Reconnaissance and Cavalry Troop* discusses their vulnerability to enemy fire, acoustic signature, and dependence on LOS communications.

This study next examined the adequacy of UAS threat planning. The primary document for this review was FM 3-04.115, *Army Unmanned Aircraft Systems Operations*, dated July 2009, the Army's capstone UAS planning publication. *Army Unmanned Aircraft Systems Operations* is the only Army publication that addresses both UAS CDL susceptibility to EMI and threats to UAS (Headquarters, Department of the Army 2009a). However, most of the threats identified are conventional and EW threats against UAS are mentioned just once in FM 3-04.115. This study finds that planning considerations and threat mitigation to improve UAS survivability against EW is inadequate.

Other Army aviation manuals, such as FM 3-04.126, *Attack Reconnaissance Helicopter Operations*, February 2007, is an excellent template for improvement. *Attack Reconnaissance Helicopter Operations* dedicates an entire appendix to planning

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considerations for aircraft survivability from a variety of threats, unlike the few paragraphs in *Unmanned Aircraft Systems Operations*.

Organization

This study examined the organizational structure of Man-Portable and Tactical UAS units to determine if the structure is adequate for EW planning. Aviation branch is the prepotency for UAS and they have progressively standardized UAS operations. Aviation branch has organized UAS units under the same design as their manned units. This has produced mixed results depending on the airframe.

It is unrealistic for units using Man-Portable UAS to mirror the manned aircraft organizational design. These units lack the SMEs found either manned aircraft or specialized UAS units. These units do not have leaders trained as UAS operators and unit UAS Master Trainers may themselves be inexperienced (Gaub 2010). This lack of experts limits their ability to identify indicators of EW or plan to counter an EA. Man-Portable organizations must expand their knowledge base to improve their EW planning capacity.

Tactical UAS units mirror their manned counterparts well. Aviation branch has exerted greater control over these units since their assimilation from Military Intelligence branch. These specialized UAS units have are standardized and professionals in the aviation community. Commanders of Tactical UAS units are not operators, but they have numerous SMEs advisors to mitigate their lack of training. These SMEs are capable of coping with and plan to counter EW if properly trained.

A ridged quality control process ensures Tactical UAS operators are thoroughly vetted professionals. Requirements for enlisting as a Tactical UAS operator are high and

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these Soldiers enter a career field that ensures continued progression. This ensures that only quality Soldiers receive training as an operator and keeping operators in the community ensures a consistently healthy talent pool (Thomas 2006).

Training

This study examined the training Man-Portable and Tactical UAS operators receive to identify EW training requirements. Training for these operators is different due to their specific operational environments.

Qualification training for Man-Portable UAS operators is very good. Soldiers from various MOSs and skill levels receive training by quality civilian and military trainers. Infantrymen, fire supporters, mechanics, engineers and cooks often train as Man-Portable UAS operators. These Soldiers attend a 10-day qualification course that focuses on learning about their UA, flight controls and EMI indicators, basic aerodynamics, mission planning, and UAS emergency procedures. The qualification course covers environmental forms of EMI, but does not discuss EW threats to aircraft survivability (Hicks 2008). Once qualified, operators receive a certificate of course completion but do not receive an ASI.

Initial entry training for Tactical UAS operators is excellent. The 23-week initial entry training course includes a fully certified FAA ground school, aerodynamics, meteorology, image analysis, aviation maintenance management, use of the AMPS, and aviation safety considerations (Thomas 2006). One critique of the initial entry course is an absence of instruction on threats to UAS survivability and counter EW planning.

Tactical UAS operators train as professionals entering a community through which they progress throughout their career. Unlike Man-Portable UAS operators, these

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Soldiers attend developmental military schooling such as the Army's Noncommissioned Officer Course (ANCOC) as they advance, and will have leadership opportunities (Thomas 2006).

Material

This study examined the vulnerabilities of UAS CDLs to an EA. These systems have not been exposed to a highly saturated EW battlefield due to their recent development but findings can be extracted by their performance against other forms of interference. The root cause of both EMI on an UAS CDL and an EA against an UAS CDL is signal interference. UAS reaction to either EMI or an EA will be similar due to both being a result of signal interference. Disruption of UAS CDLs is reflected in a systems reliability and accident rate.

This study found the reliability and accident rate of UAS surprising. In 2005, the Congressional Research Service issued a report that UAS have an accident rate 100 times greater than manned aircraft (Congressional Research Service 2005, 2). Accident data remained consistent throughout this study and data supports the findings of the 2005 Congressional Research Service report (Dunnigan 2009). Communications failure accounts for 11% of all Theater, Tactical, and Man-Portable UAS accidents (Office of the Secretary of Defense 2003, 39). Communications failure in Army systems accounts for 15% of all reportable accidents but most incidents of communication failure for Man-portable UAS go unreported (Air Task Force 2009, 6).

EW technology is available that exploits UAS CDL susceptibility to EMI. These EW systems disrupt CDLs by transmitting a more powerful signal than that produced by a UASs GCS. These systems are jammers that "out yell" a friendly transmitter using the

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electromagnetic spectrum to send data. This form of EA will cause signal interference similar to what CDLs experience due to EMI. This study reviewed three forms of jamming: broadband noise, tone, and swept jamming (Poisel 2003, 213).

Jamming disrupts communication waveforms by flooding a receiver with noise and any signal can be jammed with sufficient power. Effective noise jamming may reduce as systems communications range or it may completely deny communications (Poisel 2003, 216). Disruption of UAS CDLs will cause a system to execute its lost link programming and force an aircraft to depart the mission area (Gaub 2010).

It is possible to defend against an EA by using EP measures or conducting a defensive EA. EM shielding is means by which designers can improve systems susceptibility to external interference. Shielding can be effective, but it can also add significant weight to the aircraft (Macdonald 2010).

Defensive EA uses the electromagnetic spectrum to execute a preemptive attack against a threat system before it can conduct an EA (Headquarters, Department of the Army 2009c, 13). A counter-jammer is a device commonly used for defensive EA. These counter-jammers detect a jamming signal and transmit a counter-jamming signal toward the threat (Puttre 2004, 57). These improvements are plausible but one must consider second and third order effects when implementing such changes. Any modification used to improve UAS CDL security must account for factors such as weight, size, form, technological capabilities, and cost into any modification design (Macdonald 2010).

COMSEC can also increase UAS CDL security, but it may not prevent CDL jamming. COMSEC imparts a code on data when sending a signal and a key is required to translate the code on the receiving end. These protective measures mislead or deny

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unauthorized persons attempting to interdict friendly communication (Headquarters, Department of the Army 2009b, 253). Coding communications does provide some EP to the transmitted signal. A smart jammer attempting to hop over a specific signal will fail unless it has the correct timing and frequencies (Poisel 2003, 237). PEO AVN is working to improve COMSEC on all Army UAS (Jensen 2010). COMSEC does not make a signal jam-proof but it may make a signal jam resistant. If sufficient power is available, any frequency within the electromagnetic spectrum can be jammed (Wilson 2010).

Recommendations

This study used the DOTMLPF construct to focus the analytical process and it will continue to use this design when making recommendations to mitigate CDL vulnerabilities.

Doctrine

This study recommends the Joint community adopt classifications aligned with the Joint levels of war: Tactical UAS, Operational UAS, and Strategic UAS. The study recommends the addition of a fourth class, Theater UAS, to reflect systems above the Operational level but below the Strategic level, such as the MQ-9 Reaper. Using the doctrinally accepted levels of war eases ambiguity, prevents continuous redefining of classes, and allows non-operators to understand the general capabilities of a system. These descriptions may be too broad for use by operators and subcategories within these classes may be required for detailed planning.

This study recommends the Army clearly explain limitations and survivability considerations for UAS in maneuver doctrine. This community understands the benefits

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of this combat multiplier but many are ignorant to their limitations. This lack of understanding may be a contributing factor to the frequency of UAS CDL disruption. These forces have been trained to utilize unmanned systems, but they must be taught how to preserve these systems.

This study recommends the Army conduct a comprehensive review of counter-UAS threats and include its findings in changes to FM 3-04.115, *Army Unmanned Aircraft Systems Operations*. The audience for the revised manual is UAS operators, planners, and leaders. *Army Unmanned Aircraft Systems Operations* must be a standalone document that is applicable to all levels of war. It must account for conventional counter-air threats and EW threats against all UAS. Doctrine must dispel the belief that UAS are expendable. No UAS is expendable and the Army must do more to improve system survivability.

Organization

This study recommends a reexamination of the intent behind current Man-Portable UAS design. It is unrealistic to expect units equipped with MAN-Portable UAS to replicated manned organizations without increases in quality control and in the number of SMEs. This lack of expertise degrades the organizations ability to cope with unforeseen threats, such as an EA.

The Army must generate a standardized screening process for Man-Portable UAS operators and establish a minimum set of requirements to receive training. UAS Master Trainers must be an experienced UAS operator that understands and can plan for threat activity. Master trainers must have enough time in service to advocate UAS limitations and survivability concerns with leadership.

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UAS operators should receive an ASI on completion of initial training and they should remain proficient throughout their careers. This will allow these systems to develop a healthy talent pool comparable to Tactical UAS. This will allow Man-Portable organizations to cope with an unplanned event, such as an AE. These recommendations will increase requirements on units equipped with Man-Portable UAS. If these changes prove too disruptive, Aviation branch must reconsider the organizational design for these units.

This study has no organizational recommendations for Tactical UAS. The manned unit design is well suited for these specialized UAS organizations.

Training

This study recommends that counter EW and airframe survivability planning considerations be included in all UAS qualification training.

Man Portable UAS is the system most likely to encounter enemy contact but these operators receive limited threat training. The Man-Portable qualification course discusses environmental EMI but it does not cover EW threats to aircraft survivability. The qualification course should stress the importance of accident reporting, especially when operators suspect EMI. Accident reporting from these systems is poor and ascertaining causes of UAS failures is difficult without this data (Gaub 2010). Lastly, those who complete the qualification course should receive an ASI and be tracked throughout their careers.

Initial entry training for Tactical UAS is excellent but it lacks sufficient threat training. Aviation branch must determine threats to UAS from small arms, Air Defense Artillery (ADA), and EW. Tactical UAS training must be updated to account for these

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threats and focus its efforts on airframe survivability. These operators must understand that their systems are not expendable and they are responsible for managing its survival.

Material

This study recommends an increased effort to improve CDL protection and security. These improvements will not be universal due to the differing airframes involved. Engineers designing modifications must consider weight, size, form, technological capabilities, and cost considerations. Improvements may not be practical if they impede on system capabilities or substantially increase unit cost. Improvements of smaller systems may be limited to passive measures such as EM shielding and application of COMSEC. Larger systems may be able to integrate active measures, such as counter-jammers, into their systems. Airborne counter-jammers, such as the AN/ULQ-21, are available but current technology may not be appropriate for Army systems (Puttre 2004, 67).

Summary

UAS CDLs are vulnerable to EA and these systems may be targeted using low tech, easy to produce, jamming weapons. Jammed UAS will not complete their assigned mission, but will execute a lost link procedure in an attempt to reestablish link (Hill 2010). Disrupted UAS may reestablish their CDLs but many crash due an inability to reconnect with their GCS. The solution to rectify these flaws will not be uniform for all airframes.

Man-Portable UAS have the greatest threat of experiencing an EA, but the size of the airframe limits EP or defensive EA design options. Any modifications to Man-

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Portable UAS that increases weight or substantially raises unit cost may not be worth the effort. The solution for these systems may be improved training for operators and education for leaders. Man-Portable UAS users must plan and account for aircraft survivability when conducting pre-mission planning.

Tactical UAS are less likely to experience an EA but it is possible, especially from a sophisticated threat. The size of Tactical UAS airframes allows greater options to improve CDL protection and security. Engineers still must consider size, weight, and cost when designing modifications. An upgrade that reduces current system capabilities is inadvisable but airframe survivability must be a consideration in future designs.

This study did not focus on Theater UAS but sufficient information is available to determine that these systems are least threatened by a ground based EA. These systems are still vulnerable to EA but most likely by an airborne EW platform. The size of Theater UAS allows numerous options to improve CDL protection and security.

Military aviation is in a transitional phase. Determining the future force structure and the required equipment is a complex proposition. This transformation demands extensive research and development. US military aviation stands to remain the dominant global airpower force if their vision of the future force is correct but if their vision is incorrect, it will be fighting to regain airpower relevancy. Understanding the advantages and disadvantages of manned and unmanned aircraft is vital in determining future force structure.

Manned aircraft have a number of advantages over unmanned aviation. Statistics show that the most accident prone manned aircraft lost five aircraft for every 100,000 flight hours as opposed to the least accident prone UAS losing 40 aircraft for every

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100,000 flight hours. This lower accident rate is due to higher standards for manned aircraft design and ability of a pilot to evaluate and react to an in-flight emergency.

Manned aircraft also have a number of disadvantages when compared to unmanned systems. Combatant commanders must consider the limitations and vulnerability of pilots when assigning missions. It is unconscionable to send such airframes on a mission that has little chance of survival or a mission that presses pilots beyond human limitations. Manned aircraft are more expensive to produce and maintain than their unmanned counterparts. The weak link in manned aviation is the man.

Unmanned systems have a number of advantages over manned aircraft. The systems are unbound by human limitations. They can remain airborne for long durations, do not require life support systems, do not need to eat or sleep, and they will never say no to a mission. They may minimize friendly loss of life by conducting missions that have a minimal chance of survival.

Unmanned systems also have a number of disadvantages in comparison to manned aircraft. They have a relatively high accident rate and the cost of the systems have grown exponentially. Ground based operators control these systems and they are still prone to human error. UAS operators have minimal options if an in-flight emergency occurs and such emergencies often result in the airframe being lost. Current systems are not autonomous and depend on communications with a GCS. The weak link for UAS is their dependence on continuous communications.

The best long-term solution for the military is a balanced air force structure. The military must continue to embrace UAS technology and invest in future systems. They must also remember the self-balancing nature of warfare and diversify their employment

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options. Over dependence on a single technology can leave a force unprepared for combat. In World War II, the Army Air Corps did not recognize limitations their strategic bombing doctrine and numerous lives were lost as they scrambled to produce a viable pursuit aircraft. In the Korean War, the government did not recognize the limitations of Atomic deterrence and spent months rapidly modernizing its obsolete force. In Vietnam, the Air Force had overestimated the ability of their AAMs and modified their shortsighted fighter designs with guns. The US must prepare for future combat operations against all threats whether high intensity conflict, hybrid, or asymmetric. It cannot afford to be unprepared when an unknown adversary decides to attack.

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GLOSSARY

Abort. To terminate a mission for any reason other than enemy action. It may occur at any point after the beginning of the mission and prior to its completion (US Joint Forces Command 2009b, 8).

Above Ground Level (AGL). Above ground level is the height in which an aircraft is above the ground (Headquarters, Department of the Army 2007b, 19).

Acoustical Surveillance. Employment of electronic devices, including sound-recording, receiving, or -transmitting equipment, for the collection of information. (US Joint Forces Command 2009b, 8).

Air Defense Artillery (ADA). Weapons and equipment for actively combating air targets from the ground. (US Joint Forces Command 2009b, 18).

Air Surveillance — The systematic observation of airspace by electronic, visual or other means, primarily for the purpose of identifying and determining the movements of aircraft and missiles, friendly and enemy, in the airspace under observation. (US Joint Forces Command 2009b, 28).

Airspace Management. The coordination, integration, and regulation of the use of airspace of defined dimensions. (US Joint Forces Command 2009b, 27).

Barrage/Broadband Jamming. A type of electronic attack intended for simultaneous jamming over a wide area of frequency spectrum. (US Joint Forces Command 2009b, 47).

Chairman of the Joint Chiefs of Staff instruction. A replacement document for all types of correspondence containing Chairman of the Joint Chiefs of Staff policy and guidance that does not involve the employment of forces. An instruction is of indefinite duration and is applicable to external agencies, or both the Joint Staff and external agencies. It remains in effect until superseded, rescinded, or otherwise canceled. Chairman of the Joint Chiefs of Staff instructions, unlike Joint publications, will not contain Joint doctrine (US Joint Forces Command 2009b, 62).

Command and Control (C2). The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission (US Joint Forces Command 2009b, 79).

Communications Jamming. Electronic measures taken to deny the enemy use of communications means (Headquarters, Department of the Army, 2004, 52)

Coordinating Altitude. A procedural airspace control method to separate fixed- and rotary-wing aircraft by determining an altitude below which fixed-wing aircraft

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will normally not fly and above which rotary-wing aircraft normally will not fly (US Joint Forces Command 2009b, 98).

Directed-Energy Warfare. Military action involving the use of directed-energy weapons, devices, and countermeasures to either cause direct damage or destruction of enemy equipment, facilities, and personnel, or to determine, exploit, reduce, or prevent hostile use of the electromagnetic spectrum through damage, destruction, and disruption. It also includes actions taken to protect friendly equipment, facilities, and personnel and retain friendly use of the electromagnetic spectrum (US Joint Forces Command 2009b, 125).

Doctrine. Fundamental principles by which the military forces or elements thereof guide their actions in support of national objectives. It is authoritative but requires judgment in application (US Joint Forces Command 2009b, 130).

Drone. A land, sea, or air vehicle that is remotely or automatically controlled (US Joint Forces Command 2009b, 131).

Electromagnetic Hardening. Action taken to protect personnel, facilities, and/or equipment by filtering, attenuating, grounding, bonding, and/or shielding against undesirable effects of electromagnetic energy (US Joint Forces Command 2009b, 135).

Electromagnetic Spectrum. The range of frequencies of electromagnetic radiation from zero to infinity. It is divided into 26 alphabetically designated bands (US Joint Forces Command 2009b, 136).

Laser Rangefinder / Designator (LRFD). A device which uses laser energy for determining the distance from the device to a place or object. A device that emits a beam of laser energy which is used to mark a specific place or object (US Joint Forces Command 2009b, 233).

Mean Sea Level (MSL). Determined based on barometric pressure, MSL altitude is the distance above where sea level would be if there were no land (Headquarters, Department of the Army 2007b, 19).

Meteorology. The study dealing with the phenomena of the atmosphere including the physics, chemistry, and dynamics extending to the effects of the atmosphere on the Earth's surface and the oceans (US Joint Forces Command 2009b, 253).

Reachback. The process of obtaining products, services, and applications, or forces, or equipment, or material from organizations that are not forward deployed (US Joint Forces Command 2009b, 331).

Remotely Piloted Vehicle. An unmanned vehicle capable of being controlled from a distant location through a communication link. It is normally designed to be recoverable (US Joint Forces Command 2009b, 338).

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Spot/Tone Jamming. The jamming of a specific channel or frequency (Headquarters, Department of the Army, 2004, 187)

Sweep/Swept Jamming. A narrow band of jamming that is swept back and forth over a relatively wide operating band of frequencies (Headquarters, Department of the Army, 2004, 193)

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Knowledge, Skills, Abilities, and Other Characteristics for Remotely Piloted Aircraft Pilots and Operators

William R. Howse
Damos Aviation Services, Inc.

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This report presents the results from a review of a literature base of more than 200 publications in which eight were found to contain lists of Knowledge, Skills, Abilities, and Other Characteristics (KSAOs) for remotely piloted aircraft (RPA) crew positions, either for the purpose of system design specification or for personnel selection. The report compares KSAO lists across these studies and presents a cross reference table for them. The report also surveys past efforts to establish KSAOs in anticipation of related developments and discusses the major likely sources and nature of future changes in KSAO demand for RPA operators.

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ABSTRACT

This report presents the results from a review of a literature base of more than 200 publications in which eight were found to contain lists of Knowledge, Skills, Abilities, and Other Characteristics (KSAOs) for remotely piloted aircraft (RPA) crew positions, either for the purpose of system design specification or for personnel selection. The report compares KSAO lists across these studies and presents a cross reference table for them. The report also surveys past efforts to establish KSAOs in anticipation of related developments and discusses the major likely sources and nature of future changes in KSAO demand for RPA operators.

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KNOWLEDGE, SKILLS, ABILITIES, AND OTHER CHARACTERISTICS

FOR REMOTELY PILOTED AIRCRAFT PILOTS AND OPERATORS

Introduction

In August 2009 Damos Aviation Services (DAS) accepted Subcontract TCN 09216 from Battelle Columbus Operations under the U.S. Army Research Office Scientific Services Program, Contract W911NF-07-D-0001 / Delivery Order 0906. This report responds to the requirement to compare and contrast current and future Knowledge, Skills, Abilities, and Other Characteristics (KSAOs) for Remotely Piloted Aircraft operators. In pursuit of this requirement relevant works were extracted from more than 40 sources beginning with the bibliographic database previously produced under this Delivery Order (Howse & Damos, 2011) and expanding with search criteria tailored to remotely piloted systems. More than 200 works were reviewed and only eight were found that are relevant to identification and evaluation of KSAOs for remotely piloted aircraft personnel and that at least elicited information from practitioners and/or subject matter experts that contributed to the identification of KSAOs.

Terminology varies considerably across services and over time within services. Even the phrases used to refer to the systems of interest are different. The phrases found in common use are: Unmanned Aerial Vehicle (UAV), Unmanned Aerial System (UAS), Unmanned Combat Air Vehicle or Uninhabited Combat Aerial Vehicle (UCAV), Remotely Piloted Vehicle (RPV), Tactical Unmanned Aerial Vehicle (TUAV), Unmanned Combat Armed Rotorcraft (UCAR), Vertical Take-off UAV (VTUAV), Ground Control System (GCS), and Common Ground Station (CGS). Because the U.S. Air Force has transitioned to universally adopting the term, Remotely Piloted Aircraft, the default term for air vehicles for this report is RPA.

There are a number of crew positions that are part of RPA systems. Not all of these have been targets of research efforts to identify or develop KSAOs. Again, there are differences in terminology across services. The crew positions that are the subject of one or more efforts cited in this paper are listed with their relevant Military Occupational Specialties (MOS), Ratings, and Air Force Specialty Codes (AFSC) are listed in Table 1.

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Table 1. Duty positions and their associated MOS, Rating, AFSC.

Personnel Duty Positions	Service	MOS, Rating, AFSC	Basic Position Description
Air Vehicle Operator (AVO)	USA	96U	The tactical unmanned aerial vehicle (TUAV) operator supervises or operates the TUAV, to include mission planning, mission sensor/payload operations, launching, remotely piloting, and recovering the aerial vehicle.
	USA	15W	RPA operators are integral to providing Army personnel with information about enemy forces and potential battle areas. RPA operators are remote pilots of unmanned observation aircraft, who gather and study information that's required to design operational plans and tactics. The RPA operator supervises or operates the RPA, such as the Army's Shadow RPA, to include mission planning, mission sensor/payload operations, launching, remotely piloting, and recovering the aerial vehicle.
	USN	NEC 8363	Operates and navigates RPA during the enroute, mission, and return phase of flight.
	USMC	7413	External RPA operators execute the initial takeoff and final landing phases of RPA operations. They are also an integral part of all mission planning, takeoff and landing sequences, and crew coordination aspects of RPA flight.
	USAF	18X	Air Force RPA Pilots plan and prepare for missions. They review mission taskings, intelligence, and weather information, supervise mission planning, equipment configuration, and crew briefings. Also, they ensure ground station and aircraft are preflighted, inspected, loaded, and equipped for mission. RPA pilots operate aircraft and command crew, operate aircraft controls and equipment, perform, supervise, or direct navigation, surveillance, reconnaissance, and weapons employment operations. Further, they conduct or supervise training of crewmembers, ensure operational readiness of crew by conducting or supervising mission specific training. RPA Pilots also develop plans and policies, monitor operations, advise commanders, assist commanders and perform staff functions related to this specialty.
Internal Pilot (IP) - See AVO above			
External Pilot (EP)	USN	NEC 8362	Performs organizational level maintenance on aircraft systems. RPA External Pilot directly controls the flight of the RPA during launch and recovery operations by visual reference to the RPA.
	USMC	7413	
Mission Package Operator (MPO)	USA	96U	
	USA	15W	
	USN	NEC 8364	Operates the EO/IR RPA sensor during all phases of flight.

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	USAF	1UOX1	RPA Sensor Operators perform duties as a mission crew member on unmanned aerospace systems. They employ airborne sensors in manual or computer-assisted modes to actively and/or passively acquire, track, and monitor airborne, maritime and ground objects. Qualified personnel conduct operations and procedures in accordance with Special Instructions (SPINS), Air Tasking Orders (ATO) and Rules of Engagement (ROE). Crewmembers assist UAS pilots (who are commissioned officers) through all phases of employment to include mission planning, flight operations, and debriefings. Sensor Operators continually monitor aircraft and weapons systems status to ensure lethal and non-lethal application of airpower. At present, Air Force 1UOX1 specialists perform their duties on the MQ-1 Predator and the MQ-9 Reaper remotely piloted aircraft (RPA).
Sensor Operator (SO) - See MPO above			
Mission Commander (MC)	USN	NEC 8364	
Common Ground Station Operator (GSO)	USA	96H	The common ground station (CGS) operator supervises or participates in detecting, locating and tracking ground targets and rotary wing and slow moving fixed wing aircraft. The GSO receives Joint Surveillance Target Attack Radar System (JSTARS) near-real time radar imagery data, RPA imagery, Commander's Tactical Terminal/Joint Tactical Terminal (CTT/JTT) Signals Intelligence (SIGINT) data, and Secondary Imagery Dissemination (SIDS) products which are transmitted to the Common Ground Station (CGS) to provide situational development, battle management, and targeting information and imagery intelligence of value to the commander.
Intelligence Analyst	USA	96B	The intelligence analyst supervises, performs, or coordinates, collection management, analysis, processing, and dissemination of strategic and tactical intelligence.
Imagery Analyst (Enlisted)	USA	96D	The imagery analyst supervises or analyzes aerial and ground permanent record imagery developed by photographic and electronic means. Plans and recommends the use of imaging sensors for reconnaissance and surveillance missions.

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Imagery Analyst (Warrant Officer)	USA	350D	Provides technical expertise and manages activities engaged in imagery interpretation activities. Acts as the chief of a platoon, section, detachment, or team performing imagery interpretation. Identifies changes of terrain, equipment locations, troop movements, or other information that contributes to intelligence. Identifies equipment by nomenclature and location to develop assessments of possible threat to U.S. forces. Develops summaries and prepares reports on imagery interpretation findings. Establishes and maintains files on imagery interpretation data, findings, records, and reports. Develops map overlays which reflect changed tactical information. Conducts intelligence briefings based on information obtained.

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Historical Background

The following is an extremely brief timeline of the development and acquisition of remotely piloted systems by the U.S. military. It is included to give the reader a sense of the time-span of RPA development and the rapidity, in recent years, with which system capabilities have expanded. It will also give the reader a sense of position in the timeline for the RPA systems that were evaluated in studies cited below. A far more complete history of RPAs has been written by L.R. Newcome (Newcome, 2004). Descriptions of current and emerging RPA systems can be found in the Department of Defense's Unmanned Systems Integrated Roadmap for the years 2009 to 2034 (Department of Defense, 2009).

The first documented application of remote piloting in aviation was contained in an operating model dirigible balloon exhibited by A.J. Roberts of Australia in 1912. This balloon was radio controlled (based on designs of Nikola Tesla). The model was about 15 feet long and could be controlled at a maximum range of about 500 feet.

At the beginning of World War I Professor A.M. Low of England, whose prior efforts were related to radio range finding, developed a remotely piloted airplane for the Royal Flying Corps. He successfully developed a radio control system. However, the engine of the prototype aircraft created too much radio interference for it to function properly. The first successful flight of a practical remotely piloted dirigible balloon took place in 1924 when the Royal Aircraft Establishment's *Target* flew for 12 minutes after launch from the deck of the HMS Stronghold. This project led to the design of the *Larynx*, a monoplane designed as an unmanned aerial bomb. It first flew in 1927 but there is no record of application in combat. The DeHavilland Tiger Moth, a biplane, served as a trainer from 1932 to 1947 in England. Several hundred of these aircraft were modified as remotely piloted target aircraft (designated *Queen Bee*). A few of these were employed in coastal reconnaissance missions during World War II.

In the early 1950s the Northrop/Radioplane Company developed the YQ-1B high altitude target drone into an unmanned reconnaissance vehicle, the B-67 *Crossbow*. The YQ-1B was equipped with a warhead and a radiation seeker for attacking air defense systems. The acquisition program was cancelled in 1957 before it became operational. Another early remotely piloted air vehicle was the AQM-34A *Firebee I*. This system was a modified target drone developed by Teledyne Ryan for the U.S. Air Force. It first flew in 1960. It could autonomously fly pre-programmed reconnaissance routes and employ a variety of mission equipment modules including photographic and infrared imaging and electronic countermeasures. Firebee I was used during the Vietnam war. No records have been located regarding selection practices for system operators.

In the 1970s the Army developed the MQM-105 *Aquila*, with Lockheed Missile and Space Company as the major contractor. It was designed for multiple battlefield roles concentrating on target acquisition, designation and aerial reconnaissance. The prototype first flew in 1975 and the first full scale development air vehicle flew in 1982. It had an endurance of 3.5 hrs and carried a daylight television camera and a laser rangefinder/designator with autotracking capability. Its flight path could be preprogrammed by altering waypoints stored in the flight control system. *Aquila* was never considered a successful system and was cancelled in 1987.

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The RQ-2 *Pioneer* was procured first by the Navy in 1985 from Israeli Aircraft Industries (IAI) as a naval gunnery spotting system. It has been used by the Army, Navy and Marine Corps. It has an approximate 5 hour endurance carrying electro-optical and infrared sensors.

Another system originally developed by IAI is the RQ-5 *Hunter*, originally procured from TRW in 1993 and, starting in 2003, from Northrop Grumman as the MQ-5B. *Hunter* system acquisition ended in 1996 but existing units continue to be employed and retrofitted. These systems have an endurance of 12-18 hours. In 1999 some were equipped with a laser designator and in 2003 some were modified to carry a variant of the Brilliant Anti-Tank (BAT) guided munition. They can carry a variety of munitions as wing stores and a variety of sensor packages with electro-optical and infrared capabilities. It also can carry a radio relay package to provide extended communications ranges.

The Army began procurement of the RQ-7 *Shadow* in 1999. It has an on-station endurance of approximately 6 hours and carries a variety of electro-optical and infrared sensor packages and can be equipped with a laser designator.

The MQ-1 *Predator* was developed by General Atomics for the Air Force, though Army and Navy also use them, and has been in service since 1995. This is a long-range system capable of covering very long distances to an area of operations and loitering there for as much as 14 hours before returning. Whereas the preceding systems are controlled by line-of-sight radio link, Predator uses satellite links, allowing operators to be located nearly anywhere on the globe. It can carry a variety of sensor packages in daylight and infrared modes plus a laser designator and synthetic aperture radar. It can carry various wing-mounted stores including weapons, especially modified Hellfire missiles. Variants include the MQ-1C Extended Range/ Multipurpose (ER/MP) UAS with greater range and payload, and the MQ-9 Grey Eagle.

Identifying RPA Operator KSAOs

In 1979 an effort was made by the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) to extract from the small existing cadre of remotely piloted air vehicle operators and sensor operators a set of attributes that could be used to inform the development of selection and training systems (Crumley & Bailey, 1979). The approach was to administer two survey instruments, one to air vehicle operators and the other to sensor operators, and use their responses to guide structured group interviews. The surveys were made up of 27 multiple choice items, mostly having a Likert-type format, and one open-ended item soliciting written comments. Participants in the interviews were six airframe and sensor operators and nine support personnel and supervisors. These people were serving in the development group for the *Aquila* system. The survey items were derived from system manuals and contractor job descriptions. The group interview was guided toward consensus. The responses to the survey instruments were neither tabulated nor reported.

The authors suggested there were two personality types within their subject sample. This is based on the existence of two comparatively distinct attitudes toward continued work as system operators. Personnel who preferred the air vehicle operator role were described as having an affinity for planning and logic, those who preferred the sensor operator role were described as having an affinity for uncertainty. All operators disliked having close supervision during

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missions but agreed that a third (artillery trained) person was needed in the Ground Control Station (GCS).

The authors inferred from their data that eye/hand coordination was an important component of job performance but that physical strength, endurance, hearing acuity and color vision were not required at greater than average levels. Other attributes included patience and logic. Skill in verbal communication was also indicated as important. Two specific knowledge components were identified: map reading and photo interpretation.

After a 19 year absence of any apparent attempts to identify KSAOs for unmanned aerial system operators, Biggerstaff et al. (Biggerstaff, Blower, Portman, & Chapman, 1998) conducted a more formal project to predict training performance albeit their scope was limited to the role of the RPA external pilot (EP). This study had the expressed purpose of establishing selection criteria for entrance into training for *Pioneer* RPA operators. The attributes identified were also used to assist in making recommendations for medical screening of applicants for EP and internal pilots (IP); however, this study did not establish any training or job performance predictors for any crew position other than that of EP. The EP for the Navy version of *Pioneer* has a more extensive role in system operation than in larger RPAs. For *Pioneer* the EP is in direct interactive control of the airframe for takeoffs, landings, and while the airframe is in visual range of the crew. That is, the EP operates the airframe by manipulation of a set of flight controls similar to those of a recreational radio controlled aircraft. Takeoff and landing may be accomplished on a short airstrip or by jet-assisted launch from a pedestal and landing by capture net (shipboard operations).

The authors approached the operator tasks through task analyses, field observations, interviews (structured and unstructured), and test battery trials. An initial set of critical tasks was derived from observations and interviews of EPs, IPs, mission payload operators (MPO) and other related personnel. These tasks provided the source for personal attributes posited to affect performance. A single test battery, the Computer-Based Performance Test (CBPT) was selected to measure predictor variables (Delaney, 1992). A criterion measure was formed from an unspecified composite of instructor evaluations and flight grades, on a 0-100 scale.

The derived list of attributes, according to the authors, consisted of skills only; no specific knowledge, abilities, or other attributes were included. The derived skills were likely referred to as such because their source was a sample of fully trained, successful practitioners, rather than candidates. Therefore, personal attributes imparted by prior selection and training processes are assumed to be present. These skills were: Mental reversals/rotation, estimation of time to contact, eye-hand coordination, selective auditory attention, and multitasking (psychomotor + visual). It was determined that six subtests of the CBPT would adequately measure these skills: Psychomotor (PMT), Dichotic Listening (DLT), Horizontal Tracking (HT), Digit Cancellation (DC), Manikin, and Time Estimation (TET).

It appears to be the case that performance on the test battery components operationally defined the skill set. These test battery components are neither simple nor independent. They are designed to be administered in combinations and in specific orders progressing in complexity. PMT is combined with DLT, HT with DC, and Manikin with TET. The test components were

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associated with specific abilities: PMT with multilimb coordination, DLT with divided attention, HT with perceptual motor tracking, DC with reaction time and short-term memory, Manikin with mental rotation and short-term memory, and TET with perceptual tracking. Note that the abilities associated with DC do not directly correspond to any of the identified skills but may contribute indirectly to their measurement. The authors state that DC was used as a distracter, although no rationale for this is given. It may be that without an interfering secondary task HT was insufficiently difficult to produce measurement variance. The prototype battery was administered to eight students in EP training and six practicing EPs. It is not specified whether data from all 14 subjects were used to factor analyze eight performance scores derived from the battery. A single factor, consisting of a linear combination of the eight derived performance scores, was determined and used to predict the criterion measure using linear regression. The authors recognized that eight subjects (for whom the criterion measure was available) made for a rather small sample. Their solution was to insert 3 fictitious data points, one at the extreme low end of both predictor and criterion score, one at the extreme high end of both scores, and one at the approximate midpoints of both scores. The fictitious data points placed at the extremes were placed not at the extremes of observed scores on the predictor but rather, near the extremes of possible scores on the predictor. It is not unreasonable to expect that such manipulation would have a strong effect on the outcome of the regression. A review of the plot of factor scores versus criterion scores for 11 data points indicates that if the fictitious points were removed the slope of the regression would be similar but the dispersion far greater. The actual utility of the reported adjusted R^2 of .86 is questionable.

A job analysis intended for RPA future requirements was conducted by the Army Research Laboratory Human Research and Engineering Directorate (Barnes, Knapp, Tillman, Walters, & Velicki, 2000) that used the Job Assessment Software System (JASS) to explore manpower alternatives. The primary issues considered were the need for rated aviators and for imagery and intelligence specialists in RPA crews. This study was not intended to produce any information regarding selection of personnel for training. JASS was used to elicit relative importance ratings of two reduced sets of skills and abilities for RPA operators. The reduced skill and ability sets were extracted, presumably by the authors, from the 50 that comprise the full set in the JASS application. The 50 attributes in JASS are based on 52 abilities in Fleishman's Manual for Ability Requirements Scales (Fleishman & Quaintance, 1984). The reduced attribute sets were cognitive skills and abilities judged to be related to flight and navigation tasks for air vehicle operators (AVO) and to takeoff and landing tasks for EPs. The ratings were taken from a mix of 30 soldiers and contractors who were practicing as *Hunter* AVOs, MPOs and EPs. In addition, ratings on the EP list were taken from 16 Army aviators. (These will not be further discussed here.) Reduced attribute sets for JASS were also established for intelligence analysts and imagery analysts based on task structures for each. Rating data were collected in JASS on these attribute sets from nine intelligence analysts and eight imagery analysts. The ratings for each specialty were correlated with ratings taken from the original sample of AVOs, MPOs and EPs.

The JASS structure groups the 50 abilities taken from Fleishman into 8 categories: Communication, Conceptual, Reasoning, Speed Loaded, Vision, Audition, Psychomotor, and Gross Motor. The ratings indicate that the AVOs considered the Communications group (including oral and written comprehension and oral and written expression) to be most important, followed by the Conceptual group (including memorization, problem sensitivity, spatial

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orientation, and selective attention), and the Reasoning group (deductive reasoning, information ordering and inductive reasoning). The Vision, Audition and Gross Motor groups received comparatively low importance ratings. The ratings indicate that the EPs considered the Conceptual, Vision and Psychomotor groups most important.

The authors did not attempt any evaluation of psychomotor skills in their own work for this report but did review and report the results of previous unpublished work (Hopson, 1995) in which psychomotor ability was assessed for use in selecting RPA EPs. (We have not obtained a copy of that manuscript and so must rely on the reporting of the authors.) The instrument used in that study was the Enhanced Computer Administered Test (ECAT) battery. The ECAT battery was developed by ARI and the U.S. Navy Personnel Research and Development Center (NPRDC) to evaluate candidates for augmentation of the Armed Services Vocational Aptitude Battery (ASVAB), under ARI's Project A (Oppler et al., 1992). The authors report that the unpublished study used two of nine subtests in the battery (Oppler et al. list 10 subtests in ECAT), One-Hand Tracking (also known as Target Tracking Test 1) and Two-Hand Tracking (also known as Target Tacking Test 2). The subtests were administered to 28 EP candidates in training in both Hunter and Pioneer systems, from the Army, Navy, and Marine Corps. The authors report that the unpublished work indicated a strong relationship between the One- and Two-Handed Tracking scores and failure to complete training. No statistical analysis of the data is reported.

In another application of the JASS tool, Warner and Knapp (2000) compared the current skill requirements for Army Common Ground Station Operators with projected skill requirements for an enhanced Common Ground Station in development. They also considered whether skills and abilities possessed by Intelligence Analysts and Image Analysts should be integrated into CGS personnel. JASS was administered to 41 CGS Operators (GSO) to acquire importance ratings on seven high level functions specific to their duty position in the enhanced CGS. These were:

1. Establish Comm Links
2. Display moving target indicator (MTI) track targets
3. Respond to All Source Analysis System (ASAS) tasking
4. Respond to fire support tasking
5. Correlate sensor data from RPA, Commander's Tactical Terminal (CTT), and MTI
6. Perform target analysis
7. Use intel-ops knowledge

Of the 41 operators participating, 13 had experience in the developmental enhanced CGS. Only four of the eight JASS skill categories were considered likely to be impacted in the enhanced CGS: Communication, Conceptual, Speed Loaded, and Reasoning. These four groups contain 23 of the 52 abilities listed in Fleishman's Manual for Ability Requirements Scales (Fleishman & Qaintance, 1984). The data indicate that in the Communication group skill demands were expected to decrease for all seven functions in the enhanced CGS. Skill demands for Functions 2, 3, and 4 were also expected to decrease in all four skill groups. These decreases were attributed to expected efficiencies stemming from improved user interfaces and increased automation. For Functions 1, 5, and 7 the expectation was for an increase in skill demand for the Conceptual, Speed Loaded, and Reasoning skill groups.

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The authors also compared their rating data with ratings obtained earlier from Image Analysts and Intelligence Analysts. Their data indicated that for several of the abilities rated in JASS the Image Analysts and Intelligence Analysts tended to rate the requirement as high (an arbitrary rating of 3 or greater) on a greater proportion of the functions involved. This comparison is unclear at best because the function sets rated by the Imagery and Intelligence Analysts were different from the GSO function set and presumably different from each other. The authors concluded that fielding of the enhanced CGS would be expected to produce a shift in ability requirements toward cognitive and perceptual categories. It should be noted that the enhanced CGS that was in development during this study is not yet fully implemented.

In a 2003 presentation at the Military Testing Association Conference, Phillips et al., (Phillips, Arnold, & Fatolitis, 2003) described their effort to validate a selection battery for RPA operator training. This was a follow-on to Biggerstaff et al., described above. However, whereas Biggerstaff et al. developed their battery for EP selection, Phillips et al. conducted a validation of a similar battery for prediction of success in IP training. It is assumed that the validation is based on analysis of data that had been in existence for several years. The battery was administered to 39 individuals who were in IP training between 1995 and 1997. It is not clear at what point in training the battery was administered. The test battery was the same as that used in Biggerstaff et al. except the Time Estimation Test (TET) was not used. Scoring, however, was accomplished rather differently. Predictor variables were four Component Scores and an Index Score. The four Component Scores, each consisting of the mean of a set of standardized battery performance scores, were taken from the PMT, DL, HT, DC, and Manikin tests. The four Component Scores were named: Psychomotor, Multitasking-calculation, Multitasking-psychomotor, and Visuospatial. These score components were not independent. For example, from the simultaneous presentation of DL and the one-hand tracking portion of PMT (stick), the DL score was used in the Multitasking-calculation score component and the one-hand tracking (stick) portion was used in the Multitasking-psychomotor component. The mean of the four Component Scores comprised the Index Score.

Two criterion variables were used. The first, Training Performance, was the average of all test scores and flight evaluation grades in training. The second was dichotomous, attrition from training, presumably without regard to cause. Of the 39 students in the sample, six failed to complete training. These as a group had significantly lower performance on the predictor variables, all four Component Scores, and on the Index Score, as indicated by t-tests calculated using an alpha value of .05. The Index Score is a linear combination of the Component Scores. Considering only the Component Scores, the sum of the Type I error probability is .25. Attriting students did not exhibit significantly different training performance scores from non-attriting students. All four Component scores and, not surprisingly, the Index Score, significantly correlated with training performance. This is based on a univariate correlation matrix. No multivariate analysis was reported. The correlation between the Index Score and Training Performance was .59.

A selection test battery was developed for Army UAS operators in 2007 (Bruskiewicz, Houston, Hezlett, & Ferstl, 2007). The Army uses a single Military Occupational Specialty (MOS) for both AVO and MPO positions. Because they are completely cross-trained and interchangeable, a single battery can be used for training selection. This battery was not designed for any other

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UAS-related position. Development of the battery was in anticipation of the effects on UAS operator tasks and missions and, therefore, on relevant personal attributes that would result from the transfer of all Army UAS assets (except for Raven, which remains with the Infantry) from the Military Intelligence Branch to the Aviation Branch. Under the Military Intelligence branch the relevant MOS was 96U. Under the Aviation branch it is 15W.

Development of the battery began with a job analysis using the job inventory approach implemented through a Job Analysis Questionnaire (JAQ). Prior job analyses and training materials were reviewed to produce a preliminary task list with related KSAOs. These provided the base content of a draft JAQ. The draft JAQ was reviewed by subject matter experts who provided feedback on both content and structure, and was revised to produce an instrument with 135 task statements and 77 KSAO statements. The resulting JAQ was administered at five locations and generated valid responses from 75 individuals. Ten of these were subject matter experts (SME) who had particular knowledge of emerging UAS airframe and mission capabilities and who were asked to complete the JAQ with future KSAO requirements in mind. All of the remaining 65 respondents were current Army UAS operators. For the SME respondents the inter-rater agreement on importance of KSAO statements was .64, which is considered high. For the rest of the respondents the inter-rater agreement on importance of KSAO statements was .58, which is considered moderate.

Using a conservative Type I error rate of .10 the authors found nine KSAOs on which the SME subgroup differed from the rest of the respondents as indicated by the means of importance ratings. Using a more customary Type I error rate of .05, there are only four: Operation of Weapon Systems and Equipment, Operation of Sensor/Tracking Systems and Equipment, Risk Tolerance, and Deliberation. In the first two cases the SMEs produced higher mean importance ratings than the rest of the respondents. In the last two cases the SMEs produced lower mean importance ratings. The first two were Knowledge attributes that directly relate to weapon system operation. Only the SMEs had experience with weaponized UAS. The other two were both Other attributes. The lower mean SME rating of the importance of risk tolerance could be anchored in the increased level of responsibility, magnitude of consequences and emphasis on rules of engagement that attend weaponization of UAS. These differences did not impact decisions regarding assessment of the attributes, but they do provide indication of shifting demands relating to required personal attributes.

System specific knowledge is presumed to be imparted during the training process. It was therefore deemed unnecessary (and probably unproductive) to assess the Knowledge attributes in the prototype selection battery. The Skills, Abilities, and Other Characteristics were considered to be critical if they received a mean importance rating (from the whole sample) of 3.0 or higher. Of the 65 non-Knowledge KSAOs, 49 were considered critical. Responding to guidance to maximize the use of existing instruments rather than develop new ones, the authors selected four instruments that had been developed for or used in a preceding project to develop an aviator selection battery for the Army, the Selection Instrument for Flight Training (SIFT). These were: Army Aviation Biodata, Assessment for Individual Motivation, Perceptual Speed and Accuracy-Hidden Figures, and Perceptual Speed and Accuracy-Simple Drawings. Two subtests were selected from the Navy's Aviation Selection Test Battery (ASTB): Reading Comprehension and Spatial Apperception. Finally, a subtest was selected from the Navy's Performance Based

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Measures (PBM) battery, the Directional Orientation Test. The combination of these into a selection battery for UAS operator training selection is believed to assess 35 of the 49 critical KSAOs, while retaining an acceptable cost of administration, particularly in terms of administration time (typically less than 2 hours).

Pilot testing was conducted on the prototype battery using 20 students in Army UAS operator training. There were no indications of psychometric deficiencies among the subtests. Intercorrelations of scores appeared to be logical and consistent with expectation. None of the correlations were high enough to preclude expectation of unique contribution to predictive validity. Review of the courses of training at that time lead to a recommended set of Criterion Measures for UAS operator training selection. These include five derived from scores on written tests in specific phases of the common core training and a Behavioral Summary Scale (BSS) to be completed by instructors on a daily basis. Three additional measures would be derived from the advanced phases of training that are system specific. These would include the score on one written exam, the number of retests required to pass the Simulator-based flight portion of training, and the number of retests required to pass the flight portion of training. In addition BSS scores would also be used.

Recently the Air Force Research Laboratory 711th Human Performance Wing (Chappelle, McDonald, & King, 2010) conducted a study to identify critical personal attributes relevant to training success and career performance for RPA sensor operators. The authors approached their work through structured interviews conducted in five venues. In the Command Interviews senior commanders were interviewed individually and in a group discussion to elicit their perceptions on RPA operational roles and on personal attributes relating to success. The authors also conducted RPA Pilot interviews and Sensor Operator interviews, and Multidisciplinary Group interviews. Finally, Instructor Interviews were conducted in concert with observation of simulator-based training scenarios. A total of 69 RPA operators participated. These represented four subgroups: Commanders, instructors, pilots, and sensor operators.

Notes from the structured interviews were consolidated and a list of 130 attributes was extracted. After elimination of redundancies and elimination of knowledge and skill attributes that resulted from system training, the remaining attributes were reviewed to determine the number of subgroups that identified them as critical. Those so identified by three of the four subgroups of participants were retained. The remaining 21 critical attributes were placed into one of four groups: physical health, cognitive aptitude, personality traits, and motivation.

A related study (Chappelle, McDonald, & McMillan, 2011) was conducted to identify critical personal attributes relevant to training success and career performance for RPA pilots. This approach was based on structured interviews starting with SMEs, then senior commanders. The authors conducted individual and group interviews with RPA pilots, received 4 hrs of pilot training and conducted group interviews with pilots and sensor operators. They also interviewed a group of flight surgeons. A total of 82 individuals participated. Notes were consolidated and a preliminary list of 130 attributes was extracted (interestingly, the same number as in the previous study). Redundancies, and the knowledge- and skill-based attributes were removed. The resulting list of 21 attributes was nearly identical to that of the previous study. At this point there occurred a novel change in the process. The 21 attributes were sorted into four “domains”:

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cognitive aptitudes, intrapersonal traits, interpersonal traits, and motivational traits. Three of the four correspond to the groups used in the previous study. Physical health was eliminated and apparently the personality traits group was split into intra- and inter-personal traits. The 21 attributes from the final list were sorted into the four "domains" at which point they are referred to as "facets." Each facet was given a set of "distinct attributes." These correspond closely with the descriptions used in the previous study. What had been attributes became facets. What had been descriptions became attributes. In order to make sense of any comparison of KSAOs across studies, this shift in terminology will be ignored and the "facets" will be treated as attributes.

Comparison of RPA Operator KSAOs

Eight publications that in some form produced KSAOs for RPA crew positions were reviewed in the previous section. The KSAO lists from each of these are presented in Tables 3 through 10. As a baseline reference, and because of commonality with several of the attribute lists, Table 2 presents a list of the Abilities attributes contained in Fleishman's Manual for the Ability Requirements Scales. In Table 2 there are Abilities only, no Knowledge, Skills or Other Characteristics. Fleishman constructed this list with the goal of eventually developing a global taxonomy that could describe any task in terms of personal attributes required to complete it. This was to be a tool for comparing tasks and sorting them into categories. The list presented here contains the names of 52 human abilities with definitions for each. They can be seen still in the far larger and more complex lists of the Occupational Information Network (O*NET). The numbering of these is the same as used by Fleishman. For Job Analysis, the use of an attribute taxonomy allows greater ability to generalize across studies and behavioral situations than if attributes are named and operationally defined uniquely in every instance. That can lead to overly complex attribute labels and wide variance among job evaluators in redundancy and specificity. Additionally, it can create conditions in which attributes with the same or very similar names may refer to very different capabilities. The attribute set in Table 2, however, is far from global, covering only a portion of one major domain, abilities, that are the concern of job and task analysts.

Table 3 lists the Skills, Abilities and Other Characteristics that appeared to be contained in the report by Crumley and Bailey (1979). This report predates Fleishman's taxonomy and the work reported by them was not intended to provide a complete job analysis for RPA operators. It is the earliest example of any attempt to identify personal attributes that was found. This list contains only eight entries: Two Skills, four Abilities and two Other Characteristics. The authors did not offer any operational definitions of these attributes. They are numbered approximately in the order in which they are mentioned in the text.

Table 4 lists the attribute list derived from Biggerstaff et al. (1998). It is even shorter, with only 5 entries, all considered Skills. The operational definitions appear to be the test tasks themselves rather than qualities intrinsic to job related tasks. It appears that in this case the development of predictor measures for training performance may have been the reverse of the usual process: The personal attributes were derived from the available assessment instruments and assigned to the job of RPA External Pilot.

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The list in Table 5, from Barnes at al. (2000), is longer, with 50 attributes listed and numbered in the order in which the authors listed them. The correspondence with Fleishman's taxonomy is nearly perfect, not surprisingly since the survey tool used (JASS) is directly derived from Fleishman. The developers of JASS re-ordered the abilities and grouped them logically. They also changed a few of the definitions to make them more readable and intuitive. For example, their ability # 23, Choice Reaction Time, corresponds with Fleishman's #22, Response Orientation. This correspondence becomes clear only when the definitions are compared.

Table 6 lists 50 attributes that were identified by Warnes and Knapp (2000). These are identical to those in Table 5 because the same tool, JASS, was employed. Where Barnes et al. concentrated on AVO and EP jobs, Warnes and Knapp concentrated on the job of GSO.

The attribute list from Phillips et al. (2003) is the shortest with only four entries. As with Biggerstaff et al. (1998), it appears that the assessment instruments were more the source of attribute definition than either the job or tasks. Table 7 lists these and shows that they are identical to those in Biggerstaff et al. except for the absence of time estimation.

Things are very different in Table 8, which lists the attributes identified by Bruskiewicz et al. (2007) from a job analysis performed on both AVO and MPO positions. This list contains 77 attributes: 12 Knowledge, 6 Skills, 25 Abilities, and 38 Other Characteristics. They are numbered in the order in which the authors listed them. This large set, covering all four attribute domains exists largely because they were produced by the only study on KSAOs for RPA operators that performed a complete process for KSAO identification. The danger attendant to their approach is that there is not a strong connection to any particular taxonomy, and so many of the attributes and their definitions may be ad-hoc. Therefore, it becomes difficult to compare these with attributes listed in other works.

Table 9 presents 21 attributes identified by Chappelle at al. (2010) for MPO positions, including seven Abilities and 14 Other characteristics. Although the authors reported that Knowledge and Skill attributes had been identified, their screening process eliminated them. The attributes are numbered in the order in which the authors listed them. These attributes, derived entirely from interviews with practitioners, are largely ad hoc with little correspondence to KSAOs identified in other works. They also tend to be vague and poorly defined.

Table 10 presents the 21 attributes identified for AVOs by Chappelle at al. (2011). There is a fair amount of correspondence between this and the previous list in the attribute names. The definitions, however are in some cases identical and in others radically altered. In addition, they have been reordered. This makes comparison even between these two related studies problematic.

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Table 2. Attribute list from Fleishman's Manual for the Ability Requirements Scales (Fleishman & Quaintance, 1984).

	Attribute Name	Description
Abilities		
1	Oral Comprehension	Ability to understand spoken English words and sentences.
2	Written Comprehension	Ability to understand written sentences and paragraphs.
3	Oral Expression	Ability to use English words or sentences in speaking so others will understand.
4	Written Expression	Ability to use English words or sentences in writing so others will understand.
5	Fluency of Ideas	Ability to produce a number of ideas about a given topic.
6	Originality	Ability to produce unusual or clever ideas about a given topic or situation. It is the ability to invent creative solutions to problems or to develop new procedures to situations in which standard operating procedures do not apply.
7	Memorization	Ability to remember information, such as words, numbers, pictures, and procedures. Pieces of information can be remembered by themselves or with other pieces of information.
8	Problem Sensitivity	Ability to tell when something is wrong or is likely to go wrong. It includes being able to identify the whole problem as well as the elements of the problem.
9	Mathematical Reasoning	Ability to understand and organize a problem and then to select a mathematical method or formula to solve the problem. It encompasses reasoning through mathematical problems to determine appropriate operations that can be performed to solve problems. It also includes the understanding or structuring of mathematical problems. The actual manipulation of numbers is not included in this ability.
10	Number Facility	Involves the degree to which adding, subtracting, multiplying, and dividing can be done quickly and correctly. These can be steps in other operations, such as finding percentages and taking square roots.
11	Deductive Reasoning	Ability to apply general rules to specific problems to come up with logical answers. It involves deciding if an answer make sense.
12	Inductive Reasoning	Ability to combine separate pieces of information, or specific answers to problems, to form general rules or conclusions.
13	Information Ordering	Ability to follow correctly a rule or set of rules to arrange things or actions in a certain order. The rule or sets of rules used must be given. The things or actions to be put in order can include numbers, letters, words, pictures, procedures, sentences, and mathematical or logical operations.
14	Category Flexibility	Ability to produce many rules so that each rule tells how to group a set of things in a different way. Each different group must contain at least two things from the original set of things.
15	Speed of Closure	Involves the degree to which different pieces of information can be combined and organized into one meaningful pattern quickly. It is not known beforehand what the pattern will be. The material may be visual or auditory.
16	Flexibility of Closure	Ability to identify or detect a known pattern (such as a figure, word, or object) that is hidden in other material. The task is to pick out the disguised pattern.

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17	Spatial Orientation	Ability to tell where you are in relation to the location of some object or to tell where the object is in relation to you.
18	Visualization	Ability to imagine how something will look when it is moved around or when its parts are moved or rearranged. It requires the forming of mental images of how patterns or objects would look after certain changes, such as unfolding or rotation. One has to predict how an object, set of objects or pattern will appear after the changes are carried out.
19	Perceptual Speed	Involves the degree to which one can compare letters, numbers, objects, pictures or patterns, quickly and accurately. The things to be compared may be pictures or patterns, quickly and accurately. The things to be compared may be presented at the same time or one after the other. This ability also includes comparing a presented object with a remembered object.
20	Control Precision	Ability to move controls of a machine or vehicle. This involves the degree to which these controls can be moved quickly and repeatedly to exact positions.
21	Multilimb Coordination	Ability to coordinate movements of two or more limbs (for example, two arms, two legs or one leg and one arm), such as in moving equipment controls. Two or more limbs are in motion while the individual is sitting, standing or lying down.
22	Response Orientation	Ability to choose between two or more movements quickly and accurately when two or more different signals (lights, sounds, pictures) are given. The ability is concerned with the speed with which the right response can be started with the hand, foot or other parts of the body.
23	Rate Control	Ability to adjust an equipment control in response to changes in the speed and/or directions of a continuously moving object or scene. The ability involves timing these adjustments in anticipating these changes. This ability does not extend to situations in which both the speed and direction of the object are perfectly predictable.
24	Reaction Time	Ability to give one fast response to one signal (sound, light, picture) when it appears. This ability is concerned with the speed with which the movement can be started with the hand, foot or other parts of the body.
25	Arm-Hand Steadiness	Ability to keep the hand or arm steady. It includes steadiness while making an arm movement as well as while holding the arm and hand in one position. This ability does not involve strength or speed.
26	Manual Dexterity	Ability to make skillful coordinated movements of one hand, a hand together with its arm, or two hands to grasp, place, move or assemble objects, such as hand tools or blocks. This ability involves the degree to which these arm-hand movements can be carried out quickly. It does not involve moving machine or equipment controls, such as levers.
27	Finger Dexterity	Ability to make skillful coordinated movements of the fingers of one or both hands and to grasp, place or move small objects. This ability involves the degree to which these finger movements can be carried out quickly.
28	Wrist-Finger Speed	Ability to make fast, simple repeated movements of the fingers, hands and wrists. It involves little, if any, accuracy or eye-hand coordination.
29	Speed of Limb Movement	Involves the speed with which a single movement of the arms or legs can be made. This ability does not include accuracy, careful control or coordination of movement.

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30	Selective Attention	Ability to concentrate on a task one is doing. This ability involves concentrating while performing a boring task and not being distracted.
31	Time Sharing	Ability to shift back and forth between two or more sources of information.
32	Static Strength	Ability to use muscle force in order to lift, push, pull or carry objects. It is the maximum force that one can exert for a brief period of time.
33	Explosive Strength	Ability to use short bursts of muscle force to propel oneself or an object. It requires gathering energy for bursts of muscle effort over a very short time period.
34	Dynamic Strength	Ability of the muscles to exert force repeatedly or continuously over a long time period. This is the ability to support, hold up or move the body's own weight and/or objects repeatedly over time. It represents muscular endurance and emphasizes the resistance of the muscles to fatigue.
35	Trunk Strength	Involves the degree to which one's stomach and lower back muscles can support part of the body repeatedly or continuously over time. The ability involves the degree to which these trunk muscles do not fatigue when they are put under such repeated or continuous strain.
36	Extent Flexibility	Ability to bend, stretch, twist, or reach out with the body, arms or legs.
37	Dynamic Flexibility	Ability to bend, stretch, twist, or reach out with the body, arms and/or legs, both quickly and repeatedly.
38	Gross Body Coordination	Ability to coordinate the movement of the arms, legs and torso together in activities in which the whole body is in motion.
39	Gross Body Equilibrium	Ability to keep or regain one's body balance or stay upright when in an unstable position. This ability includes maintaining one's balance when changing direction while moving or standing motionlessly.
40	Stamina	Ability of the lungs and circulatory systems of the body to perform efficiently over long time periods. This is the ability to exert oneself physically without getting out of breath.
41	Near Vision	Capacity to see close environmental surroundings.
42	Far Vision	Capacity to see distant environmental surroundings.
43	Visual Color Discrimination	Capacity to match or discriminate between colors. This capacity also includes detecting differences in color purity (saturation) and brightness (brilliance).
44	Night Vision	Ability to see under low light conditions.
45	Peripheral Vision	Ability to perceive objects or movements towards the edges of the visual field.
46	Depth Perception	Ability to distinguish which of several objects is more distant from or nearer to the observer or to judge the distance of an object from the observer.
47	Glare Sensitivity	Ability to see objects in the presence of glare or bright ambient lighting.
48	General Hearing	Ability to detect and to discriminate among sounds that vary over broad ranges of pitch and/or loudness.
49	Auditory Attention	Ability to focus on a single source of auditory information in the presence of other distracting and irrelevant auditory stimuli.
50	Sound Localization	Ability to identify the direction from which an auditory stimulus originated relative to the observer.
51	Speech Hearing	Ability to learn and understand the speech of another person.
52	Speech Clarity	Ability to communicate orally in a clear fashion understandable to the listener.

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Table 3. Attribute list from Crumley & Bailey, 1979.

	Attribute Name	Description
	Skills	
1	Map Reading	
2	Photo Interpretation	
	Abilities	
3	Oral Comprehension	
4	Situational Awareness	
5	Oral Expression	
6	Multilimb Coordination	
	Other Characteristics	
7	Affinity for Planning and Logic	
8	Affinity for Uncertainty	

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Table 4. Attribute list from Biggerstaff et al., 1998.

	Attribute Name	Description
	Skills	
1	Mental reversals/rotation	Manikin test performance
2	Estimation of time to contact	Time Estimation Test (TET) performance
3	Eye-hand coordination	Horizontal Tracking (HT) Test performance
4	Selective auditory attention	Dichotic Listening Test (DLT) performance
5	Multitasking (psychomotor + visual)	Psychomotor Test (PMT) performance

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Table 5. Attribute list from Barnes et al., 2000.

	Attribute Name	Description
	Abilities	
1	Oral Comprehension	Ability to understand spoken English words and sentences.
2	Written Comprehension	Ability to understand written sentences and paragraphs.
3	Oral Expression	Ability to use English words or sentences in speaking so others will understand.
4	Written Expression	Ability to use English words or sentences in writing so others will understand.
5	Memorization	Ability to remember information, such as words, numbers, pictures, and procedures. Pieces of information can be remembered by themselves or with other pieces of information.
6	Problem Sensitivity	Ability to tell when something is wrong or is likely to go wrong. It includes being able to identify the whole problem as well as the elements of the problem.
7	Originality	Ability to produce unusual or clever ideas about a given topic or situation. It is the ability to invent creative solutions to problems or to develop new procedures to situations in which standard operating procedures do not apply.
8	Fluency of Ideas	Ability to produce a number of ideas about a given topic.
9	Flexibility of Closure	Ability to identify or detect a known pattern (such as a figure, word, or object) that is hidden in other material. The task is to pick out the disguised pattern.
10	Selective Attention	Ability to concentrate on a task one is doing. This ability involves concentrating while performing a boring task and not being distracted.
11	Spatial Orientation	Ability to tell where you are in relation to the location of some object or to tell where the object is in relation to you.
12	Visualization	Ability to imagine how something will look when it is moved around or when its parts are moved or rearranged. It requires the forming of mental images of how patterns or objects would look after certain changes, such as unfolding or rotation. One has to predict how an object, set of objects or pattern will appear after the changes are carried out.
13	Inductive Reasoning	Ability to combine separate pieces of information, or specific answers to problems, to form general rules or conclusions.
14	Category Flexibility	Ability to produce many rules so that each rule tells how to group a set of things in a different way. Each different group must contain at least two things from the original set of things.
15	Deductive Reasoning	Ability to apply general rules to specific problems to come up with logical answers. It involves deciding if an answer make sense.

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16	Information Ordering	Ability to follow correctly a rule or set of rules to arrange things or actions in a certain order. The rule or sets of rules used must be given. The things or actions to be put in order can include numbers, letters, words, pictures, procedures, sentences, and mathematical or logical operations.
17	Mathematical Reasoning	Ability to understand and organize a problem and then to select a mathematical method or formula to solve the problem. It encompasses reasoning through mathematical problems to determine appropriate operations that can be performed to solve problems. It also includes the understanding or structuring of mathematical problems. The actual manipulation of numbers is not included in this ability.
18	Number Facility	Involves the degree to which adding, subtracting, multiplying, and dividing can be done quickly and correctly. These can be steps in other operations, such as finding percentages and taking square roots.
19	Time-Sharing	Ability to shift back and forth between two or more sources of information.
20	Speed of Closure	Involves the degree to which different pieces of information can be combined and organized into one meaningful pattern quickly. It is not known beforehand what the pattern will be. The material may be visual or auditory.
21	Perceptual Speed	Involves the degree to which one can compare letters, numbers, objects, pictures or patterns, quickly and accurately. The things to be compared may be pictures or patterns, quickly and accurately. The things to be compared may be presented at the same time or one after the other. This ability also includes comparing a presented object with a remembered object.
22	Reaction Time	Ability to give one fast response to one signal (sound, light, picture) when it appears. This ability is concerned with the speed with which the movement can be started with the hand, foot or other parts of the body.
23	Choice Reaction Time	Ability to choose between two or more movements quickly and accurately when two or more different signals (lights, sounds, pictures) are given. The ability is concerned with the speed with which the right response can be started with the hand, foot or other parts of the body.
24	Near Vision	Capacity to see close environmental surroundings.
25	Far Vision	Capacity to see distant environmental surroundings.
26	Night Vision	Ability to see under low light conditions.
27	Visual Color Discrimination	Capacity to match or discriminate between colors. This capacity also includes detecting differences in color purity (saturation) and brightness (brilliance).
28	Peripheral Vision	Ability to perceive objects or movements towards the edges of the visual field.
29	Depth Perception	Ability to distinguish which of several objects is more distant from or nearer to the observer or to judge the distance of an object from the observer.
30	Glare Sensitivity	Ability to see objects in the presence of glare or bright ambient lighting.
31	General Hearing	Ability to detect and to discriminate among sounds that vary over broad ranges of pitch and/or loudness.
32	Auditory Attention	Ability to focus on a single source of auditory information in the presence of other distracting and irrelevant auditory stimuli.
33	Sound Localization	Ability to identify the direction from which an auditory stimulus originated relative to the observer.

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34	Control Precision	Ability to move controls of a machine or vehicle. This involves the degree to which these controls can be moved quickly and repeatedly to exact positions.
35	Rate Control	Ability to adjust an equipment control in response to changes in the speed and/or directions of a continuously moving object or scene. The ability involves timing these adjustments in anticipating these changes. This ability does not extend to situations in which both the speed and direction of the object are perfectly predictable.
36	Wrist-Finger Speed	Ability to make fast, simple repeated movements of the fingers, hands and wrists. It involves little, if any, accuracy or eye-hand coordination.
37	Finger Dexterity	Ability to make skillful coordinated movements of the fingers of one or both hands and to grasp, place or move small objects. This ability involves the degree to which these finger movements can be carried out quickly.
38	Manual Dexterity	Ability to make skillful coordinated movements of one hand, a hand together with its arm, or two hands to grasp, place, move or assemble objects, such as hand tools or blocks. This ability involves the degree to which these arm-hand movements can be carried out quickly. It does not involve moving machine or equipment controls, such as levers.
39	Arm-Hand Steadiness	Ability to keep the hand or arm steady. It includes steadiness while making an arm movement as well as while holding the arm and hand in one position. This ability does not involve strength or speed.
40	Multi-Limb Coordination	Ability to coordinate movements of two or more limbs (for example, two arms, two legs or one leg and one arm), such as in moving equipment controls. Two or more limbs are in motion while the individual is sitting, standing or lying down.
41	Extent Flexibility	Ability to bend, stretch, twist, or reach out with the body, arms or legs.
42	Dynamic Flexibility	Ability to bend, stretch, twist, or reach out with the body, arms and/or legs, both quickly and repeatedly.
43	Speed of Limb Movement	Involves the speed with which a single movement of the arms or legs can be made. This ability does not include accuracy, careful control or coordination of movement.
44	Gross Body Equilibrium	Ability to keep or regain one's body balance or stay upright when in an unstable position. This ability includes maintaining one's balance when changing direction while moving or standing motionlessly.
45	Gross Body Coordination	Ability to coordinate the movement of the arms, legs and torso together in activities in which the whole body is in motion.
46	Static Strength	Ability to use muscle force in order to lift, push, pull or carry objects. It is the maximum force that one can exert for a brief period of time.
47	Explosive Strength	Ability to use short bursts of muscle force to propel oneself or an object. It requires gathering energy for bursts of muscle effort over a very short time period.
48	Dynamic Strength	Ability of the muscles to exert force repeatedly or continuously over a long time period. This is the ability to support, hold up or move the body's own weight and/or objects repeatedly over time. It represents muscular endurance and emphasizes the resistance of the muscles to fatigue.

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49	Trunk Strength	Involves the degree to which one's stomach and lower back muscles can support part of the body repeatedly or continuously over time. The ability involves the degree to which these trunk muscles do not fatigue when they are put under such repeated or continuous strain.
50	Stamina	Ability of the lungs and circulatory systems of the body to perform efficiently over long time periods. This is the ability to exert oneself physically without getting out of breath.

Table 6. Attribute list from Warner & Knapp, 2000.

	Attribute Name	Description
	Abilities	
1	Oral Comprehension	Ability to understand spoken English words and sentences.
2	Written Comprehension	Ability to understand written sentences and paragraphs.
3	Oral Expression	Ability to use English words or sentences in speaking so others will understand.
4	Written Expression	Ability to use English words or sentences in writing so others will understand.
5	Memorization	Ability to remember information, such as words, numbers, pictures, and procedures. Pieces of information can be remembered by themselves or with other pieces of information.
6	Problem Sensitivity	Ability to tell when something is wrong or is likely to go wrong. It includes being able to identify the whole problem as well as the elements of the problem.
7	Originality	Ability to produce unusual or clever ideas about a given topic or situation. It is the ability to invent creative solutions to problems or to develop new procedures to situations in which standard operating procedures do not apply.
8	Fluency of Ideas	Ability to produce a number of ideas about a given topic.
9	Flexibility of Closure	Ability to identify or detect a known pattern (such as a figure, word, or object) that is hidden in other material. The task is to pick out the disguised pattern.
10	Selective Attention	Ability to concentrate on a task one is doing. This ability involves concentrating while performing a boring task and not being distracted.
11	Spatial Orientation	Ability to tell where you are in relation to the location of some object or to tell where the object is in relation to you.
12	Visualization	Ability to imagine how something will look when it is moved around or when its parts are moved or rearranged. It requires the forming of mental images of how patterns or objects would look after certain changes, such as unfolding or rotation. One has to predict how an object, set of objects or pattern will appear after the changes are carried out.
13	Inductive Reasoning	Ability to combine separate pieces of information, or specific answers to problems, to form general rules or conclusions.

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14	Category Flexibility	Ability to produce many rules so that each rule tells how to group a set of things in a different way. Each different group must contain at least two things from the original set of things.
15	Deductive Reasoning	Ability to apply general rules to specific problems to come up with logical answers. It involves deciding if an answer make sense.
16	Information Ordering	Ability to follow correctly a rule or set of rules to arrange things or actions in a certain order. The rule or sets of rules used must be given. The things or actions to be put in order can include numbers, letters, words, pictures, procedures, sentences, and mathematical or logical operations.
17	Mathematical Reasoning	Ability to understand and organize a problem and then to select a mathematical method or formula to solve the problem. It encompasses reasoning through mathematical problems to determine appropriate operations that can be performed to solve problems. It also includes the understanding or structuring of mathematical problems. The actual manipulation of numbers is not included in this ability.
18	Number Facility	Involves the degree to which adding, subtracting, multiplying, and dividing can be done quickly and correctly. These can be steps in other operations, such as finding percentages and taking square roots.
19	Time-Sharing	Ability to shift back and forth between two or more sources of information.
20	Speed of Closure	Involves the degree to which different pieces of information can be combined and organized into one meaningful pattern quickly. It is not known beforehand what the pattern will be. The material may be visual or auditory.
21	Perceptual Speed	Involves the degree to which one can compare letters, numbers, objects, pictures or patterns, quickly and accurately. The things to be compared may be pictures or patterns, quickly and accurately. The things to be compared may be presented at the same time or one after the other. This ability also includes comparing a presented object with a remembered object.
22	Reaction Time	Ability to give one fast response to one signal (sound, light, picture) when it appears. This ability is concerned with the speed with which the movement can be started with the hand, foot or other parts of the body.
23	Choice Reaction Time	Ability to choose between two or more movements quickly and accurately when two or more different signals (lights, sounds, pictures) are given. The ability is concerned with the speed with which the right response can be started with the hand, foot or other parts of the body.
24	Near Vision	Capacity to see close environmental surroundings.
25	Far Vision	Capacity to see distant environmental surroundings.
26	Night Vision	Ability to see under low light conditions.
27	Visual Color Discrimination	Capacity to match or discriminate between colors. This capacity also includes detecting differences in color purity (saturation) and brightness (brilliance).
28	Peripheral Vision	Ability to perceive objects or movements towards the edges of the visual field.
29	Depth Perception	Ability to distinguish which of several objects is more distant from or nearer to the observer or to judge the distance of an object from the observer.
30	Glare Sensitivity	Ability to see objects in the presence of glare or bright ambient lighting.

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31	General Hearing	Ability to detect and to discriminate among sounds that vary over broad ranges of pitch and/or loudness.
32	Auditory Attention	Ability to focus on a single source of auditory information in the presence of other distracting and irrelevant auditory stimuli.
33	Sound Localization	Ability to identify the direction from which an auditory stimulus originated relative to the observer.
34	Control Precision	Ability to move controls of a machine or vehicle. This involves the degree to which these controls can be moved quickly and repeatedly to exact positions.
35	Rate Control	Ability to adjust an equipment control in response to changes in the speed and/or directions of a continuously moving object or scene. The ability involves timing these adjustments in anticipating these changes. This ability does not extend to situations in which both the speed and direction of the object are perfectly predictable.
36	Wrist-Finger Speed	Ability to make fast, simple repeated movements of the fingers, hands and wrists. It involves little, if any, accuracy or eye-hand coordination.
37	Finger Dexterity	Ability to make skillful coordinated movements of the fingers of one or both hands and to grasp, place or move small objects. This ability involves the degree to which these finger movements can be carried out quickly.
38	Manual Dexterity	Ability to make skillful coordinated movements of one hand, a hand together with its arm, or two hands to grasp, place, move or assemble objects, such as hand tools or blocks. This ability involves the degree to which these arm-hand movements can be carried out quickly. It does not involve moving machine or equipment controls, such as levers.
39	Arm-Hand Steadiness	Ability to keep the hand or arm steady. It includes steadiness while making an arm movement as well as while holding the arm and hand in one position. This ability does not involve strength or speed.
40	Multi-Limb Coordination	Ability to coordinate movements of two or more limbs (for example, two arms, two legs or one leg and one arm), such as in moving equipment controls. Two or more limbs are in motion while the individual is sitting, standing or lying down.
41	Extent Flexibility	Ability to bend, stretch, twist, or reach out with the body, arms or legs.
42	Dynamic Flexibility	Ability to bend, stretch, twist, or reach out with the body, arms and/or legs, both quickly and repeatedly.
43	Speed of Limb Movement	Involves the speed with which a single movement of the arms or legs can be made. This ability does not include accuracy, careful control or coordination of movement.
44	Gross Body Equilibrium	Ability to keep or regain one's body balance or stay upright when in an unstable position. This ability includes maintaining one's balance when changing direction while moving or standing motionlessly.
45	Gross Body Coordination	Ability to coordinate the movement of the arms, legs and torso together in activities in which the whole body is in motion.
46	Static Strength	Ability to use muscle force in order to lift, push, pull or carry objects. It is the maximum force that one can exert for a brief period of time.
47	Explosive Strength	Ability to use short bursts of muscle force to propel oneself or an object. It requires gathering energy for bursts of muscle effort over a very short time period.

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48	Dynamic Strength	Ability of the muscles to exert force repeatedly or continuously over a long time period. This is the ability to support, hold up or move the body's own weight and/or objects repeatedly over time. It represents muscular endurance and emphasizes the resistance of the muscles to fatigue.
49	Trunk Strength	Involves the degree to which one's stomach and lower back muscles can support part of the body repeatedly or continuously over time. The ability involves the degree to which these trunk muscles do not fatigue when they are put under such repeated or continuous strain.
50	Stamina	Ability of the lungs and circulatory systems of the body to perform efficiently over long time periods. This is the ability to exert oneself physically without getting out of breath.

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Table 7. Attribute list from Phillips et al., 2003.

	Attribute Name	Description
	Skills	
1	Mental reversals/rotation	Manikin test performance
2	Eye-hand coordination	Horizontal Tracking (HT) Test performance
3	Selective auditory attention	Dichotic Listening Test (DLT) performance
4	Multitasking (psychomotor + visual)	Psychomotor Test (PMT) performance

Table 8. Attribute list from Bruskiewicz et al., 2007.

	Attribute Name	Description
	Knowledge	
1	Unit/Command Objectives	Unit's function and operations; METL, mission briefs and commander's intent
2	Aviation Principals	Fundamentals of flight; force; gravity; speed; velocity; distance; motion; altitude, direction; object rotation; geography/terrain
3	Basic Operation Procedures	Loading/unloading procedures for internal and external load operation; emergency procedures; safety procedures; post-flight checks
4	Unmanned Aerial System Operations	Navigation; sensors; weapons
5	Communication Procedures	Radio, data, intercom operation; system display indicator operation; tactical report transmission; crew coordination
6	Threat Categories and Indicators	Types of enemy systems; warning and detection systems; identification
7	Reconnaissance Procedures	Scanning assigned sectors; aerial observation; route, zone, and area reconnaissance
8	Engagement Procedures	Weapons control measures; firing position operations; weapons initialization; weapon system operation; masking and unmasking; target handover procedures
9	Meteorology	Ambient light; clouds and precipitation; forces and winds; air masses and fronts; weather forecasting; storms; effects of weather on aircraft operations
10	Aeronautical Terminology	Principles and practices of navigation; aviation phraseology; standard crew terminology

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11	Operational Terms and Graphics	Chart and map reading, topography, symbology
12	Flight Rules and Regulations	Civil, military, and unit specific regulations (SOP)
	Skills	
13	Operation and Maneuvering of Unmanned Aircraft Systems	Adjusting altitude; maintaining airspeed; changing flight direction; flight control precision; recognition of flight parameters
14	Operation of Communication Systems and Equipment	Radio/aircraft systems; intercom communication systems; digital communications systems
15	Operation of Navigation Systems and Equipment	Electronic systems; navigation radio; homing; etc.
16	Operation of Sensor/Tracking Systems and Equipment	Lasers, illuminators
17	Operation of Weapon Systems and Equipment	Hellfire missile system; stinger system
18	Performance of Unmanned Aircraft Systems Operational Checks	Security checks; engine checks; run-up and taxi checks; preflight checks; after-takeoff checks; inflight checks; post-launch checks
	Abilities	
19	Management of Stressors	Recognize and cope with stress in self and others
20	Situational Awareness	Accurately perceive self, others, and aircraft in relation to the environment
21	Psychomotor Ability: Control Precision	Make highly controlled and precise adjustments in moving controls of an aircraft precisely and repeatedly
22	Psychomotor Ability: Multi-limb Coordination	Coordinate movements of two or more limbs at once (e.g., two arms, one leg and one arm)
23	Psychomotor Ability: Simple Reaction Time	Give a fast response to a signal when it appears
24	Psychomotor Ability: Choice Reaction Time	Choose between two or more movements quickly and correctly when there is more than one choice
25	Psychomotor Ability: Rate Control	Adjust an equipment control in response to changes in the speed or direction of a continuously moving object or scene, (e.g., keeping aircraft at a given altitude in turbulent weather or tracking a moving target)

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26	Perceptual Speed and Accuracy	Perceive and process visual information quickly and accurately; to notice subtle visual details
27	Oral Communication	Speak in a clear, concise and persuasive manner; to give clear directions and information; to ask questions to clarify and ensure understanding
28	Oral Comprehension	Listen to and understand information and ideas that are presented orally
29	Written Communication	Write in a logical, well-organized manner; to use correct punctuation and grammar
30	Reading Comprehension	Perceive and understand principles governing the use of verbal concepts and symbols; to interpret meaning from written information
31	Mathematical Ability	Understand and apply basic (e.g., addition, rounding) and advanced (e.g., algebra) math principles; arithmetic reasoning
32	Mechanical Comprehension	Perceive physical relationships and practical problems in mechanics; to understand the operation of mechanical equipment
33	Analytical Ability	Reason logically and critically to draw correct, well-supported, and consistent conclusions
34	Planning	Develop courses of action to accomplish objectives and avoid potential problems; to manage activities effectively; to actively prepare for high workload/problem situations
35	Organization/Time Management	Prioritize activities and determine which ones require immediate attention; to manage and allocate time effectively
36	Judgment/Decision-Making/Problem Solving	Make high quality and timely decisions; to assess the level of risk associated with a given course of action; to recognize when additional information is required to make a decision or solve a problem; to identify potential and/or novel solutions to problems; to anticipate the consequences of decisions
37	Spatial Visualization and Orientation	Recognize and distinguish shapes and patterns; to identify an object at different angles; to anticipate a moving object's spatial orientation over time; to recognize one's own physical orientation in an unfamiliar environment; to estimate location after traveling for a period of time; to read a map and understand it's content
38	Information Processing Ability: Divided Attention	Pay attention to multiple tasks occurring at the same time
39	Information Processing Ability: Selective/Focused Attention	Focus on and process information related to a single task amid the presence of competing information or background noise
40	Information Processing Ability: Working Memory	Temporarily hold information in memory, use it while performing ongoing tasks, and update it continually to reflect the current situation
41	Information Processing Ability: Long-Term Memory	Remember information for long periods of time; to recall information that was learned some time ago
42	Vigilance	Stay alert and be attentive to one's surroundings over long periods of time, including small details; to recognize hazards and threats within one's environment; to perform repetitive tasks effectively

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43	Cognitive Task Prioritization	Properly pay attention to tasks in order to achieve subgoals which support the overall mission goal; that is, ensure the Operator is "doing what he or she should be doing at all times"
	Other Characteristics	
44	Assertiveness	Tendency to act in an appropriately bold and energetic fashion in order to accomplish objectives; willingness to communicate appropriate urgency when delivering information
45	Followership	Tendency to follow requests or orders; to accept suggestions and guidance from other crewmembers without being defensive
46	Self-Regulation	Tendency to keep oneself focused on a task/work even when external factors make it difficult to do so.
47	Excitement-Seeking	Tendency to crave excitement and stimulation, but not to the point of being reckless
48	Risk-Tolerance	Willingness to accept risk and engage in activities that involve a lack of certainty or fear of failure, but without being reckless
49	Work Ethic	Tendency to strive for competence in one's work; willingness to work long hours when appropriate; tendency to reliably complete one's work in a timely fashion and complete the mission
50	Initiative	Tendency to take personal initiative in accomplishing tasks and to see tasks through until their completion
51	Self-Confidence	Being sure of one's abilities without being over-confident or arrogant
52	Straightforwardness	Tendency to be frank, sincere, and genuine
53	Helpfulness	Tendency to have an active concern for others' welfare; expressed through generosity, consideration of others, and a willingness to assist others in need of help
54	Teamwork	Tendency to function effectively as part of a team; to cooperate with other crewmembers to accomplish goals and solve problems
55	Interpersonal Skills	Tendency to understand and deal effectively with a variety of people; to treat others with courtesy and respect; to be considerate of others' needs
56	Dutifulness	Tendency to adhere to one's set of ethical principals and to strictly follow rules and regulations
57	Achievement Striving	Tendency to set ambitious goals for oneself and to work hard to attain a high level of work proficiency
58	Self Discipline	Tendency to control one's conduct and impulses
59	Deliberation	Tendency to think carefully before acting, time permitting
60	Dependability	Tendency to be reliable, planful, well-organized, disciplined, and determined
61	Responsibility	Tendency to assume responsibility and accept consequences of own decisions and actions
62	Perseverance	Tendency to stick with a task until completion in spite of obstacles
63	Integrity	Tendency to behave in a moral or ethical manner
64	Loyalty	Tendency to remain loyal to one's country, unit, superiors, peers, and subordinates
65	Stress Tolerance	Tendency to maintain composure in challenging and threatening situations
66	Adaptability/Flexibility	Tendency to adjust easily to changing situations or conditions; to quickly adapt and change priorities when needed

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67	Learning Orientation	Tendency to seek out and acquire new knowledge; natural curiosity about how things function in one's environment
68	Control	Belief that one has high levels of control over what happens in one's life and the rewards and punishments one receives
69	Resourcefulness	Tendency to use one's resources both creatively and effectively to accomplish tasks
70	Leadership: Delegation	Preference for assigning tasks and giving orders to others
71	Leadership: Performance Management	Monitor crewmember performance and take action when performance is substandard
72	Leadership: Provide Feedback	Provide performance feedback and coaching to crewmembers as necessary; able to effectively inform crewmembers of mistakes or potential problems
73	Leadership: Motivation	Motivate crewmembers to perform effectively under difficult circumstances
74	Leadership: Resolving Conflicts	Resolve conflict among crewmembers; to foster an environment of teamwork and camaraderie
75	Attention to Detail	Tendency to keep track of details; to notice even subtle changes or inconsistencies in a person or situation
76	Work in Confined Spaces	Tolerate small/confined spaces for long periods of time
77	Physical Conditioning	Tendency to be active and participate in sports, exercise and physical activity.

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Table 9. Attribute list from Chappelle et al., 2010.

	Attribute Name	Description
	Abilities	
2	Stamina (2)	Physical stamina for sitting and sustaining vigilance for extended periods. Postural strength & endurance. Resilience to physical and cognitive fatigue.
3	Cognitive Proficiency	General cognitive ability. Speed and accuracy of information processing.
4	Visual Perception	Visual acuity, scanning and discrimination. Visual recognition, tracking and analysis.
5	Attention	Vigilance to multiple sources of visual & auditory information (situational awareness). Sustained and divided attention to visual and auditory information.
6	Spatial Processing	Spatial analysis and orientation. Spatial reasoning and construction (manipulation of 2-diminesional information into 4-dimensional mental imagery).
7	Memory	Visual and auditory memory (working, immediate, and delayed). Spatial memory (working, short-term, and delayed).
8	Reasoning	Real time general and deductive reasoning (problem solving). Carefully and quickly assess risk, likely outcomes, and potential repercussions (forward thinking). Quickly perceives the next steps and multi·tasks high level of information and procedures (task prioritization and management).
	Other Characteristics	
1	General Health	No significant or chronic injuries, illnesses, or defects affecting performance (e.g., manual dexterity, vision, posture) or reliability. Resilience to shift work adjustments.
9	Composure	Remains composed and in control of behavior and emotions under stress. Effectively compartmentalizes emotions.
10	Resilience	Emotional stamina and hardiness in response to monotony, confined workspace, and high pressure situations.
11	Self-Certainty	Clear sense of self-confidence. Clear sense of role as war-fighter. Maintains confidence during performance feedback.
12	Conscientiousness	Deliberate, methodical, and organized. Self disciplined.
13	Success Oriented	Self-motivated and driven to succeed. Committed to self-improvement.
14	Perseverance	Sustains a high level of effort over long periods of time despite hardships.
15	Decisiveness	"Real time" decision making during monotony and high pressure situations.
16	Humility	Effectively recognizes the need and asks for help. Seeks and accepts performance feedback from others.
17	Cohesiveness	Values the role and supportive of other personnel. Participates in morale building exchanges.
18	Assertiveness	Speaks up and effectively voices concerns in "real time." Provides appropriate and decisive feedback.
19	Adaptability	Generally flexible, realistic, and effectively responds to change and unpredictable stressors.

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20	Moral Interest	Motivated to save lives and protect U.S. and coalition forces. Personal beliefs and world views (spiritual, religious) support combat operations.
21	Occupational interest	Possess a sense of duty as a war fighter. Realistically understands and intrinsically appreciates RPA platform. Critical to retention: Enjoys duties of the position and contribution to daily operations in theater, strong intrinsic interest in advanced and emerging avionic RPA technology. Strong interest in advancing national interests and mission objectives.

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Table 10. Attribute list from Chappelle et al., 2011.

	Attribute Name	Description
	Abilities	
1	Cognitive Proficiency	General cognitive ability. Speed & accuracy of information processing.
2	Visual Perception	Visual acuity, scanning and discrimination. Visual recognition, tracking and analysis.
3	Attention	Vigilance to multiple sources of visual and auditory information (situational awareness). Sustained and divided attention to visual and auditory information.
4	Spatial Processing	Spatial analysis and orientation. Spatial reasoning and construction (manipulation of 2-diminesional information into 4-dimensional mental imagery).
5	Memory	Visual and auditory memory (working, immediate, and delayed). Spatial memory (working, short-term, and delayed).
6	Reasoning	Real time general and deductive reasoning (problem solving). Task prioritization. Carefully and quickly assess risk, likely outcomes, and potential repercussions (forward thinking). Cognitive flexibility (thinking outside the box).
7	Psychomotor Processing	Fine motor dexterity and reaction time. Psychomotor-spatial coordination and accuracy.
	Other Characteristics	
8	Emotional Composure	Remains calm, composed, and in control of behavior and emotions under stress (e.g., does not readily show or experience fear, sadness, or irritability).
9	Resilience	Emotional stamina and hardiness in response to monotony, confined workspace, and high pressure situations.
10	Self-Certainty	Clear sense of self-confidence across routine and high pressure tasks and situations. Clear sense of role as an officer and war-fighter.
11	Conscientiousness	Deliberate, methodical, and highly organized. Highly dependable, reliable and self disciplined.
12	Perseverance	Completes tasks despite boredom, hardship, and potential distractions. Sustains a high level of effort over long periods of time despite hardships.
13	Success Oriented	Self-motivated and driven to succeed and achieve . Seeks new and innovative ways to improve performance. Strong interest in mastering challenging tasks and in emerging computer-based technology.
14	Decisiveness	Makes decisions in real time, under pressure, and within operational deadlines. Operationally patient in making the right decision and committing to a course of action.
15	Adaptability	Effectively sizes up and deals with problematic situations and environmental demands. Generally flexible, realistic, and effectively understands problematic stressors in occupational and personal settings. Finds good ways of managing and resolving stressors and conflicts. Effective compartmentalization of personal stress from occupational duties.
16	Humility	Ability to recognize the need and willingness to seek help from leadership and others.

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17	Extraversion	Open and accepting of critical feedback from peers, subordinates and others. Shares credit for success, accepts responsibility for mistakes. Receptive and approachable. Socially engaging and outgoing; fosters positive relations. Understands and effectively responds to emotional states of others.
18	Judgment	Comfortable with different personality styles and working under constrained and varied conditions. Situationally aware; responsive; effectively resolves/diffuses interpersonal conflict. Social behavior at work and off-base settings demonstrates prudence for national security and the integrity of military operations.
19	Team Oriented	Comfortable leading, working with enlisted personnel as a team. Competitive disposition but does not jeopardize group and mission goals for individual goals. Interest in teaching others and promoting morale. Trusting of other aircrew and military personnel.
20	Moral	Motivated to save lives and protect U.S. and coalition forces. Personal beliefs and world views (spiritual, religious) support combat operations.
21	Occupational	Possesses a sense of duty as an officer and warfighter. Realistically understands and appreciates RPA platform. Strong interest in advanced and emerging avionic RPA technology. Enjoys duties of the position and contributes to daily operations in theater. Strong interest in advancing national interests and mission objectives.

A simple means of comparing attributes across studies is presented in Table 11. This table lists all of the identified KSAOs that were used in one way or another, for example in the construction of a selection battery. As a result, for example, the Knowledge and Skills identified in Bruskiewicz et al. are not listed here because they were excluded from construction of the selection battery on the grounds that the Knowledge and Skills identified would be imparted in the training process. The left most column in Table 11 lists the unique attribute names from all of the studies reviewed here. In the columns to the right are the attribute numbers of the study named in their headers. With the exception of the second column, which lists the attribute numbers from Fleishman and Qaintance (1984), the attribute lists are not in numeric order. The numbers have been placed in the row that best corresponds, according to compared definitions, to the attribute name in the left column. Attribute numbers may appear in more than one row because of overlapping definitions or lack of specificity, in more than one row. Therefore Table 11 is a cross reference of KSAOs identified and used among the studies reviewed in this report.

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Table 11. Cross reference of KSAOs for RPA operators.

Attribute Name	Fleishman & Quaintance, 1984	Crumley & Bailey, 1979: AVO, MPO	Biggerstaff et al., 1998: EP	Barnes et al., 2000: AVO, EP	Warner & Knapp, 2000: GSO	Phillips et al., 2003: IP	Bruskiewicz et al., 2007: AVO, MPO	Chappelle et al., 2010: MPO	Chappelle et al., 2011: AVO
KNOWLEDGE									
SKILLS									
Map reading		1							
Photo interpretation		2							
Communication procedures							5		
ABILITIES									
Oral comprehension	1	4		1	1				
Written comprehension	2			2	2		30		
Oral expression	3	5		3	3				
Written expression	4			4	4				
Fluency of ideas	5			8	8				
Originality	6			7	7				
Memorization	7			5	5			7	
Problem sensitivity	8			6	6				
Mathematical reasoning	9			17	17				
Number facility	10			18	18				
Deductive reasoning	11			15	15		33	8	
Inductive reasoning	12			13	13		33	8	
Information ordering	13			16	16			8	
Category flexibility	14			14	14				
Speed of closure	15			20	20			3	
Flexibility of closure	16			9	9				
Spatial orientation	17		1	11	11	1	37	6	
Visualization	18			12	12			6	
Perceptual speed	19			21	21		26	5	
Control precision	20		3	34	34	2			7
Multlimb coordination	21	3	3	40	40	2			7
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Future KSAOs

Of the reports reviewed above there are three that identified KSAOs with an intent to anticipate future requirements. The first two, Barnes et al. (2000) and Warner et al. (2000), were not aimed at development of personnel selection instruments, but rather design considerations for future systems and their impact on manpower requirements. The first issue for consideration in Barnes et al. concerned the need for rated aviators as operators rather than enlisted personnel. The authors did not find evidence to support the replacement of enlisted personnel in either the AVO or EP positions with rated aviators. They instead pointed to training solutions as the best alternative for addressing the demands of expected design changes. Additionally, the authors found no evidence to compel the introduction of image or intelligence analysts into the RPA crew complement. They did conclude that some of the skills possessed by image and intelligence analysts could have application within the RPA crew for certain missions. Again, their recommended solution was to approach this through training.

Warner and Knapp (2000) were concerned with the impact of an enhanced CGS, then in development, on manpower and personnel requirements. Most, but not all, of the features of that

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developmental system have been implemented. The authors predicted a skill shift toward increased demand for analytical skills (and presumably the abilities that enable those skills) in the enhanced CGS. Much of that shift was expected to stem from increased reliance on and intelligence and imagery analysis by the RPA crew. As in the previous study, the authors concluded that the introduction of imagery and intelligence analysts into the RPA crew would not be cost effective and that it would be more practical to augment training for Army RPA operators to impart the needed skills. The recommendations of both of these studies regarding training solutions have been partly implemented and are continuing. However, there is a long road ahead, at least for the Army, in implementing sufficient training enhancements to cover the needs of future systems.

Government guidance at the outset of the project that produced the Bruskiewicz et al. (2007) report was specific in the need to consider the likely impact of near future changes on personal attribute demands that could affect personnel selection criteria. To address this, the authors included a sample of SMEs who had special knowledge of developments in the RPA arena in their administration of the JAQ. These SMEs were requested to apply their knowledge of coming changes to their ratings. This approach appears to have had an effect because the SME subgroup produced somewhat different ratings, as illustrated in the review above.

The emphasis in these three examples of anticipation of shifts in operator KSAO demand is on design changes to the RPA systems. These changes were expected both in the user interface (CGS) and in expanded system capabilities (e.g. weaponization). System design changes constitute only one of several sources that can drive shifts in KSAO demand. Other drivers include changes in organization, manpower and missions.

Addition of new system capabilities or expansion of existing system capabilities most often increase total demand while differentially affecting demand across attribute domains. Even "improved" designs can be a double edged sword. The control interface and display systems for RPA operation are getting improvements that are intended to reduce total workload and reduce demand on perceptual-motor abilities, but as workload decreases it is common to see an increase in expectations that translate into expanded mission requirements or addition of still more new capabilities. Likewise, increases in automation are often viewed as opportunities to add new requirements. Another area within system capabilities is the continued weaponization of RPA systems. Introduction of an onboard munition adds far more than the requirement for knowledge and skills relevant to operation of that subsystem. It also adds intellectual and decision making requirements related to knowledge and interpretation of the current rules of engagement, commander's intent for the current mission, and understanding of the performance envelope and constraints of the weapon and its terminal effects (e.g., burst radius). Attitudinal and personality attributes that previously were not particularly prominent may take on much greater importance when the system that a person is operating becomes deadly. The addition of weapons also changes the system's area and timeline of influence in a mission. Even if the decision to employ a weapon is made outside the CGS, the crew inside are faced with another set of decision points that have a characteristic of immediacy. Therefore the personal attributes that mediate decision speed will be in greater demand.

There also has been, over the past decade, increasing effort expended toward development of the capability for a RPA crew to control multiple RPAs simultaneously. Beyond the obvious impact on total workload, this capability places increased demand for KSAOs that mediate situation

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awareness. With multiple airframes under their control, AVOs and MPOs need greater application of selective and divided attention, spatial orientation, and time sharing.

Changes in organization can have both direct and indirect effects on KSAO demand. The recent transfer of Army UAS assets and responsibility from the Military Intelligence (MI) Branch to the Aviation Branch (AVN) is having a large effect on attribute demands for UAS operators. Under MI, UAS missions, and therefore training (especially on-the-job training), concentrated on intelligence, surveillance, and reconnaissance (ISR). Under AVN there is a transition to a much broader scope that parallels manned aviation assets. This includes not only reconnaissance, surveillance, and target acquisition (RSTA), but also command, control, communications and intelligence (C3I) as well as other roles and functions. This transition has been shown (Stewart, Bink, Barker, Tremlett, & Price, 2011) to have resulted in gaps in training that are slowly being addressed. Rectification, through augmented training content, in itself will increase demand for cognitive abilities. In addition, the transition involves increased requirements for RPA operators to interact with personnel outside their immediate (RPA) community.

The Air Force is beginning to confront a major change in manpower relevant to RPA systems. The transition from requiring RPA pilots first be qualified manned aircraft pilots to personnel who have only completed the Undergraduate Remotely Piloted Aircraft Training (URT) course with much less hands-on flying training is a step that may produce shifts in the experiential background and attitudes of the RPA pilot population. Changes in the general population from which all RPA operators are ultimately obtained can also alter the complement of abilities and other attributes of people available for entry into RPA crew positions.

Changes in RPA missions can result from changes in organization and/or system capabilities, as well as other causes. In recent years the scope of RPA missions has greatly increased to include a far broader range of reconnaissance and targeting, and is now moving into the attack realm. This increase in mission scope has consequences in communications, cognitive abilities, and other attributes such as time-sharing and teamwork. A major increase in mission scope is the expanding use of manned-unmanned arial teaming (MUM). In MUM missions a RPA is teamed with one or more manned aircraft (e.g. OH-58D Kiowa Warrior) to carry out reconnaissance/ attack operations. This requires close interaction between the system crews, as well as with supporting and commanding ground units. As a result, RPA crews and manned aircraft crews must acquire knowledge of each others system capabilities and limitations and develop a common lexicon for efficient communications. In addition, demand for time-sharing and situational awareness are increased because of the need to maintain awareness of the status of every system in the team. Recently, Pavlas et al. (2009) analyzed the features of MUM teaming to identify knowledge, skills, and attitudes that are demanded by these missions and will require augmented training. They identified a combined 60 areas that acquire increased demand in MUM operations. While their focus is on training solutions, their findings should be reviewed to determine where the training burden could be mitigated by shifts in KSAOs used for selection.

Table 12 presents the KSAO list from Table 11 and expresseses expected shifts in demand based on consideration of the factors outlined above. A "+" indicates an expected increase in demand, a "–" indicates an expected decrease. A "0" indicates no expected change and an "X" indicates the attribute is not well enough defined to be evaluated, and should be dropped.

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Table 12. Expected shift in KSAO demand.

Attribute Name	
KNOWLEDGE	
SKILLS	
Map reading	X
Photo interpretation	X
Communication procedures	+
ABILITIES	
Oral comprehension	+
Written comprehension	+
Oral expression	0
Written expression	0
Fluency of ideas	0
Originality	0
Memorization	+
Problem sensitivity	0
Mathematical reasoning	+
Number facility	+
Deductive reasoning	+
Inductive reasoning	+
Information ordering	+
Category flexibility	+
Speed of closure	+
Flexibility of closure	+
Spatial orientation	+
Visualization	+
Perceptual speed	+
Control precision	-
Multlimb coordination	-
Response orientation	-
Rate control	-
Reaction time	-
Arm-hand steadiness	-
Manual dexterity	-
Finger dexterity	-
Wrist-finger speed	-
Speed of limb movement	-
Selective attention	+
Time sharing	+
Static strength	0
Explosive strength	0
Dynamic strength	0
Trunk strength	0
Extent flexibility	0
Dynamic flexibility	0
Gross body coordination	0
Gross body equilibrium	0
Stamina	0

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Near vision	0
Far vision	0
Visual color discrimination	0
Night vision	0
Peripheral vision	0
Depth perception	0
Glare sensitivity	0
General hearing	0
Auditory attention	+
Sound localization	0
Speech hearing	0
Speech clarity	0
Estimation of time to contact	+
Situational awareness	+
Organization/Time management	+
Judgement/Decision-making/Problem solving	+
Vigilance	+
Cognitive task prioritization	+
Adaptability/Flexibility	+
Cognitive proficiency	+
Stamina (2)	X
Visual perception	+
Attention	+
Spatial processing	+
Memory	+
Reasoning	+
OTHER ATTRIBUTES	
Affinity for planning and logic	X
Affinity for uncertainty	X
Management of stressors	X
Assertiveness	0
Followership	0
Self regulation	0
Work ethic	0
Initiative	+
Self confidence	0
Straightforwardness	X
Helpfulness	X
Teamwork	+
Interpersonal skills	+
Achievement striving	X
Self discipline	0
Dependability	0
Responsibility	0
Stress tolerance	0
Leadership: Performance management	0
Leadership: Provide feedback	0
Leadership: Motivation	0
Leadership: Resolving conflicts	0
Attention to detail	+
General health	X

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Composure	X
Resilience	X
Self-certainty	X
Conscientiousness	+
Success oriented	X
Perseverance	X
Decisiveness	X
Humility	X
Cohesiveness	X
Adaptability	X
Moral interest	X
Occupational interest	X
Extraversion	X
Judgment	X
Team-oriented	X

Conclusion

There are very few published treatments of KSAOs for RPA operators and most of those have severe methodological deficiencies. Of those reviewed here only three (Barnes et al., 2000; Bruskiewicz et al., 2007; Warner & Knapp, 2000) could be considered rigorous and systematic in their approach. There appear to be no instances of RPA operator selection instruments that have been validated. The closest to that would be the battery developed by Bruskiewicz, et al, which could be implemented for validation in a short time. Services should, however, conduct studies of training failure rates to determine if the costs of development and fielding selection instruments are justifiable.

The demand for specific abilities and other attributes in persons entering training as RPA operators is driven by changes occurring in system capabilities, organization, manpower, and missions. Overall, the positions within RPA crew are acquiring an increased demand although some attributes are likely to see decreases. These changes are likely to have an even greater impact on training requirements.

The area of RPA KSAOs is prone to confusion stemming from differences in terminology regarding operational systems and their names, and names and definitions of crew positions. Greater confusion stems from conflicting definitions of personal attributes, loosely defined attributes and a proliferation of ad hoc attributes with little or no theoretical basis. There is a critical need for a KSAO taxonomy that minimizes overlap between attributes and covers the range of behaviors critical to system operation.

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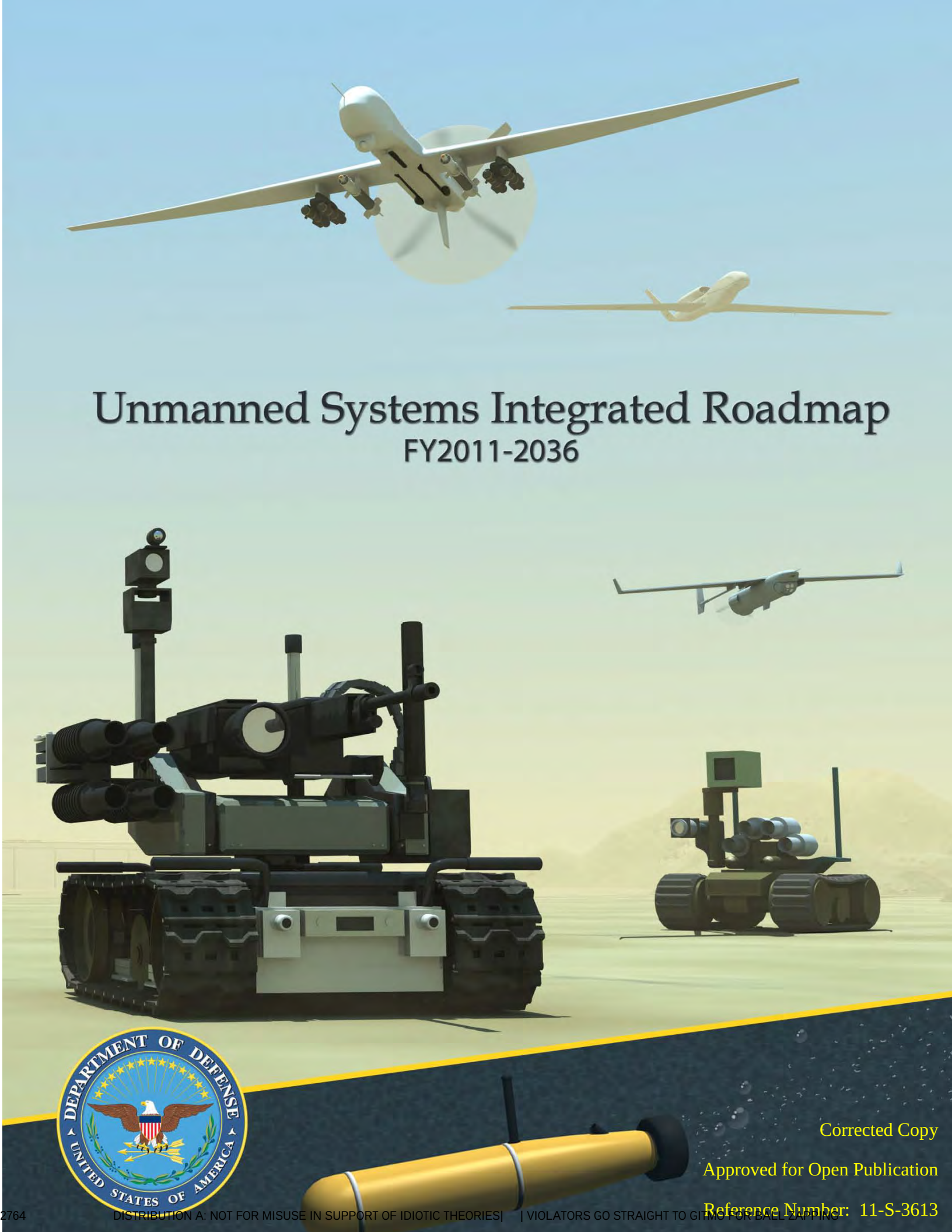
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Unmanned Systems Integrated Roadmap

FY2011-2036

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THE UNMANNED SYSTEMS INTEGRATED ROADMAP

FY2011-2036

James A. Winnefeld, Jr., Admiral, USN
Vice Chairman of the Joint Chiefs of Staff

Frank Kendall
Acting Under Secretary of Defense
for Acquisition, Technology and Logistics

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EXECUTIVE SUMMARY

U.S. and allied combat operations continue to highlight the value of unmanned systems in the modern combat environment. Combatant Commanders (CCDRs) and warfighters value the inherent features of unmanned systems, especially their persistence, versatility, and reduced risk to human life. The U.S. military Services are fielding these systems in rapidly increasing numbers across all domains: air, ground, and maritime. Unmanned systems provide diverse capabilities to the joint commander to conduct operations across the range of military operations: environmental sensing and battlespace awareness; chemical, biological, radiological, and nuclear (CBRN) detection; counter-improvised explosive device (C-IED) capabilities; port security; precision targeting; and precision strike. Furthermore, the capabilities provided by these unmanned systems continue to expand.

The Department of Defense (DoD) has been successful in rapidly developing and fielding unmanned systems. DoD will continue to focus on responding rapidly to CCDR requirements, while ensuring systems are acquired within the framework of DoD's new wide-ranging Efficiencies Initiatives[1]. In the fiscal environment facing the Nation, DoD, in concert with industry, must pursue investments and business practices that drive down life-cycle costs for unmanned systems. Affordability will be treated as a key performance parameter (KPP) equal to, if not more important than, schedule and technical performance. DoD will partner with industry to continue to invest in unmanned systems technologies while providing incentives for industry to implement cost-saving measures and rewarding industry members that routinely demonstrate exemplary performance.

> My Acquisition Decision Memorandum (ADM) approving formal program commencement of the program will contain an affordability target to be treated by the Program Manager like a Key Performance Parameter (KPP) such as speed, power, or data rate ….
>
> *–Under Secretary of Defense Memorandum for Acquisition Professionals, Better Buying Power, September 2010*[1]

This document provides a DoD vision for the continuing development, fielding, and employment of unmanned systems technologies. Since publication of the last DoD Roadmap in 2009, the military Services have released individual Service roadmaps or related strategy documents. This roadmap defines a common vision, establishes the current state of unmanned systems in today's force, and outlines a strategy for the common challenges that must be addressed to achieve the shared vision.

The challenges facing all military Services in the Department include:

1) Interoperability: To achieve the full potential of unmanned systems, these systems must operate seamlessly across the domains of air, ground, and maritime and also operate

[1] Better Buying Power, Guidance for Obtaining Greater Efficiency and Productivity in Defense Spending, OUSD(AT&L) Memo, Dr. Ashton B. Carter, 14 September 2010.

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seamlessly with manned systems. Robust implementation of interoperability tenets will contribute to this goal while also offering the potential for significant life-cycle cost savings.

2) Autonomy: Today's iteration of unmanned systems involves a high degree of human interaction. DoD must continue to pursue technologies and policies that introduce a higher degree of autonomy to reduce the manpower burden and reliance on full-time high-speed communications links while also reducing decision loop cycle time. The introduction of increased unmanned system autonomy must be mindful of affordability, operational utilities, technological developments, policy, public opinion, and their associated constraints.

3) Airspace Integration (AI): DoD must continue to work with the Federal Aviation Administration (FAA) to ensure unmanned aircraft systems (UAS) have routine access to the appropriate airspace needed within the National Airspace System (NAS) to meet training and operations requirements. Similar efforts must be leveraged for usage of international airspace.

4) Communications: Unmanned systems rely on communications for command and control (C2) and dissemination of information. DoD must continue to address frequency and bandwidth availability, link security, link ranges, and network infrastructure to ensure availability for operational/mission support of unmanned systems. Planning and budgeting for UAS Operations must take into account realistic assessments of projected SATCOM bandwidth, and the community must move toward onboard pre-processing to pass only critical information.

5) Training: An overall DoD strategy is needed to ensure continuation and Joint training requirements are in place against which training capabilities can be assessed. Such a strategy will improve basing decisions, training standardization, and has the potential to promote common courses resulting in improved training effectiveness and efficiency.

6) Propulsion and Power: The rapid development and deployment of unmanned systems has resulted in a corresponding increased demand for more efficient and logistically supportable sources for propulsion and power. In addition to improving system effectiveness, these improvements have the potential to significantly reduce life-cycle costs.

7) Manned-Unmanned (MUM) Teaming: Today's force includes a diverse mix of manned and unmanned systems. To achieve the full potential of unmanned systems, DoD must continue to implement technologies and evolve tactics, techniques and procedures (TTP) that improve the teaming of unmanned systems with the manned force.

This Roadmap leverages individual Service roadmaps and visions, and identifies challenges that might stand in the way of maturing those visions to a shared Joint vision. The vignettes provided at the beginning of the Roadmap give the reader a glimpse into potential unmanned systems capabilities. They do not serve as requirements—the individual Services will continue to identify requirements gaps and utilize the Joint Capabilities Integration and Development System (JCIDS) to determine which requirements to fund. The chapters that follow the vignettes identify core areas that are challenges for further growth in unmanned systems and chart out science, technology, and policy paths that will enable unmanned systems to fulfill an expanding role in

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supporting the warfighter. Success in each of these areas is critical to achieve DoD's shared vision and realize the full potential of unmanned systems at an affordable cost.

> … the ability to understand and control future costs from a program's inception is critical to achieving affordability requirements.
>
> *–Under Secretary of Defense Memorandum for Acquisition Professionals, Better Buying Power, September 2010*[1]

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1 INTRODUCTION/SCOPE

1.1 Purpose

The purpose of this document is to describe a vision for the continued integration of unmanned systems into the Department of Defense (DoD) Joint force structure and to identify steps that need to be taken to affordably execute this integration. DoD has seen rapid growth, sparked in large part by the demands of the current combat environment, in the development, procurement, and employment of unmanned systems. Today's deployed forces have seen how effective unmanned systems can be in combat operations. This experience has created expectations for expanding the roles for unmanned systems in future combat scenarios. This Roadmap establishes a vision for the next 25 years and outlines major areas where DoD and industry should focus to ensure the timely and successful adoption of unmanned systems.

1.2 Scope

This Roadmap follows the path originally laid out in the 2007 and 2009 Roadmaps in addressing all three unmanned domains: air, ground, and maritime. However, this document deviates from the earlier editions, primarily as a result of the following:

- An Unmanned Systems Roadmap survey conducted by the Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics) (OUSD(AT&L))
- Publication of service-specific roadmaps for unmanned systems

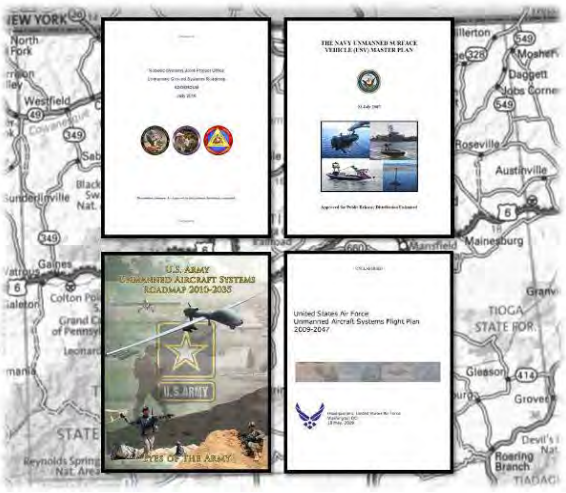
Shortly after the publication of the 2009 Roadmap, OUSD(AT&L) conducted a survey of key stakeholders and users of the Roadmap. The survey sampled a wide audience, including: Office of the Secretary of Defense (OSD), Service headquarters, warfighting commands, Service acquisition organizations, Service laboratories, multiple Joint organizations, other government agencies, industry (both large and small businesses), and academia. One of the major outcomes of this survey was a decision to capture the catalog function of the Roadmap in a separate, online tool. The reason for this decision is that the online tool provides greater functionality than that of the two-dimensional, hard-copy catalog, including the capability for more frequent updates than the biennial printed Roadmap. The catalog can be found on the Unmanned Warfare Information Repository site at: **https://extranet.acq.osd.mil/uwir/**.

The survey also helped define the audience for the 2011 edition. This Roadmap provides a common vision and problem set to help shape military Service investments. The document also describes DoD's direction to help industry participants shape their investments, particularly with respect to independent research and development.

Since the publication of the 2009 Roadmap, each military Service has developed its own roadmap or equivalent document (listed in Appendix A). The U.S. Air Force (USAF) released its "Unmanned Aircraft Systems Flight Plan" in 2009 outlining an actionable plan across the diverse spectrum of doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy (DOTMLPF-P). In 2009, the U.S. Army published the "Unmanned Ground Systems Roadmap," providing a common resource document for Army and U.S. Marine Corps (USMC) stakeholders in unmanned ground vehicles (UGVs). The Army released its unmanned

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aircraft systems (UAS) Roadmap in 2010, which established a broad vision for developing, organizing, and employing UAS across the spectrum of Army operations. In November 2009, the USMC published its "Concept of Operations for USMC Unmanned Aircraft Systems Family of Systems (CONOPS for USMC UAS FoS)." Finally, the U.S. Navy published its "Information Dominance Roadmap for Unmanned Systems" in December 2010. In light of these recent publications (see right), this Roadmap was tailored to focus on common issues facing all Services as well as to articulate a vision for achieving these goals in today's fiscal environment. The goal for this document is to serve as a single, unified source to clearly articulate the DoD common vision for unmanned systems and to identify a common problem set facing DoD in maximizing the military utility offered by these versatile and innovative systems.



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2 VISION

The Department of Defense's vision for unmanned systems is the seamless integration of diverse unmanned capabilities that provide flexible options for Joint Warfighters while exploiting the inherent advantages of unmanned technologies, including persistence, size, speed, maneuverability, and reduced risk to human life. DOD envisions unmanned systems seamlessly operating with manned systems while gradually reducing the degree of human control and decision making required for the unmanned portion of the force structure.

… to ensure safe, effective and supportable capabilities are provided while meeting cost, schedule and performance. The parallel vision is to provide continuous improvement of unmanned system capabilities to meet current and future Warfighter objectives.

– Mission and Vision, Robotic Systems Joint Project Office Unmanned Ground Systems Roadmap, July 2009

… develop and field cost-effective USVs to enhance Naval and Joint capability to support: Homeland Defense, the Global War on Terror, Irregular Warfare, and conventional campaigns.

– The USV vision, The Navy Unmanned Surface Vehicle Master Plan, 23 July 2007

… adopt innovative strategies to provide cost effective logistical support …

– Goals and Objectives, US Army Roadmap for UAS 2010-2035

… to harness increasingly automated, modular, globally connected, and sustainable multi-mission unmanned systems resulting in a leaner, more adaptable and efficient Air Force that maximizes our contribution to the Joint Force.

– USAF vision, USAF Unmanned Aircraft Systems Flight Plan 2009-2047

2.1 Future Operational Environment

The strategic environment and the resulting national security challenges facing the United States for the next 25 years are diverse. The United States faces a complex and uncertain security landscape in which the pace of change continues to accelerate. The rise of new powers, the growing influence of nonstate actors, the spread of weapons of mass destruction and other irregular threats, and continuing socioeconomic unrest will continue to pose profound challenges to international order.

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Over the next two decades, forces will operate in a geostrategic environment of considerable uncertainty with traditional categories of conflict becoming increasingly blurred. This era will be characterized by protracted confrontation among state, nonstate, and individual actors using violent and nonviolent means to achieve their political and ideological goals. Future adversaries will rely less on conventional force-on-force conflicts to thwart U.S. actions and more on tactics that allow them to frustrate U.S. intentions without direct confrontation.

> The future operating environment will be one of constant and accelerating change. Economic, demographic, resource, climate, and other trends will engender competition locally, regionally, and globally…. State and non-state actors will find new and more deadly means of conducting operations in all domains, to include land, air, maritime, and cyberspace to further their aims … otherwise leveraging land, air, and maritime areas to ensure their freedom of movement and deny it to others..
>
> *– Joint Operational Concept, Irregular Warfare: Countering Irregular Threats*

As technological innovation and global information flows accelerate, nonstate actors will continue to gain influence and capabilities that, during the past century, remained largely the purview of states. Chemical and biological agents will become increasingly more accessible, lethal and sophisticated. Both state and nonstate actors will actively pursue nuclear weapons, sophisticated and/or bioengineered biological agents, and nontraditional chemical agents.

> The next quarter century will challenge U.S. Joint Forces with threats and opportunities ranging from regular and irregular wars in remote lands, to relief and reconstruction in crisis zones, to cooperative engagement in the global commons …. There will continue to be opponents who will try to disrupt the political stability and deny free access to the global commons that is crucial to the world's economy…. In this environment, the presence, reach, and capability of U.S. military forces, working with like-minded partners, will continue to be called upon to protect our national interests.
>
> *– Joint Operating Environment 2010: Ready For Today, Preparing For Tomorrow*

Unmanned systems can help in countering these threats by reducing risk to human life and increasing standoff from hazardous areas.

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2.2 DoD's Vision

The DoD, along with industry, understands the effect that innovation and technology in unmanned systems can have on the future of warfare and the ability of the United States to adapt to an ever-changing global environment. DoD and industry are working to advance operational concepts with unmanned systems to achieve the capabilities and desired effects on missions and operations worldwide. In building a common vision, DoD's goals for unmanned systems are to enhance mission effectiveness, improve operational speed and efficiency, and affordably close warfighting gaps.

DoD is committed to harnessing the potential of unmanned systems and strengthening mission effectiveness while maintaining fiscal responsibility. DoD will also work on establishing a complementary relationship between manned and unmanned capabilities while optimizing commonality and interoperability across space, air, ground, and maritime domains.

Open architecture (OA) and open interfaces need to be leveraged to address problems with proprietary robotic system architectures. Standards and interface specifications need to be established to achieve modularity, commonality, and interchangeability across payloads, control systems, video/audio interfaces, data, and communication links. This openness will enhance competition, lower life-cycle costs, and provide warfighters with enhanced unmanned capabilities that enable commonality and joint interoperability on the battlefield.

By prudently developing, procuring, integrating, and fielding unmanned systems, DoD and industry will ensure skillful use of limited resources and access to emerging warfighting capabilities. Pursuing this approach with unmanned systems will help DOD sustain its dominant global military power and provide the tools required by national decision-makers to influence foreign and domestic activities while adapting to an ever-changing global environment. The following quotation captures the breadth of the challenge:

> I speak for the Navy, that unmanned systems have to address all of the domains in which the Navy operates…. We operate on the surface, above the surface, into space, but then we operate below the surface. So when we talk about unmanned and … as we knit all of this capability together and capacity together, it has to take into account that we're operating in all those different domains.
>
> *– Admiral Gary Roughead, Chief of Naval Operations (CNO)*

With the current fiscal environment of constrained budgets, affordability is a factor across the entire acquisition cycle and must be actively engaged by the program managers, users, trainers, and testers to identify problems early, and address cost throughout the life cycle. A dollar saved early results in hundreds of saved dollars compared to problems resolved in production or worse yet during operations and support. While "open systems architecture and data rights" are critical to keeping costs in check, emphasizing the removal of obstacles to competition and the

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opportunities in test and evaluation (T&E) to facilitate competitive analysis is equally important to reduce developmental costs.

The assembly line of activity involved in producing unmanned systems must address risk across the life cycle to address the new challenges of testing autonomous functionality in the initial stages, and evaluating the operation and support issues involved in sustainment for increasing reliability, availability, and maintainability. The emphasis on vignettes at a mission level only indirectly emphasizes the increasing need for an evolutionary capability in unmanned systems production that is resilient and responsive to the dynamic situation faced by today's warfighter. New technology, methodologies, and human resourcing are critical for establishing rapid acquisition environments that maximize the potential for unmanned systems production.

2.3 Vignettes

The following vignettes offer examples of the increased capability and flexibility inherent in unmanned systems as DoD continues to field unmanned technologies and integrate resulting systems into its existing force structure. These vignettes are not intended to present an exhaustive list of the possibilities, but rather to present a few examples to illustrate the vision described throughout this Roadmap.

2.3.1 Interoperability Across Domains Vignette, 2030s

Location: Northern Pacific Littoral Areas

Situation: The number and boldness of coordinated, provocative efforts between the Republic of Orangelandia (ROO) and the increasing number of radicalized Islamic nation-states within the tropic zones (± 20° latitude) have increased over the past 15 years. ROO has demonstrated a delivery capability for nuclear intercontinental ballistic missiles, and several radical Islamic nations now openly possess nuclear weapon technology. Although nuclear power's role is expanding, oil remains the energy resource of preference even though gaining access to oil by Western nations has become increasingly constrained and expensive. The United States' gross domestic product (GDP) is being challenged by China.



Scenario: A 50-year-old, former Soviet-era, *Akula* class, nuclear-powered attack submarine sails out of ROO's Molan harbor at night unobserved by Western reconnaissance satellites. Movements of ROO submarines are of high interest due to their rarity (fewer than a dozen occurrences a year) and primarily due to ROO's status as a rogue, nuclear-capable nation-state. The submarine's departure is detected by the underwater surveillance grid, which is monitoring vessel movements in and out of the ROO waters. Ahead of the submarine, a glider unmanned underwater vehicle (UUV) is autonomously

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detached from the local network to intercept the faster submarine. Closing to within 50 yards as the submarine passes, the UUV succeeds in attaching a tether to the submarine, which begins pulling the UUV along (see figure right). As the submarine dives below the UUV's operating depth, the UUV adjusts the tether to maintain its position close to the surface. Every three hours, it glides to the surface and transmits a low-power position report.

The position reports are received by an orbiting communications relay, Baton One, an EQ-25 UAS operating at 75,000 ft in the eastern Pacific region. The EQ-25 is an extreme-endurance UAS, capable of operating for two months on station without refueling. As the submarine enters the Sea of Okhotsk and heads toward the North Pacific Ocean, U.S. military commanders are faced with a decision. Despite the advanced battery technology of the UUV, the battery life is finite; therefore, the operators have three courses of action affecting their surveillance operation: (1) continue surveillance by shifting the orbit of Baton One to maintain reception range on the UUV, which will otherwise be lost in 12 hours (2) save the UUV by detaching it when its remaining power is still sufficient for it to recover itself (within three days) or (3) expend the UUV by keeping it attached until its power is exhausted (within six days). Because ROO submarines seldom sortie beyond the littoral seas of northeastern Asia, they decide to shift Baton One's orbit and wait to decide the UUV's fate until the submarine's intent becomes clearer.

By the third day, the submarine is heading toward the mid-Pacific and the Hawaiian Islands. Because the value of the mission exceeds the cost of the asset, the decision is made to expend the low-cost UUV to buy time for a naval anti-submarine warfare (ASW) ship to intercept and track the submarine. The following day, the submarine reverses course. Two days later, the still-attached UUV converts to beacon mode to conserve its dwindling power reserves, Baton One returns to its planned orbit, and the ASW ship turns for Pearl Harbor. A Broad Area Maritime Surveillance (BAMS) UAS, MQ-4C, is launched from Guam to track the beacon. It recovers the beacon's signal and determines that it is stationary. Autonomously descending with its internal airborne sense and avoid (ABSAA) system to maintain "due regard," the BAMS UAS is able to visually acquire the UUV, floating in mid-ocean and no longer attached to the ROO submarine — potentially detached by the submarine's crew. The submarine's position and intent are now unknown.

Ten days later, a weak seismic disturbance is detected 150 miles southeast of Anchorage, Alaska (see map below). Several minutes later, a much more significant event registers 3.5 on the Richter scale. An interagency DoD/homeland defense reconnaissance UAS is launched out of Elmendorf Air Force Base (AFB) and detects a radiation plume emanating near Montague Island at the mouth of Prince William Sound. The UAS maps the plume as it begins spreading over the sound, and a U.S. Coast Guard offshore patrol cutter deployed from Kodiak employs its



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embarked unmanned helicopter to drop buoys with chemical, biological, radiological, and nuclear (CBRN) sensors in the Sound and within narrow passes to measure fallout levels. The plume begins to spread over the sound and threatens the city of Valdez. All vessel traffic, mainly oil tankers, transiting in and out of the Sound is stopped, and operations at the oil terminal are suspended. Oil storage facilities at the terminal are quickly filled to capacity, and the flow from Prudhoe Bay is shut down. The port of Valdez, the largest indigenous source of oil for the United States, is effectively under quarantine.

Due to the growing contamination of the local environment, disaster response officials decide to request the support of the military because of their experience both with operations in CBRN zones and with unmanned systems, which are the tools of choice because of the contamination hazards to personnel. The amphibious transport dock ship USS *New York* anchors near an entrance to Prince William Sound and begins operations with its unmanned surface vehicles (USVs) and MQ-8 detachments. An EQ-25 orbit is established over the Sound to ensure long-term, high-volume communication capability in the high-latitude, mountainous region. With data compression technology fielded in the transmitting and relay systems, the EQ-25 is capable of handling all the theater data relay requirements. A USV proceeds to the focus of contamination and lowers a tethered remotely operated vehicle (ROV) to conduct an underwater search for the source. The USV's sonar quickly locates a large object in very shallow water and, on closer inspection by the ROV, images the severely damaged hull of what appears to be an *Akula* class submarine. The hull is open to the sea, and the ROV places temperature gradient sensors on the hull and inserts gamma sensors into the exposed submarine compartments. The Joint Task Force that was formed to manage the disaster quickly determines that the reactor fuel core is exposed to the sea and that the reactor was not shut down and is still critical. Suspicion of the submarine's origin centers on its being from ROO, but all evidence that this vessel is the lost *Akula* submarine is currently circumstantial.

The radiation plume has now encompassed the evacuated town of Valdez, and MQ-8s fly repeated sorties to the town, dock, and terminal areas to deploy UGVs with sensors and collect samples for analysis. Returning USVs and MQ-8s are met and serviced by personnel in hazmat gear and washed down after each sortie. With conditions deteriorating, two unmanned Homeland Defense CBRN barges fitted with cranes, containers, and remote controls arrive from Seattle. USVs are stationed in the narrow straits leading into the Sound with hydrophones to broadcast killer whale sounds to frighten fish outside the Sound away from the contaminated area. Over the next two weeks, with the assistance of U.S and coalition ROVs equipped with cutting torches, grappling fixtures, and operating from USVs, one remotely operated submersible barge is able to work around the clock with impunity against exposure levels to recover the exposed fuel sources and to isolate them in specially designed containers. A second barge similarly retrieves sections of the crippled submarine. Both barges operate with a high degree of autonomy, limiting exposure of personnel to the radioactive contamination.

The UGVs continue monitoring contamination levels and collecting samples, but now also start conducting decontamination of the oil terminal control station and the local power and water facilities. Highly contaminated soil is placed into steel drums, and larger UGVs are used to dig pits and bury contaminated building and pipeline materials. Advanced sensor technology and control logic allows the UGVs to operate around the clock with human operators serving solely in a monitoring function. USVs are used to collect carcasses floating in the Sound and bring

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them to shore for disposal. UUVs crisscross the seafloor of the Sound to locate and tag remnants of the submarine for later collection. Unmanned aircraft (UA) fly continuously through the National Airspace System (NAS) at low altitude to monitor and map the declining radiation contours, at medium altitude to map cleanup operations, and at high altitude to relay control commands and data from the nearly one hundred unmanned vehicles at work. Decontamination, refueling, and repair shops have been established in nearby Cordova to service the vehicles and aircraft and on the USS *New York* to service the boats and submersibles. It is the largest coordinated use of international air, ground, and maritime unmanned systems ever conducted.

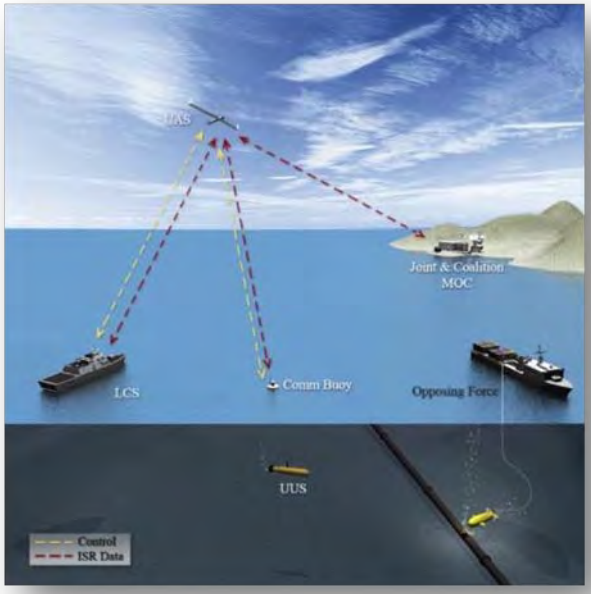
2.3.2 African Maritime Coalition Vignette, 2030s

Location: Gulf of Guinea off the coast of Africa

Situation: An UAS and an UUV, deployed from littoral combat ship (LCS) *Freedom*, are on patrol monitoring the littoral oil infrastructure of a developing nation-state. This nation-state has recently adjusted its geopolitical stance to ally itself militarily and economically with the United States and friendly European governments.

Scenario: The *Freedom*'s UUV in its assigned patrol area detects an anomaly, a remote pipeline welder controlled by an unknown force. The underwater remote welder is positioning itself to intersect a major underwater oil pipeline. Using its organic "smart software" processing capability, the UUV evaluates the anomaly as a possible threat and releases a communications buoy that transmits an alert signal and a compressed data "snapshot" from the UUV's onboard video/acoustic sensor.

The communications buoy's low probability of intercept (LPI) data are relayed via a small tactical unmanned aircraft system (STUAS) to other units in the area and to the Joint Maritime Operations Center (JMOC) ashore. The commander on the LCS directs the UUV and the UAS to provide persistent intelligence, surveillance, and reconnaissance (ISR) and command and control (C2) relay support. Simultaneously, the UAS transmits corroborating ISR data on a suspect vessel near the UUV anomaly. Thanks to a recently fielded, advanced technology propulsion upgrade, the STUAS is able to stay on station for 24 hours before being relieved (see graphic right).



Meanwhile, the JMOC analysts recognize the pipeline welder in the UUV data snapshot as one recently stolen and acquired by rebel antigovernment forces. The JMOC then dispatches an Allied quick reaction force (QRF) via 160th Special Operations Aviation Regiment (SOAR) aircraft and USAF CV-22 Osprey from a nearby airfield. The JMOC retasks a special warfare combatant-craft crewman (SWCC) Mk V to

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investigate and neutralize the potential hostile surface vessel controlling the stolen pipeline welder. The SWCC Mk V launches its own small UA to provide a low-level ISR view ahead of its navigation track while providing an LPI secure communications path among the special forces QRF team. The SWCC Mk V's UA provides a real-time common data link (CDL) common operational picture (COP) data stream via the higher altitude UAS to the LCS and JMOC.

The JMOC receives a signals intelligence (SIGINT) alert that the suspect hostile surface vessel is launching a Russian Tipchak, a medium-altitude, long-endurance (MALE) UA. The latest Tipchak variant is a hybrid UA with US-derived systems and avionics. This Tipchak is capable of launching short-range air-to-air missiles (AAMs) or air-to-surface missiles (ASMs). Its host platform, the suspect hostile vessel, has an early warning suite and has probably detected the LCS nearby or visually sighted the SWCC Mk V's UA. An update to the SIGINT alert at the JMOC reveals the Tipchak is being launched for a surveillance sweep and counter-air/counter-UA mission.

Realizing the hostile UA could pose a risk or even jeopardize the QRF, the JMOC commander launches a USAF MQ-1000 UA optimized for air interdiction and ground strike. The MQ-1000 UA, empowered by rules of engagement (ROE) allowing autonomous operation, immediately conducts an air-to-air engagement and neutralizes the Tipchak UA.

The SWCC Mk V's special forces team then conducts a visit, board, search, and seizure (VBSS) on the suspected hostile vessel supporting the UUV pipeline interdictor. Since the threat is neutralized, the unmanned systems update their patrol status, cancel the alert status, and recover or resume their assigned patrol sectors.

2.3.3 Complex Unmanned Systems Test and Evaluation Scenario

As unmanned systems become more complicated, more integrated, more collaborative, and more autonomous, establishing test-driven development constructs and infrastructure for supporting early-onset test and evaluation (T&E) and life-cycle T&E will become increasingly

> "The key to successful acquisition programs is getting things right from the start with sound systems engineering, cost estimating, and developmental testing early in the program cycle. The bill that we are introducing today will require the Department of Defense to take the steps needed to put major defense acquisition programs on a Sound footing from the outset. If these changes are successfully implemented, they should help our acquisition programs avoid future cost overruns, schedule delays, and performance problems."
> *–Senator Carl Levin, Chairman, Senate Armed Services Committee*
>
> "The Weapon System Acquisition Reform Act of 2009 is an important step in efforts to reform the defense acquisition process. This legislation is needed to focus acquisition and procurement on emphasizing systems engineering; more effective upfront planning and management of technology risk; and growing the acquisition workforce to meet program objectives."
> *–Senator John McCain, Ranking Member, Senate Armed Services Committee*

critical. The Weapon Systems Acquisition Reform Act (WSARA) of 2009 sets the stage for

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advancing T&E that will address cost saving through early-on engagement and effective sustainment in facilitating unmanned systems acquisition.

The two previous vignettes have focused on the utility of unmanned systems, but it is also helpful to focus on unmanned systems acquisition. The acquisition of systems with increasing net-centricity and automated functionality will introduce unexpected levels of risk. Systems engineering involves decomposing a design into separable elements, characterizing the intended relationships between them, and verifying the system built to specification operates as intended. The systems engineering "V" represents decomposition and design on the downstroke and integration, verification, and validation on the upstroke. As systems become more complex, the difficulties of addressing the upstroke of the "V" increase. T&E is critical for addressing this risk. The systems engineering of complex systems is gets scrutinized when major problems lead to program delays, cost overruns, and even cancellations. The issues typically lie with unintended and unanticipated interactions between elements that are uncovered only during integration, testing, or once in service. The T&E of manned systems has created optimal strategies for reducing risk in the areas of frequency, performance, support systems, and safety. The primary challenge for today's defense acquisition system is to execute acquisition programs without major schedule delays and cost overruns. Meeting that challenge has been the goal of acquisition reform improvements for decades.

Unmanned systems raise new issues of artificial intelligence, communications, autonomy, interoperability, propulsion and power, and manned-unmanned (MUM) teaming that will challenge current T&E capabilities. These problems will get more serious as systems become more interactive and more automated. Failures often occur at the interfaces between system elements, in many cases, between interfaces thought to be separate. The exponential trends in software and network communications increasingly mean that many elements of a system can now affect one another. The incredible complexity of millions of lines of software requires new approaches for detecting problems earlier in the design phase where cost mitigation is most effective. As systems get much of their functionality from software and multisystem interactions, complexity is no longer separate and distinct. Complexity is about the whole ecosystem, and systems engineering has to become more holistic. Model-based systems engineering, already in use by the software and circuit industries, is augmenting document-driven approaches in important ways. Executable models can be effective conveyors of information throughout a supply chain. Models designed to provide contextual information about the degrees of freedom and the interactions could potentially pass from the Government to the prime supplier and on to second- and third-tier suppliers from early concept through Milestones A, B, and C into the operations and support phase.

Location: DoD T&E Centers Across the World

Situation: In a rapid acquisition support environment, integrated T&E teams work with trainers and the user to accelerate the production of unmanned systems. The model involves industries that must leverage test frameworks to take advantage of Moore's Law advances that are exploitable every 18 months. The same technologies are actually subcomponents in the payload, communication, command system, and remote sensor support systems that currently compose various unmanned system of systems configurations.

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Scenario: Warfighters need next-generation system capability to support an 18-month battlespace fielding requirement. The system involves new sensors supporting a remote sensor team. The platform will utilize several new algorithms to mitigate human support functions limited by human reaction time and communication anomalies. The platform will also have new decision algorithms supporting mission functions due to new payload capabilities. The system will use a new communication protocol evaluation system for onboard teams and for ground control teams communicating over a series of relay station and satcom grids. Platform support includes mission-driven T&E to validate autonomous support capabilities enabling nonlethal support functions. This migration will use technology for air traffic management that the Federal Aviation Administration (FAA) and DoD are co-evaluating for the automated notification of an aircraft's position to ground-based controllers as well as to other manned and unmanned aircraft.

The support situation calls for an assessment of the latest Standardization Agreement (STANAG) recovery algorithms in the event of communications link disruption with collaborating manned and unmanned systems supporting a teaming operation. Interoperability tests will be necessary to support several new services and remote service support teams translating data from the payload. The teams will leverage mission information from a variety of semantic databases across the Defense Grid to generate actionable intelligence. A new aspect of this deployment will involve the utilization of both trainers and users interacting with simulators to explore the adequacy of human systems integration algorithms to discover problems for algorithm refinement and problem discovery. Red team T&E technology will expand scenario assessment to provide forecasting without historical data using Bayesian probability models utilizing expert opinions. The T&E system will be designed to determine false positives, false negatives, dynamic limits, and integrity limits regarding mission effectiveness, suitability, survivability, and effectiveness. This wholesale advancement in T&E will result in a tenfold reduction in cycle time and cost.

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3 CURRENT STATE

Over the past decade, unmanned systems have played an increasing role in U.S. military operations. DoD uses a vast array of unmanned systems, from underwater to the upper regions of the atmosphere, from the size of a matchbox to the size of a Boeing 737.

These unmanned systems continue to prove their value in combat operations in Afghanistan, where military operations are planned and executed in extremely challenging environments. Adversaries are fighting using increasingly unconventional means, taking cover in the surrounding populations, and employing asymmetric tactics to achieve their objectives. In future conflicts, we must be prepared for these tactics as well as a range of other novel methods, including so-called "hybrid" and anti-access approaches to blunting U.S. power projection. Unmanned systems will be critical to U.S. operations in all domains across a range of conflicts, both because of capability and performance advantages, and the ability for unmanned systems to take greater risk.

As unmanned systems have proven their worth on the battlefield, DoD has allocated an increasing percentage of its budget to developing and acquiring these systems. Table 1 below reflects the budget request allocated to the three unmanned domains: air, ground, and maritime.

Table 1. 2011 President's Budget for Unmanned Systems ($ Mil)

Unmanned Funding ($ Mil)							
Fiscal Year Defense Prog		FY11	FY12	FY13	FY14	FY15	Total
Air	RDTE	1,106.72	1,255.29	1,539.58	1,440.57	1,296.25	6,638.40
	PROC	3,351.90	2,936.93	3,040.41	3,362.95	3,389.03	16,081.21
	OM	1,596.74	1,631.38	1,469.49	1,577.65	1,825.45	8,100.71
Domain Total		6,055.36	5,823.59	6,049.48	6,381.17	6,510.72	30,820.32
Fiscal Year Defense Prog		FY11	FY12	FY13	FY14	FY15	Total
Ground	RDTE	297.70	271.79	304.78	158.68	157.98	1,190.93
	PROC	20.10	843.24	481.77	426.65	834.17	2,605.93
	OM	207.06	233.58	237.50	241.50	245.96	1,165.60
Domain Total		524.86	1,348.61	1,024.05	826.83	1,238.11	4,962.46
Fiscal Year Defense Prog		FY11	FY12	FY13	FY14	FY15	Total
Sea	RDTE	29.69	62.92	65.72	48.60	47.26	254.19
	PROC	11.93	45.45	84.85	108.35	114.33	364.90
	OM	5.79	4.71	3.76	4.00	4.03	22.28
Domain Total		47.41	113.08	154.32	160.94	165.62	641.37
Fiscal Year Defense Prog		FY11	FY12	FY13	FY14	FY15	Total
All Unmanned	RDTE	1,434.11	1,590.00	1,910.07	1,647.84	1,501.50	8,083.52
	PROC	3,383.93	3,825.62	3,607.02	3,897.95	4,337.53	19,052.04
	OM	1,809.59	1,869.67	1,710.75	1,823.15	2,075.44	9,288.59
Domain Total		6,627.63	7,285.28	7,227.85	7,368.94	7,914.46	36,424.15

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Although unmanned systems have experienced widespread growth in funding, current world economic conditions and DoD initiatives necessitate increased efforts and focus toward the acquisition of affordable and convergent systems. DoD must continue to support diverse mission sets and capabilities, but must focus on acquiring Joint and interoperable platforms, systems, software, architecture, payloads and sensors due to today's increasingly austere fiscal environment. In addition, the ability for commanders to take risks with unmanned vehicles depends significantly on their cost. In order to be expendable, which is often the intent of building an unmanned system, the vehicle must be low-cost. The importance of procuring common platforms with core C2 systems cannot be overstated as it will yield enormous collective benefits by reducing training costs, reducing supply chain diversity, improving availability, and offering a cost-effective procurement path by exploiting the benefits of scale and software/technology reuse.

> Eliminate redundancy within warfighter portfolios.
>
> *–Under Secretary of Defense Memorandum for Acquisition Professionals, Better Buying Power, September 2010*

The cost overruns, schedule slips, and sustainability issues of unmanned systems cannot go unnoticed or unanswered. Operational T&E is not sufficient for addressing budget, schedule, and sustainment issues in unmanned systems acquisition. WSARA 2009 guidance set the stage for leveraging developmental T&E as a key factor in T&E strategy to address Milestone A and B test challenges. Unmanned system T&E must not only consider physics effects but other areas that have an effect on algorithm development such as human factors, autonomous functionality, peering, collaboration, and autonomy-driven, red-team-based T&E limit testing. The goal to gradually reduce the degree of human control and decision making required for the unmanned portion of the force structure will mean that autonomous functionality will gradually increase and new ways to test this functionality will be required.

The need to maintain simplicity and overcome bureaucracy in unmanned system acquisition is an ongoing challenge. As these programs transition to acquisition programs, there is a unique opportunity to enable productive process and oversight appropriate to producing safe, suitable, survivable, and effective systems in a rapid acquisition framework.

There is a need to leverage OA and open interfaces to overcome the problems associated with proprietary robotic system architectures. Standards and interface specifications need to be established to achieve modularity, commonality, and interchangeability across payloads, control systems, video/audio interfaces, data, and communication links. Standardization will enhance competition, lower life-cycle costs, and provide warfighters with enhanced unmanned capabilities that enable commonality and joint interoperability on the battlefield.

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Addressing factors inhibiting the growth of unmanned systems will provide more interoperability, more autonomy, better artificial intelligence, better communications, human systems integration, training standardization, more propulsion and power options, and better MUM teaming. These factors are addressed through the Joint Capability Integration and Development System (JCIDS) process.

3.1 Requirements Development and Systems Acquisition

There has been substantial growth in unmanned platforms of all sizes and shapes with a corresponding increase in payload numbers and capability. Many of these systems have been rapidly acquired and immediately fielded for warfighter use through the Joint Urgent Operational Needs (JUON) process. JUONs have successfully added significant capability to joint warfighting. While those unmanned systems were rapidly developed to meet the immediate needs of the warfighter in the short term, they have not undergone rigorous requirements review and joint coordination through the normal JCIDS process, to include systems interdependencies and interoperability. Further, their long term affordability, sustainability, and potential to contribute to long term enterprise-wide capability portfolios have not been fully considered. Consequently, they have not received due consideration in the context of broader joint capability areas (JCA) which provide structure and organization to Requirements Development.

DoD is moving toward revision of the JCIDS process which will streamline urgent and deliberate Capability Development to enable requisite timeliness in meeting warfighter needs, while giving important consideration to long term affordability and sustainability. JCIDS is a key supporting process for DoD acquisition and Planning, Programming, Budgeting, and Execution (PPBE) processes. It ensures the capabilities required by the warfighter are identified with their associated operational performance criteria in order to successfully execute the missions assigned. This process allows better understanding of the warfighting needs early in capability development and provides a more comprehensive set of valid prioritized requirements. The Department's acquisition arm can then focus on choosing options to meet well defined requirement capability.

Given today's highly constrained fiscal environment, it is imperative that the Department look at many areas where efficiencies can be gained to create unmanned systems that are both effective and affordable. The DoD will look at capitalizing upon commonality, standardization, and joint acquisition strategies among others. Also, the Department demands these unmanned systems be affordable at the outset and not experience significant cost growth in their development and production evolution. Additionally, it must provide the PPBE process with affordability advice by assessing the development and production lifecycle cost at the outset.

Capability requirements, validated by the JCIDS process, inform prioritization activities in the competition for funding during the PPBE process. The objective of the PPBE process is to provide the best mix of forces, equipment, and support attainable within fiscal constraints according to DoD Directive 7045.14, *Planning, Programming, Budgeting System (PPBS)*. To meet this objective, the PPBE process aims to meet goals established by the President and the Secretary of Defense (SECDEF) in the Strategic Planning and Joint Planning Guidance. In the PPBE process, the Services match available resources (fiscal, manpower, material) against validated requirements to achieve the strategic plan. A key task is to develop a

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balanced/affordable capabilities-based Service program objective memorandum (POM). The POM position for the capability to meet a given requirement is reviewed by OSD and the final position becomes the President's Budget.

The Joint Capability Areas (JCAs)[2] are currently the preferred method the Department of Defense uses for reviewing and managing capabilities. The JCA framework provides the structure around which capabilities and capability gaps can be aligned across the Department and across the various portfolios to correlate similar needs, leverage effective solutions, and synchronize related activities. Also, various frameworks, such as the Universal Joint Task List (UJTL), are readily available to aid in identifying and organizing the tasks, conditions and required capabilities.

3.2 Unmanned Systems Applied to Joint Capability Areas

Mapping current and projected unmanned systems against the JCAs provides a sense of the Product Line Portfolio of unmanned systems and how it currently, and could in the future, contribute to the missions of the Department. Each JCA represents a collection of related missions and tasks that are typically conducted to bring about the desired effects associated with that capability. Nine Tier One JCAs are defined, and assessments identified that unmanned systems have the potential to be key contributors for Battlespace Awareness, Force Application, Protection, Logistics, and Building Partnerships. Although assessments have not yet been completed for the Force Support and Net Centric capability areas, missions and tasks in those JCAs receive significant support from unmanned systems as well.

Current technology and future advancements can and will enable single platforms to perform a variety of missions across multiple capability areas. This represents an opportunity for the Department to achieve a greater return on investment. Furthermore, the projections show that there will be opportunities for joint systems to conduct missions for each of the Services, just as there will be situations in which domain conditions or Service missions will dictate unique solutions. Detailed descriptions of each of the systems identified for the capability areas, including specific tasks, performance attributes and integrated technologies can be found at the Unmanned Warfare Information Repository site: **https://extranet.acq.osd.mil/uwir/**. Below are the descriptions for the most relevant JCA.

3.2.1 Battlespace Awareness (BA)

Battlespace Awareness is a capability area in which unmanned systems in all domains have the ability to significantly contribute well into the future to conduct ISR and environment collection related tasks. To achieve this, unmanned systems development and fielding must include the Tasking, Production, Exploitation, and Dissemination (TPED) processes required to translate vast quantities of sensor data into a shared understanding of the environment. There are many ongoing efforts to streamline TPED processing. Applications in this JCA range from tasks such as aerial and urban reconnaissance, which is performed today by Predators, Reapers and Global Hawks in the air and by PackBots and Talons on the ground, to tasks such as Expeditionary Runway Evaluation, Nuclear Forensics, and Special Reconnaissance. In the future, technology will enable

[2] http://www.dtic.mil/futurejointwarfare

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mission endurance to extend from hours to days to weeks so that unmanned systems can conduct long endurance persistent reconnaissance and surveillance in all domains. Because unmanned systems will progress further with respect to full autonomy, on-board sensors that provide the systems with their own organic perception will contribute to Battle Space Awareness regardless of their intended primary mission. This capability area is one that lends itself to tasks and missions being conducted collaboratively across domains, as well as teaming within a single domain.

3.2.2 Force Application (FA)

Force Application is another JCA which includes a proliferation of unmanned systems contributing to maneuver and engagement. Today, Predator, Reaper and Gray Eagle UAS are weaponized to conduct offensive operations, irregular warfare, and high value target / high value individual prosecution, and this trend will likely continue in all domains. In the air domain, projected mission areas for UAS include air-to-air combat and suppression and defeat of enemy air defense. On the ground, UGVs are projected to conduct missions such as non-lethal crowd control, dismounted offensive operations, and armed reconnaissance and assault operations. In the maritime domain, UUVs and USVs are projected to be particularly suited for mine laying and mine neutralization missions.

DoD personnel must comply with the law of war, including when using autonomous or unmanned weapon systems. For example, Paragraph 4.1 of DoD Directive 2311.01E, DoD Law of War Program, May 9, 2006, requires that: "[m]embers of the DoD Components comply with the law of war during all armed conflicts, however such conflicts are characterized, and in all other military operations." Current armed unmanned systems deploy lethal force only in a fully human-operated context (level 1) for engagement decisions. For these systems, the decisions both to employ force and to choose which specific target to engage are made by a human. The United States operates defensive systems for manned ships and installations that have human-supervised autonomous modes (level 3), and has operated these systems for decades. For the foreseeable future, decisions over the use of force and the choice of which individual targets to engage with lethal force will be retained under human control in unmanned systems.

3.2.3 Protection

Protection has particular unmanned systems applicability to assist in attack prevention or effects mitigation. Unmanned systems are ideally suited for many protection tasks that are deemed dull, dangerous or dirty. As the future enables greater automation with respect to both navigation and manipulation, unmanned systems will be able to perform tasks such as fire fighting, decontamination, forward operating base security, installation security, obstacle construction and breaching, vehicle and personnel search and inspection, mine clearance and neutralization, sophisticated explosive ordnance disposal, casualty extraction and evacuation, and maritime interdiction. In the Protection JCA teaming within domains and collaboration across domains will likely prevail.

3.2.4 Logistics

The Logistics joint capability area is also ideally suited for employing unmanned systems in all domains to deploy, distribute, and supply forces. Transportation of supplies is an applicable, routine task, particularly suited for unmanned systems in all types of ground terrain.

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Maintenance related tasks such as inspection, decontamination, and refueling can be performed by unmanned systems. Munitions and material handling, and combat engineering are ideal tasks that can be allocated to unmanned systems to enhance safety as well as increase efficiency. Additionally, casualty evacuation and care, human remains evacuation, and urban rescue can also be tasks performed by unmanned systems. Unmanned systems will perform Logistics tasks on home station as well as forward deployed.

Table 2. DoD Unmanned Capabilities by Program below is a sample mapping of JCA tasks to the current unmanned inventory and is provided for determining current unmanned systems capabilities.

Table 2. DoD Unmanned Capabilities by Program

AIRCRAFT					
System	Lead Service	Primary JCA	Mission Capabilities	ACAT	Acquisition Status
GROUP 1					
RQ-16B T_Hawk	US Navy	N/A	ISR/RSTA, EOD	Non-ACAT	Other
Wasp	US Air Force	BA	ISR/RSTA	Non-ACAT	Other
RQ-11B Raven	US Army	BA	ISR/RSTA	IV(T)	Production
Puma AE	USSOCOM	N/A	ISR/RSTA, FP	III	Production/Sustainment
GROUP 2					
Scan Eagle	US Navy , US Marines	N/A	ISR/RSTA, Force Protection	Non-ACAT	Other
GROUP 3					
RQ-7B Shadow	US Army, US Marines	BA	ISR/RSTA, C3, Force Protection	II	Production
S 100	USSOCOM	N/A	ISR/RSTA, EW, Force Protection	III	Design &Development
STUAS RQ-21A	US Navy , US Marines	BA	ISR/RSTA, EOD, Force Protection	III	Design &Development
Viking 400	USSOCOM	N/A	ISR/RSTA, EW, Force Protection	III	Design &Development
GROUP 4					
MQ-5B Hunter	US Army	N/A	ISR/RSTA, C3, Log, PS/TCS, FP	N/A	Other
MQ-1C Gray Eagle	US Army	BA	ISR/RSTA, C3, Log, PS/TCS, FP	I D	Production
MQ-1B Predator	US Air Force	BA	ISR/RSTA, PS/TCS, FP	I D	Sustainment
MQ-8B VTUAV	US Navy		ISR/RSTA, ASW, SUW/ASUW,	I C	MS-C
GROUP 5					
MQ-4 BAMS	US Navy		ISR/RSTA, EW, PS/TCS, SUW/ASUW, FP	I D	Design &Development
MQ-9A Reaper	US Air Force	FA	ISR/RSTA, EW, PS/TCS, FP	I D	Production
RQ-4A Global Hawk	US Air Force	BA	ISR/RSTA, C3, PS/TCS	I D	Sustainment
RQ-4B Global Hawk	US Air Force	BA	ISR/RSTA, C3, PS/TCS	I D	Production/Sustainment
MR UAS	US Navy	N/A	TBD	N/A	Concept
UCLASS	US Navy	N/A	TBD	N/A	Concept
MQ-X	US Air Force	FA	ISR/RSTA, PS/TCS, FP	N/A	Concept
Group 4	US Marines	N/A	TBD	N/A	Concept

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Table 2. DoD Unmanned Capabilities by Program (continued)

GROUND VEHICLES					
System	Lead Service	Primary JCA	Mission Capabilities	ACAT	Acquisition Status
WHEEL					
MARCbot IV N	US Army	N/A	ISR/RSTA, IED Inv.	Other	Other
Throwbot	US Army	N/A	ISR/RSTA	Other	Other
Mine Area Clearance Equipment (MACE)	US Air Force	N/A	Mine, EOD, FP	Other	Concept
Defender	US Air Force	N/A	FA, FP, Fire	Other	Concept
TRACK					
ISR UGV	US Navy	N/A	ISR/RSTA, Fire Support, EOD	Other	Other
xBot	US Army	N/A	ISR/RSTA, EOD, IED Inv.	Other	Other
PackBot FIDO	US Army	N/A	ISR/RSTA, EOD, IED Inv.	Other	Other
M 160	US Army	N/A	Mine Neutralization	III	Design &Development
RC50 60	US Army	N/A	EOD, Mine Neutralization	Other	Other
Mini EOD	US Army	N/A	EOD	Other	Other
ANDROS HD 1	US Army	N/A	EOD	Other	Other
PackBot EOD	US Army	N/A	EOD	Other	Other
TALON IIIB	US Army	N/A	EOD, route clearance	Other	Other
TALON IV	US Army	N/A	EOD, route clearance	Other	Other
Panther II	US Army	N/A	EOD, Mine Neutralization	Other	Other
MK 1 MOD 0 Robot EOD	US Navy	N/A	EOD	IV	Sustainment
MK 2 MOD 0 Robot EOD	US Navy	N/A	EOD	IV	Sustainment
MK 2 MOD 0 RONS	US Navy	N/A	EOD	IV	Sustainment
All-Purpose Remote Transport System (ARTS)	US Air Force	N/A	Mine, EOD, FP, Fire	Other	Other
F6A ANDROS	US Air Force	N/A	EOD	Other	Other
HD 1	US Air Force	N/A	EOD	Other	Other
IVAN	US Air Force	N/A	EOD, FP	Other	Concept

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Table 2. DoD Unmanned Capabilities by Program (continued).

MARITIME CRAFT					
System	Lead Service	Primary JCA	Mission Capabilities	ACAT	Acquisition Status
SURFACE					
Autonomous Unmanned Surface Vehicle (AUSV)	US Navy	N/A	ISR/RSTA	Other	Other
Mine Countermeasures (MCM) Unmanned Surface Vehicle USV	US Navy	BA	MIW/OMCM	Other	Concept
Anti-Submarine Warfare (ASW) Unmanned Surface Vehicle (USV)	US Navy	N/A	ASW	Other	Other
Sea Fox	US Navy	N/A	ISR/RSTA, FP	Other	Other
Remote Minehunting System (RMS), AN/WLD-1(V)1	US Navy	BA	MIW/OMCM	I D	Design &Development
Modular Unmanned Surface Craft Littoral	US Navy	N/A	ISR/RSTA	Other	Other
UNDERWATER					
Sea Stalker	US Navy	N/A	ISR/RSTA	Other	Other
Sea Maverick	US Navy	N/A	ISR/RSTA	Other	Other
Echo Ranger	Commercial	N/A	Insp/ID, Oceanogrpahic Survey	Other	Other
Marlin	Commercial	N/A	Insp/ID, Oceanogrpahic Survey	Other	Other
Surface Countermeasure Unmanned Undersea Vehicle	US Navy	BA	MIW/OMCM	III	Concept
MK18 Mod 2 Kingfish UUV System	US Navy	Protection	SUW/ASUW, MIW/OMCM, Insp/ID	PIP	Production
Surface Mine Countermeasure Unmanned Undersea Vehicle User Operational Evaluation System Increment 2	US Navy	N/A	MIW/OMCM	Other	Other
Surface Mine Countermeasure Unmanned Undersea Vehicle User Operational Evaluation System Increment 1	US Navy	N/A	MIW/OMCM	Other	Other
Battlespace Preparation Autonomous Underwater Vehicle (BPAUV)	US Navy	N/A	MIW/OMCM	Other	Other
HULS	US Navy	Protection	MIW/OMCM, EOD, Insp/ID	Abbr Acq	Production
MK18 Mod 1 Swordfish UUV System	US Navy	Protection	MIW/OMCM, EOD, Insp/ID	Abbr Acq	Sustainment
Large Displacement Unmanned Underwater Vehicle (LDUUV)	US Navy		ASW, ISR, MCM	Other	Concept
MK18 Mod 1 Swordfish UUV System	US Navy		MIW/OMCM, EOD, Insp/ID	Abbr Acq	Sustainment

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3.3 Unmanned Aircraft Systems (UAS)

The air domain has received the greatest concentration of visibility as DoD has embraced unmanned technologies. Table 1 depicts that UAS investments will continue to consume a large share of the overall DoD investment in unmanned systems. These efforts have fielded a large number of UAS capable of executing a wide range of missions. Originally, UAS missions focused primarily on tactical reconnaissance; however, this scope has been expanded to include most of the capabilities within the ISR and battlespace awareness mission areas. UAS are also playing a greater role in strike missions as the military departments field multiple strike mission-capable weapon systems for time-critical targeting. Figure 1 below illustrates the variety of platforms in today's force structure.

DoD Unmanned Aircraft Systems (As of 1 JULY 2011)

General Groupings	Depiction	Name	(Vehicles/GCS)	Capability/Mission	Command Level
Group 5 • > 1320 lbs • > FL180		•USAF/USN RQ-4A **Global Hawk/BAMS-D** Block 10 •USAF RQ-4B **Global Hawk** Block 20/30 •USAF RQ-4B **Global Hawk** Block 40	•9/3 •20/6 •5/2	•ISR/MDA (USN) •ISR •ISR/BMC	•JFACC/AOC-Theater •JFACC/AOC-Theater •JFACC/AOC-Theater
		•USAF MQ-9 **Reaper**	•73/85* *MQ-1/MQ-9 same GCS	•ISR/RSTA/EW/ STRIKE/FP	•JFACC/AOC- Support Corps, Div, Brig, SOF
Group 4 • > 1320 lbs • < FL180		•USAF MQ-1B **Predator**	•165/85*	•ISR/RSTA/STRIKE/FP	•JFACC/AOC-Support Corps, Div, Brig
		•USA MQ-1 **Warrior**/MQ-1C **Gray Eagle**	•31/11	•(MQ-1C Only-C3/LG)	•NA
		•USN **UCAS**- CVN Demo	•2/0	•Demonstration Only	•NA
		•USN MQ-8B **Fire Scout** VTUAV	•14/8	•ISR/RSTA/ASW/ ASUW/MIW/OMCM/ EOD/FP	•Fleet/Ship
		•SOCOM/DARPA/USA/USMC A160T **Hummingbird**	•8/3	•Demonstration Only	•NA
Group 3 • < 1320 lbs • < FL180 • < 250 knots		•USA MQ-5 **Hunter**	•45/21	•ISR/RSTA/BDA	•Corps, Div, Brig
		•USA/USMC/SOCOM RQ-7 **Shadow**	•368/265	•ISR/RSTA/BDA	•Brigade Combat Team
		•USN/USMC **STUAS**	•0/0	•Demonstration	•Small Unit
Group 2 • 21-55 lbs • < 3500 AGL • < 250 knots		•USN/SOCOM/USMC RQ-21A **ScanEagle**	•122/13	•ISR/RSTA/FORCE PROT	•Small Unit/Ship
Group 1 • 0-20 lbs • < 1200 AGL • < 100 knots		•USA / USN / USMC / SOCOM RQ-11 **Raven**	•5628/3752	•ISR/RSTA	•Small Unit
		•USMC/ SOCOM **Wasp**	•540/270	•ISR/RSTA	•Small Unit
		•SOCOM SUAS AECV **Puma**	•372/124	•ISR/RSTA	•Small Unit
		•USA **gMAV** / USN **T-Hawk**	•270/135	•ISR/RSTA/EOD	•Small Unit

Figure 1. DoD UAS

As the number of fielded systems has expanded, flight hours have dramatically increased as depicted in Figure 2.

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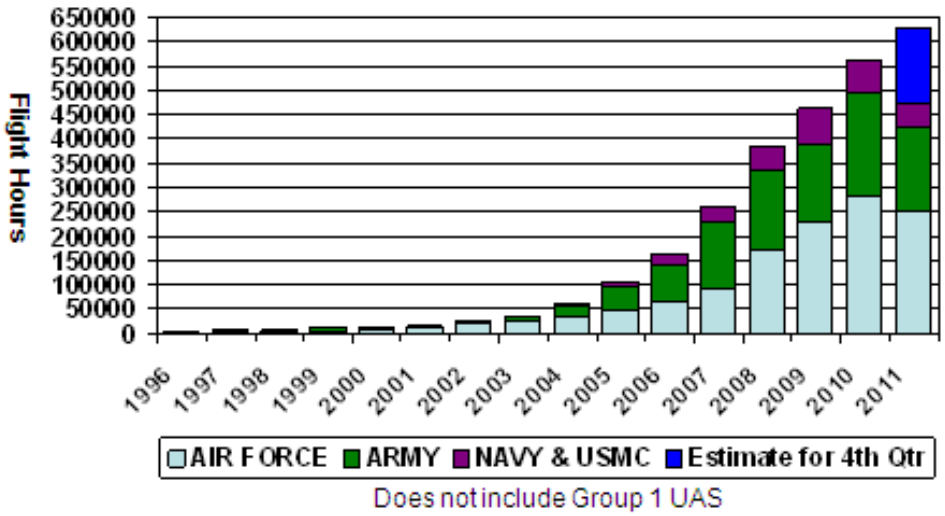


Figure 2. UAS Flight Hours (1996–Present)[3]

In 2009, DoD completed almost 500,000 UAS flight hours just in support of Operation Enduring Freedom and Operation Iraqi Freedom. In May 2010, unmanned systems surpassed one million flight hours and in November 2010 achieved one million combat hours. As these systems continue to demonstrate their value, this number will continue to grow.

> … remotely piloted vehicles have flown more than 21,000 sorties so far this year, already surpassing the roughly 19,000 drone flights last year.
>
> – *"U.S. Uses Attacks to Nudge Taliban Toward a Deal," New York Times, October 15, 2010.*

3.4 Unmanned Ground Systems (UGS)

Since operations in Iraq and Afghanistan began, DoD has acquired and deployed thousands of UGS. These systems support a diverse range of operations including maneuver, maneuver support, and sustainment. Maneuver operations include closing with and neutralizing the enemy using speed and firepower. Maneuver support missions include mitigating natural and artificial obstacles and hazards. Sustainment missions leverage maintenance and support UGVs associated with combat services support.

Approximately 8,000 UGVs of various types have seen action in Operation Enduring Freedom and Operation Iraqi Freedom. As of September 2010, these deployed UGVs have been used in over 125,000 missions, including suspected object identification and route clearance, to locate and defuse improvised explosive devices (IEDs). During these counter-IED missions,

[3] Updated 30 June 2011.

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Army, Navy, and USMC explosive ordnance teams detected and defeated over 11,000 IEDs using UGVs, such as the one depicted in Figure 3.



Figure 3. Talon Ordnance Disposal Robot Preparing to Unearth Simulated IED

The lessons collected on the battlefield must be translated into programs that can be sustained. The rapid fielding and proliferation of unmanned systems and the subsequent battlefield modernization they provided have met the mission, but resulted in configuration and maintenance challenges. These ground systems continue to provide tremendous benefit to the ground commander, but improvements in user interfaces, reliability, survivability, and advances in 360° sensing, recording fidelity, and CBRN and explosive detection are required to meet the challenges anticipated in future conflicts. Figure 4 shows the UGS Family of Systems (FoS).

> On Gordon's (UGV) final days, he was launched out of the truck and was searching an intersection for a possible deep buried IED. As he was on his way to the intersection, the IED was detonated about 10 ft from his location. Still functioning, he continued to search the area. On the opposite side of the road, another IED was detonated and had turned him upside down. Everything was still working until a fire fight started.
>
> Gordon took 7 rounds to the underside and was done for the day. I took him to the robot shop for repair. It took 3 days. When he was returned to us, I put him back in the truck to get him back on duty. But this was shortly lived as he was searching a gate at a house for possible booby-traps that detonated directly next to him. Gordon was mangled beyond repair. Now his replacement "Flash" is here to finish his job.
>
> -- Insight from an End User: *"Gordon" TALON Defeats IEDs and Saves Lives in Baghdad,* submitted by an EOD operator, summer 2007, Iraq.

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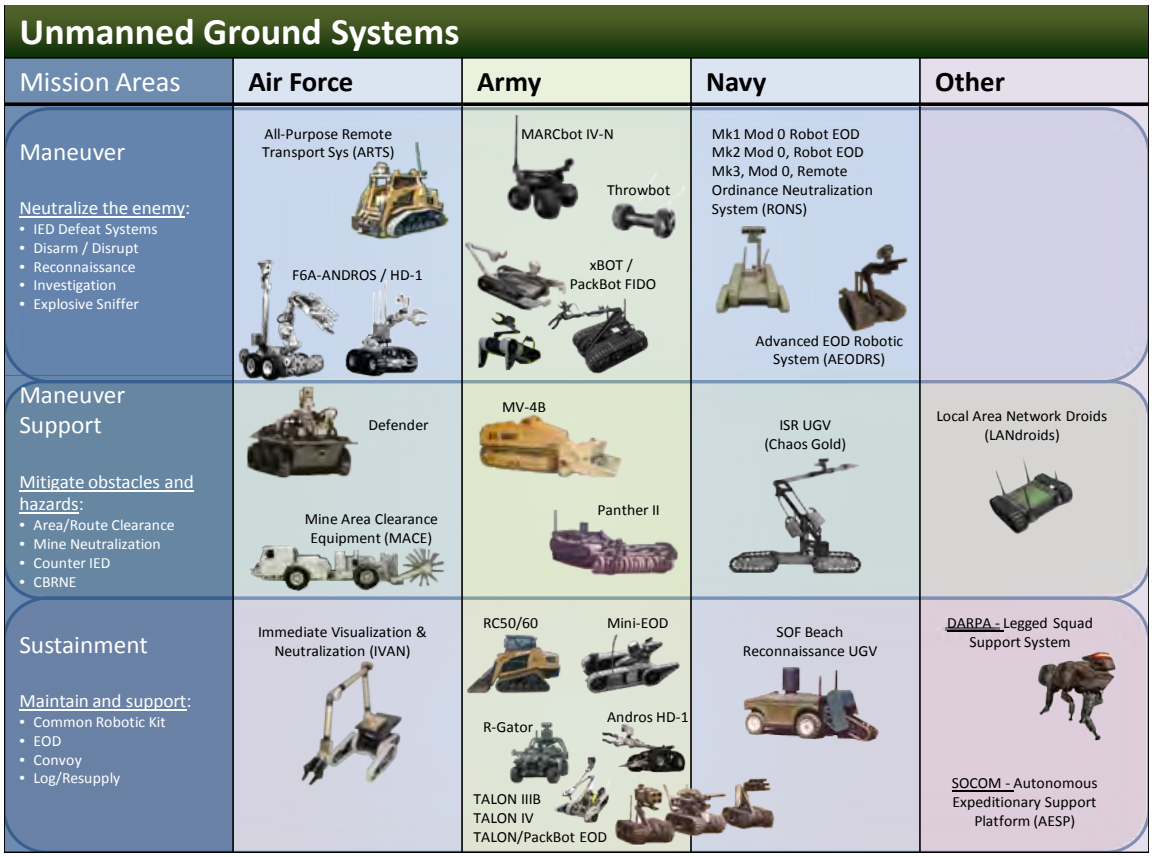


Figure 4. UGS FoS

3.5 Unmanned Maritime Systems (UMS)

Over 90% of the information, people, goods, and services that sustain and create opportunities for regional economic prosperity flow across the maritime domain. With emerging threats such as piracy, natural resource disputes, drug trafficking, and weapons proliferation, a rapid response capability is needed in all maritime regions. DoD continues to expand the range of missions supported by unmanned systems in the maritime domain. A recent study concluded

> USVs, along with UUVs, will have an important role in the conduct of MCM [mine countermeasures] as they are particularly well suited for the 'dirty - dull - dangerous' tasks that MCM entails. They provide persistence, which permits significant mine hunting and sweeping coverage at lower cost by multiplying the effectiveness of supporting or dedicated platforms. Additionally, they provide the potential for supporting an MCM capability on platforms not traditionally assigned a mine warfare mission.
>
> *– USV mission descriptions, The Navy Unmanned Surface Vehicle Master Plan, 23 July 2007*

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that unmanned maritime systems "have the potential to provide critical enabling capabilities for current NATO [North Atlantic Treaty Organization] maritime missions that can improve Alliance security and stability".[4]

Like UAS and UGS, UMS have the potential to save lives, reduce human risk, provide persistent surveillance, and reduce operating costs. UMS priority missions are listed below.

UMS can be defined as unmanned vehicles that displace water at rest and can be categorized into two subcategories: unmanned underwater vehicles (UUV) and unmanned surface vehicles (USV). USVs are UMS that operate with near-continuous contact with the surface of the water, including conventional hull crafts, hydrofoils, and semi-submersibles.[5] UUVs are made to operate without necessary contact with the surface (but may need to be near surface for communications purposes) and some can operate covertly.



The use of UMS is not new. After World War II, USVs were used to conduct minesweeping missions and test the radioactivity of water after each atomic bomb test. Another example occurred during the Vietnam War in an area south of Saigon, where remotely controlled USVs conducted minesweeping operations. More recently, UUVs conducted mine-clearing activities during Operation Iraqi Freedom in 2003. A complementary suite of UMS serve as the foundation for MCM operations from the Littoral Combat Ship (LCS) and small diameter UUVs are currently the main mine detection capability for ports & harbor and in the Very Shallow Water zone.

At a recent Science and Technology Conference hosted by the Office of Naval Research, Chief of Naval Operations (CNO) Admiral Gary Roughead made a number of statements expressing UMS goals for the Department of the Navy. Solving the power consumption problem would be the "one thing" CNO would most like to see the Navy's scientists accomplish.[6] Rear Admiral Nevin Carr, Chief of Naval Research, explained the current efforts in filling the needs in this unmanned maritime area and went on to describe where and how this technology might be applied in the future: "Two options are under exploration: fuel-cell technologies and radioscope thermoelectric generators that can provide low amounts of power for very long periods of time. We might start thinking about setting up drone refueling stations. You might deploy a remotely manned underwater generator that sits on the bottom in a secure area, which is a secure location where your forward-deployed vehicles might come back and recharge."

Figure 5 illustrates the variety of platforms and maritime missions supporting today's operations by UMS and those planned for operation in the near future. They have the potential

[4] The Combined Joint Operations from the Sea Centre of Excellence (CJOS/COE) Study (2009) for Maritime Unmanned Systems (MUS) in NATO, 8 December 2009.
[5] Consistent with Navy USV Master Plan, 2007.
[6] Ackerman, Spencer, Navy Chief Presses Nerds to Power Up Undersea Drones, Danger Room, Wired.com, 8 November 2010.

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for even greater integration, especially UUVs, to the point of assisting the current submarine and surface fleet in replacing fixed underwater sensor grids; using UUVs and distributed netted sensors to expand our submarine's sphere of influence; and weaponizing UUVs.

However, there are currently limitations to realizing the full potential of UMS:

- Endurance
- Underwater C2 and deconfliction
- Survivability in an unforgiving environment
- Launch and recovery
- Communication technology for dynamic tasking, querying, and data dissemination

These challenges are areas for further technical exploration. Despite these challenges, the future for UMS is very promising. Building on the experience and contribution from this first generation of fielded UMS, the shift is underway from UMS merely serving as an extension of the sensor systems of manned ships and submarines into an integrated FoS to provide full mission capabilities with increased autonomy.

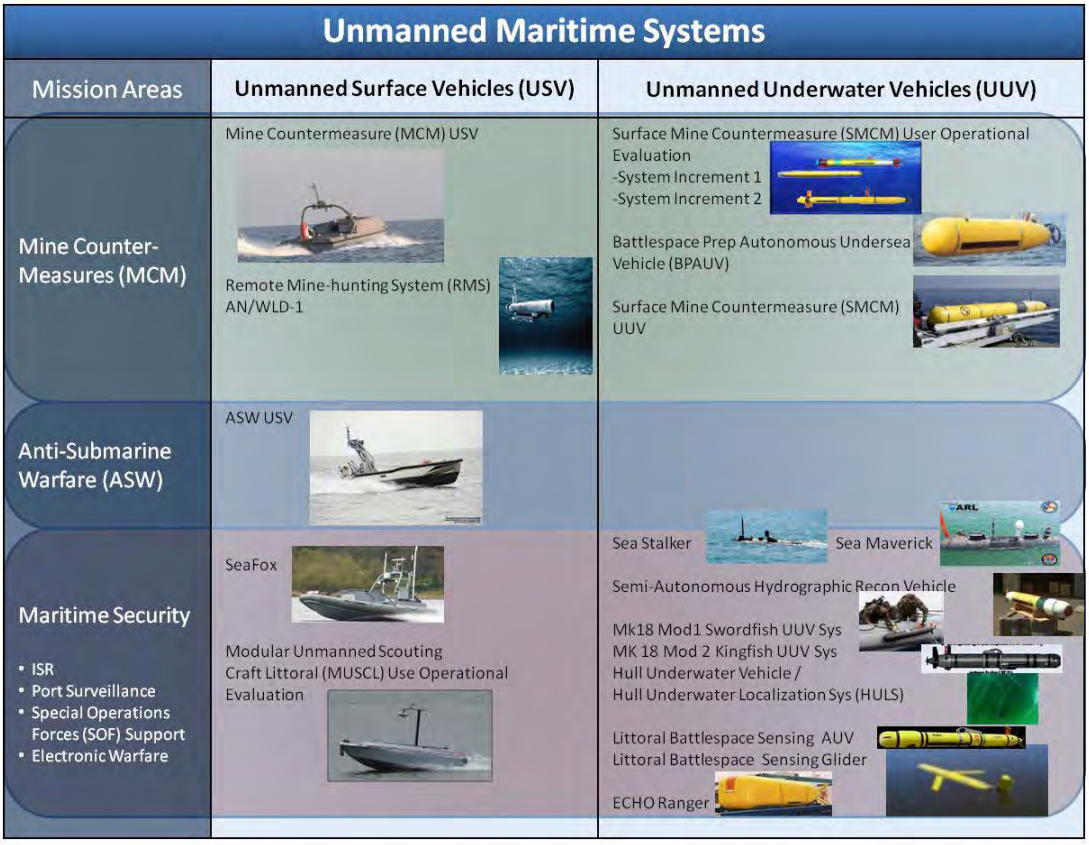
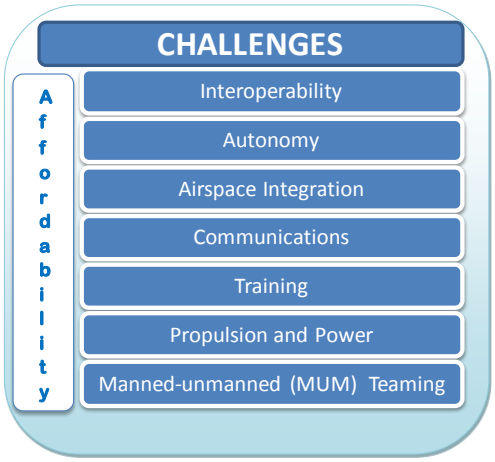


Figure 5. DoD UMS FoS

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3.6 Challenges for Unmanned Systems

The number of fielded systems and the range of missions supported by unmanned systems continue to grow at a dramatic rate. As DoD steers a path toward the vision described in Section 2, the challenges listed on the right must be overcome in order to realize the full potential offered by unmanned systems. The following subsections summarize these challenges and the remainder of this document provides details and future goals for dealing with each challenge.



3.6.1 Interoperability

To maximize the potential of unmanned systems, the systems must be capable of operating seamlessly with each other and with manned systems across the air, ground, and maritime domains. System interoperability is critical in achieving these objectives and requires the implementation of mandated standards and Interoperability Integrated Product Team (I-IPT) profiles. Properly implemented, interoperability can serve as a force multiplier, improve joint warfighting capabilities, decrease integration timelines, simplify logistics, and reduce total ownership costs (TOC). One of the most powerful tools in maximizing interoperability and achieving these objectives is the adoption of the open systems architecture concept.

3.6.2 Autonomy

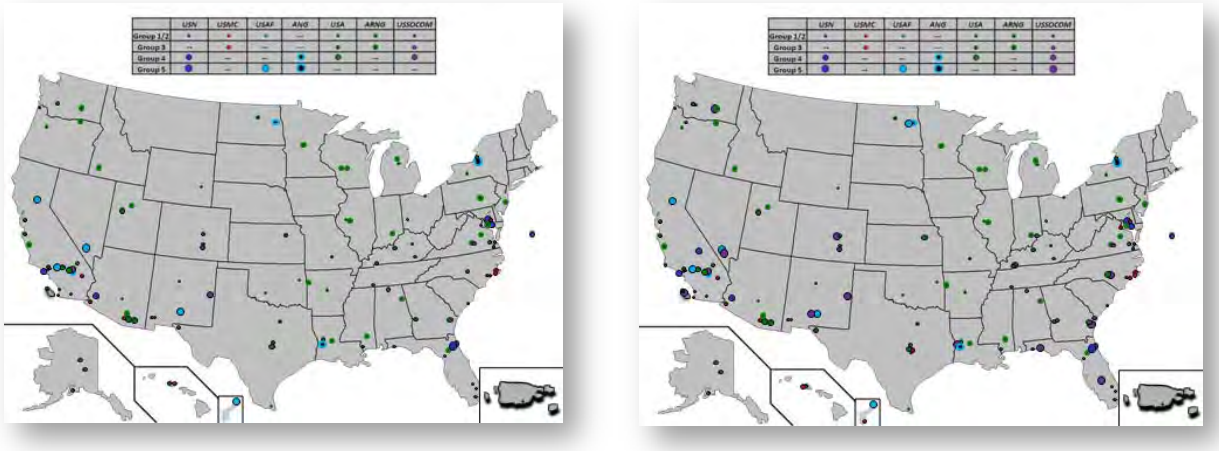
The rapid proliferation of unmanned systems and the simultaneous operation of manned and unmanned systems as unmanned systems expand into additional roles have created a manpower burden on the Services. With limited manpower resources to draw upon, the Services are seeking ways to improve the efficiency of operations. For instance, introducing a greater degree of system autonomy will better enable one operator to control more than one unmanned system, and has the potential to significantly reduce the manpower burden. Additional benefits are greatly reducing high bandwidth communication needs and decreasing decision cycle time. Similar efficiencies can be gained by automating the tasking, processing, exploitation, and distribution (TPED) of data collected by unmanned systems. Autonomy can help extend vehicle endurance by intelligently responding to the surrounding environmental conditions (e.g., exploit/avoid currents) and appropriately managing onboard sensors and processing (e.g., turn off sensors when not needed). Implementing a higher degree of autonomy faces the following challenges:

- Investment in science and technology (S&T) to enable more capable autonomous operations
- Development of policies and guidelines on what decisions can be safely and ethically delegated and under what conditions
- Development of new Verification and Validation (V&V) and T&E techniques to enable verifiable "trust" in autonomy

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3.6.3 Airspace Integration (AI)

The rapid increase in fielded UAS has created a strong demand for access within the NAS and international airspace. The demand for airspace to test new systems and train UAS operators has quickly exceeded the current airspace available for military operations. Figure 6 shows the projected number of DoD UAS locations in the next six years, many without access to airspace compatible for military operations under the current regulatory environment.



2011 **2017**

Figure 6. Representative DoD UAS Locations from 2011 to 2017.

NAS access for UAS is currently limited primarily due to regulatory compliance issues and interim policies. DoD UAS operations conducted outside of restricted, warning, and prohibited areas are authorized only under a (temporary) Certificate of Waiver or Authorization (COA) from the FAA. The COA process is adequate for enabling a small number of flights, but does not provide the level of airspace access necessary to accomplish the wide range of DoD UAS missions at current and projected operational tempos (OPTEMPOs). This constraint will only be exacerbated as combat operations in Southwest Asia wind down and systems are returned to U.S. locations.

3.6.4 Communications

Current unmanned systems operations involve a high degree of human interaction with the systems via various means for C2 and transmission of operational data. Protection of these communication links and the information flowing through them is critical to these operations. As the number of fielded systems grows, communications planners face challenges such as communication link security, radio frequency spectrum availability, deconfliction of frequencies and bandwidth, network infrastructure, and link ranges. Intelligent means of data parsing is needed to enable TPED and counter communication challenges.

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3.6.5 Training

The rapid proliferation of numbers and types of UAS in response to wartime demand coupled with an expected redeployment of forces back to a peacetime footing will result in continuation training greater than what has been required in the past. This has caused pause to examine UAS training and to develop an overall strategy. At present, due to high demand for UAS assets in real world contingencies, most day-to-day, continuation training is accomplished under in-theater combat conditions. At the same time, disparate efforts by a number of organizations across the Department are underway to try to address UAS training requirements. As UAS forces drawdown in theater and redeploy, the Services will require comprehensive continuation and Joint force training in the peacetime environment at UAS bed-down and selected Joint training locations.

3.6.6 Propulsion and Power

The dramatic increase in the development and deployment of unmanned systems across the entire spectrum of air, ground, and maritime missions has led to a concurrent increase in the demand for efficient, powerful, often portable, and logistically supportable solutions for unmanned system propulsion and power plant requirements. As these systems continue to demonstrate their value, operators want them to function longer without refueling and to do more tasks; these demands tax the internal power sources. The laboratories of the military Services and industry are focusing their efforts to find efficient solutions to the demand for improved propulsion and power plants. Regardless of energy source, total vehicle design, from materials used to autonomous response to the physical environment, needs to be considered up front to maximize endurance.

3.6.7 Manned-Unmanned (MUM) Teaming

MUM teaming refers to the relationship established between manned and unmanned systems executing a common mission as an integrated team. U.S. military forces have demonstrated early progress in integrating unmanned systems within the existing manned force structure, but much more needs to be done to achieve the full potential offered by unmanned technology. Improving MUM teaming is both a technology challenge (such as connecting the systems) and a policy challenge (such as establishing the rules of engagement for operating semi-autonomous unmanned with manned systems).

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4 INTEROPERABILITY

4.1 Overview

There is a clear benefit for warfighters to be able to seamlessly command, control, communicate with, exploit and share sensor information from unmanned systems across multiple domains. The Unmanned Systems Interoperability Initiative (UI2) led by the OSD UAS Task Force is in the process of developing an overarching strategy for increasing unmanned systems interoperability, with the long-range vision of producing a strategy that can be leveraged across the full spectrum of both unmanned and manned systems. DoD's goal is to move from Service/Agency-unique, stand-alone capabilities toward substantially improved interoperability standards that lead to an improved collaborative operational environment.

> Lack of UAV interoperability has had a real-life impact on U.S. operations … there have been cases where a Service's UAV, if it could have gotten data to another Service, another component, it may have provided better situational awareness on a specific threat in a specific area that might have resulted in different measures being taken.
>
> *– Dyke Weatherington (PSA/UW)*

4.2 Functional Description

Interoperability is the ability to operate in synergy in the execution of assigned tasks.[7] Properly implemented, it can serve as a force multiplier, improve warfighter capabilities, decrease integration timelines, simplify logistics, and reduce TOC. DoD Directive (DODD) 5000.1 establishes the requirement to acquire systems and FoSs that are interoperable.[8] DoD's unmanned systems will need to demonstrate interoperability in a number of areas:

- *Among similar components of the same or different systems.* The plug-and-play use of different sensors on an unmanned vehicle.
- *Among different systems of the same modality.* An open common ground control station (GCS) architecture for multiple, heterogeneous unmanned vehicles.
- *Among systems of different modalities.* The ability of air, ground, and maritime vehicles to work cooperatively.
- *Among systems operated by different Military Departments under various CONOPS and TTP, i.e., in joint operations.* Joint service systems working in concert to execute a common task or mission.

[7] Definition found in Joint Publication (JP) 1-02, Department of Defense Dictionary of Military and Associated Terms, 12 April 2001 (as amended through 17 March 2009).
[8] DODD 5000.1, Enclosure 1, paragraph E1.10.

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- *Among systems operated and employed by coalition and allied militaries under the governance of various concepts of employment (CONEMPs), TTPs, e.g., in multinational combined operations or NATO STANAGs.* The ability of coalition and allied systems to work in concert to execute a common task or mission based on predefined roles and responsibilities.
- *Among military systems and systems operated by other entities in a common environment.* The ability of military UAS to share the NAS and international airspace with commercial airliners and general aviation.
- *Among systems operated by non-DoD organizations, Allies, and coalition partners, i.e., in combined operations.* The ability of assets from organizations such as Customs and Border Protection (CBP) and Department of Homeland Security (DHS) to coordinate, interoperate, and exchange information with DoD assets of the same modality and same model.

> The interoperability goal for Unmanned Systems is an ability to provide data, information, material, and services to and accept the same from other systems, units, or forces … and to use the exchanged data, information, material, and services to enable them to operate effectively together.

The Joint Unmanned Aircraft Systems Center of Excellence (JUAS COE)[9] maintains the Joint CONOPS for UAS, which provides a joint vision for the operation, integration, and interoperability of UAS and touches on several of the areas mentioned above. Figure 7 illustrates joint, cross-domain interoperability.

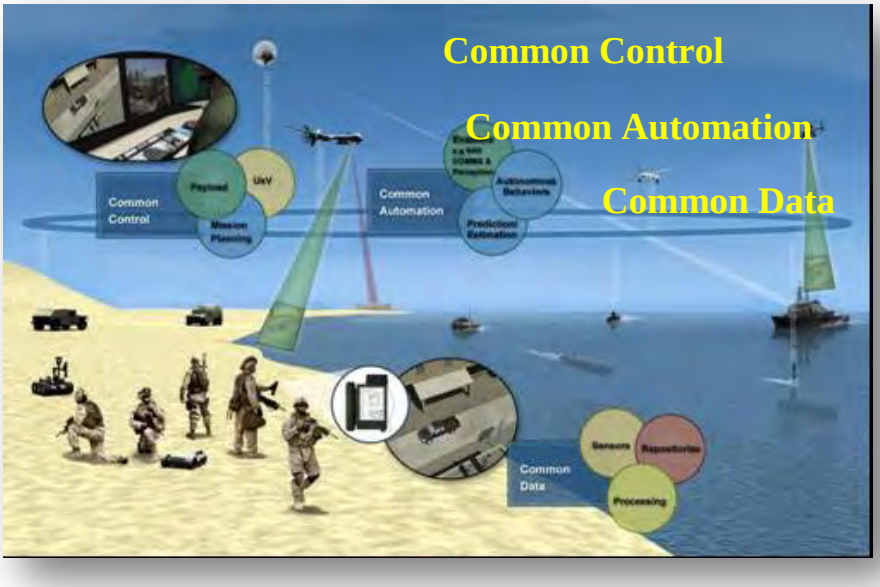


Figure 7. Joint Cross-Domain Interoperability.

[9] JCOE is being disbanded June 2011 and its tasks are being transferred to the Joint Staff.

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4.3 Today's State

The historical approach to software and hardware acquisition relied on dedicated design for each system to accomplish a specific mission or capability. This approach may be optimal for a single system, but it unfortunately produces a collection of discrete, disjointed solutions with significant functional overlap and no method to exploit common components of each system.

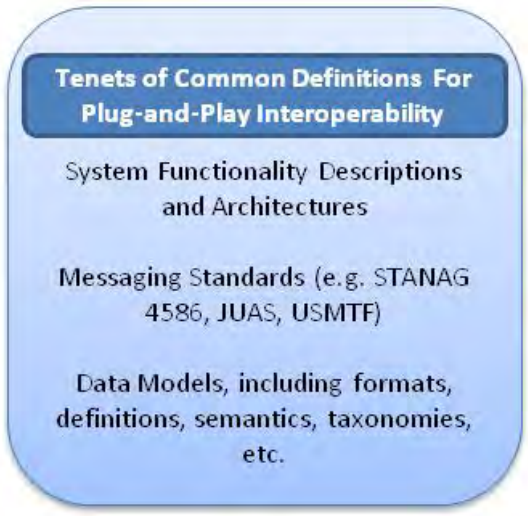
Open architecture (OA) facilitates interoperability between systems by effectively leveraging the following concepts:

- Common capability descriptions in system requirements
- Common, open data models, standards, interfaces, and architectures in system design
- Common components in system acquisition strategies

OSD defines OA as a multifaceted strategy providing a framework for developing joint interoperable systems that adapt and exploit open-system design principles and architectures. This framework includes a set of principles, processes, and best practices that:

- Provide more opportunities for competition and innovation
- Rapidly field affordable, interoperable systems
- Minimize total ownership cost
- Optimize total system performance
- Yield systems that are easily developed and upgradeable
- Achieve component software reuse[10]

These (predominantly) acquisition issues are aided by a solid framework for software, component, and systems interoperability.



Traditionally, efforts have focused on system functionality descriptions, with interoperability focused at the messaging layer (e.g., the Joint Architecture for Unmanned Systems (JAUS) and STANAG 4586) to achieve standards-based interoperability. However, the tenets of common definitions and understanding listed on the left are required to achieve a true plug-and-play level of interoperability in which software capabilities from multiple vendors can be developed and integrated into a single system, supporting the exchange, interpretation, and action on data from other systems.

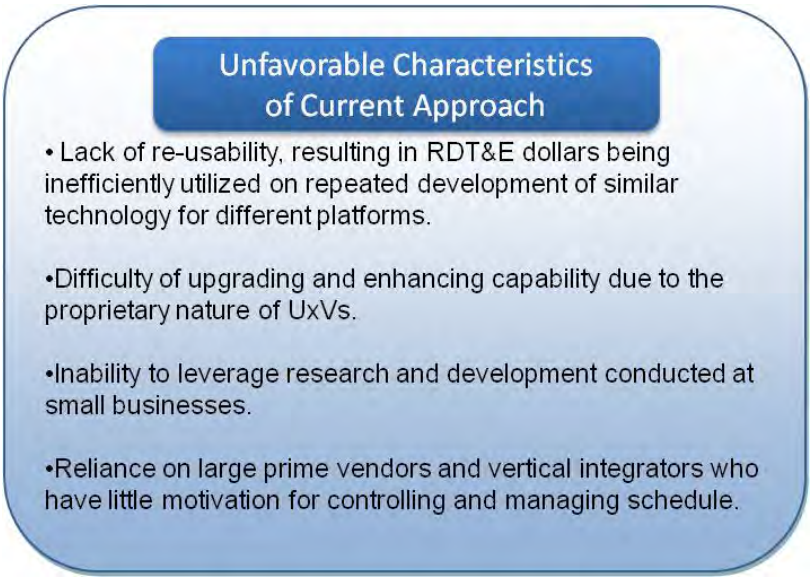
Through implementation and program-level

[10] Terms and Definitions, Defense Acquisition University, https://acc.dau.mil/CommunityBrowser.aspx?id=22108.

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adoption of these three tenets, DoD intends to address the issue of single proprietary vendor dependency within the acquisition system and improve conditions allowing for full competition.

4.4 Problem Statement



Over the last decade, the DoD has achieved great successes from the use of unmanned systems for both peacetime and wartime operations. These successes led to a significant increase in the number of unmanned systems planned and procured, and the future looks to see an exponential increase in the quantity and diversity of unmanned systems applications. Traditionally, each unmanned system was procured as a vertically integrated, vendor-proprietary solution, consisting of the vehicle system, control station, communications channels, and encryption technologies. These single-system variants were typically "closed" systems utilizing proprietary interfaces. Development of the entire system was conducted in parallel with close interdependencies between components and procured as a whole through the platform prime contractor. As the number of new unmanned systems programmed in the Service budgets increased, the magnitude of RDT&E requirements for development skyrocketed. In addition to cost, this approach resulted in a number of unfavorable acquisition and growth characteristics that impeded progress as depicted above. Further, silence about the lack of interoperability and standards failed to foster dialog on how to overcome them. Over time, this resulted in an inhibition to innovation; increased vulnerability to threats where attacks on common attributes can impact multiple systems; increased complexity to systems engineering, development, and test; increased upfront costs; increased costs to system upgrades that cannot be made without changes to the interoperable dependencies of multiple systems; and budgeting protocols that treat interservice and coalition interoperability as fiscal trade-space.

These issues have significantly hampered unmanned systems acquisition activities. However, urgent wartime needs dictated that such concerns be relegated to the background, in the interest of rapid initial deployment. As the unmanned systems industry matures, however, the acquisition process must evolve in parallel. Addressing and enabling interoperability within unmanned systems will help accomplish this goal.

4.5 The Way Ahead

The technical approach to achieve the interoperability vision leverages the tight connection between interoperability and OAs, and consists of several elements. Each of the following elements is required, and none is sufficient in its own right to implement an OA:

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- Development of a standard data model and service definitions that support OA concepts.
- Development of multiple repositories of models, software components, interface standards, and infrastructure services that can be used across the Services to extend, adapt, and compose unmanned systems and support software component reuse. These repositories should encourage the use of commercial, off-the-shelf (COTS) solutions where available, and are not intended to be "single point bottlenecks" as other efforts have been in the past. The goal is to provide multiple collection points across the Services for best practices, interfaces, and implementations.
- Collaboration among Government, industry, and academia to extend and manage the repositories and to validate components.
- Migration of current and developing systems to the OA approach.

To meet current interoperability standards, DoD will rely more heavily on spiral and incremental development initiatives ensuring services are compliant with these standards.

4.5.1 Open Architecture (OA)

OA utilizes a common set of interfaces and services; associated data models; robust, standard data busses; and methods for sharing information to facilitate development. OA involves the use of COTS components with published, standard interfaces, where feasible, at all levels of system design. This approach avoids proprietary, stove-piped solutions that are vendor-specific and enables innovation to be better captured and integrated into systems design. The OA approach allows for expanded market opportunities, simplified testing and integration, and enhanced reusability throughout the program life cycle. The Navy's Cruiser Modernization Program is one such effort.



The OA process encourages innovation, allows information sharing among competitors, and rewards Government and industry for this collaboration. It allows programs to include small businesses in systems acquisition activities as a valuable, affordable, and innovative source of technologies and capabilities. The result is a better product.

DoD unmanned systems consist of a wide range of programs, architectures, and acquisition approaches. To create a common framework for development and acquisition, DoD adopted principles of OA and service-oriented architecture (SOA). While the OA is the contracting, architecture, and business process methodology used to develop and acquire systems, a SOA is a specific way of designing software, in a standardized architecture, that uses interchangeable and interoperable software components called *services*. When coupled together, the result is a business approach to acquiring software developed within a common engineering construct that promotes reuse, cost reduction, competition, growth opportunity, expandability, innovation, and interoperability among similar systems.

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SOA provides a set of principles or governing concepts that are used during the phases of systems development and integration. This type of architecture attempts to package functionality as interoperable services within the context of the various business domains that use it. SOAs increase functionality by incorporating new services, which are developed separately but integrated within the system's common framework as a new capability. Their interfaces are independent of application behavior and business logic, and this independence makes the interfaces agile in supporting application changes and enables operations across heterogeneous software and hardware environments.

Programs and efforts to date have strongly tied together unmanned systems capability requirements and definitions, along with underlying technology selections. In recognition of the rapidly changing technology, unmanned systems architectures would benefit strongly from being defined at a platform-independent model (PIM) level, which is devoid of technology dependence.

The PIM level allows for definition of domains, software components, interfaces, interaction patterns, and data elements without flattening them to a specific set of computing, communications, and middleware technologies. Aside from enabling technology-independent design, this approach, as formalized in model-driven engineering principles, fosters interoperability.

At a minimum, a common set of interfaces and messaging standards is required for interoperability. Without a common semantic understanding of what data represent, there is significant opportunity for lack of interoperability, even if messages are correctly parsed and interfaces are followed. Therefore, a key final aspect is the recognition that data modeling is a separate, core aspect for defining interoperable systems. This aspect includes specifying definitions, taxonomies, and other semantic information to ensure there is a common understanding about what information a specific data item imparts.

This approach supports the involvement of multiple organizations in the development of one or more services, and results in increased innovation, flexibility, and improved performance. SOAs, however, constitute only one approach to implementation of OAs. Certain programs may not need SOAs. The program manager will determine the correct architecture to implement. Regardless of whether SOA approach is used, DoD has mandated an OA approach in software development. The program manager will be responsible for implementing an environment that will support OA in both programmatic and technical areas.

4.5.2 Service Repositories

DoD recognizes that there is rarely a one-size-fits-all solution to the challenging problem of software and service reuse. However, service repositories fill a growing need within DoD for commonality, reuse, and reduced duplication of effort, all of which aid interoperability by leveraging common interfaces. Programs will have access to the service repositories for their use in planning and implementation. In addition, programs will be encouraged to contribute services (within Government Data Rights constraints) to the repositories for future reuse. Where programs have requirements that cannot be met by software within the repositories, existing

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services may be extended to add functionality, and this approach should result in cost savings over the creation of brand new capabilities.

Constructing such repositories requires a commitment to OA, along with the adoption of existing and upcoming standards (e.g., SAE JAUS, STANAG 4586, UCS), so that a common framework exists with which to develop services. In addition, tools are necessary to ease adoption, reduce learning curves, and provide validation and certification capabilities. See Figure 8.

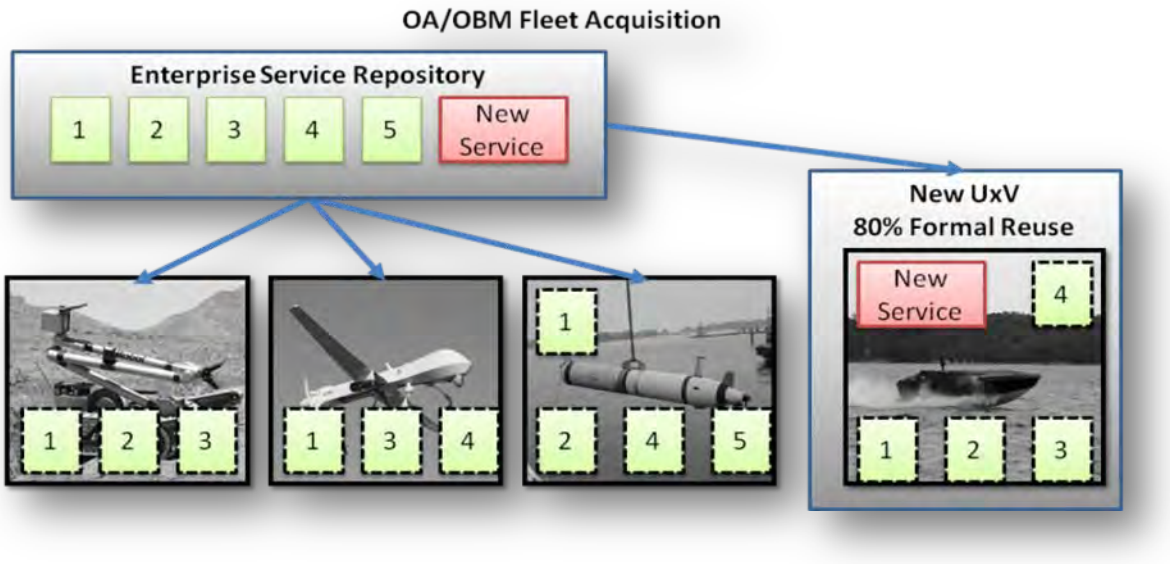


Figure 8. Cross-Domain Service Reuse Through an Enterprise Service Repository.

OA allows components to be developed once rather than redeveloped for each warfare area or mission. OA exploits software reuse and open interfaces to ensure unnecessary costs are not incurred in the redevelopment of core software. The OA approach described in this section utilizes collaboration among Government, industry, and academia to comply with principles of modularity, reusability, interoperability, affordability, and competition to develop reusable products.

Through implementation of the OA approach, DoD will develop and establish a domain service portfolio management (DSPM) repository for new acquisition and in-service programs. This repository will contain program-related software services information including standard architectures, design guidelines, service interfaces, and specifications for designing new systems or modifying existing systems. Programs will be required to consult with the DSPM repository for software reuse, where applicable. As programs design new and unique software and services, they are required to populate the DSPM repository with new information and make the service available for reuse, within Government Data Rights constraints.

4.5.3 Collaborating Communities

DoD has long recognized the value in fostering collaboration between Government, industry, and academia in open forums to address interoperability and common standards. To that end, a

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number of integrated product teams, working groups, and other communities have formed, under the auspices and support of OUSD(AT&L), to address the interoperability challenge. These forums have enabled the Government to engage with industry at all levels, from grassroots to executive, and have enabled DoD personnel to aid in the systems and architecture design process, rather than simply being customers. These collaborating communities exist within a variety of national and international standards bodies, span the domains of unmanned systems (i.e., UAS, UGS, UMS), and address key cross-domain areas as well as domain-unique capabilities. DoD intends to continue to support this type of collaboration as it fosters the development of OAs. Current examples of these communities include the following:

- The OUSD(AT&L)-chartered UAS Task Force to coordinate critical DoD UAS issues and develop a path to enhance operations, enable interdependencies, facilitate interoperability, and streamline UAS acquisition. Within the UAS Task Force, the I-IPT has been chartered to promote UAS interoperability across the Services. The I-IPT establishes a central coordination forum for the Services' acquisition organizations and participating industry partners to share ideas that will allow the Department to build interoperability within the deployed UAS infrastructure, individual systems, and interfaces with appropriate manned weapons systems and C2 capabilities.
- Under the guidance of the Defense Science and Technology Advisory Group, the Autonomy Systems Community of Interest (CoI) closely examine the DoD's S&T investments in the enabling of autonomous systems. Specifically, this CoI identifies potential investments to advance and initiate critical enabling technology developments and strategically assesses the challenges, gaps, and opportunities to develop and advance autonomous systems.
- The National Geospatial-Intelligence Agency (NGA) is a member of the U.S. Intelligence Community and a Department of Defense (DoD) Combat Support Agency. NGA provides support to civilian and military leaders and contributes to the state of readiness of U.S. military forces by providing geospatial intelligence (GEOINT) imagery, imagery intelligence and geospatial data (e.g., mapping, charting and geodesy), and information to ensure the knowledge foundation for planning, decision and action. NGA also contributes to humanitarian efforts, such as tracking floods and disaster support, and to peacekeeping. NGA provides unmanned systems, topographical and terrestrial data, geodesy and geophysical data, imagery and precise position and target data for unmanned system mission planning and UAS flight operations. GEOINT support includes aeronautical and safety of navigation data, vertical obstruction, digital terrain elevation data and hydrographic data.
- NATO's Joint Capability Group on Unmanned Aerial Vehicles (JCGUAV) directs interoperability efforts in unmanned aviation. JCGUAV subsumed NATO's three Military Department UAS-related groups (PG-35, Air Group 7, and Task Group 2) in 2006. Its major accomplishments to date include STANAG 4586 for UAS message formats and data protocols, STANAG 4671 for UAV Airworthiness Standard, and STANAG 7085 for the CDL communication system, which has been mandated by OSD since 1991.
- NATO's Joint Capability Group Intelligence Surveillance and Reconnaissance (JCGISR) provides interoperability between NATO and Coalition ISR systems and includes

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standards related to imagery formats and interfaces, data storage interfaces, motion imagery, electronic intelligence reporting, and imaging systems data links.

- Current UAS System Interoperability Profiles (USIPs), produced by the I-IPT, define the standard interface for payload products and the data link between a control station and air vehicle for line of sight (LOS) and beyond line of sight (BLOS) scenarios. Future USIPs will address other aspects of interoperability to include data encryption, additional data link technologies such as bandwidth efficient common data link (BE-CDL), and enhanced capabilities provided by future sensors.
- The Joint Architecture for Unmanned Systems (JAUS) began in 1995 as an effort by the Army's program office for UGVs in the Aviation and Missile Research, Development and Engineering Center (AMRDEC) at Redstone Arsenal to establish a common set of message formats and data protocols for UGVs. Deciding to convert JAUS to an international industry standard, the program office approached the Society of Automotives Engineers (SAE), a standards development organization (SDO) with robotics experience, which established the AS-4 Unmanned Systems Committee in August 2004. AS-4 has three subcommittees focused on requirements, capabilities, and interfaces and an experimental task group to test its recommended formats and protocols before formally implementing them. The migration to the SAE is complete, and the first set of SAE JAUS standards, focusing on the JAUS Service Interface Definition Language (JSIDL), core services, mobility services, manipulation services, and environmental sensing services, has been balloted and released. Although AS-4 is open to its members creating standards on other aspects of unmanned systems beyond message formats and data protocols for UGVs, much of this broader work is now being undertaken by other UAS-related SDOs. STANAG 4586 is unmanned aviation's counterpart to JAUS.
- The Navy's Program Executive Officer of Littoral and Mine Warfare (PEO(LMW)) formally adopted JAUS message formats and data protocols for use with its UUVs, USVs, and UGVs in 2005. Working through SAE AS-4, the Naval Undersea Warfare Center (NUWC) expanded JAUS to serve the UMS community. It found only 21% of UMS message formats to be directly compatible with the formats of JAUS, with the high percentage of new formats needed possibly due to the operation of UMS in three dimensions versus the two dimensions of UGVs, for which JAUS was developed. UUV variants of JAUS services are in active development and have been presented to the SAE AS-4 committees.
- Under direction from the OUSD(AT&L),[11] the UAS Task Force chartered the UAS Control Segment (UCS) Working Group, which is tasked to develop and demonstrate a common, open, and scalable UAS architecture supporting UAS Groups 2 to 5 (see Fig 1. DoD UAS for Groupings). The UCS Working Group comprises Government and industry representatives and operates using a technical society model where all participants are encouraged to contribute in any area of interest. This effort incorporates the best practices of current Army, Air Force, and Navy development efforts to include, but not limited to, the following:

[11] OUSD(AT&L) Acquisition Decision Memorandum, 11 February 2009.

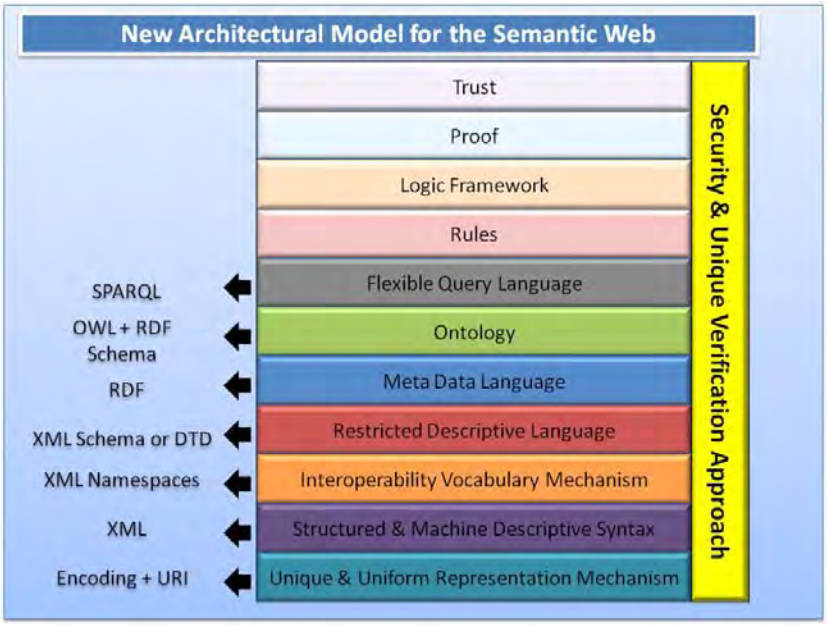
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- Definition of a common functional architecture, interface standards, and business rules
- Use of open-source and Government-owned software as appropriate
- Competitive acquisition options
- Refinement of message sets to support all operational requirements of the systems previously defined

In addition to the definition of common capability descriptions, standards, data models, and architectures, DoD continues to promote the development of OA tools and to aid system acquisition and development in embracing the OA concepts. These efforts extend across the technology and unmanned vehicle spectrum, from software development kits, to complete architectures, addressing UGVs, UMVs, and UAVs, across all Services. Examples of such tools include:

1. The JAUS Tool Set (JTS) is a tool to help developers build JAUS-compliant software components without having to be intimately familiar with the details of JAUS. JTS allows an unmanned system designer to focus on behavior rather than messaging, protocol, and other considerations by providing a graphical user interface (GUI) service editor, validator, internal repository, C++ code generation, and hypertext markup language (HTML) document generation.

   The Navy and OSD have supported and promoted the use of the JTS and have had success incorporating it into development and acquisition efforts. Use of JTS on programs accrues benefits to a number of stakeholders in the acquisition chain and RDT&E community. These benefits include enabling a fair basis for competition among vendors so that true capabilities are evaluated; reducing vendor lock-in on unmanned systems; and enabling the development of a service repository for JAUS capabilities that have been developed and are available for reuse. JTS reduces the threshold for entry into developing JAUS-compliant systems, opens the market to small businesses, and drives competition and innovation focused on core technology. In addition, JTS provides an accepted, common validation capability, which is critical to ensure systems maintain compliance with JAUS.



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2. The STANAG 4586 Compliance Toolkit (4586CT) is an integrated set of software tools that provides passive, interactive, and automated test capability. Its core function is to verify the structure and content of data link interface (DLI) messages against both STANAG 4586 and "private" messages as defined to support service-, mission-, or platform-specific requirements. This nonintrusive capability is provided either in real time or during post-run analysis. Additionally, 4586CT can be interoperable with other DLI-compatible systems in either manual mode (where an engineer monitors and injects DLI messages into the network) or automated mode (in which 4586CT interacts directly with other DLI systems according to user-defined scripts and procedures).

   These capabilities enable 4586CT to perform compliance testing at both the message level and the higher protocol session levels of unmanned systems relative to the STANAG 4586, and other more specific interoperability profiles. Complex DLI message dialogs can be monitored and system interaction sequencing verified as 4586CT follows user-defined test programs. Because 4586CT can function as a proxy for other unmanned system components, it is also used during system development and task-specific integration testing to provide insight into unmanned system interaction and performance. Multiple instances of 4586CT can also be utilized to perform rapid prototyping of interoperation protocols during profile design; as a result, 4586CT can be a useful tool during the development of interoperability standards themselves.

The T&E of interoperability continues to evolve with the growth of unmanned systems. The C2 of these systems presents unique test challenges as autonomous functionality expands to operating complex equipment over wireless links. The spectrum of test includes assessment of standards compliance, electromagnetic frequency testing, sensor standards, payload standards, systems interoperability, quantifiable task assessment, performance measurement, metrics development, congestion management, and performance baseline measures. The scope of operation includes operator, platform, communications grid, C2 teams, ground stations, sensor teams, and collaborating systems. While today's test represents a migration of the test challenge represented by proprietary data exchange and data formats towards service-oriented architecture exchange, it is also conceivable that the cognitive nature of unmanned systems algorithm development may actually accelerate the need for semantic knowledge exchange T&E.

The rapid acquisition of quickly evolving unmanned systems will require an unmanned systems T&E capability that evolves at a pace that exceeds this evolution. The T&E of unmanned systems interoperability requires investment in information architectures, methodology, test scenario synthesis, model-based T&E, and cross-UAS usage case repositories.

4.5.4 System Migration

Services working with OUSD(AT&L) are exploring the business case for adopting an OA approach for current and in-development systems. While various challenges still remain in the adoption of OA, the goal in the next 12 months is to identify migration pathways for all current programs of record (see Figure 9).

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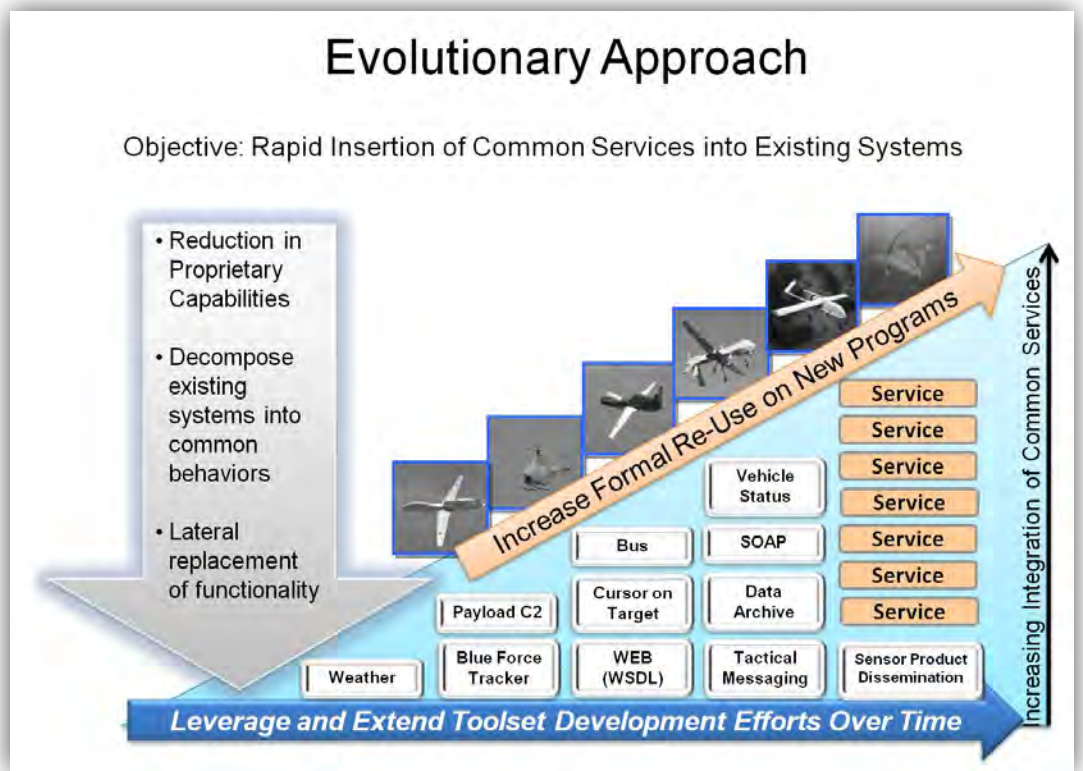


Figure 9. OA Migration Approach.

Quantifiable progress toward migration has already been achieved. The USAF Advanced Cockpit Block 50 (under development by General Atomics) has adopted UCS services and a common data bus. The July 2010 Block 50 implementation of takeoff, flight, payload C2, and landing utilized UCS-based software in a simulated flight environment demonstrated the architecture's utility. Additionally, Northrop Grumman has now agreed to tie its product lines into a common, open product line, with a joint mission-planning-mission-control system document signed by Northrop Grumman executives for synergy and collaboration between Broad Area Maritime Surveillance (BAMS) and Global Hawk unmanned systems. Advanced Explosive Ordnance Robotic System (AEODRS), utilizing an OA approach for hardware and software, is adopting SAE JAUS for messaging and is also developing interoperability profiles to ensure common system functionality descriptions, architectures, and data models. AEODRS is developing three classes of vehicles (dismounted operations, tactical operations, and base/infrastructure operations) with a common architecture and capability modules across the FoS. The AEODRS architecture defines the logical, mechanical, and electrical interfaces for the FoS. The AEODRS is entering Milestone B, and the development of increment 1 (dismounted operations) is now starting.

In addressing interoperability for ground systems, Robotic Systems Joint Project Office (RS-JPO) is utilizing SAE JAUS for messaging (with custom extensions as necessary) and primarily focusing on communications, payloads, power, architecture, and controller. Progress has already been made, with a modeling and simulation demonstration and an Input/Output (IO) Specification Build V1 planned for 2012.

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4.6 Summary

We can no longer afford to acquire independent, proprietary unmanned systems that do not leverage interoperability. The lines in the battlespace are blurring, and the need to share information, sensors, payloads, and platforms is real. The fiscal battlespace is also blurring, and vendors must shift strategies to adhere to standards, drive toward OAs, reuse software, and develop robust repositories. The goal is to provide more capable unmanned systems to the warfighter on time, and interoperability will ultimately play a large role in this effort by enabling the composition of novel systems capabilities on a faster timescale. Figure 10 depicts an interoperability path for the future as industry and DoD strive to become more efficient.

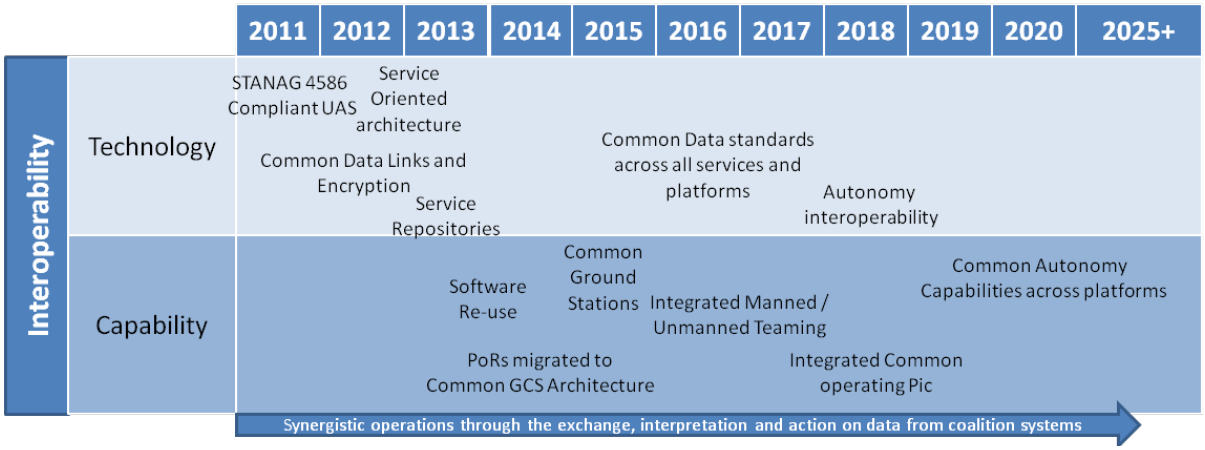


Figure 10. Interoperability Roadmap.

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5 AUTONOMY

Dramatic progress in supporting technologies suggests that unprecedented levels of autonomy can be introduced into current and future unmanned systems. This advancement could presage dramatic changes in military capability and force composition comparable to the introduction of "net-centricity." DoD must understand and prepare to take maximum practical advantage of advances in this area.[12]

5.1 Functional Description

Automatic systems are fully preprogrammed and act repeatedly and independently of external influence or control. An automatic system can be described as self-steering or self-regulating and is able to follow an externally given path while compensating for small deviations caused by external disturbances. However, the automatic system is not able to define the path according to some given goal or to choose the goal dictating its path.

By contrast, autonomous systems are self-directed toward a goal in that they do not require outside control, but rather are governed by laws and strategies that direct their behavior. Initially, these control algorithms are created and tested by teams of human operators and software developers. However, if machine learning is utilized, autonomous systems can develop modified strategies for themselves by which they select their behavior. An autonomous system is self-directed by choosing the behavior it follows to reach a human-directed goal. Various levels of autonomy in any system guide how much and how often humans need to interact or intervene with the autonomous system, and these levels will be discussed shortly. In addition, autonomous systems may even optimize behavior in a goal-directed manner in unforeseen situations (i.e., in a given situation, the autonomous system finds the optimal solution).

The special feature of an autonomous system is its ability to be goal-directed in unpredictable situations. This ability is a significant improvement in capability compared to the capabilities of automatic systems. An autonomous system is able to make a decision based on a set of rules and/or limitations. It is able to determine what information is important in making a decision. It is capable of a higher level of performance compared to the performance of a system operating in a predetermined manner.[13]

5.2 Today's State

In 2010, the USAF released the results of a year-long study highlighting the need for increased autonomy in modern weapon systems, especially given the rapid introduction of UAS. This study, "Technology Horizons," identified the need for greater system autonomy as the "*single greatest theme*" for future USAF S&T investments. The study cited the potential for increased autonomy to improve effectiveness through reduced decision cycle time while also enabling manpower efficiencies and cost reductions.

[12] USD AT&L *Memo to Chairman, Defense Science Board, Subj Terms of Reference*, 29 March 2010.
[13] NATO Industrial Advisory Group, Study Group 75, Annex C - Autonomous Operations, 2004.

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Autonomous capabilities have been enabled by advances in computer science (digital and analog), artificial intelligence, cognitive and behavioral sciences, machine training and learning, and communication technologies. In order to achieve operational acceptance and trust of these autonomous capabilities in the highly dynamic unmanned system environment, improvement is essential in advanced algorithms that provide robust decision-making capabilities (such as machine reasoning and intelligence); automated integration of highly disparate information; and the computational construct to handle data sets with imprecision, incompleteness, contradiction, and uncertainty.

In response to CCDR needs, the USAF has aggressively expanded UAS capabilities to a target of 65 combat air patrols (CAPs). According to the USAF, 1750 pilots from the Total Force (Active, Guard, and Reserve) are required to maintain these CAPs, which operate around the clock. This increasing manpower requirement is occurring at a time when constrained budgets are limiting growth in Service manpower authorizations. This challenge is not limited to the USAF, but is facing all the military Services. Today's unmanned systems require significant human interaction to operate. As these systems continue to demonstrate their military utility, exploit greater quantities of intelligence, and are fielded in greater numbers, the demand for manpower will continue to grow. The appropriate application of autonomy is a key element in reducing this burden.

> Our Program Managers should be scrutinizing every element of program cost, assessing whether each element can be reduced relative to the year before, challenging learning curves, dissecting overheads and indirect costs, and targeting cost reduction with profit incentive—in short, executing to what the program should cost.
>
> *–Under Secretary of Defense Memorandum for Acquisition Professionals, Better Buying Power, September 2010*

5.3 Problem Statement

The increased manpower to operate unmanned systems is adding stress to the overall workload of the armed forces. This stress highlights the need to transition to a more autonomous, modern system of warfare. The USAF Chief of Staff General Norton Schwartz emphasized the need for more automation in the following statement:[14]

> [The trend] cannot continue indefinitely. There is a place for automation here that reduces the manpower requirement, both to operate and to process the backend data stream.
>
> *– Gen Norton Schwartz, Air Force Chief of Staff*

[14] Fontaine, Scott, "Schwartz outlines possible future changes," *Air Force Times*, 30 August 2010.

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For unmanned systems to fully realize their potential, they must be able to achieve a highly autonomous state of behavior and be able to interact with their surroundings. This advancement will require an ability to understand and adapt to their environment, and an ability to collaborate with other autonomous systems, along with the development of new verification and validation (V&V) techniques to prove the new technology does what it should. Each of these topics is discussed in more detail below. Advances in autonomy at the system level must proceed with awareness of potential disadvantages and vigilance for unintended consequences, which may include diminished command over parts of the forces structure. Every operation includes rules of engagement, air tasking order (ATO)/special instructions (SPINS), and options of dynamic changes of command direction; and intent must not be traded off. The ability to respond to the unexpected cannot be diminished. For example, dealing with volcanic ash in the atmosphere cannot be reliably predicted at the beginning of an eruption. The ability to respond and avoid affected airspace is an example of a condition that may be difficult for autonomy to address. Implementing autonomy can lead to a loss of human attention to vital oversight in matters having potentially dangerous or lethal consequences. Caution must be used at the system-of-systems level, and constraints applied in some operations in order to allow autonomy in others. Finally, surrendering decision trust to a software-based and self-learning design outside the context of specific operations is a matter of high rigor, and must be examined in the context of organizational-unit and theater CONOPS.

5.4 Way Ahead

Significant advances have been made in autonomy, but many challenges still exist. For relatively static environments and undemanding missions and objectives, rule-based autonomous systems can be highly effective. However, most DoD environments and mission tasks dictate that unmanned systems operate in complex and uncertain environments as well as possess the ability to interact and collaborate with human operators and human teammates. Additionally, autonomous systems need the capability to interact and work together with other autonomous systems, to adapt to and learn from changes in the environment and missions, and to do so safely and reliably. One goal of automation is to leap forward in capabilities using human augmentation. Automated assistance of whatever kind does not simply enhance our ability to perform the task: it changes the nature of the task itself.[15]

5.4.1 Transcending to Higher Levels of Autonomy

Autonomy reduces the human workload required to operate systems, enables the optimization of the human role in the system, and allows human decision making to focus on points where it is most needed. These benefits can further result in manpower efficiencies and cost savings as well as greater speed in decision making. Autonomy can also enable operations beyond the reach of external control or where such control is extremely limited (such as in caves, under water, or in areas with enemy jamming or degraded communications). Advances in autonomy will further increase operational capability, manpower efficiencies, and cost savings.

[15] Norman, D. A., "How might people interact with agents?" *Software Agents*, J. M. Bradshaw, Ed. Cambridge, MA: The AAAI Press/The MIT Press, 1997, pp. 49–55.

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> … the ability to understand and control future costs from a program's inception is critical to achieving affordability requirements.
>
> *–Under Secretary of Defense Memorandum for Acquisition Professionals, Better Buying Power, September 2010*

While reduced reliance on human operators and analysts is the goal of autonomy, one of the major challenges is how to maintain and facilitate interactions with the operator and other human agents. An alternative statement of the goal of autonomy is to allow the human operator to "work the mission" rather than "work the system." In other words, autonomy must be developed to support natural modes of interaction with the operator. These decision-making systems must be cognitively compatible with humans in order to share information states and to allow the operator and the autonomous system to interact efficiently and effectively. The level of autonomy should dynamically adjust based on workload and the perceived intent of the operator. Common terms used for this concept are *sliding autonomy* or *flexible autonomy*. The goal is not about designing a better interface, but rather about designing the entire autonomous system to support the role of the warfighter and ensure trust in the autonomy algorithms and the system itself. Table 3 contains the most commonly referenced description of the levels of autonomy that takes into account the interaction between human control and the machine motions.

Table 3. Four Levels of Autonomy

Level	Name	Description
1	Human Operated	A human operator makes all decisions. The system has no autonomous control of its environment although it may have information-only responses to sensed data.
2	Human Delegated	The vehicle can perform many functions independently of human control when delegated to do so. This level encompasses automatic controls, engine controls, and other low-level automation that must be activated or deactivated by human input and must act in mutual exclusion of human operation.
3	Human Supervised	The system can perform a wide variety of activities when given top-level permissions or direction by a human. Both the human and the system can initiate behaviors based on sensed data, but the system can do so only if within the scope of its currently directed tasks.
4	Fully Autonomous	The system receives goals from humans and translates them into tasks to be performed without human interaction. A human could still enter the loop in an emergency or change the goals, although in practice there may be significant time delays before human intervention occurs.

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> The single greatest theme to emerge from "Technology Horizons" is the need, opportunity, and potential to dramatically advance technologies that can allow the Air Force to gain the capability increases, manpower efficiencies, and cost reductions available through far greater use of autonomous systems in essentially all aspects of Air Force operations. Increased use of autonomy — not only in the number of systems and processes to which autonomous control and reasoning can be applied but especially in the degree of autonomy that is reflected in these — can provide the Air Force with potentially enormous increases in its capabilities, and if implemented correctly can do so in ways that enable manpower efficiencies and cost reductions.
>
> *– USAF Report on Technology Horizons: A Vision for Air Force Science and Technology During 2010-2030, 15 May 2010*

5.4.2 Ability to Understand and Adapt to the Environment

To operate in complex and uncertain environments, the autonomous system must be able to sense and understand the environment. This capability implies that the autonomous system must be able to create a model of its surrounding world by conducting multisensor data fusion (MDF) and converting these data into meaningful information that supports a variety of decision-making processes. The perception system must be able to perceive and infer the state of the environment from limited information and be able to assess the intent of other agents in the environment. This understanding is needed to provide future autonomous systems with the flexibility and adaptability for planning and executing missions in a complex, dynamic world.

Although such capabilities are not currently available, recent advancements in computational intelligence (especially neuro-fuzzy systems), neuroscience, and cognition science may lead to the implementation of some of the most critical functionalities of heterogeneous, sensor net-based MDF systems. The following developments will help advance these types of processing capabilities:

1. **Reconfigurability of sensor weighting:** When a heterogeneous sensor net is used for an MDF system, each sensor has a different weight for different applications. As an example, regardless of whether a dissimilar MDF methodology is used to identify an object, an image sensor has much higher weight than radar. On the other hand, when an MDF methodology is used to measure a distance from the sensor to an object, a rangefinder or radar has a much higher weight than an image sensor.
2. **Adaptability of malfunctioning sensors and/or misleading data:** Even if an MDF methodology is used to identify an object, an image sensor cannot perform if it is faced to the sun. Data from the image sensors will either be saturated or need to be calibrated. Additionally, the image sensor data needs to be continuous calibrated if the weather is cloudy and changing because the measured data will be different based on shadows and shading. Therefore, the environment of a heterogeneous sensor net is a key parameter to be considered for design and implementation of an MDF system.

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3. **Intelligent and adaptive heterogeneous data association:** Heterogeneous, sensor net-based MDF systems must process different data simultaneously, such as one-dimensional radar signals, two-dimensional imaging sensor data, etc. As the combination of heterogeneous sensors change, the data combination is changed. Therefore, adaptive data association must be performed before conducting MDF and data input to the decision-making module.
4. **Scalability and resource optimization of self-reconfigurable fusion clusters:** The limiting factor of an MDF system is the scalability of self-reconfiguring the fusion cluster to adapt to a changing battlefield and/or the malfunction of one or more sensors. As the number of sensors used for a sensor net increases, the combinatorial number of reconfigurations exponentially increases. To manage such complexity, the MDF system will require a highly intelligent, fully autonomous, and extremely versatile reconfigurable algorithm, including sensor resource management and optimization. Great progress has been made in sensor management algorithms and cross-cued sensor systems, but true optimization is an elusive goal that is currently unavailable. Such capability can be obtained only from intelligent computing technology, which is currently in its infancy.

While robustness in adaptability to environmental change is necessary, the future need is to be able to adapt and learn from the operational environment because every possible contingency cannot be programmed *a priori*. This adaptation must happen fast enough to provide benefits within the adversary's decision loop, and the autonomy should be constructed so that these lessons can be shared with other autonomous systems that have not yet encountered that situation. Yet even in a hostile, dynamic, unstructured, and uncertain environment, this learning must not adversely affect safety, reliability, or the ability to collaborate with the operator or other autonomous systems. The flexibility required of autonomous systems in dynamic, unstructured environments complicates the predictability needed for U.S. commanders to "trust" the autonomy.

"Trust" will be established through robust operational T&E along with safeties and safeguards to ensure appropriate behavior. Complex autonomous systems must be subject to rigorous "red team" analysis in order to evaluate the full range of behaviors that might emerge in environments that simulate real-world conditions. Safeties and safeguards are also required to mitigate the consequences of failures. Because artificial systems lack the human ability to step outside a problem and independently reevaluate a novel situation based on commander's intent, algorithms that are extremely proficient at finding optimal solutions for specific problems may fail, and fail badly, when faced with situations other than the ones for which they were programmed. Robust safeties and control measures will be required for commanders to trust that autonomous systems will not behave in a manner other than what is intended on the battlefield.

5.4.3 Enabling Greater Autonomy in TPED Processes

In addition to C2 processes, traditional TPED processes offer huge opportunities for reducing the degree of human involvement. Near-term developments could introduce a greater degree of automation, ultimately evolving to more autonomous systems. Current TPED processes are manpower intensive. In today's combat environment, most full-motion video (FMV) and still imagery is monitored and used in real time, but then stored without being fully analyzed to exploit all information about the enemy. This challenge is not unique to the unmanned

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environment, but it has been exacerbated by the large numbers of ISR-capable, long-endurance unmanned systems being fielded. These systems are collecting great quantities of information and overwhelming current TPED processes. Near-term steps might include implementation of change detection and automatic target recognition software to enable automated cueing that identifies and calls attention to potential threats. Applications of face recognition software could enable high-fidelity FMV to identify individuals of interest. Increased automation in communications intelligence sensors has the potential to identify key words and even specific voices to rapidly alert operators to targets of interest. Ultimately, automated cross-cueing of different sensor types in a networked environment could enable greater autonomy in tasking systems and their sensors to identify and track threats more rapidly.

Increased processing power and information storage capacities also have the potential to change how unmanned systems operate. For example, many current UAS transmit ISR data that is processed and exploited in ground stations. If more processing and exploitation processes can be accomplished onboard a UAS (like the automatic target recognition or communications intelligence examples discussed above), the system can disseminate actionable intelligence for immediate use and reduce bandwidth requirements. FMV ISR, for example, uses roughly an order of magnitude more bandwidth than the C2 data for a UA. By accomplishing more of the TPED process onboard the unmanned system, the link bandwidth can then be focused on transmitting only what's needed, and the overall bandwidth requirements can be reduced.

> Today an analyst sits there and stares at Death TV for hours on end trying to find the single target or see something move or see something do something that makes it a valid target. It is just a waste of manpower. It is inefficient!
>
> *– Gen James Cartwright, Vice Chairman of the Joint Chiefs of Staff, during remarks to the U.S. Geospatial Intelligence Foundation on 4 Nov 2010*

5.4.4 Ability to Collaborate with Other Autonomous Systems



In addition to understanding the environment, unmanned systems must also possess the ability to collaborate through the sharing of information and deconfliction of tasking. Collaborative autonomy is an extension of autonomy that enables a team of unmanned systems to coordinate their activities to achieve common goals without human oversight. This trend in autonomy will continue to reduce the human role in the system. Autonomously coordinated unmanned systems may be capable of faster, more synchronized fire and maneuver than would be possible with remotely controlled assets. This trend will lead to a shift toward strategic decision making for a team of vehicles and away from direct control of any single vehicle.

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The ability to collaborate is one of the keys to reducing force structure requirements. The collaborative autonomy that is developed must be scalable to both larger numbers of heterogeneous systems as well as increased mission and environment complexity. Collaborative autonomy must be able to adapt to the air, ground, and maritime traffic environment and to changes in team members, operators, and the operational environment.

5.4.5 Development of New Approaches to Verification and Validation (V&V)

To ensure the safety and reliability of autonomous systems and to fully realize the benefits of these systems, new approaches to V&V are required. V&V is the process of checking that a product, service, or system meets specifications and that it fulfills its intended purpose. These components are critical in a quality management system such as ISO 9000. Today's V&V processes will be severely stressed due to the growth in the amount and complexity of software to be evaluated. They utilize existing industry standards for software certification that are in place for manned systems (e.g., DO-178B). Without new V&V processes, such as the use of trust audit trails for autonomy, the result will be either extreme cost growth or limitations on fielded capabilities.

Efforts leading to advancements in computational intelligence as well as the appropriate V&V processes are essential. Enhanced V&V technologies would provide both near-term cost reduction and enhanced capabilities for current autonomous systems and would enable otherwise cost-prohibitive capabilities in the future. New autonomous system test and analysis capabilities are also required to assess intelligent single-vehicle and group behaviors. These technological enhancements and policy actions would lead to more effective development, testing, and operations of current and future autonomous systems.

5.4.6 Policy Guidelines to Ensure Safe Operation

Additional measures, beyond V&V, will be required to ensure safe operation of autonomous systems. No V&V process can guarantee 100% error-free operation of complex systems. As software complexity increases, predicting the precise behavior of autonomous systems in real-world environments will be increasingly difficult. Policy guidelines are necessary in order to ensure that if failures or malfunctions occur, or if an unmanned system encounters an unanticipated situation, the system continues to operate appropriately.

Policy guidelines will especially be necessary for autonomous systems that involve the application of force. Current armed, unmanned systems deploy lethal force only in a fully human-operated context (level 1) for engagement decisions. For these systems, the decisions both to employ force and to choose which specific target to engage are made by a human. The United States does operate defensive systems for manned ships and installations that have human-supervised autonomous modes (level 3), and has operated these systems for decades. For the foreseeable future, decisions over the use of force and the choice of which individual targets to engage with lethal force will be retained under human control in unmanned systems.

5.5 Summary

Technological advances in autonomy are critical as the need to field greater numbers of unmanned systems stresses the limited number of available operators. Challenges in the area of

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autonomy address not only functionality, but also transparency to the operator, safety, and reliability. Figure 11 provides a vision into the future of the autonomy advances that are required to maintain an affordable force structure and confidently operate unmanned systems in an increasingly complex environment. Initially, autonomy will improve the safe operations of unmanned systems within the increasingly complex environment of military operations as well as reduce operator workload associated with mundane and noncritical processes. Ultimately, autonomy will increase warfighter effectiveness by enhancing unmanned systems capabilities and expanding their capacity to effect results in the battlespace.

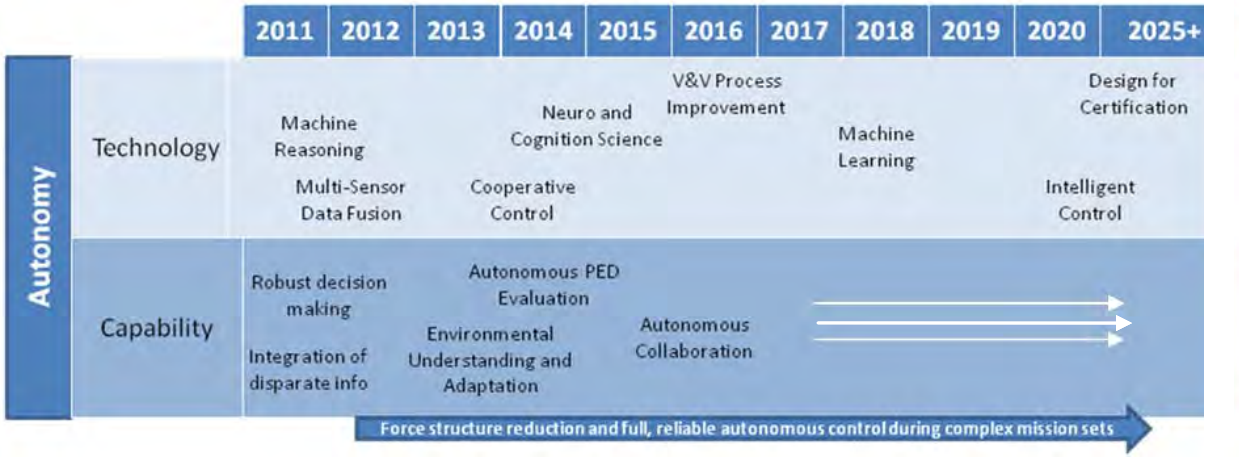


Figure 11. Autonomy Roadmap.

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6 AIRSPACE INTEGRATION (AI)

6.1 Functional Description

Over the past several years, UAS have become a transformational force multiplier for DoD. The numbers and roles of UAS have expanded dramatically to meet mission demands, and operational commanders have come to rely upon robust and persistent ISR support from unmanned platforms executing their core missions against hostile forces. DoD UAS require routine NAS access in order to execute operational, training, and support missions and to support broader military and civil demands. UA will not achieve their full potential military utility to do what manned aircraft do unless they can go where manned aircraft go with the same freedom of navigation, responsiveness, and flexibility. Military aviation is a major contributor to the virtue of maneuver for our forces in warfare.

While the force structure continues to grow, the ability to integrate UAS into the NAS has not kept pace. Current access for UAS is greatly limited primarily due to FAA regulatory compliance issues that govern UAS operations in the NAS. DoD UAS operations conducted outside of restricted, warning, and prohibited areas are authorized only under a (temporary) COA from the FAA. Similar issues need to be resolved for access to international and foreign national airspace.

The *DoD UAS Airspace Integration Plan, March, 2011* provides a more comprehensive discussion on the topic of AI. In this plan, DoD provides an incremental approach strategy to provide DoD UAS access to a given operations profile that leads to a full dynamic operations solution. This methodology recognizes that DoD requires access to differing classes and types of airspace as soon as possible and that routine dynamic operations will likely take several years to implement. Figure 12 depicts the six access profiles.

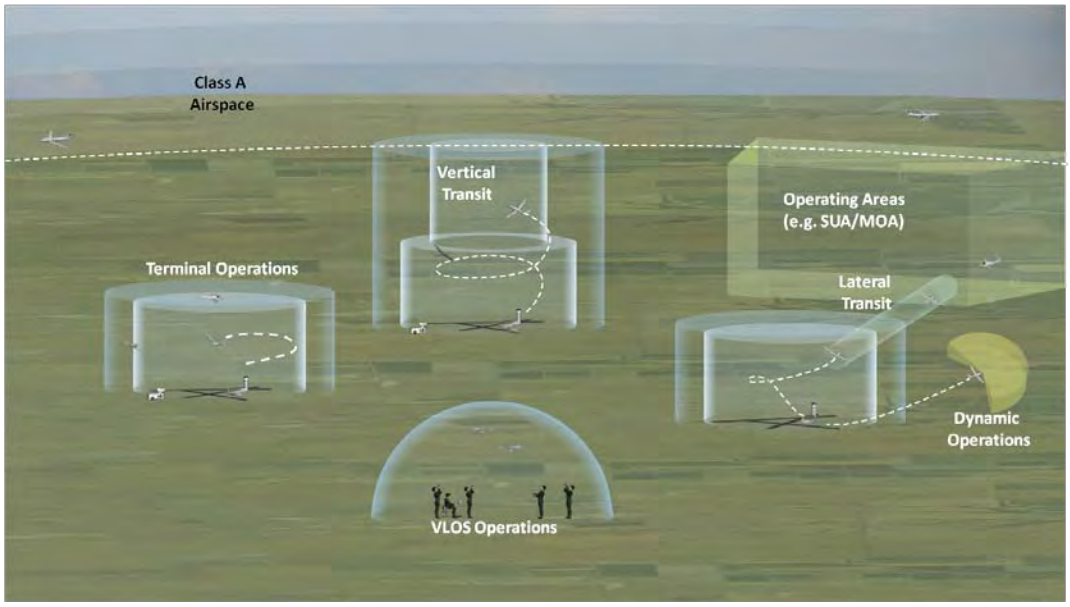
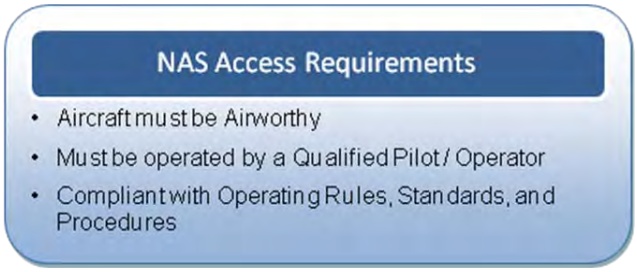


Figure 12. Operational View.

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6.1.1 Vision

DoD's vision is to ensure UAS have routine access to the appropriate airspace required to meet mission needs. For military operations, UAS will operate with manned aircraft using CONOPS that make manned or unmanned aircraft distinctions transparent to air traffic services (ATS) authorities and airspace regulators. Having robust UAS AI capabilities for all classes of U.S. airspace is fundamental to flexible worldwide UAS deployment.



> … it is vital for the Department of Defense and the Federal Aviation Administration to collaborate closely to achieve progress in gaining access for unmanned aerial systems to the National Airspace System to support military requirements.
>
> *– 110th Congress, NDAA for FY09, Sect 1039*

6.1.2 Precepts

The *2010 DoD Airspace Integration Plan* outlines DoD's approach, which is summarized by four overarching precepts (see right). The U.S. military will use its vast experience to develop the safest, most capable UAS fleet possible. We will strive for maximum compliance with existing regulatory guidance and inform regulatory processes when changes are needed. DoD will fully leverage statutory authorities to design, test, and ultimately certify its UAS in compliance with applicable standards, regulations, and orders. The regulatory and policy changes may be broad in scope to affect multiple Military Departments and Combatant Commands (CCDRs); therefore, UAS AI activities should make every effort to be coordinated prior to engaging with FAA or other external agencies.



6.2 Today's State

In order for any military aircraft — manned or unmanned — to fly routinely in domestic and international airspace, three foundational requirements must be met. These three requirements are essential and form the foundation for UAS AI. Title 10 of the United States Code (USC) is the legal underpinning for the roles, missions, and organization of DoD and provides authority for the military departments to organize, train, and equip U.S. forces to fulfill the core duties for national defense. Consistent with this statutory authority and longstanding practice and reinforced by interagency agreements, DoD is responsible for establishing airworthiness and

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pilot training/qualification requirements for the military and ensuring rigorous military standards are satisfied.[16] The third and most complex requirement, regulatory compliance, encompasses both internal military department regulations and external FAA and International Civil Aviation Organization (ICAO) flight regulations.



6.2.1 Airworthiness

Airworthiness is a basic requirement for any aircraft system, manned or unmanned, to enter the NAS. The primary guidance for DoD airworthiness certification is found in MIL-HDBK-516B, *Airworthiness Certification Criteria.* This document defines airworthiness as "*the ability of an aircraft system/vehicle to safely attain, sustain and terminate flight in accordance with an approved usage and limitation.*"[17] Airworthiness certification ensures that DoD aircraft systems are designed, manufactured, and maintained to enable safe flight. Certification criteria, standards, and methods of compliance establish a minimum set of design and performance requirements for safely flying a given category and class of aircraft. The DoD is expanding current military airworthiness guidance to include criteria that address those component and system attributes that are unique to UA. UAS-unique standards derived from NATO STANAGs (e.g., 4671[18], 4705, and 4703) will be reviewed and incorporated as appropriate.



6.2.2 Pilot/Operator Qualification

The DoD determines where and how it will operate its aircraft, and each Military Department creates the qualification training programs necessary to safely accomplish the missions of that aircraft or weapon system. The standards to train and qualify pilots/operators of UAS will remain under the authority of the Military Departments and appropriate CCDRs. UAS pilot/operator training requires a different skill set from the set needed for flying manned aircraft due to differences such as the means of takeoff, cruising, and landing by visual remote, aided visual, or fully autonomous methods. Therefore, the Military Departments and CCDRs must apply the minimum training standards outlined in CJCSI 3255.01 to their respective training programs to ensure the requisite knowledge, skills, and abilities are addressed appropriately.



[16] Title 10 provisions relating to service authority to organize, train, and equip include 10 U.S.C. Sec. 8062 (Air Force), 10 U.S.C. Sec. 3062 (Army), 10 U.S.C. Sec. 5062 (Navy), and 10 U.S.C. Sec. 5063 (Marine Corps). Multiple service instructions address airworthiness standards, e.g., Air Force Instruction 62-601, dated 11 June 2010.
[17] MIL-HDBK-516B with change 1, *Airworthiness Certification Criteria*, 29 February 2008.
[18] NATO STANAG 4671, Unmanned Aerial Vehicle Systems Air Worthiness Requirements (USAR).

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6.2.3 Regulatory Compliance

The Military Departments have a robust process for establishing manned aircraft flight standards and procedures. However, the current ambiguity and lack of definition in national and international regulatory guidelines and standards for UAS make it difficult to know, with consistency or certainty, whether UAS can comply. In fact, some current UAS may already be operating at appropriate levels of safety; however, until the necessary UAS-specific standards, regulations, and agreed-upon compliance methodologies are defined, establishing regulatory compliance for more routine operations is difficult. In the meantime, UAS operations within the NAS are treated as exceptions through the COA process.

While many requirements can be met through the use of existing manned aircraft, many missions are more efficiently and safely accomplished by using unmanned platforms. Technology advancements may be able to help resolve regulatory compliance issues for UA (particularly Title 14 of the U.S. Code of Federal Regulations (14 CFR) 91.113 containing the see and avoid provision); however, the level and complexity of technology required to resolve today's regulatory compliance issues will negatively affect system affordability.

6.3 Problem Statement

The number of UAS in the DoD inventory is growing rapidly. The increase in numbers, as well as the expanding roles of UAS, has created a strong demand for access to national and international airspace and has quickly exceeded the current airspace available for military operations.

6.4 Way Ahead

6.4.1 Methodology

DoD's UAS NAS access methodology includes the array of UAS platform capabilities, required airspace, technology improvement, and implementation activities/products required to attain routine operations within the NAS. This methodology uses an incremental approach to provide DoD UAS access to a given operations profile that leads to a full dynamic operations solution (see Figure 13). This methodology recognizes that DoD requires access to differing classes and types of airspace as soon as possible and that routine dynamic operations will likely take several years to implement.

The profiles, as outlined in an operational view (Figure 12) and DoD's AI Plan, may be used individually to access specific local airspace or integrated together to satisfy additional airspace requirements. Visual LOS operations establish a means to conduct UAS operations in Visual Flight Rules conditions. The terminal area profile is intended to facilitate UAS operations in a confined volume of airspace, such as Class D airspace or near restricted airspace. UAS operating areas, such as special use airspace (e.g., restricted area, or military operations area (MOA)), can be accessed either by flying through a lateral corridor (through Class E) or by vertically ascending to Class A airspace and flying across. While operating areas are limited to restricted or warning areas, MOAs are desirable because they offer a wide variety of airspace spanning 43 states to provide a robust, nationwide UAS training capability without the creation of new airspace.

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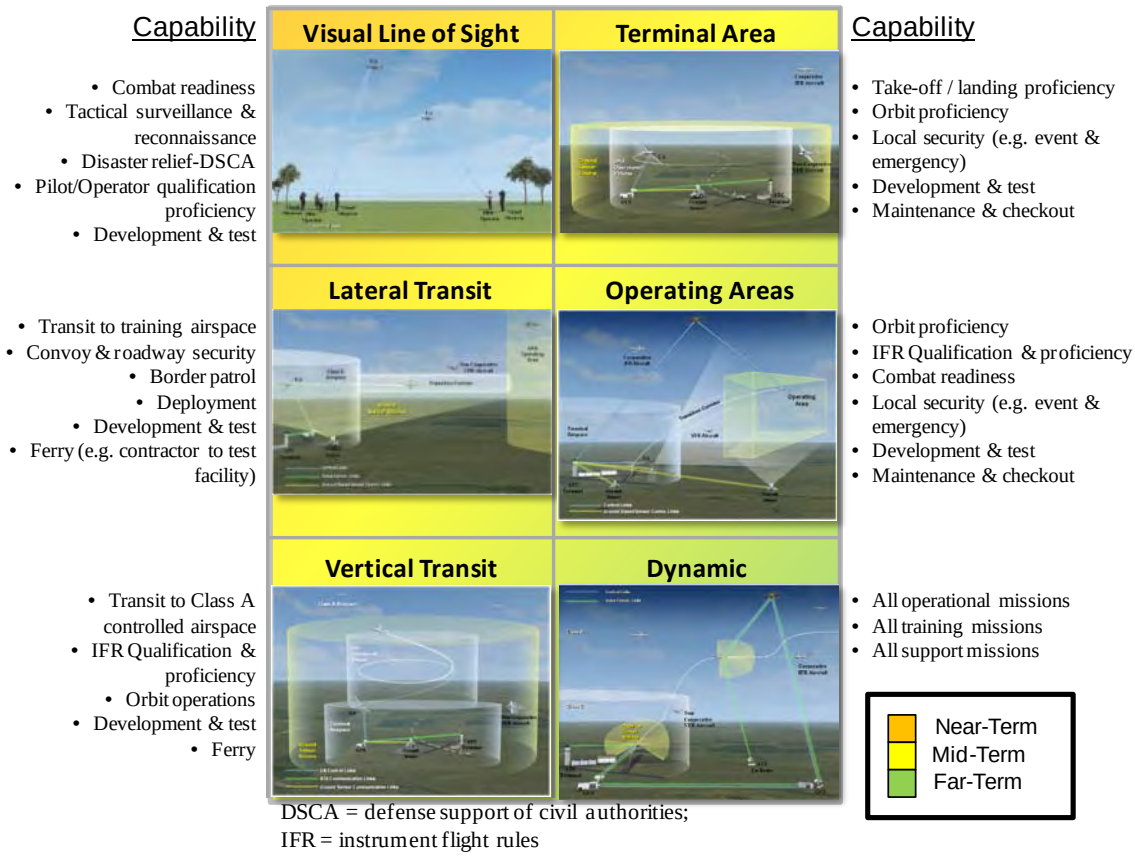


Figure 13. Incremental Approach to Regulatory Compliance.

Plans and programs to enable UAS operations within a profile will be evaluated for joint applicability and NAS access utility. For example, because most of the required near-term airspace for DoD UAS will be in Class D, E, and G, DoD intends to focus much of its near-term resources on addressing this major need.

6.4.2 Policy

Policy agreements can maintain the safety of the NAS while also allowing certain requirements to be fulfilled. In 2007, DoD and FAA signed a Memorandum of Agreement (MoA) allowing limited UAS operations for small UAS below 1200 ft above ground level (AGL) and UAS within DoD-controlled, non-joint-use Class D airspace. The 2007 MoA will be updated periodically, as needed, to allow DoD to incrementally increase access to the NAS. For example, the small UAS special federal aviation regulation is expected to be complete in 2013, but DoD can immediately leverage this work by seeking to incorporate many of the recommendations into an updated DoD-FAA MoA.

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The Policy Board on Federal Aviation (PBFA) serves as the DoD liaison with the FAA on federal air traffic control and airspace management. The board provides policy and planning guidance to ensure the Military Departments have sufficient airspace to fulfill requirements. With support from OSD and the Military Departments, the board is working with FAA to update the 2007 MoA.

Where broader issues involve other agencies, the DoD participates in the UAS Executive Committee (ExCom). The ExCom acts as a focal point for senior leaders from FAA, DoD, DHS, and National Aeronautics and Space Administration (NASA) to meet periodically to resolve any policy and procedural disputes and to identify solutions to the integration of UAS into the NAS. The ExCom has established a working group to address COA issues, published a plan to Congress in October 2010, and continues to address specific issues such as collecting and sharing UAS safety data.

6.4.3 Technology

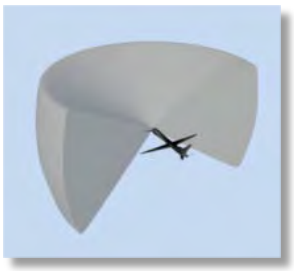
Current UAS are built to different specifications for different purposes; therefore, showing individually that each system is safe for flight in the NAS can be complicated, time consuming, and costly. Routine access cannot happen until DoD and FAA agree to an acceptable level of safety for UAS, and the appropriate standards are developed to meet that threshold. With developed standards, UA will be operationally treated as manned systems, and such treatment will improve interoperability with other systems, cost savings, and development transparency.

Until those necessary UAS-specific standards are established, requirements will be dependent on the individual system and intended flight environment (access profiles). Each system's mission requirements will drive the selection of sense and avoid (SAA) solutions and process for implementation. Ground-based sense and avoid (GBSAA) can provide an initial means to maintain aircraft separation requirements for multiple profiles, while improvements to sensor and automation technology will continue to improve an airborne SAA (ABSAA) solution.



GBSAA efforts are focused on developing methods to provide aircraft separation within a prescribed volume of airspace using a ground-based system that includes sensors, displays, communications, and software. GBSAA solutions will incrementally relieve restrictions on existing COAs and facilitate UAS training and operations in the NAS. This effort is establishing requirements, gathering data, performing modeling and simulation, testing and verifying collected data, and obtaining airworthiness approvals, as appropriate. GBSAA can particularly benefit smaller UAS where other SAA solutions are cost prohibitive.

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ABSAA efforts are focused on developing onboard capability to perform both self-separation and collision avoidance that ensure an appropriate level of safety. Current programs have phased validation schedules for due regard, en-route/Class A, and divert/ Class E/G operations as technology innovation and integration allow. GBSAA and ABSAA may be applied as a single or combined solution to some access profiles to maximize safety and/or reduce operational costs.

6.4.4 CONOPS Development

The DoD is developing an AI CONOPS to provide a framework for common UAS practices, procedures, and flight standards in NAS and international airspace. It is intended to standardize UAS access methodologies and procedures, implement appropriate methods for compliance with see-and-avoid requirements, and inform development of an UAS AI Initial Capabilities Document (ICD). It will establish a standard suite of lost-link, lost-communications, and lost-SAA procedures for DoD UAS in all phases of flight. These procedures will help define methods for notification and the appropriate action to either regain link or recover/divert the UA. The CONOPS also provides the operational and procedural construct to employ the access profiles at bases across the United States and to inform the process of basing UAS in locations outside the continental United States (OCONUS).

6.4.5 Requirements Development

The CONOPS, along with the Military Departments' individual location airspace requirements, will feed development of an UAS AI ICD. The UAS AI ICD is intended to identify the financial requirements for UAS integration into the NAS across the United States and OCONUS. As the initial SAA technologies mature through development and validation, they can be applied to the appropriate profiles and documented in the UAS AI ICD. This effort will allow the Military Departments to accurately estimate the costs to operate UAS at any given individual location as needed.

> … limited access to airspace is having a negative impact on the unmanned aviation community and many regions of the U.S. that are ready to support UAS industry growth.… over the next 15 years more than 23,000 UAS jobs could be created in the U.S. as the result of UAS integration into the NAS.
>
> *– Aerospace Industries Association. (2010). Total Employment: Annual Calendar Years 1990-2009. Available at AIA website: http://www.aia-aerospace.org/assets/stat12.pdf*

6.4.6 Timing of Activities

The DoD is focusing on near-term, mid-term, and far-term activities. This timing allows for immediate improvements in NAS access, while working toward viable long-term solutions.

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- Near-term activities address small UAS, DoD-controlled airspace, and operations under COAs**.** Priority is given to initiatives that reduce COA requirements and streamline the FAA approval process. DoD believes significant near-term improvement in UAS NAS access is achievable through COA, policy, and procedural initiatives.
- Mid-term activities address local airfield and transit operations. Where policy and procedures fall short of achieving the long-term objective of routine access, a significant investment in standards and technology development is necessary. Priority is given to developing validated AI requirements and associated standards and to establishing an SAA capability that will provide NAS access through special rules and policy, new procedures, and use of ground-based sensor technology.
- Far-term activities address most UAS missions in any operating location and airspace to include FAA's Next Generation Air Traffic Control System (NextGen). The end state is routine NAS access comparable to manned aircraft for all DoD UAS.

6.5 Summary

DoD UAS have become a critical component of military operations. Many DoD UAS now require rapidly expanded access to the NAS and international civil airspace to support operations, training, testing, and broader governmental functions.

In order for military aircraft to fly routinely in domestic and international airspace, the aircraft must be certified as airworthy, operated by a qualified pilot/operator in the appropriate class(es) of airspace, and comply with applicable regulatory guidance. DoD exercises sole certification authority for its aircraft and pilots/operators, consistent with authority provided in Title 10 of the US Code.

DoD's UAS NAS access methodology uses an incremental approach to provide DoD UAS critical access to a given operations profile prior to implementing a full dynamic operations solution. DoD's immediate focus is gaining near-term mission-critical access while simultaneously working toward far-term routine NAS access. DoD's efforts will have positive affordability effects by championing utilization of UAS within the NAS. This progress will be accomplished through policy and procedural changes as well as technology and standards development and is thoroughly outlined in the AI Plan. The end state is routine NAS access comparable to manned aircraft for all DoD UAS operational, training, and support missions.



Figure 14. UAS NAS Roadmap.

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7 COMMUNICATIONS

> "Ongoing operations in Southwest Asia continue to drive the voracious demand for pilots, support personnel and bandwidth above all"
>
> *– Col. J.R. Gear, USAF, speaking at recent C4ISR Journal Conference in Washington.*

7.1 Functional Description

DoD unmanned systems need a process for operational control and mission data distribution, especially for nonautonomous systems. For some ground and maritime systems, these types of exchanges of information can use a cable for the transmission path, but for highly mobile unmanned operations, the exchange is more likely to use signals sent across the electromagnetic spectrum (EMS) or by other means (e.g., acoustical or optical). The EMS is highly regulated at the national[19] and international[20] levels. While numerous over-the-air communication systems have been designed, built, and fielded and have performed reasonably well, others have been fielded in a noncompliant status and have not met difficult operational constraints.

DoD's desire is to operate unmanned systems in theater or within the United States and its possessions so that communication constraints do not adversely affect successful mission execution. Specifically, DoD must significantly improve communication transmission efficiencies; attain better bandwidth efficiencies; increase transmitter and receiver efficiencies; and acquire communications systems that are of less size and weight, require less power, and provide more efficient cooling to operate.

The operational employment of Unmanned Aircraft Systems requires access to a range of SATCOM capabilities. Planning and budgeting for UAS operations must take into account realistic assessments of projected SATCOM bandwidth (both military and commercial) in a range of operational scenarios. Investments in UAS systems must be matched with appropriate investments in the military and commercial SATCOM capabilities that are required to support UAS operations.

7.2 Today's State

The state of unmanned systems communication systems differs greatly among the air, ground, and maritime environments. In supporting operations in OIF, Operation New Dawn (OND), and OEF there has been a large number of new sensors and communication systems installed on various fielded unmanned systems. These have significantly increased the amount of data that has been collected, and that is desired to be sent to local and remote warfighters. To

[19] For the U.S. Government, see the National Telecommunications and Information Administration's *Manual of Regulations and Procedures for Federal Radio Frequency Management*. Washington, DC, January 2008 edition, September 2009 revision (incorporated by reference under 47 CFR 300.1).
[20] International Telecommunication Union (ITU), Radio Regulations, Geneva, Switzerland. 2007 Edition.

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get the needed data to the remote warfighters, the DoD pays significant funds to several commercial large data transmission companies. Many current unmanned systems have experienced the impact of frequency congestion, interference from systems operating in adjacent frequency bands, and the physical limits associated with the spectrum that has been made available.

The following paragraphs describe the current communication environments by domain.

7.2.1 Unmanned Ground Systems (UGS)

Until recently, most unmanned systems utilized several radios: one for data, one for video, and sometimes one for voice. Because of congestion, frequency competition, and regulatory challenges in several theaters, many of these communication systems were redesigned to operate at higher frequencies. However, use of these higher frequencies reduced the operational effectiveness in dense foliage and urban areas.

7.2.2 Unmanned Aircraft Systems (UAS)

Small, hand-carried and/or hand-launched systems (e.g., the Raven) utilize LOS communications, while large aircraft (e.g., the Predator, Reaper, Gray Eagle, and Global Hawk) utilize both LOS and BLOS communications, the latter generally using satellite communications.

Initial small UAS (< 20 lbs) communication systems utilize industry analog designs, but most now utilize the Army-developed digital data link (DDL) system.[21] The DDL design incorporates aspects of a software-defined radio with the ability to "field-select"[22] the frequency band in which to operate, the channel frequency within that band, the bandwidth of each channel, and the radiated power level.[23] Larger UAS operating LOS incorporate the common data link (CDL) that has been mandated for use in ISR platforms.

7.2.3 Unmanned Maritime Systems (UMS)

There are unique challenges related to UMS: dealing with the air water interface, transmission loss communicating underwater, and negotiating the dynamics of the sea surface. Intermittent communications are the norm in maritime systems and multispectral capabilities are utilized to meet communications requirements. Primary tradeoffs to be considered when evaluating a mode of communication for a USV or UUV that supports dynamic tasking, querying, and data dissemination include data rate, processing capability, range, detectability, and negotiating the maritime environment. These are of particular concern for the ISR and the

[21] Developed by the Army's Natick Soldier Research, Development & Engineering Center. An alternative DDL for small UAS is also being developed that could use a version of CDL. NATO has developed STANAG 4660, Interoperable Command and Control Data Link for Unmanned Systems (IC2DL), which is based on the DDL.
[22] This selection process is not by software but by switches. Moving to software control is being considered during a future upgrade of the DDL.
[23] The USAF Cryptographic Modernization Program Office and the Army developed a prototype encryptor for this DDL.

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ASW missions when communication is desired without exposing either the sender or receiver to possible hostile interception.[24]

7.3 Problem Statement

There are alarming red flags early in this Roadmap's time horizon regarding the amount of data that future UMS sensors will be collecting. How to best deal with that amount of data and distributing the needed information within that data to the right warfighters at the right time will be a major challenge. Left unchecked, sending all that data to local or remote sites will tax current technology and available funding (e.g., COMSAT links). The DoD needs communication technologies and tactics, techniques, and procedures that overcome these limitations and that are agile, robust, redundant, efficient, and affordable. Those needed technologies are discussed throughout Section **7.4 Way Ahead**. However, improved communication transmission technologies alone cannot achieve the necessary capacity. The DoD must pursue a fundamental shift to a future state where we pre-process the collected data, rapidly pass only critical data on to the warfighters, and then store for later retrieval the remaining data that may be needed.

In addition to achieving these technology advances[25], their application in UMS needs to meld with overall DoD wireless network communication concepts, meet national objectives for unmanned systems, and properly address regulatory policies and their limitations. All this needs to be done early in the requirements development process so those advances can be incorporated within future UMS.

In particular, tomorrow's UMS will need to utilize technical strategies which can more efficiently deal with extremely large data sets. In managing this data, better data compression, encryption and processing algorithms need to be employed in preprocessing, transmission and data fusion. These strategies also need to mandate efficient use of the spectrum, reduce frequency use overhead, allow for data security and ensure improved clarity of the available frequency spectrum. To support DoD's goals, communication systems need to support multiple frequency bands, limited bandwidth, variable modulation schemes, error correction, data encryption, and compression. All this support, of course, needs to be done so that no electromagnetic interference (EMI)[26] is caused within those systems or within other nearby spectrum-dependent systems (SDS).

There are numerous challenges to meeting this goal. First, operating a higher density of unmanned systems within relatively small areas creates increased local data rate demands. Second, size, weight, power and cooling (SWaP-C) are limiting factors on many platforms, for both onboard systems and ground/surface control systems. Third, the fidelity of the communication links must be ensured. Fourth, latency associated with digital systems must be reduced, especially for takeoff and landing of large UAS. These challenges will be exacerbated

[24] U.S. Navy Undersea Dominance Roadmap.
[25] These advances need to include government ownership of critical data and intellectual property to ensure the best return on our research investment.
[26] The development of the resulting on-board and ground stations needs to address EMI hardening and the units tested per MILSTD-464A and MILSTD-461F.

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by an expected decrease in available spectrum available due to an increase in the civil[27] uses of spectrum, an objective within the Federal Communications Commission's (FCC's) National Broadband Plan[28]and directed by the White House[29].The challenges in attaining this goal include developing, procuring, testing, and fielding communication systems that can operate with greater effectiveness, efficiency, and flexibility even in congested and adversarial environments.

Spectrum testing in unmanned systems today involves communications across a global environment with various levels of spectrum management. The communication challenges require investment in multiple technologies for leveraging communications across the radio frequencies and ultimately the optical spectrum. The impediments to unmanned systems communications are largely restricted to better use of the spectrum through investment in technologies that expand communication efficiencies. The problem today is largely a physics problem, which increases in complexity exponentially as one considers the air, ground, and maritime domain challenges. The testing of cognitive algorithms that can opportunistically leverage communications facilitating advanced mission oversight or multisystem collaboration remains in its infancy.

7.4 Way Ahead

Current DoD policies and guidance stress the need for new systems[30] to have a balance among improved interoperability; increased agility[31]; greater adaptability; improved spectral efficiency; compliance with U.S. national, host nation, and international spectrum policies[32]; and lower production costs. The ability to update and reconfigure parts of a communication system by software changes (e.g., software-defined radios) has been available for several years. In addition, these systems should conform to a standards-based architecture (e.g., service-orientated architecture) that supports multiple networks to enable rapid and transparent configuration changes without removing the radios from operation. Such multiple-input, multiple-output (MIMO), multicarrier, and multiwaveform capabilities, along with the software control of these functions, are needed within future subsystem developments. Ultimately, it is desired that these reconfiguration changes be done "automatically" so the systems adapt dynamically (Figure 11. Autonomy Roadmap.) in response to sensed changes in the operational environment[33] (> 2020).

The need to support operations in which there are intermittent wireless propagation links has become common place. This support has resulted in increased use of advanced error control coding, MIMO configurations, various path diversity techniques, integrated networking, and data diversity — all to provide improved end-to-end quality of service. Future effectiveness of unmanned communication systems is contingent on continued advancements in antennas,

[27] Both in CONUS and OCONUS.
[28] FCC's National Broadband Plan, Washington, DC, 2010.
[29] Presidential Memorandum "Unleashing the Wireless Broadband Revolution." June 28, 2010,
[30] This goal includes systems used in networking, communications, electronic warfare, navigation, intelligence, and sensors.
[31] This goal would include assured and secure communications.
[32] See DOD Instruction (DODI) 4650.01, Management and Use of the Electromagnetic Spectrum, Washington, DC, 9 January 2009, and DODI 4630.8, Procedures for Interoperability and Supportability of Information Technology (IT) and National Security Systems (NSS).
[33] Also see Section 5 of this Roadmap.

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transmit/receive systems, underwater communications, spectrum considerations, signal processing, network systems, and optical communications. A description of those advancements is given in the following subsections.

> … Reinvigorate the industry's independent research and development and protect the defense industrial base.
>
> *–Under Secretary of Defense Memorandum for Acquisition Professionals, Better Buying Power, September 2010*

7.4.1 Antennas

Communication with highly mobile systems requires high-gain, rugged, and lower cost multidirectional antennas. The larger UAS systems may also use highly focused beams to achieve connectivity with more distant systems.[34] Developments in phased array antennas and "smart" antennas (to include combining signals from multiple antennas) could offer an alternative to traditional dish antennas; however, they require tradeoffs among SWaP-C. DoD and industry will need to continue developing such techniques as multifocused and super-cooled antenna systems. The multi-focused systems would permit multiple users to receive information and not rely on point-to-point systems and subsequent relaying of data via other communication systems to local users.

Future antenna systems need to be able to send and receive signals over a broad range of frequencies. Phased arrays are a viable approach. For SWaP-C and low-profile considerations, phased array antennas need to be conformal (e.g., using metamaterial) that will be molded within the vehicle surfaces. The utilization of common apertures has called for the development of new interference mitigation methodologies that minimize co-site interference effects and improve the potential for achieving simultaneous transmit and receive operations within adjacent frequency bands.

7.4.2 Transmitter/Receiver Systems

Current transmitter solid-state power amplifiers (SSPAs) are typically made with gallium arsenide (GaAs) substrate. Gallium nitride (GaN) SSPAs, currently in development, provide significant advantages over GaAs SSPAs. They offer more than double the efficiency of GaAs amplifiers; they increase the amplifier operational bandwidth; and GaN SSPAs may provide for a wider range of frequency of operation. The high transmit efficiency of GaN systems will also reduce the cooling requirements. In order to achieve some of these benefits, the amplifier designs are being enhanced with adaptive operating point control that adjusts to the instantaneous power being demanded from the amplifier. This enhancement significantly reduces the average prime power required by the amplifier by allowing it to effectively turn itself off when not in use, yet adjusting to maintain proper conditions to ensure minimal distortion at higher instantaneous powers. The GaN technologies are currently available for selected frequency bands and will soon

[34] Global positioning system (GPS) has been used to aid in this connectivity.

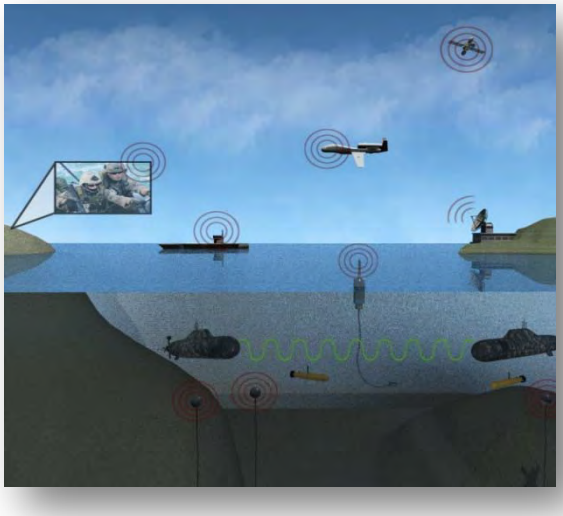
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be available for fielding (2014). The amplifiers may also utilize signal-processing-based signal predistortion techniques to compensate for the basic nonlinearity of the amplifier's transfer characteristics.

Instantaneous bandwidth performance and analog-to-digital converter sampling speeds have continued to improve year after year.[35] In addition, improvements in integrated chip fabrication methods have allowed for significant miniaturization and reductions in part counts and for various transmit/receive and antenna functions and components to be integrated on a single chip (2013). Fiber optics has been used to speed up the data and signal transfers from and to the antenna and the signal processing hardware (2012).[36] Microminiature mechanical device developments should provide smaller size, more flexibility, and greater performance in receiver designs[37] (2015). Future developments are expected to provide improvements in reliability and fabrication yields, reduced thermal characteristics, reduced integration complexity, and lower production costs.

7.4.3 Underwater Communications

Ocean dynamics challenge underwater and surface communications and are unique to UUVs and USVs. These systems gain efficiency and effectiveness with real-time, two-way communications that do not undermine mission accomplishment. The Navy's *Undersea Dominance Roadmap* (under development) will identify current and future architectures to link UUVs, distributed netted systems, and tactical platforms. Future developments described in that roadmap will leverage existing technologies and potential new capabilities that will come through the Office of Naval Research S&T research and development efforts.



7.4.4 Spectrum Considerations

U.S. military operations are now occurring in many parts of the world where adequate spectrum is not available. There is a significant increase in the numbers of SDS being deployed by the United States, our partners, and our coalition forces to address current and expected future

[35] Lundberg, Kent H., *High-Speed Analog-to-Digital Converter Survey*, MIT Press, 2002.
[36] See the DARPA Optical RF Communications Adjunct and the Office of Naval Research's Enabling Capability programs. This application is more for ground-based systems than for airborne systems. This use also significantly minimizes the signal loss and allows more advantageous placement of selected components.
[37] C. T.-C. Nguyen, "Microelectromechanical devices for wireless communications (invited)," *Proceedings*, 1998 IEEE International Micro Electro Mechanical Systems Workshop, Heidelberg, Germany, Jan. 25-29, 1998, pp. 1-7.

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mission areas. In addition, these SDS collect more information, and missions often require greater bandwidths to send their information directly to warfighters. This latter consideration has been seen within OEF missions where new ISR UAS have included wide area surveillance sensors; alternative spectrum bands have been identified[38] to help address the wider bandwidths needed by those systems. Also, mission areas are becoming more spectrally "noisy" because of increasingly cluttered and hostile spectrum environments. As such, a continual demand for improved spectrum efficiency and effectiveness is being placed on all DoD SDS.[39] All unmanned systems must complete during their development process a spectrum supportability and risk assessment in accordance with DODI 4650.01 to identify and mitigate regulatory, technical, and operational spectrum supportability. Because national and international spectrum rules and policies can rapidly change,[40] developers should maintain a close liaison with appropriate DoD spectrum offices before finalizing communication system designs.

The use of LOS datalinks also supports missions where there is a denial of or impaired service to SATCOM systems. Under such conditions, the demand for LOS spectrum will be extended to support the need for improved spectrum use efficiency and effectiveness.

The Defense Advanced Research Projects Agency's (DARPA's) Next Generation (XG) project and its follow-on Wireless Network after Next (WNaN) program demonstrated the feasibility of dynamic spectrum access (DSA). DSA offers the ability to change frequency band use based on other adjacent SDS actual use and nonuse of certain bands. The Joint Tactical Radio System (JTRS) program is investigating the feasibility of integrating DSA technologies into its system. The U.S. Army is also considering having WNaN become part of an Army program of record. However, a recent USAF Scientific Advisory Board study said that DSA is far from being proven technology. Developmental challenges include susceptibility to countermeasures, costs of integrating with existing systems, developing standards (including regulatory aspects), and co-site interference (2015).

Alternative technology advances should aid in the spectral efficiency challenge to include internal and external EMI mitigation advances such as coherent signal cancellation, space-time adaptive processing, polarization diversity, and adaptive digital beam forming.

[38] OASD NII memo dated March 22, 2011 Subject: Department of Defense (DoD) Common Data Link (CDL) Usage in Operation Enduring Freedom (OEF) Theater

[39] All new and modified SDS programs now need to conduct a spectrum supportability and risk assessment prior to Milestone B (source: DODI 4650.01).

[40] Relatively near-term spectrum usage changes could come from the ITU and its 2011 Worldwide Radiocommunication Conference (WRC); UAS spectrum use is a conference agenda item. Changes in frequency band usage for UAS may also come from the FAA and the ICAO as part of the UAS operations in the NAS airspace and in other nation-states' airspace.

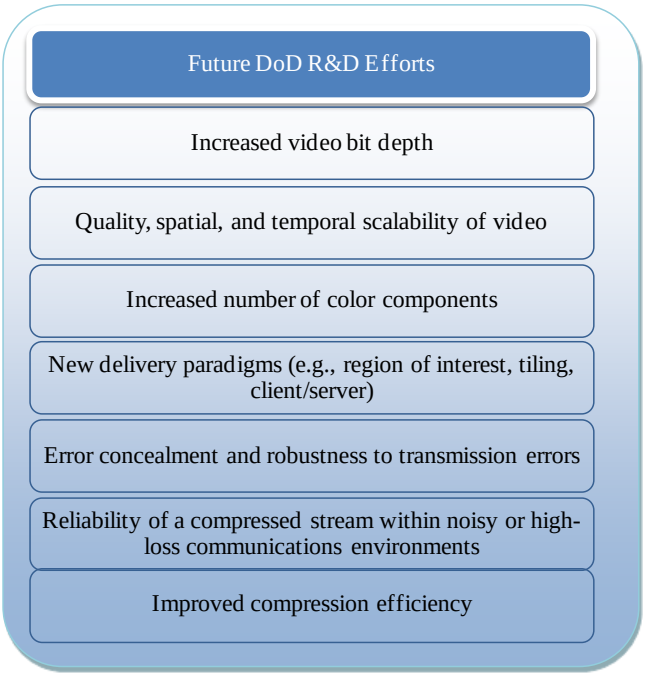
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7.4.5 Communications and Signal Processing

7.4.5.1 RF Waveforms

All ISR systems are to use the CDL waveform specification[41] whenever possible.[42] A mini-CDL system[43] is finishing development to allow CDL usage within smaller platforms than were possible in the past. Candidate future CDL waveform developments include adding a "dial-a-rate" capability for transmission speeds (with multiple bits-per-hertz and operating within the gigabit-per-second range) and a more efficient forward error correction (FEC) coding (both 2014). Also, several UAS program offices are pursuing such performance advances as more efficient CDL waveforms, operation in additional frequency bands, expanded communications security,[44] low probability of intercept (LPI) or low probability of detection (LPD), improved anti-jam, and greater link throughput. Corresponding improvements in surface and ground stations that receive the CDL signals have also been or are being made. There have also been significant efforts to improve commonality of these systems through the UAS Task Force and its I-IPT.[45]

Future CDL improvements will include, as feasible, the incorporation of advancements being offered by DARPA, industry, and academia. Four of the most appropriate DARPA programs that are being closely followed are the DARPA Interference Multiple Access and Disruption Tolerant Networking programs.



7.4.5.2 Preprocessing

Considering the anticipated large amounts of data projected to be collected by unmanned systems in an environment of limited bandwidth capability, one challenge is determining how much of that data needs to be sent back in near real time to a ground station. There is ongoing interest in addressing how best to select portions of images and to track those portions over time and send back "just" those selected images in near real time. These selection activities are currently being developed within classified TPED programs. As these activities progress, they should be applied in preprocessing efforts onboard

[41] These developments follow DODI 4630.09, DoD Wireless Communications Waveform Development and Management. The currently approved version is Standard CDL (STD-CDL) Rev H.
[42] The main reason for nonuse would be SWaP-C issues.
[43] This effort mostly focused on SWaP-C issues.
[44] Two cryptographic solutions (one classified and one unclassified) are used currently.
[45] See Section 4 of this Roadmap.

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unmanned systems. Improved preprocessing must be accompanied by sensor and processor miniaturization to reduce SWaP-C so as to maintain the persistent nature of UMS.

7.4.5.3 Compression

Compression techniques have tremendous potential to reduce bandwidth requirements, resulting in lower operating costs and increased operational flexibility. For example, FMV, synthetic aperture radar (SAR), inverted SAR (ISAR), and multispectral images can generate high bandwidth requirements (> 360 Mbit/s data rates). When compressed, the datalink bandwidth requirement could be in the range of only 1 to 30 Mbit/s.[46] Current compression techniques are described in the motion imagery systems matrix (MISM).[47] This matrix defines a recommended practice for the simple identification of broad categories of motion imagery systems. The intent of the MISM is to give user communities an easy-to-use, common shorthand reference language to describe the fundamental technical capabilities of DoD/Intelligence Community (IC)/National System for Geospatial Intelligence (NSG) motion imagery systems. The video quality needed for unmanned systems would nominally be MISM levels 4M/4H and 3M/3H. Currently the H.264 standard, which is firmly engrained in the commercial market,[48] offers twice the performance as Motion Picture Experts Group-2 standard (MPEG-2), and advanced encoding options will give even greater improvements[49] (albeit with potentially increased encoder latency).[50] The goal of the United Nations' ITU is for the H.265 standard to provide a chosen quality level at half the bit rate of H.264 (2018). For unmanned applications, future research and development should be undertaken by DoD and industry within areas depicted in the graphic on the right.

Beyond technical compression of all the collected data, there are logical advances that could reduce the amount of information that needs to be sent. This would include incorporation of logical bases for "just" replacing old information about a target's position with a more recent update, but not resending the unchanging background around the target.

> In addition to performance enhancements, compression techniques have tremendous potential to reduce bandwidth requirements and thereby reduce operating costs.

[46] Operational needs should determine the data rate that should be sent. Commanders in the field should be encouraged to require the lowest possible resolution and other parameters that meet their needs.
[47] See Motion Imagery Standards Profile (MISP) Recommended Practice 9720d, MISM, Standard Definition Motion Imagery.
[48] It is widely used within Blu-ray and digital video disk (DVD) systems.
[49] Over the past several decades, each generation of standardized video compression has provided a halving of the required bit rate for a given quality level relative to the prior generation.
[50] The latency introduced by some compression schemes can be so great that data links using such compressions cannot be utilized during such critical times as takeoffs, landings, and weapon launches.

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7.4.5.4 Encryption

Unmanned systems incorporation of data encryption includes National Security Agency (NSA) Type 1 (for protection of classified and unclassified information) or Federal Information Processing Standards (FIPS) Publication 140-2 certified solutions (for sensitive but unclassified information).[51] Several encryption solutions exist (e.g., Type 1 systems) for protection of unmanned systems communications (see DODI 4660). Numerous other policies and initiatives are under development within the NSA to significantly streamline the certification processes and reduce costs.[52] Future encryption solutions (2015) will inherently contain Suite B (public) encryption algorithms[53] to allow for secure classified information sharing with coalition and friendly forces. Additionally, an increasing number of encryption solutions will be based on such concepts as open standards for remote management; dynamic group keying (to support machine-to-machine information exchanges), common radio and system agnostic cryptographic interfaces (e.g., improving cryptographic component reuse and portability); software-based solutions for protection of classified data;[54] multifunctional single-chip data-in-transit and data-at-rest encryption; and single-chip all-encapsulated encryption modules (e.g., encrypt/decrypt/random key generation/key management).

7.4.5.5 Multiple Input, Multiple Output (MIMO) Systems

MIMO is a proven technology and is currently being used in commercial fourth generation (4G) wireless systems which have standards calling for a minimum of 100 Mbps for train and car speeds and 1 Gbps for stationary and walking speed. [55] MIMO combines information theory, FEC coding, signal processing, propagation theory, and consequently the mathematics behind MIMO and space-time coding is complicated. MIMO would utilize multiple paths (although not necessarily independent) with lower data rates on each path; apply space-time coding and capacity optimization to achieve a total high data rate mission; apply power saving to jammer margin; and evaluate performance in benign and stressed conditions.

With further improvements in E-discovery, interface design, and adaptive protocols, self-forming and self-healing mesh networks may enable unmanned systems to operate in multi-platform, multi-sensor type networks.

7.4.5.6 Protected Communications

In general, unmanned systems have been predominantly operated in benign environments. However, efforts are addressing improvements that are required to enable such systems to have assured and secure communications when operating in contested environments. These efforts leverage LPI, LPD, and Anti Jamming (AJ) activities that are underway in other communication systems developments. When moving UMS operations into contentious environments, a

[51] Source: Memorandum from NII, Subject: Cryptographic Methods for Protection of Unmanned Aircraft (UAS) Wireless Communications, 6 August 2003.
[52] Management Directive 17, (U) Requirements for the Pilot Implementation to Develop Information Assurance Government Off-The-Shelf (GOTS) Secret and Below (SAB) Products and Commercial Solutions for Classified.
[53] CNSSP 15, dated March 2010.
[54] Ongoing efforts by NSA/I851.
[55] The conditions in UAS applications are much different than those for commercial cell phones.

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classified System Threat Assessment Report needs to be developed such that the appropriate LPI, LPD and AJ techniques are selected for incorporation into the system's design. LPD generally seeks to hide specific mission activities and involves techniques such as low power, spread spectrum, pulsed transmissions and/or directional antennas. Certain aspects of DSA could also benefit LPD. A key technique for LPI is the use of bit cover sequences within waveforms. AJ techniques include incorporating randomization at the protocol level and frequency hopping. Some aspects of DSA software implementation could offer some AJ protection.

7.4.6 Network Systems

Networking of multiple unmanned systems may be necessary to better ensure connectivity of the systems in non-LOS, urban, hostile, and/or noisy EMS environments to relay or transfer the collected information. One such concept under development is within the DARPA's LANdroids program,[56] which calls for the deployment of small, inexpensive, smart robotic radio network relay nodes that can leverage their mobility to coordinate and move autonomously. It seeks to demonstrate the capabilities of self-configuration, self-optimization, self-healing, tethering, and power management. Another concept would be the application of service-orientated architecture approaches to future network configurations.

7.4.7 Optical Communications

The application of lasers in unmanned systems communications could provide increased target detection capabilities, improved anti-jam performance, and decreased EMI within the communication subsystem. Optical communication systems are hampered by atmospheric absorption challenges, yet they offer far greater bandwidth (measured in gigabits-per-second) capabilities. LOS optical links have been successfully demonstrated at link ranges in excess of 50 km. Applications could apply to fixed locations and in air-to-air and ship-to-ship scenarios. Theoretical estimates indicate that air-to-ground links are feasible at rates up to 100 Mbit/s for link slant ranges up to 100 km, depending upon atmospheric conditions. Due to the extreme narrow beamwidth of such systems, maintaining pointing accuracy to and from a moving unmanned system will be a major challenge (> 2020).

7.5 Future Trends

Based on the force multiplier that unmanned systems have provided to our combat troops, it is expected that there will be a continued and increasing demand for supported capabilities communication systems. Those demands will include such capabilities as a single operator conducting more real-time analysis of multiple situations, while the unmanned system performs many of its assigned functions autonomously. Future communications equipment will need to be simple plug-and-play payloads that are easily, quickly, and cost-effectively modified, updated, and/or upgraded.

[56] Source: http://www.darpa.mil/ipto/programs/ld/ld.asp.

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Future communications equipment will need to be simple plug-and-play payloads that are easily, quickly, and cost-effectively modified, updated, and/or upgraded.

7.6 Summary

There is tremendous worldwide competition for a finite amount of bandwidth. Concurrently, there is an increased demand for our unmanned systems to provide greater resolution, more persistent coverage, and continuous information flow. Technology supporting physical and software advances, and a fundamental shift in how we process and move vast quantities of data must be used to help overcome these conflicting requirements. Figure 15 provides a glimpse into the future capability and technologies we can expect throughout the course of this Roadmap.

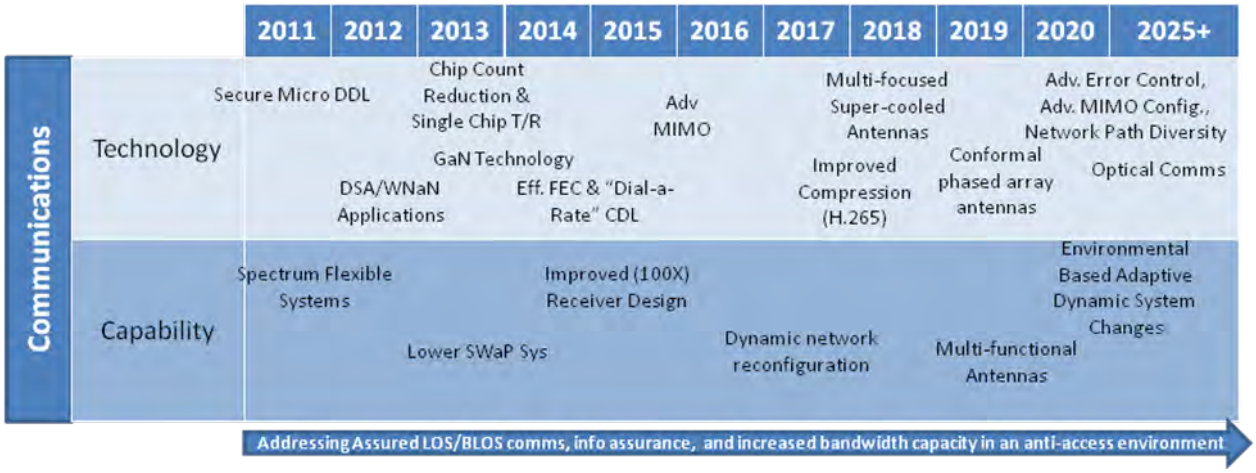


Figure 15. Communications Roadmap.

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8 TRAINING

8.1 Functional Description

Training is a critical link in delivering warfighter capability. DoD can acquire and deliver the most technologically advanced piece of machinery, but if the operators, maintainers, and support personnel are not properly trained, there is no warfighting capability. The criticality of this fact is emphasized by the requirement for acquisition program managers to "work with the training community to develop options for individual, collective, and joint training" as part of the acquisition process.[57]

Training is a learning process that involves the acquisition of knowledge, sharpening of skills, concepts and rules, or changing of attitudes and behaviors to enhance performance. Once initial training is complete, proficiency is maintained through continuation and Joint training. Unmanned systems present a unique training challenge due to the following factors:

- Availability of training areas/NAS integration.
- Frequency spectrum management.
- The rapid proliferation of numbers and types of unmanned systems in response to wartime demand.
- Differing organizational perspectives on vehicle operator qualifications, sensor operator qualifications, and support personnel requirements across the growing number of systems in all classes of UAS, UGS, and UMS.
- The reality that most USAF day-to-day continuation training is accomplished under in-theater combat conditions due to the high demand for UAS assets in real-world contingencies. This trend provides limited opportunity for the USAF to integrate its unmanned systems in pre-deployment training as the Army and USMC routinely do.
- Lack of operator interoperability and universal design standards for unmanned systems control stations.
- Lack of formalized joint tactics across the Services.

8.2 Today's State

As unmanned systems have matured and acquisition programs of record have emerged in all Services, a concerted effort has been made to ensure, wherever practical and possible, that the Services share logistics costs and burdens to include training and training systems. To date, many success stories can serve as a template for moving toward the vision of maximum joint training standard(s) for unmanned systems:

- USMC and Army personnel operate a joint Shadow UAS qualification course at the Army's training facility in Fort Huachuca, Arizona. While the Navy does not operate

[57] DoD Instruction 5000.02 Operation of the Defense Acquisition System, December 8, 2008, p.61.

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Shadows, Navy operators and maintainers were asked to help bridge a high-priority capabilities gap. This task was accomplished with no change in training hardware and software, simulation, or practical hands-on training. Navy personnel successfully deployed the Shadow system.

- The Chief of Staff of the Air Force and the Chief of Naval Operations signed a MoA to better utilize joint efficiencies in the Air Force Global Hawk and the Navy BAMS UAS programs. The goals of the working group are transparency between systems and a common work environment for both USAF and Navy operators.
- Army and Navy/USMC personnel share Raven B training and equipment, including maintenance requirements and GCSs.
- The JUAS COE[58] developed joint CONOPS, training qualification standards, and Tactics, Techniques, and Procedures for UAS.

Despite these success stories, given the DoD mandate to maximize training procedures and standardization for unmanned systems, the current state of unmanned systems training is still very much a work in progress.

The need for a comprehensive UAS training strategy was highlighted in UAS training workshops held in July and November 2009, hosted by the Office of the Deputy Assistant Secretary of Defense for Readiness, Directorate for Training Readiness and Strategy (ODASD(R)TR&S). The workshops were attended by all four Services, CCDRs, OSD, and Joint organizations involved with UAS issues. Additionally, a recent Government Accountability Office report recognized the lack of UAS training planning and called for the development of a DOD results-oriented strategy to resolve challenges that affect the ability to train personnel for UAS operations.[59]

> Provide soldiers and leaders the ability to excel in a challenging and increasingly complex future operating environment by developing tools and technologies that enable more efficient and effective training through live, virtual, constructive and mixed venues. Future training must enable the future force to impart more skills, faster, at lower cost and with greater retention than currently achievable. Soldiers and units must be able to be trained using non-traditional home station training techniques and technology and train prior to employment. Future training must enhance and account for individual proficiencies and learning rates (i.e. outcome based training). Future training and leader development must be completely adaptable and scalable to cover the full spectrum of operational challenges facing the Soldier.
>
> *– Capability Gap/Deficiencies, Robotic Systems Joint Project Office Unmanned Ground Systems Roadmap, July 2009*

[58] JCOE is being disbanded June 2011 and its tasks are being transferred to the Joint Staff and UAS Task Force.

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8.3 Problem Statement

As forces drawdown in theater and redeploy, the Services will require comprehensive continuation and Joint-forces training in the peacetime environment at beddown and selected Joint-training locations. Failure to prepare for this eventuality will result in a loss of combat gained experience.

8.4 Way Ahead

The ODASD(R)TRS is leading efforts to develop a comprehensive DoD UAS training strategy. The strategy will leverage the skills and expertise of each organization and build on foundational efforts already completed or underway within the Services. The study will investigate and assess the adequacy of existing and forecast joint, Service, and CCDR UAS plans and programs that identify and describe qualification, continuation, and joint training requirements and CONOPS. The strategy will identify and describe individual, unit, and large force training requirements of all groups of UAS. The result will be a UAS Training Roadmap that guides UAS training shortfall and mitigation analyses, provides UAS training recommendations, and proposes investment considerations for the UAS community. The UAS Training Roadmap will serve as a companion piece to this Unmanned Systems Roadmap to provide a total look at efforts related to delivering UAS capabilities to the warfighter.

Intuitively, some issues that will need to be addressed in the future include:

Policy: As attention shifts more towards day-to-day continuation training and UAS are further integrated into the NAS, unforeseen disconnects in the ability to train will need to be addressed in policy.

Education: UAS need to be habitually integrated into the kill chain in training scenarios. Commanders must be educated on the use of UAS as combat resources, and learn how to train with these relatively new assets. Tactical, Operational, and Strategic level UAS and ISR doctrine should be included in appropriate professional military education courses of instruction. Issues involving operator currency, flight minimums, and continuation training requirements must be learned and opportunities to train must be must be emphasized during home station training, combined exercises, and Joint Combined Training Center rotations.

Training Automation and Simulation: Rapidly expanding weapons systems capability requires associated expansion in training simulation. This expansion will need improved simulation fidelity and integration with live platforms for both effective/efficient use of resources. This will require improvements in training environments and classroom courseware.

Basing and Acquisition: As training requirements are defined, existing capabilities at proposed basing locations must be assessed against that which must be acquired to provide effective training.

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[59] GAO-10-331, UNMANNED AIRCRAFT SYSTEMS: Comprehensive Planning and a Results-Oriented Training Strategy Are Needed to Support Growing Inventories, March 2010.

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> … UAS operators advised that the use of simulation is critical to their preparation for combat. UAS simulation is so accurate and realistic that, specifically for the Shadow UAS, it is hard to tell the difference between the simulator and actual flight.
>
> *– SFC Brian Miller, UAS Standardization NCO, Directorate of Evaluation and Standards, USAACE, Fort Rucker*
>
> The majority of flight training is simulation.
>
> *– SSG Brian Morton, 15W UAS Instructor/Standardization NCO, UAS Training Battalion, Fort Huachuca*

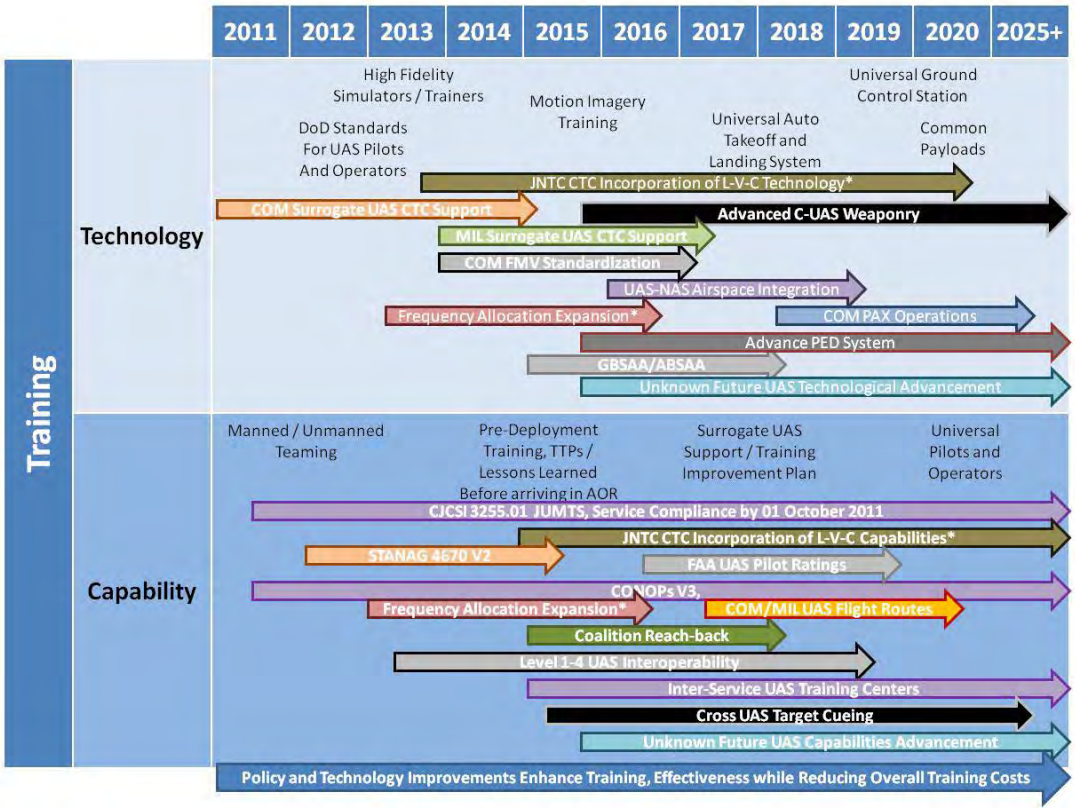


Figure 16. Training Timeline is notional. A DoD UAS Training Strategy is currently in development that will add specificity once developed.

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9 PROPULSION AND POWER

9.1 Functional Description

The dramatic increase in the development and deployment of unmanned systems across the entire spectrum of air, ground, and maritime mission requirements has led to a concurrent increase in the demand for efficient, powerful, often portable, and logistically supportable solutions for unmanned system propulsion and power plant requirements.

For the purpose of this section, propulsion and power consist of the prime power to provide thrust and electrical power conversion, management, and distribution necessary for the operation of the electrically driven subsystems required to perform an unmanned vehicle's mission.

9.2 Today's State

A wide array of propulsion systems is used in unmanned systems, including combustion engines powered by heavy fuel or gasoline, jet engines, electric systems, fuel cells, solar power, and hybrid power systems. These propulsion systems can be divided into three groups according to vehicle size and mission: turbine engines, internal combustion, and electrical. The thresholds are not simple or clean cut, but are highly dependent on mission goals. Some of the parameters taken into consideration to determine the optimum propulsion system include size, weight, airflow, range, efficiency, and speed. Similarly, numerous power systems are in use, including batteries, engine-driven generators, solar power and hybrid systems.

The T&E of propulsion and power is critical as we consider a world of declining energy reserves and the strategic initiatives in alternative energy being made by the DoD.

9.3 Problem Statement

Endurance is perhaps one of the most compelling aspects of unmanned systems. While power and propulsion systems are much improved over comparable manned systems, the search continues for even more efficient systems to provide greater endurance, speed and range such as the X-51A Scram Jet shown in Figure 17 preparing for first flight.



Figure 17. X-51A Scram Jet.

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9.4 Way Ahead

9.4.1 Propulsion

> A primary long-term goal in aircraft propulsion is to reduce system specific fuel consumption by more than 30 percent over (current) gas turbine engines…. Technical challenges being pursued include efficiency, high-overall-pressure-ratio compression systems; variable-cycle engine technologies; advanced high-temperature materials and more effective turbine blade cooling; and techniques to more efficiently recuperate energy while satisfying thermal and power requirements.
>
> *– The National Plan for Aeronautics Research and Development and Related Infrastructure*

These challenges are currently being addressed for UAS applications under the highly efficient embedded turbine engine (HEETE) and efficient small-scale propulsion (ESSP) products, which are part of the Versatile Affordable Advanced Turbine Engines (VAATE) Program.

HEETE will demonstrate engine technologies that enable fuel-efficient, subsonic propulsion that supports future extreme endurance and range requirements with embedded engines incorporating complex inlets and exhausts. Covering the thrust class of 20,000 to 35,000 lbs, HEETE has two challenges: packing a high-bypass engine internally and delivering large amounts of electrical power regardless of throttle or flight condition. The HEETE design provides very small, high-powered cores to enable high bypass within the diameter constraints of an internally packaged engine. The propulsive efficiency is provided by highly efficient fans designed with the distortion tolerance needed to run behind complex inlets. The HEETE cores run at impressive pressure ratios, greater than 2.3 times the current state-of-the-art, and such ratios enable high tolerance of auxiliary power at high-altitude, long-endurance (HALE) altitudes. See Figure 18 HEETE cutaway view.



Figure 18. Highly Efficient Embedded Turbine Engine (HEETE).

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ESSP will cover a full spectrum of technologies for propulsion systems for vehicles ranging from 100 to 2500 lbs. These products promise game-changing system capabilities. The S&T challenge to meet the ESSP goals is the simultaneous combination of high power density with high efficiency (low specific fuel consumption) in a design space not typically addressed by either gas turbine or piston engine systems (see Figure 19. Efficient Small-Scale Propulsion (ESSP).).

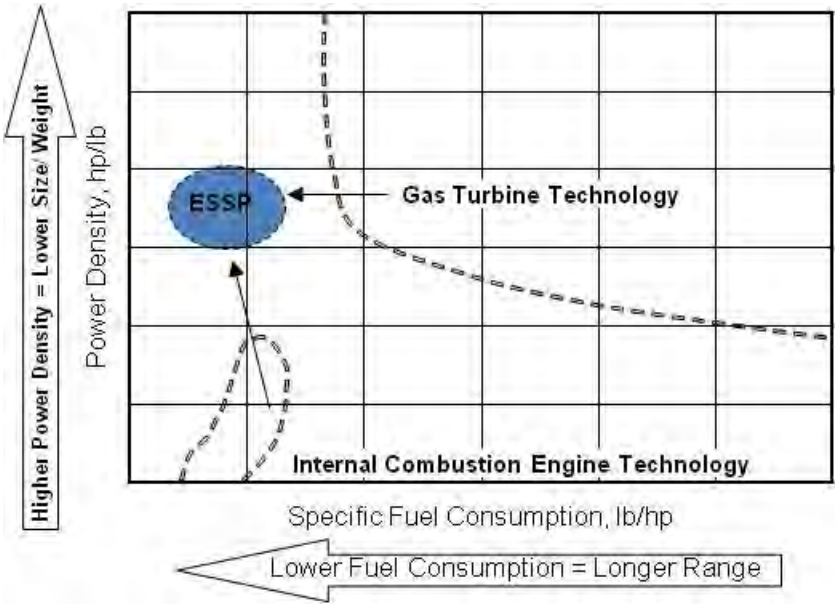


Figure 19. Efficient Small-Scale Propulsion (ESSP).

ESSP will conduct various demonstrations leading to reduced specific fuel consumption (SFC), increased power density, and a heavy fuel consumption capability. These demonstrations include a ducted fan, a nutating engine, a heavy fuel engine conversion, and a recuperator. ESSP is also designing and rig-testing high pressure ratio compressors and high temperature capable turbine concepts aimed at long-term capability.

The ducted fan is the most complex of the near-term demonstrations. The two main technologies to be demonstrated are the high-bypass geared ducted fan and the variable turbine nozzle. The test demonstrates the capability to run the high-bypass ducted fan with airflow from two different distributed core gas generators for maximum power during takeoff and maneuvering and then turning off one core gas generator, as a variable cycle feature, at cruise to cut the fuel consumption (conventional high-bypass turbofans would have to pull back the power setting to attain cruise condition, and this method would decrease engine speed, reduce the pressure ratio, and decrease component efficiencies resulting in increased SFC). The remaining core gas generator used to drive the ducted fan at cruise condition continues to operate at its design point for best cycle SFC. The variable turbine nozzle matches the airflow changes to maintain efficient turbine performance and drive the ducted fan.

The nutating disk engine leverages small business innovation research (SBIR) contracts for both the 4-inch and 8-inch disk engines. Both engines utilize the OSD SBIR-derived advanced microcomponents to enable engine performance potential. The major technical challenges are the

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development of micro-fuel injectors and radial engine seals and the understanding of the thermodynamics process. Both sizes of disk engine have undergone initial testing and show a significant increase in power density, to 1.38. The nutating disk is scalable to multiple UAV platforms by scaling the disk size.

The heavy fuel conversion engine, i.e., the Rotax used in the Predator, runs on aviation gasoline (AvGas, 100 octane). The Rotax concept demonstration is aimed at running the engine initially with lower octane fuels and ultimately with JP-8 heavy fuel. Engine testing has been completed successfully with 70 octane fuel. Although octane level is not specified for JP-8 fuel, fuel analysis to date has shown variations between a 20 to 50 octane level. Testing is on-going to demonstrate the operation of the Rotax engine on JP-8 fuel with targeted completion by the end of 2010. In parallel, there are SBIR efforts working to convert the Shadow UEL AR-741 engine to JP-8 fuel. Conversion efforts are aimed at maintaining engine performance levels while operating with JP-8 fuel.

The WTS126 turbo generator, developed by Williams International to drive the General Motors electric car, has a highly efficient recuperator, but is too heavy and large for installation into a flight vehicle. VAATE II studies indicated that a less efficient recuperator appeared to be the best balance among performance, size, and weight for a flight vehicle application. The WTS126 is an alternative heavy fuel propulsion system candidate for the Shadow. Testing and evaluation of the baseline WTS126 and the version with the less efficient flight weight recuperator are both underway.

For smaller platform applications, fuel cells offer an attractive alternative for internal combustion engines as field power generators, ground vehicle and aircraft auxiliary power units (APUs), and primary power units for small UAS. Fuel cells are devices that electrochemically combine fuel and air to produce high-quality electrical power. Because these systems do not generate power via combustion processes, they offer significantly lower SFC rates relative to advanced heavy fuel engines or diesel power generators (see Figure 20).

Solid oxide fuel cell (SOFC) systems represent a compelling power system option due to their high efficiencies, fuel flexibility, and low audible signature. Compared to other fuel cell approaches, the thermal environment and conductivity mechanism in SOFCs allow for a considerable improvement in fuel tolerance and provide a path forward for electrochemical logistic fuel operation.

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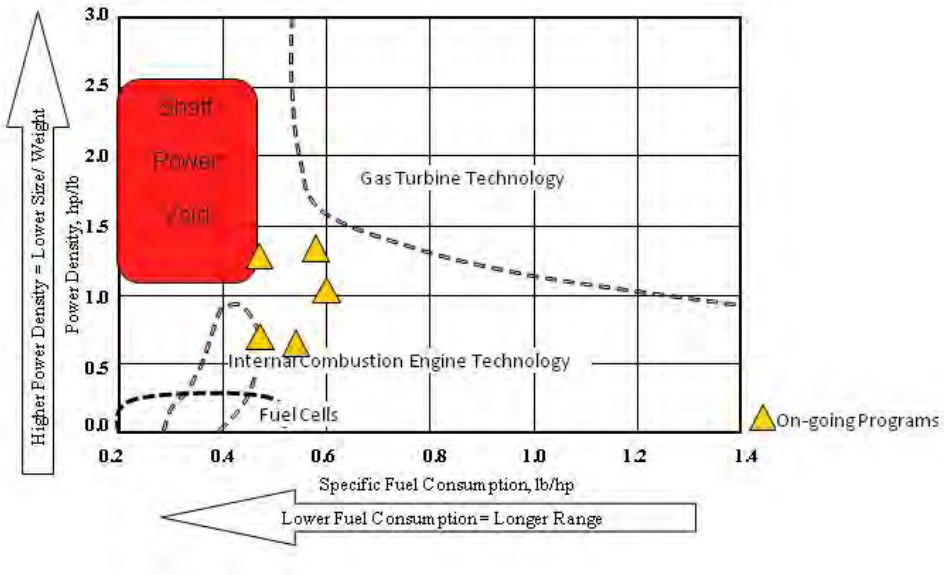


Figure 20. Fuel Cell Efficiency.

9.4.2 Power

Power sources are critical enablers for all of the desired unmanned systems capabilities. Improved power sources will have to be compact, lightweight, and reliable; provide enough power for the desired mission; and satisfy a full range of environmental and safety requirements. Design of power sources must be optimized for specific platforms and use profiles. Depending on the platform and mission requirements, applicable technologies may include energy harvesting (e.g., photovoltaic), electrical energy storage devices, fuel cells, and generators. It may be attractive to hybridize two or more of these technologies depending on the expected use profile. To implement these hybrid systems, the development of the proper control schemes must also be conducted. Recently, there has been a lot of effort invested to improve the power density of power generation systems with very good progress, but work is still needed to improve other power systems critical metrics. Some of these needed metrics and improvements are life, reliability, efficiency, optimized performance over varying engine speed, wide temperature range, production variability, control strategy, and parameters that capture the fact that unmanned subsystems typically do not have the redundancy of manned systems. Early scrutiny of the vehicle design will lead to improved power management. Form factor, materials, autonomy in sensor usage and route planning, and consideration of the undersea physical environment will minimize the energy demands and give back energy to extend the endurance or meet other mission goals.

Advances in mission equipment are providing much greater capabilities, but at a cost of greater demand for electric power, which results in greater power extraction from the engine. Power-sharing architectures allow for tailoring the source of power generation to minimize the cost in fuel burn. For example, if low-pressure (LP) power extraction is more economical than high-pressure (HP) power extraction, then the SSPCs can be turned on to power the bus that was previously powered by the HP-driven generator. Engine power extraction technologies related to power sharing between the HP spool and LP spool promise to provide significant benefit to

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bridging the gap between the platform power requirements and the engine power extraction limitations. Additionally, LP power extraction promises to provide improvements to SFC for overall air vehicle energy efficiency. Some of the key technologies needed to implement a power-sharing architecture are reliable power management control logics, high-power high-speed solid-state power controllers (SSPCs), a modulating generator control unit (GCU), and high-capacity electrical accumulator units (EAUs).

The HP GCU can be used to reduce the HP generator output and thus in a similar manner reduce the load on the HP spool to allow the LP generator to fulfill the power demand. The EAUs will be used to support radar peak-power demands and the power demands of short-duration, defensive-directed energy weapons.

9.4.3 Future Opportunity

Work is still needed to demonstrate the shaft power void. However, the large-engine approach of high overall pressure ratios (going to typical small-engine-corrected flow levels) is not available to small engines because of the physical size constraints of turbomachinary. Therefore, nontraditional configurations need to be emphasized to achieve the next level of capability.

Concerning battery chemistries and fuel cells, in the near term (up to 5 years), incremental power and energy performance improvements will continue to be made in the area of rechargeable lithium ion batteries. Lithium ion batteries will see broader military and commercial application, and significant cost reductions will be made as the manufacturing base matures. Near-term availability of small, JP-8 fuel-compatible engines is expected. There is mid-term (5 to 15 years) potential for significant incremental performance advances through the discovery and development of alternative lithium ion chemistries. Mid-term development of fuel cells with moderate power levels (100 W class) will begin to be introduced based on low-weight hydrocarbon fuels (e.g., propane). The technical feasibility of heavy hydrocarbon-fueled (e.g., JP-8) fuel cell systems will be proven at the kilowatt class. In the long term (beyond 15 years), there is the potential for revolutionary improvements through the discovery and development of completely new battery chemistries and designs. Figure 21 charts a course for power and propulsions capabilities and technologies.

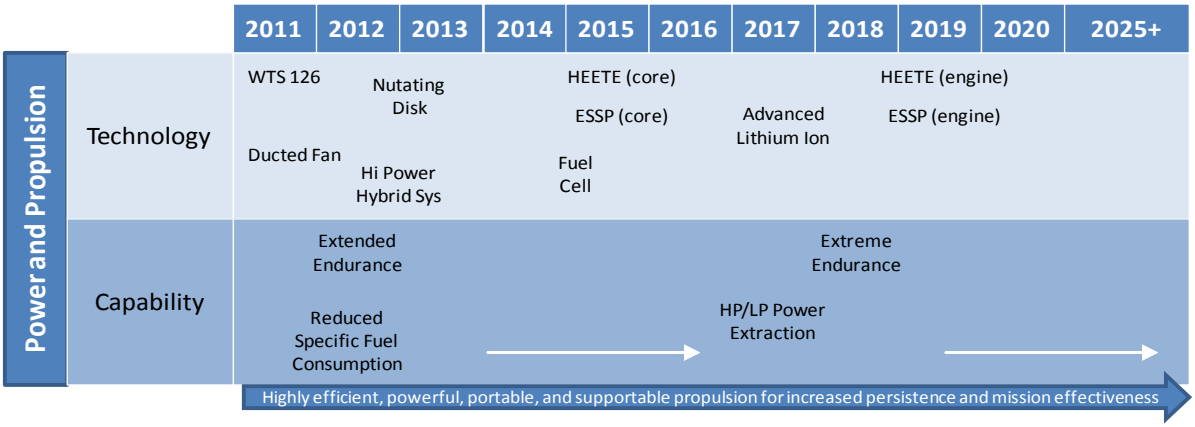


Figure 21. Propulsion and Power Roadmap.

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10 MANNED-UNMANNED (MUM) TEAMING

10.1 Functional Description

For this discussion, MUM teaming refers to the relationships established between manned and unmanned systems personnel prosecuting a common mission as an integrated team. More specifically, MUM teaming is the overarching term used to describe platform interoperability and shared asset control to achieve a common operational mission objective. This term also includes concepts of "loyal wingman" for air combat missions and segments of missions such as MUM air refueling. This capability is especially vital for missions such as target cueing and handoff between manned and unmanned systems, where the operators not only require direct voice communications between the participants, but also a high degree of geospatial fidelity to accurately depict each team member's location with regard to the object being monitored.



MUM teaming was first employed in the late 1960s when the USAF flew AQM-34 equipped with Maverick missiles from airborne C-130 aircraft. Over the intervening years, other experimental UAS were flown from manned aircraft and during the Predator ACTD from a submarine. In 2002, the USAF demonstrated the ability to fly the MQ-1 from a flying C-130 also equipped with a FMV camera to prove a rapid, small-footprint deployment capability, and the ability to cooperatively prosecute targets with onboard and off-board systems. The Army also conducted MUM demonstrations beginning with the Airborne Manned/Unmanned Systems Technology (AMUST) Demonstration in 2001 with a follow-on Hunter Standoff Killer Team (HSKT) ACTD in 2006. During that demonstration, an AH-64D executed level of interoperability (LOI) 4 control of a RQ-5B Hunter UAS during a live fire exercise where Apaches lased for their own Hellfire missiles with the Hunter payload.[60] At these demonstrations, the Army Aviation Applied Technology Directorate successfully integrated a Mobile Commander's Associate[61], including UAS control, Link 16, and other various data links, into an Army airborne C2 system. This integration enabled an airborne C2 system operator located in a UH-60 Black Hawk helicopter to control a Hunter UAS and its sensor, for the first time, as well as send and receive tactical information in flight between strike aircraft such as the FA-18, and reconnaissance aircraft such as JSTARS.[62] To date, each of the demonstrations merely changed the location of the control of the vehicle off the ground. This

[60] "Hunter Standoff Killer Team Successfully Tests Military Interoperability," 16 September 2005, http://aero-defense.ihs.com/news/2005/navy-air-systems-link-16.htm?WBCMODE=presenta.
[61] "Mobile Commander's Associate (MCA), Lockheed Martin, USA", http://defense-update.com/products/m/mca.htm .
[62] Colucci, Frank, "MUM's The Word," *Rotor & Wing Magazine*, 1 November 2004, http://www.aviationtoday.com/rw/military/attack/1817.html.

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change was still significant because of the ability to more effectively conduct certain types of missions through collaboration of all assets.

10.2 Today's State

Practical applications of MUM teaming continue to evolve as confidence in unmanned vehicle reliability and functionality matures. Employment concepts are limited by data links, vehicle control interfaces, and level of autonomy. One recent example of practical application is when the USMC fielded a laser designation capability for Shadow as an enhancement/enabler of sensor-to-shooter operations for enemy/target of interest engagement in April 2010.

10.2.1 Unmanned Ground Vehicles (UGVs)



MUM teaming has steadily increased as technology has improved and users have found new and innovative methods to exploit this enhanced mission capability. Current missions include reconnaissance, surveillance, and target acquisition (RSTA); transport; countermining; explosive ordnance disposal; and the use of armed unmanned tactical wheeled vehicles for checkpoint security inspections. The integration of one-system remote video terminal (OSRVT) technology and distributed UGV control into ground combat vehicles is leading to the adaptation of TTPs because all parties now receive the same picture at the same time, regardless of their location.[63] With over 4,000 OSRVT or like systems fielded between the Army, USMC, and USAF to date, it is clear that MUM teaming is becoming ever more pervasive in ground operations. These developments have also been the catalyst for the creation of the common robotic controller, a joint project between the Army and USMC to develop a universal, wearable controller to operate a wide variety of unmanned systems, including UGVs, UA, and unattended ground sensors. This effort is currently aimed at smaller platforms, but could be transitioned to include limited control (i.e., payload only) for larger platforms as the technology matures.

[6363] Lt. Col. Adam Hinsdale, former Chief, UAS Division, Department of the Army Aviation Directorate, was quoted in October 2007: "Everyone, regardless of the platform, receives the same information at the same time, leading to true interoperability, the Army's key goal. The OSRVT is a vital component of manned/unmanned teaming, allowing all elements, air and ground, to view the same synchronized area of interest simultaneously for coordinated engagement, with either kinetic or nonkinetic effects." *UAS Video Terminal Connects Boots On The Ground To Eyes In The Sky*, by Kim Henry, Redstone Arsenal, AL, (AFNS), 9 October 2007.

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10.2.2 Unmanned Aircraft Systems (UAS)



MUM teaming has been successfully demonstrated in combat operations to provide CCDRs with enduring surveillance of hostile activities in real/near-real time to accurately geolocate potential targets, to laser-designate targets, and to provide battle damage assessment. UAS have proven successful in performing their missions largely because they are able to remain visually and aurally undetected by hostile forces. They are providing the CCDR with critical tactical data, which are used to plan and support combat operations. When used in support of ground operations, UAS have proven invaluable in providing near-real-time intelligence to commanders engaged in combat and have directly contributed to successful mission completion. Armed UAS have the ability to engage targets directly or cooperatively with other air and ground systems. Additionally, LOI 3 (control and monitoring of the UA payload in addition to direct receipt of UA data) has been demonstrated successfully in combat operations with attack helicopter crews. The attack helicopter crew is able to see on their cockpit display the sensor outputs that give them overhead views to the target and surrounding area. This capability greatly enhances the attack helicopter crew's ability to identify, classify, and verify target locations to reduce the risk of fratricide. In September of 2010, the Army conducted an integration exercise featuring Apache helicopter pilots controlling Shadow, Hunter and Raven UAs.

The success of the exercise resulted in the inclusion of the LOI 2 and 3 UA control requirement into the AH-64, which gives the manned aircraft sensor and flight-path control and monitoring of the UA (less launch and recovery). The Apache Block III initial fielding is scheduled for 2012 and will incorporate LOI 2, 3, and 4 UA control. The AH-64 BLK III will have the capability to receive real-time UA FMV and the associated metadata (LOI 2), control the UA electro-optical/infrared (EO/IR) payload (LOI 3), and dynamically task the UA flight path (LOI 4), all from the front seat of the Apache. The initial combat operations in Afghanistan and Iraq validated the urgent need to integrate UAS capabilities with manned aircraft, specifically the attack platforms. Commanders recognized that they could dramatically reduce sensor-to-shooter times and improve situational awareness of helicopter pilots, while drastically reducing collateral damage and the potential for fratricide. They crafted an Operational Needs Statement for attack helicopter MUM teaming capability that led to a rapid prototype system for the Apache called Video from Unmanned Aircraft Systems for Interoperability Teaming – Level 2 (VUIT-2). The VUIT-2 system allows the AH-64 crew to receive video feeds from UA utilizing C-Band transmission. The Army has renamed this effort MUMT-2 and expanded it to UH-60 Black Hawk and OH-58D Kiowa Warriors.

Current MUM teaming applications are limited due to the fact the control interface currently requires a dedicated crew member to fly the UAS while another crew member flies the manned aircraft. However, some automated MUM mission segments are being developed. For example, the Navy and USAF have developed and demonstrated technology for MUM air refueling and have simulated cooperative MUM air combat missions.

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10.2.3 Unmanned Maritime Systems (UMS)

MUM teaming is critical for the maritime environment. This is especially true for the undersea domain where physics prevent man from safely performing tasks to the same fidelity. There are many different aspects of MUM teaming for UMS that have been explored and implemented in various degrees: long-endurance undersea gliders send data ashore and receive human-initiated mission updates in near real-time; UUVs enable efficient port security, harbor defense, and mine clearance operations through change detection and autonomous investigation of mine-like objects; likewise, UUVs extend the footprint of manned hydrographic and bathymetric survey platforms to gather higher volumes of data while enabling people to focus on the tasks that require human oversight. Near-term enhancement, development and codification of Water Space Management/Prevention of Mutual Interference (WSM/PMI) doctrine and procedures will allow sophisticated collaboration between submarine or surface vessel operations and unmanned assets for mission accomplishment. Given the inherent challenges of the maritime environment, the future of MUM teaming will consist of multiple types of unmanned systems (UUV, USV, UAV, UGV) used collaboratively with manned platforms to collect, process, exploit, and disseminate data. An enduring and integrated net of undersea sensors partnered with USVs or UAVs for communication and controlled from a common command center will revolutionize how undersea missions are conducted by bringing transparency to an otherwise opaque battlespace. All maritime missions will benefit from reduced timelines and improved accuracy of information from which the combat commander can make engagement decisions.

10.3 Problem Statement

While strides have been made over the past decade to further enhance MUM teaming capabilities, several challenges persist that will continue to affect the amount of time it takes this technology to transition from the invention and adaptation phase to the acceptance phase. This timing will also directly affect the development of MUM teaming TTPs, which in turn will dictate the speed of MUM teaming from CONOPS into DoD doctrine.

Some of these challenges are technical. They range from near-term issues such as the limited ability to integrate and deconflict various radio frequencies across a secure communications network, to far-term issues such as the ability of one person to control multiple UASs and UGVs simultaneously while flying his or her primary aircraft. This ability requires a high degree of hardware and software interoperability, scalable autonomy, human system interfaces (HSIs), new collaborative control algorithms, and network mission tools. The platforms must do significant levels of onboard processing to not only reduce bandwidth required, but also collaborate with other unmanned vehicles without operator input. Other technical challenges result from the need to make tradeoffs between size, weight, and power limitations on the various platforms and the desire for increased performance and capability. One of the biggest potential challenges to MUM operations stems from the Services' desire to introduce swarms (large numbers



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of micro-UAS operating semi-autonomously) into military operations with other manned and unmanned systems.

> "Everyone, regardless of the platform, receives the same information at the same time, leading to true interoperability; this is the Army's key goal.
>
> - *Lt. Col. Adam Hinsdale, Chief, UAS Division, Department of the Army Aviation Directorate*

Other MUM missions have different challenges including cargo, air refueling, interdiction in contested areas, electronic/network attack (EA), suppression of enemy air defenses (SEAD), and other traditional air combat missions. The ability to communicate from a highly maneuverable aircraft to a highly maneuverable future UAS will require significant advances in autonomy and HSI. This advancement can be compounded if LPI communication is needed for missions such as EA, SEAD, or control of long-dwell insect-size vehicles collecting information inside buildings.

10.4 Way Ahead (2011–2036)

Some key events will affect the future of MUM teaming over the next 25 years. As improvements in communications and sensor technologies evolve, new tactics will surely follow. For instance, it should be expected that there will be a shift away from the current reliance on video with operators incorporating other sensors (such as audio or tactile) to augment the tactical picture. Also, as commanders continue to integrate multiple manned and unmanned systems into their operations, they will soon be able to implement a "field of view" approach, similar to the "God's eye" perspective seen in many current video games. A commander will be able to view a target from multiple perspectives (i.e., UGV, UAS, or manned sensors), using multiple sensors, to obtain more robust and comprehensive situational awareness. As MUM advances, new HSI and autonomy will change the role of people in mission execution and dramatically increase their effectiveness.

The most significant advances in MUM operations will begin as Services migrate away from the current closed-loop scenario between sensor and shooter to networked systems. High endurance UAS already have mission teams geographically separated from the platform and from each other. Wide-area sensors are also changing the paradigm on STANAG 4586 LOIs and USIP development. Employing MUM segments as nodes on a larger network will change how missions are executed and will dramatically affect the combat effectiveness.

Investments in technologies such as automated air refueling, tactical data link control of maneuverable aircraft, and autonomy in the near term will enable "loyal wingman" operations. The effectiveness of air missions will not be achieved by a collection of assets, but collaboration between manned and unmanned systems within the context of a network. These nodes on the network will have scalable transparent control, not the brittle closed-loop control and inflexible autonomy algorithms used today.

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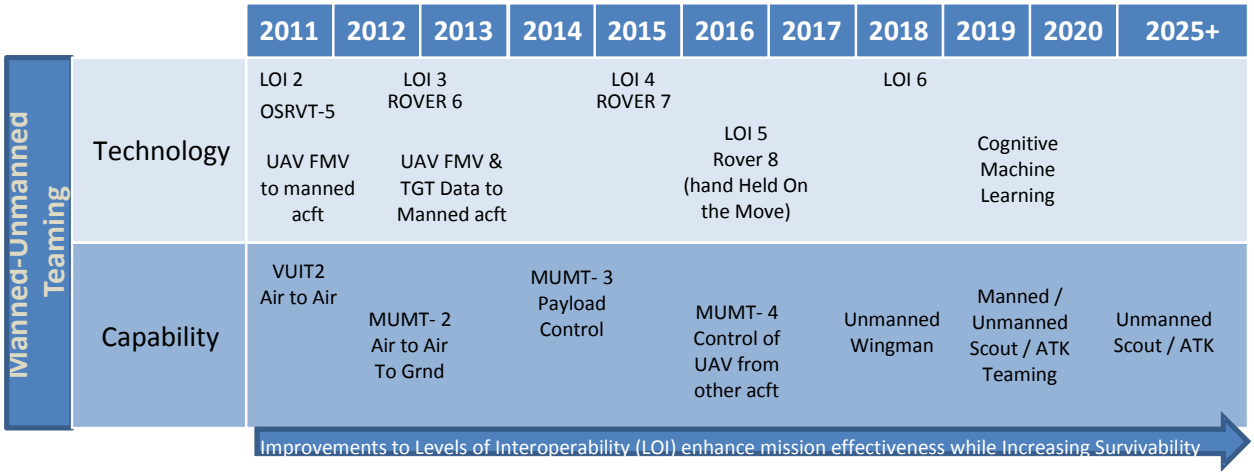


Figure 22. Manned Unmanned Teaming Roadmap.

The rapid growth in the OPTEMPO and demand for unmanned systems is a validation of their value to the CCDR. New concepts for the use of UAS, UGS, and UMS will result from experiences gained in combat. In the near future, it is likely that MUM teaming will be incorporated into an expanded set of operations.

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11 SUMMARY

DoD has made great strides in developing, producing, and fielding unmanned systems. These systems have been effectively integrated across air, ground, and maritime domains to support a wide range of Joint warfighting needs. The inherent advantages of unmanned systems, including persistence and reduced risk to human life, have been clearly demonstrated in combat operations in Iraq and Afghanistan.

DoD envisions the continued expansion of unmanned systems in the future force structure. This expansion will include fielding additional systems in capability areas already supported by unmanned technologies, but also expanding into new mission areas not currently covered. As DoD defines a path toward this vision, a common set of challenges is apparent that cuts across all military Services, budgets, and all three domains of air, ground, and maritime. DoD, working together with industry, academia, and other Government agencies, will continue to map an affordable path forward to address these common challenges. Success in addressing the common issues discussed in this document and following the technology roadmaps summarized in Figure 23 (see next page) is critical to achieving the full potential offered by unmanned systems technologies.

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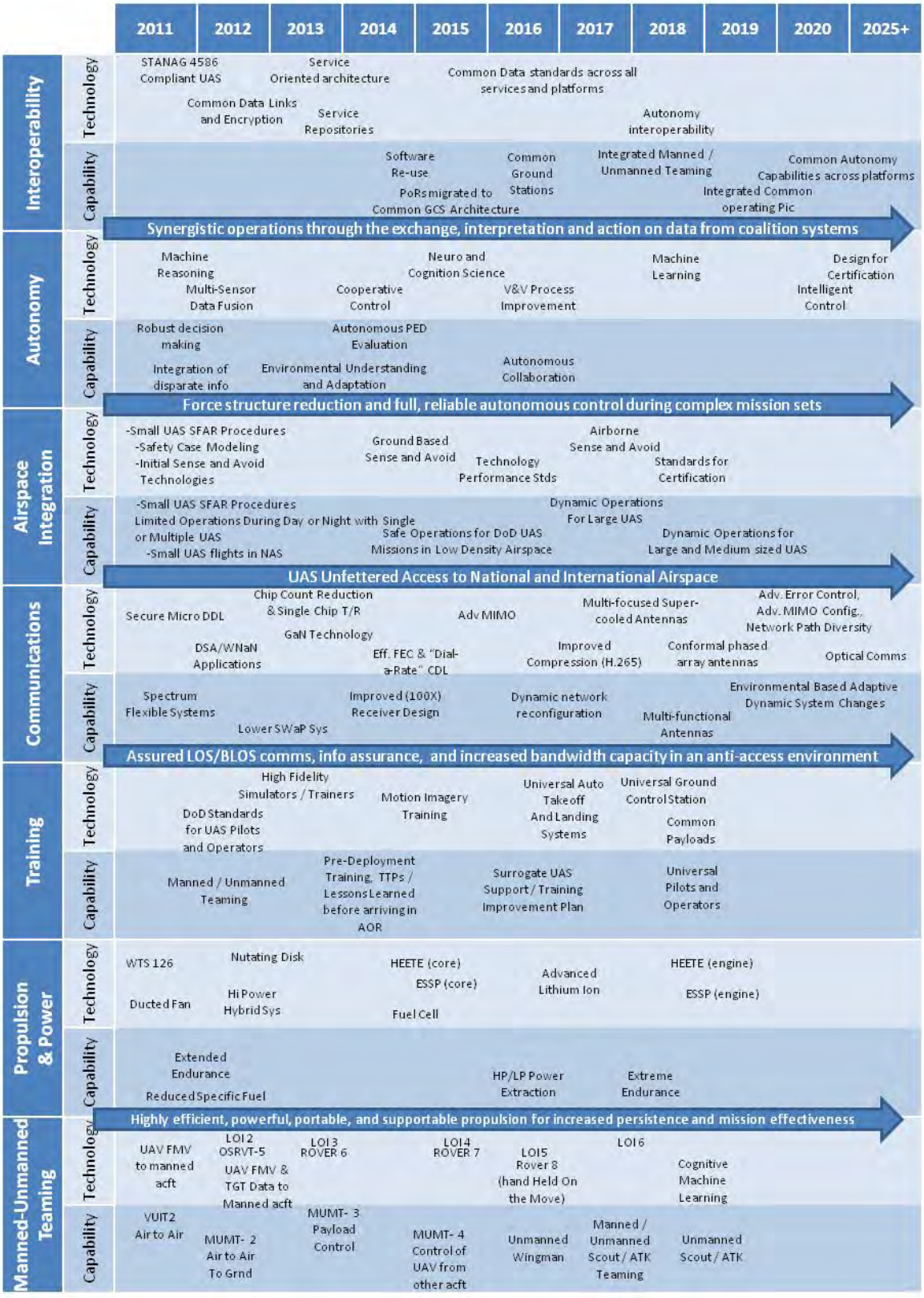


Figure 23. Summary of Technology Roadmaps.

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APPENDIX B: ABBREVIATIONS

4G	fourth generation
AAM	air-to-air missile
AATD	Army Aviation Applied Technology Directorate
ABSAA	airborne sense and avoid
ACAT	Acquisition Category
ACTD	Advanced Concept Technology Demonstration
ADC	analog-to-digital converter
AECV	All Environment Capable Variant
AEODRS	Advanced Explosive Ordnance Robotic System
AI	airspace integration
AMRDEC	Aviation and Missile Research, Development and Engineering Center
AMUST	airborne manned/unmanned systems technology
APU	auxiliary power unit
ASM	air-to-surface missile
ASW	anti-submarine warfare
ATS	air traffic services
AvGas	aviation gasoline
BA	Battlespace Awareness
BAMS	broad-area maritime surveillance
C2	command and control
CA	collision avoidance
CAP	Combat Air Patrol
CBP	Customs and Border Protection
CCDR	Combatant Commander
CDL	common data link
CFR	Code of Federal Regulations
CNO	Chief of Naval Operations
COA	Certificate of Waiver or Authorization
CONEMP	concept of employment
CONOPS	concept(s) of operations
COP	common operational picture
COTS	commercial, off-the-shelf
CSS	combat services support
CV	cargo variant
DDL	digital data link
DHS	Department of Homeland Security
DIMA	DARPA Interference Multiple Access
DLI	data link interface
DoD	Department of Defense
DOTMLPF	doctrine, organization, training, materiel, leadership and education, personnel, and facilities
DOTMLPF-P	doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy
DPRK	Democratic People's Republic of Korea
DSA	dynamic spectrum access
DSPM	domain service portfolio management
EAU	electrical accumulator unit
EMI	electromagnetic interference
EMS	electromagnetic spectrum
ESSP	efficient small scale propulsion
EW	early warning
FA	Force Application
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FCS	Future combat system
FEC	forward error correction

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FMV	full-motion video
GaAs	gallium arsenide
GaN	gallium nitride
GBSAA	ground-based sense and avoid
GCS	ground control station
GCU	generator control unit
GDP	gross domestic product
gMAV	Gasoline-powered Micro Air Vehicle
GPS	global positioning system
GUI	graphical user interface
HAIPE	High Assurance IP Encryption
HEETE	highly efficient turbine engine
HSKT	Hunter Standoff Killer Team
ICAO	International Civil Aviation Organization
IED	improvised explosive device
I-IPT	Interoperability Integrated Product Team
IPSEC	Internet Protocol Security
ISR	intelligence, surveillance, and reconnaissance
ITU	International Telecommunication Union
JAUS	Joint Architecture for Unmanned Systems
JCA	Joint Capability Area
JCGUAV	Joint Capability Group Unmanned Aerial Vehicle
JMOC	Joint Maritime Operations Center
JSIDL	JAUS Service Interface Definition Language
JTRS	Joint Tactical Radio System
JTS	JAUS Tool Set
LCS	littoral combat ship
LOS	line of sight
LRU	line replaceable unit
MALE	medium-altitude, long-endurance
MDF	multisensor data fusion
MIMO	multiple-input, multiple-output
MISM	motion imagery systems matrix
MISP	motion imagery standards profile
MOA	Memorandum of Agreement
MPG	multiple power pod gas generator
MUM	manned-unmanned
NAS	National Airspace System
NII	national information infrastructure
NSA	National Security Agency
NSRDEC	Natick Soldier Research, Development & Engineering Center
NUWC	Naval Undersea Warfare Center
OA	open architecture
ODUSD(R)RTPP	Office of the Deputy Under Secretary of Defense (Readiness), Readiness and Training Policy and Programs
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OPTEMPO	operational tempo
OSD	Office of the Secretary of Defense
OSRVT	one-system remote video terminal
OUSD(AT&L)	Office of the Under Secretary of Defense, Acquisition, Technology and Logistics
PEO(LMW)	Program Executive Officer of Littoral and Mine Warfare
QRF	quick reaction force
RFI	request for information
ROV	remotely operated vehicle
RS-JPO	Robotic Systems Joint Project Office
RSTA	reconnaissance, surveillance, and target acquisition
S&T	science and technology

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SAA	sense and avoid
SAE	formerly known as the Society of Automotive Engineers, now known simply as SAE
SAR	synthetic aperture radar
SATCOM	satellite communications
SBIR	small business innovation research
SBU	sensitive but unclassified
SDO	standards development organization
SDS	spectrum-dependent system(s)
SF	special forces
SFC	specific fuel consumption
SIGNT	signals intelligence
SOA	service oriented architecture
SOCOM	Special Operations Command
SOFC	solid oxide fuel cell
SSPA	solid state power amplifier
SSPC	solid-state power controller
SSRA	spectrum supportability and risk assessment
STANAG	Standardization Agreement
STD-CDL	standard common data link
STUAS	small tactical unmanned aircraft system(s)
SuDDL	secure micro-digital datalink
SWaP-C	size, weight, power, and cooling
SWCC	special warfare combatant-craft crewman
TOC	total ownership costs
TPED	tasking, processing, exploitation, and distribution
TTP	tactics, techniques, and procedures
UA	unmanned aircraft
UAS	unmanned aircraft system(s)
UCAS	unmanned combat aircraft system
UGS	unmanned ground system(s)
UGV	unmanned ground vehicle
UMS	unmanned maritime system(s)
UMV	unmanned maritime vehicle
USC	United States Code
USIP	UAS System Interoperability Profiles
USV	unmanned surface vehicle
UUV	unmanned underwater vehicle
UW	unconventional warfare
VAATE	versatile affordable advanced turbine engine
VBSS	visit, board, search, and seizure
V&V	verification and validation
WSARA	Weapon Systems Acquisition Reform Act
WGS	Wideband Global SATCOM
WNaN	Wireless Network after Next
WRC	Worldwide Radio Communication Conference

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APPENDIX C: GLOSSARY

Analysis and Production – The ability to integrate, evaluate, and interpret information from available sources and develop intelligence products that enable situational awareness.

Battlespace Awareness – The ability to understand dispositions and intentions as well as the characteristics and conditions of the operational environment that bear on national and military decision-making.

Building Partnerships – The ability to set the conditions for interaction with partner, competitor or adversary leaders, military forces, or relevant populations by developing and presenting information and conducting activities to affect their perceptions, will, behavior, and capabilities.

Collection – The ability to obtain required information to satisfy intelligence needs.

Command and Control – The ability to exercise authority and direction by a properly designated commander or decision maker over assigned and attached forces and resources in the accomplishment of the mission.

Communicate – The ability to develop and present information to domestic audiences to improve understanding; and, to develop and present information to foreign audiences to affect their perceptions, will, behavior and capabilities to further U.S. national security or shared global security interests.

Communicate Intent and Guidance – The ability to promulgate a concise expression of the operational purpose, assessment of acceptable operational risk, and guidance to achieve the desired end state.

Decide – The ability to select a course of action informed and influenced by the understanding of the environment or a given situation.

Deployment and Distribution – The ability to plan, coordinate, synchronize, and execute force movement and sustainment tasks in support of military operations. Deployment and distribution includes the ability to strategically and operationally move forces and sustainment to the point of need and operate the Joint Deployment and Distribution Enterprise. (JL(D) JIC pg 5 and pages 14-21)

Direct – The ability to employ resources to achieve an objective.

Engagement – The ability to use kinetic and non-kinetic means in all environments to generate the desired lethal and/or non-lethal effects from all domains and the information environment.

Force Application – The ability to integrate the use of maneuver and engagement in all environments to create the effects necessary to achieve mission objectives.

Health Readiness – The ability to enhance DoD and our Nation's security by providing health support for the full range of military operations and sustaining the health of all those entrusted to our care.

Information Transport – The ability to transport information and services via assured end-to-end connectivity across the NC environment.

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Intelligence, Surveillance and Reconnaissance – The ability to conduct activities to meet the intelligence needs of national and military decision-makers.

Intelligence, Surveillance and Reconnaissance Dissemination – The ability to present information and intelligence products that enable understanding of the operational environment to military and national decision-makers.

Intelligence, Surveillance and Reconnaissance Planning and Direction – The ability to synchronize and integrate the activities of collection, processing, exploitation, analysis and dissemination resources to meet information requirements of national and military decision-makers.

Kinetic Means – The ability to create effects that rely on explosives or physical momentum (i.e., of, relating to, or produced by motion).

Logistics – The ability to project and sustain a logistically ready joint force through the deliberate sharing of national and multi-national resources to effectively support operations, extend operational reach and provide the joint force commander the freedom of action necessary to meet mission objectives.

Maneuver – The ability to move to a position of advantage in all environments in order to generate or enable the generation of effects in all domains and the information environment.

Maneuver to Engage (MTE) – The ability to move to a position of advantage in all environments in order to employ force.

Maneuver to Influence (MTInfl) – The ability to move to a position of advantage in all environments in order to affect the behavior, capabilities, will, or perceptions of partner, competitor, or adversary leaders, military forces, and relevant populations.

Maneuver to Insert (MTI) – The ability to place forces at a position of advantage in all environments.

Maneuver to Secure (MTS) – The ability to control or deny (destroy, remove, contaminate, or block with obstacles) significant areas, with or without force, in the operational area whose possession or control provides either side an operational advantage.

Mitigate – The ability to minimize the effects and manage the consequence of attacks (and designated emergencies on personnel and physical assets.

Monitor – The ability to adequately observe and assess events/effects of a decision.

Net-Centric – The ability to provide a framework for full human and technical connectivity and interoperability that allows all DoD users and mission partners to share the information they need, when they need it, in a form they can understand and act on with confidence, and protects information from those who should not have it.

Non-Kinetic Means – The ability to create effects that do not rely on explosives or physical momentum. (e.g., directed energy, computer viruses/hacking, chemical, and biological).

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Prevent – The ability to neutralize an imminent attack or defeat attacks on personnel (combatant/non-combatant) and physical assets.

Processing / **Exploitation** – The ability to transform collected information into forms suitable for further analysis or action.

Protection – The ability to prevent/mitigate adverse effects of attacks on personnel (combatant/non-combatant) and physical assets of the United States, allies and friends.

Shape – The ability to conduct activities to affect the perceptions, will, behavior, and capabilities of partner, competitor, or adversary leaders, military forces, and relevant populations to further U.S. national security or shared global security interests.

Supply – The ability to identify and select supply sources, schedule deliveries, receive, verify, and transfer product and authorize supplier payments. It includes the ability to see and manage inventory levels, capital assets, business rules, supplier networks and agreements (to include import requirements) as well as assessment of supplier performance.

Understand – The ability to individually and collectively comprehend the implications of the character, nature, or subtleties of information about the environment and situation to aid decision-making.

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UNMANNED SYSTEMS: OPERATIONAL CONSIDERATIONS FOR THE 21ST CENTURY JOINT TASK FORCE COMMANDER AND STAFF

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements for the degree

MASTER OF MILITARY ART AND SCIENCE
Joint Planning Studies

by

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The Fiscal Year (FY) 2001 National Defense Authorization Act (NDAA) signed into law a mandate directing the Department of Defense (DoD) to develop and procure Unmanned Systems through FY 2030. These unmanned air, ground, and sea systems are being designed to support Full Spectrum Operations (FSO) in a hybrid-threat environment.The impact for the 2020 Joint Task Force (JTF) is that it will operate with unmanned systems that will revolutionize the way it conducts its operations. Furthermore, the 2020 JTF will be required to leverage cutting-edge information technologies that will ensure a secure and collaborative command and control network in a security environment that is increasingly competitive due to the proliferation of advanced unmanned systems. The challenge then is to posture the 2020 JTF to integrate these revolutionary unmanned systems. The essential tasks are to ensure operational reach and establish operational access throughout operations which are increasingly ready to be accomplished with revolutionary unmanned systems in lieu of manned systems.

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Unmanned Systems, Unmanned Ground Vehicles, Unmanned Surface Vehicles, Unmanned Underwater Vehicles, Hybrid threat, Joint Task Force, anti-acess/area denial

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

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ABSTRACT

UNMANNED SYSTEMS: OPERATIONAL CONSIDERATIONS FOR THE 21ST CENTURY JOINT TASK FORCE COMMANDER AND STAFF, by MAJ Ronny A. Vargas, 95 pages.

The Fiscal Year (FY) 2001 National Defense Authorization Act (NDAA) signed into law a mandate directing the Department of Defense (DoD) to develop and procure Unmanned Systems through FY 2030. These unmanned air, ground, and sea systems are being designed to support Full Spectrum Operations (FSO) in a hybrid-threat environment. The impact for the 2020 Joint Task Force (JTF) is that it will operate with unmanned systems that will revolutionize the way it conducts its operations. Furthermore, the 2020 JTF will be required to leverage cutting-edge information technologies that will ensure a secure and collaborative command and control network in a security environment that is increasingly competitive due to the proliferation of advanced unmanned systems. The challenge then is to posture the 2020 JTF to integrate these revolutionary unmanned systems. The essential tasks are to ensure operational reach and establish operational access throughout operations which are increasingly ready to be accomplished with revolutionary unmanned systems in lieu of manned systems.

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ACRONYMS

AFRL	U.S. Air Force Research Laboratory
AI	Air Interdiction
ARCIC	Army Requirements Capabilities Integration Center
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CBP	Complex Battle Position
CBRNE	Chemical, Biological, Radiological, Nuclear, and High Yield Explosives
CCDR	Combatant Commander
DARPA	Defense Advanced Research Projects Agency
DIOCC	Defense Intelligence Operation Coordination Center
DCJ2	Deployable Joint Command and Control Systems
DoD	Department of Defense (also DOD)
EOD	Explosive Ordnance Disposal
FY	Fiscal Year
GCS	Ground Control Station
GFMAP	Global Force Management Allocation Plan
IR&D	Industry Independent Research and Development
ISR	Intelligence, Surveillance, and Reconnaissance
JCA	Joint Capability Area
JCIDS	Joint Capabilities Integration and Development System
JCSE	Joint Communications Support Element
JCTD	Joint Capabilities Technology Demonstration
JDT	Joint Deployable Team

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JECC	Joint Enabling Capabilities Command
JFC	Joint Force Commander
JFCC-ISR	Joint Functional Component Command for Intelligence, Surveillance and Reconnaissance
JIAC	Joint Interagency Coordination Group
JIIM	Joint, Interagency, Intergovernmental, and Multi-national
JROC	Joint Requirements Oversight Council
JSCP	Joint Strategic Capabilities Plan
JTF	Joint Task Force
JUTL	Joint Universal Task List
JWE	Joint War Fighting Experiments
MUM	Manned-Unmanned Teaming
NDAA	National Defense Authorization Act
NIE	Network Integration Evaluation
ONR	Office of Naval Research
OSD	Office of the Secretary Defense
QDR	Quadrennial Defense Review
UAS	Unmanned Aircraft System
UAV	Unmanned Aircraft Vehicle
UCAS	Unmanned Combat Air System
UGS	Unattended Ground Sensor
UGV	Unmanned Ground Vehicle
UMS	Unmanned Systems
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle

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RJP	Ready JEC Package
RSJPO	Robotic System Joint Program Office
R&D	Research and Development
WMD	Weapons of Mass Destruction
WMD-E	Weapons of Mass Destruction - Elimination

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CHAPTER 1

INTRODUCTION

> We must recognize that we are living in a machine age and in interest of national defense 'cut its cloth' accordingly . . . in the commercial world, the machine has largely replaced manpower; we to the fullest degree must use machines in place of manpower in order to occupy and hold without terrific losses.[1]
>
> — *Cavalry Journal*, January 1930

The Fiscal Year (FY) 2001 National Defense Authorization Act (NDAA) signed into law a mandate directing the Department of Defense (DoD) to develop and procure Unmanned Systems through FY 2030.[2] These unmanned air, ground, and sea systems are being designed to support Full Spectrum Operations (FSO) in a hybrid-threat environment. The impact for the 2020 Joint Task Force (JTF) is that it will operate with unmanned systems that will revolutionize the way it conducts its operations. Furthermore, the 2020 JTF will be required to leverage cutting-edge information technologies that will ensure a secure and collaborative command and control network in a security environment that is increasingly competitive due to the proliferation of advanced unmanned systems.[3] The challenge then is to posture the 2020 JTF to integrate these revolutionary unmanned systems. The essential tasks are to ensure operational

---

[1]"Mechanized Force Recommended," based on recommendations by the 1930 War Department Mechanized Development Board. *Cavalry Journal* 39 no. 1 (January 1930): 112. Ft. Leavenworth CARL Library, Microfiche section; 2361 Armor, v. 37-43. January 1928-December 1934 reel.

[2]National Defense Authorization Act for Fiscal Year 2001, Public Law 106-398, Section 220, U.S. Statutes at Large 114 (2001).

[3]Chairman, Joint Chiefs of Staff, *Chairman's Strategic Direction to the Joint Force* (Washington, DC: Government Printing Office, 6 February 2012), 6.

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reach and establish operational access throughout operations which are increasingly ready to be accomplished with revolutionary unmanned systems in lieu of manned systems.

Background

The FY2001 NDAA, in conjunction with the FY2007 NDAA, provides DoD with guidance on unmanned systems. The key points that the documents emphasize are, (1) identifying a preference for unmanned systems in acquisitions of new systems, (2) addressing joint development and procurement of unmanned systems and components, and (3) transitioning Service unique unmanned systems to joint systems as appropriate.[4]

The 2006 Quadrennial Defense Review (QDR) further identified four national security challenges for the 21st century. These challenges will require future joint platforms with (1) greater reach (independent reach), (2) greater persistence (ability to loiter over the target area), (3) improved stealth (ability to survive in contested airspace), and (4) improved networking (ability to operate within a joint multidimensional network).[5] In order to address these challenges the Department of Defense (DoD) invests heavily within Research and Development (R&D) Directorates. The lead R&D directorate for the Department of Defense is the Defense Advanced Research Projects Agency (DARPA), which focuses on creating multi-disciplinary innovative technologies

[4]Department of Defense, *FY 2009-2034 Unmanned Systems Integrated Roadmap* (Washington, DC: Government Printing Office, 2009), 4.

[5]These four challenges are: defending the homeland in depth; fighting the long war against radical extremists and defeating terrorist networks; preventing state and non-state actors from acquiring or using weapons of mass destruction; and hedging against the rise of a power or powers capable of competing with the United States militarily, http://www.csbaonline.org/publications/2008/06/carrier-based-unmanned-combat-air-system/ (accessed 26 November 2011).

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to support the operational commander. Other R&D stakeholders are the Office of Naval Research (ONR) that focuses on producing revolutionary capabilities for the U.S. Navy (USN) and the U.S. Marine Corps (USMC); the U.S. Air Force Research Laboratory (AFRL) is responsible for the Air Force's Science and Technology Program; the USMC War Fighting Laboratory, Office of Science and Technology (OS&T) serves as the Office of the Secretary Defense (OSD) office of record for the Joint Capabilities Technology Demonstration (JCTD) program and Joint Testing and Evaluation (JT&E).

The unmanned systems developed by these R&D directorates not only address the challenges highlighted in the 2006 QDR, they also focus on three critical additional areas: first, reducing risks to the Service members while operating across the operational domains; second, replacing prolonged and mundane workloads performed by Service members; and third, enabling unprecedented operational capabilities throughout the air, ground and sea operational domains. In other words, the future operational capabilities from these revolutionary unmanned systems will support full spectrum superiority, which consists of persistent intelligence, surveillance, and reconnaissance (ISR) requirements, full-dimensional security, precise enemy engagement from extended standoff ranges, and unmanned sustainment operations/support with minimal forces on the ground. Due to the revolutionary speed and capabilities becoming available to employ UMSs across the operational domains (air, ground, and sea), the capability of seizing, retaining, and exploiting the initiative will dramatically facilitate the 2020 JTF throughout its operations.

> The surest way to achieve decisive results is to seize, retain, and exploit the initiative. Seizing the initiative dictates the nature, scope, and tempo of an operation . . . commanders use initiative to impose their will on an enemy or

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adversary or to control a situation. Seizing, retaining, and exploiting the initiative are all essential to maintain the freedom of action necessary to achieve success and exploit vulnerabilities.[6]

Primary and Secondary Research Questions

The following research questions will assist in focusing the research to be conducted: The primary research question is will the 2020 JTF be postured to utilize mandated unmanned systems? The secondary research questions will be (1) what future training will be required for the JTF to employ UMSs? and (2) how will the incorporation of robust UMS capability impact the organization of a JTF in 2020?

Assumptions

There are three assumptions that are considered in developing the framework of this thesis. First, that DoD continues to regard the benefits from employing UMSs demonstrated in OIF/OEF for future operations. Second, that DoD continues to regard UMSs as a vital platform in providing persistent ISR and strike capabilities to the JTF in lieu of manned aerial systems. Finally, that the U.S. Congress, domestic industry, and Academia continue to support DoD's vision on UMS Research and Development (R&D).

Definition of Key Terms

The following definitions are based on *the Autonomy Levels for Unmanned Systems (ALFUS)* Framework developed by the National Institute of Standards and Technology (NIST).[7] The document was produced by the Federal Agencies Ad Hoc

[6]Department of the Army, Field Manual (FM) 3-0, *Operations* (Washington, DC: Government Printing Office, 2008), Appendix A, A-1.

[7]Federal Agencies Ad Hoc Autonomy Levels for Unmanned Systems Working Group Participants, Autonomy Levels for Unmanned Systems (ALFUS) Framework,

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Autonomy Levels for Unmanned Systems Working Group. The working group consisted of unmanned systems professionals from government agencies and their supporting contractors on a voluntary basis. The intent is to develop a lexicon for unmanned systems (definitions not based on the ALFUS framework will be cited with the corresponding source).

Anti-access. Refers to those long –range capabilities and actions to prevent an opposing force from entering an operational area. Also known as A2 (Joint Operational Access Concept, version 1.0, 17 January 2012, Executive Summary, i).

Area-denial. Refers to those short-range actions and capabilities designed to limit freedom of action within the operational area. Also known as AD (Joint Operational Access Concept, version 1.0, 17 January 2012, Executive Summary, i).

Autonomous. Operation of an unmanned system (UMS) wherein the UMS receives its mission from the human and accomplishes that mission with or without further human-robot interaction (HRI). The level of HRI, along with other factors such as mission complexity, and environmental difficulty, determine the level of autonomy for the UMS.

Autonomous Collaboration. The ability of a UMS to collaborate with one or more manned vehicles or UMS without the need for an external controlling element.

Classifications. The "R" is the DoD designation for reconnaissance aircraft. The "M" is the DOD designation for multi-role, and "Q" means unmanned aircraft system. The number "1, 2, 3 . . ." refers to the aircraft series of remotely piloted aircraft systems.

Volume I: Terminology Version 1.1, edited by Hui-Min Huang, National Institute of Standards and Technology, September 2004, www.nist.gov/el/isd/ks/upload/ NISTSP_1011_ver_1-1.pdf. (accessed 20 September 2011).

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Additionally, a change in designation from “RQ-1” to “MQ-1” signifies the addition of armament, i.e. the AGM-114 Hellfire missiles (Author interpretation).

Fully Autonomous. A mode of operation of an UMS wherein the UMS is expected to accomplish its mission, within a defined scope, without human intervention.

Human Assisted. The type of HRI that that refers to situations during which human interactions are needed at the level of detail of task plans, i.e., during the execution of a task.

Human Delegated. The type of HRI that refers to situations during which human interactions are mainly at the task level.

Human Robot Interaction/Interface (HRI). The activity by which human operators engage with UMSs to achieve the mission goals. The Operator is the role assumed by the person performing remote control or teleoperation. The Supervisor monitors one or more robots with respect to progress on the mission, can task the robot(s) at the mission level, monitors mission progress, provides mission level directions, coordinates missions, and can assign an operator to assist a robot if needed. A commander would be an example of a person who performs the supervisor-only role.

Human Supervised. The type of HRI that refers to situations during which humans play the monitoring role and human interactions are mainly at the mission level.

ISR. (Intelligence, Surveillance, and Reconnaissance) An activity that synchronizes and integrates the planning and operation of sensors, assets, and processing,

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exploitation, and dissemination systems in direct support of current and future operations. This is an integrated intelligence and operations function.[8]

Joint Capability Areas (JCAs). Collections of like DoD capabilities functionally grouped to support capability analysis, strategy development, investment decision making, capability portfolio management, and capabilities-based force development and operational planning (J7- Joint Concepts to Capabilities Division (JCCD) JCA 2010 Refinement approved 8 April 2011, http://www.dtic.mil/futurejointwarfare/jca.htm).

Methods of Control. The interface, either software or hardware, such as a joystick, waypoint selection via a map interface, natural language, hand signals, etc., that operators use to control a UMS.

Operational Access. The ability to project military forces into an operational area with sufficient freedom of action to accomplish the mission (Joint Operational Access Concept, version 1.0, 17 January 2012, Executive Summary, i).

Operational Reach. The distance and duration across which a unit can successfully employ military capabilities. The limit of a unit's operational reach is its culmination point (ADRP 3-0, 22 September 2011, 4-5).

Remote Control. A mode of operation of a UMS wherein the human operator, without benefit of video or other sensory feedback, directly controls the actuators of the UMS on a continuous basis, from off the vehicle and via a tethered or radio linked control device using visual line-of sight cues, in this mode, the UMS takes no initiative and relies on continuous or nearly continuous input from the user.

[8]Chairman, Joint Chiefs of Staff, Joint Publication (JP) 1-02, *Department of Defense Dictionary of Military and Associated Terms* (Washington, DC: Government Printing Office, as amended through 15 November 2011), 171.

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Robot/Robotic. An electro-mechanical system that can react to sensory input and carry out predetermined missions. A robot is typically equipped with one or more tools or certain capabilities, including knowledge so that it can perform desired functions and/or react to different situations that it may encounter.

Semi-Autonomous. A mode of operation of a UMS wherein the human operator and/or the UMS plan(s) and conduct(s) a mission and require various levels of HRI.

Sensor. Equipment that detects, measures, and/or records physical phenomena, and indicates objects and activities by means of energy or particles emitted, reflected, or modified by the objects and activities.

Sensor Fusion. A process in which data, generated by multiple sensory sources, is correlated to create information and knowledge. Sensor information, when fused, may yield immediately actionable combat information and/or intelligence. The capabilities are of four essential types: *Detection*, *Classification*, *Recognition*, and *Identification*.

Sensory Processing. Computing processes that operate either on direct sensor signals or on low-level sensory signatures to detect, measure, and classify entities and events and derive useful information, at proper resolutions and at levels of abstractions, about the world. Sensory processes can be organized hierarchically with proper relative spatial and temporal resolutions and organized horizontally with assigned but coordinated focuses.

Teaming. A method of operation where a system uses the combined sensing, information exchange, decision-making, and acting capabilities of humans and robots function together to carry out missions within the planned scope. In the situations of manned–unmanned teaming, air-to-ground teaming means that the manned system is in

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the air with UMS on the ground. Similarly, there could be air-to-air, ground-to-ground, and ground-to-air types of teaming.

Teleoperation. A mode of operation of a UMS wherein the human operator, using video feedback and/or other sensory feedback, either directly controls the actuators or assigns incremental goals, waypoints in mobility situations, on a continuous basis, from off the vehicle and via a tethered or radio linked control device . In this mode, the UMS may take limited initiative in reaching the assigned incremental goals.

Telepresence. The capability of a UMS to provide the human operator with some amount of sensory feedback similar to that which the operator would receive if he were in the vehicle.

Tether. A physical communications cable or medium that provides connectivity between an unmanned system and its controlling element that restricts the range of operation to the length of the physical medium.

Unmanned System (UMS). An electro-mechanical system, with no human operator aboard, that is able to exert its power to perform designed missions. May be mobile or stationary. Includes categories of unmanned ground vehicles (UGV), unmanned aerial vehicles (UAV), unmanned underwater vehicles (UUV), unmanned surface vehicles (USV), unattended munitions (UM), and unattended ground sensors (UGS). Missiles, rockets, and their sub munitions, and artillery are not considered unmanned systems.

Limitations

The thesis framework is the following; first, it will not be a detailed unmanned system capability brief; the intent is to focus on the impact of these various systems on

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the ability of the 2020 JTF to conduct operations. Second, an analysis of a revolution of military affair (RMA) is outside the scope this paper. Finally, the topics and research will remain unclassified and will not relate information, capabilities, or missions that have been classified otherwise.

Significance

The continued development of unmanned systems will revolutionize the operational capabilities of the 2020 JTF. First, it will continue to impact the entire doctrine, organization, training, materiel, leadership and education, personnel and facilities (DOTMLPF) analysis process. Most important for this thesis are organization and training. Second, a full spectrum superiority concept as outlined in Joint Publication (JP) 3-03, *Joint Interdiction*, can be achieved through the employment of unmanned systems throughout the entire joint area of operation in lieu of manned systems (see figure 1).

> The cumulative effect of dominance in the air, land, maritime, and space domains and information environment (which includes cyberspace) permits the conduct of joint operations without effective opposition or prohibitive interference.[9]

The significance of continuous UMS development for all leaders was aptly reflected in a statement by the US Forces Command (FORSCOM) commander, General (GEN) David M. Rodriguez, that "in my first 20 years in the Army we probably got about

[9]Chairman, Joint Chiefs of Staff. Joint Publication (JP) 3-03, *Joint Interdiction* (Washington, DC: Government Printing Office, 14 October 2011), I-10.

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20 to 30 new systems . . . in the 15 months [in Afghanistan], when I was a division commander, I got 172 new ones."[10]

Third, with the accelerated development and proliferation of unmanned systems, our allies and foreign militaries are procuring or developing their own unmanned systems programs. This proliferation of UMSs will impact the risk for the 2020 JTF throughout its operations, thereby creating an emphasis on counter-UMS mitigation considerations.

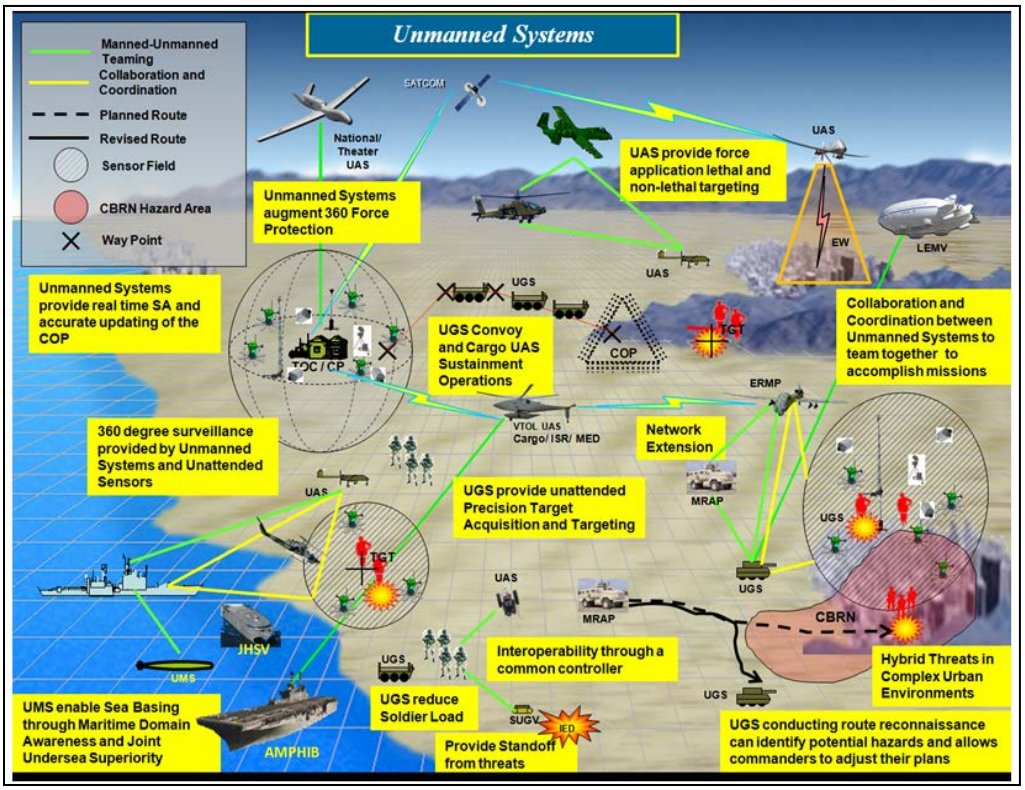


Figure 1. Example of a UMS Full Spectrum Dominance Concept (Unclassified)

Source: Maneuver, Aviation and Soldier Division, "Initial Capabilities Report for Unmanned Systems (Air, Ground, and Maritime)," prepared for a Material Development Decision, draft version 2.2 (Fort Monroe, VA: 2010), Appendix A.

[10]Associated Press, "New FORSCOM boss: Soldiers to be spread thin," *Army Times*, 26 September 2011, 25.

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CHAPTER 2

LITERATURE REVIEW

The purpose of this thesis is to answer the primary research question: Will the 2020 JTF be postured to utilize mandated unmanned systems? The following literature review will assist in this research by focusing on the major concepts of unmanned systems in order to establish a common understanding of their capabilities and employment considerations.

The breakdown for this chapter is as follows: (1) reviews the base documents and the NDAA's that establish the mandate for DoD unmanned systems acquisition and development; (2) identifies the Service's UMS roadmaps and major programs; (3) highlights Joint DoD publications that establish the doctrinal framework for establishing a JTF; (4) investigates academic publications that provide justification for the incorporation of UMS throughout military operations; and (5) provides an overview of UMS proliferation both adversary and friendly.

Why is DoD investing in Unmanned Systems?

The Fiscal Year (FY) 2001 National Defense Authorization Act (NDAA) mandated DOD to develop and procure unmanned Systems thru FY2030. It mandated two requirements that (1) by 2010, one-third of the aircraft in the operational deep strike force aircraft fleet are unmanned and that (2) by 2015, one-third of the operational ground combat vehicles are unmanned. It further instructed DoD to provide a description and assessment of the acquisition strategy for unmanned advanced capability combat aircraft and ground combat vehicles planned. This report will include a detailed estimate

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of all research and development, procurement, operation, support, ownership, and other costs required to carry out such strategy through the year 2030.[11]

The impact to the 2020 Joint Task Force is that it will operate in a foreseeable hybrid-threat environment with unmanned systems that will revolutionize the way it executes its missions. The complexity of this hybrid-threat environment will require the Joint Force Commander (JFC) and his staffs to collect, analyze, and disseminate information thru an integrated battle command systems network integrated with unmanned systems.[12] The DoD *Unmanned Systems Integrated Roadmap: FY2011-2036* provides a centralized source for DOD's vision for unmanned systems.

> The DOD vision for unmanned systems is the seamless integration of diverse unmanned capabilities that provide flexible options for Joint War fighters while exploiting the inherent advantages of unmanned technologies, including persistence, size, speed, maneuverability, and reduced risk to human life. DoD envisions unmanned systems seamlessly operating with manned systems while gradually reducing the degree of human control and decision-making.[13]

Joint Capabilities Areas (JCA)

The Department of Defense (DoD) established JCAs as the preferred method to manage UMS capabilities. Each JCA represents a collection of related missions and tasks

[11]National Defense Authorization Act for Fiscal Year 2001, Public Law 106-398, Section 220, U.S. Statutes at Large 114 (2001).

[12]Maneuver, Aviation and Soldier Division, "Initial Capabilities Report for Unmanned Systems (Air, Ground, and Maritime)," prepared for a Material Development Decision, draft version 2.2, (Fort Monroe, VA: 2010), 2.

[13]Department of Defense, *Unmanned Systems Integrated Roadmap, FY2011-2036* (Washington, DC: Government Printing Office, October 2010), 3.

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that are typically conducted to bring about the desired effects associated with that capability.[14] Table 1 highlights the density of UMSs to their respective JCA's.

Table 1. UMS by JCA and Domain

Unmanned Systems by JCA and Domain Numbers of Named Systems					
Battlespace Awareness	**84**	**Corporate Management & Support**	**1**	**Logistics**	**28**
▪ Air	30	▪ Air	0	▪ Air	6
▪ Ground	38	▪ Ground	1	▪ Ground	22
▪ Maritime	16	▪ Maritime	0	▪ Maritime	0
Building Partnerships	**32**	**Force Application**	**42**	**Net-Centric**	**18**
▪ Air	6	▪ Air	22	▪ Air	8
▪ Ground	18	▪ Ground	10	▪ Ground	10
▪ Maritime	8	▪ Maritime	10	▪ Maritime	0
Command & Control	**20**	**Force Support**	**20**	**Protection**	**66**
▪ Air	8	▪ Air	2	▪ Air	11
▪ Ground	12	▪ Ground	18	▪ Ground	42
▪ Maritime	0	▪ Maritime	0	▪ Maritime	13

Source: Department of Defense, *FY2009–2034: Unmanned Systems Integrated Roadmap* (Washington, DC: Government Printing Office, 2009), 8.

Battle space Awareness (BA) is focused primarily on ISR which utilizes the Tasking, Production, Exploitation, and Dissemination (TPED) process to translate the sensor data into a common picture. Current platforms that support BA are the Predator, Reaper, and RQ-4 Global Hawk. The immediate requirement for BA ISR platforms is to operate with full autonomy extending their persistence capabilities from days to weeks across all of the domains.[15]

Force Application (FA) is focused on maneuver and engagement. Current UAV platforms that support force application are the Predator, Reaper, and MQ-1C Gray Eagle. The immediate end state for UGVs is to support and execute dismounted offensive

[14]Ibid., 16.

[15]Ibid.

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operations, armed reconnaissance and assault operations. In maritime operations, unmanned surface vehicles (USVs) and unmanned underwater vehicles (UUVs) will support mine countermeasures (MCM), anti-submarine warfare (ASW), maritime domain awareness (MDA) and maritime security (MS).[16]

Protection platforms will assist in force protection (FORCEPRO), to include assuming tasks that are determined to be "dirty, dull, and dangerous." The immediate end state is for fully autonomous platforms to assume responsibility for FOB security, obstacle construction/breach, sophisticated explosive ordnance disposal, and casualty extraction and evacuation.[17]

Logistics is suitable for the employment of UMSs to deploy, distribute, and resupply units.[18] In March 2010 the A160T Hummingbird unmanned helicopter successfully completed a cargo delivery demonstration under a U.S. Marine Corps War Fighting Laboratory contract. The demonstration proved the Hummingbird's ability to resupply frontline troops operating in restrictive terrain. The A160T Hummingbird exceeded all of the demonstration requirements, being able to deliver at least 2,500 pounds of cargo from one simulated FOB to another located 75 nautical miles away under the required six hours.[19] Furthermore, a detachment from Marine Unmanned Aerial Vehicle Squadron 1 from Twenty-Nine Palms, California, completed the first combat of a

[16]Ibid., 17.

[17]Ibid., 17.

[18]Ibid., 17.

[19]"A160T Hummingbird unmanned helicopter proves resupply capability for U.S. Marines," http://www.armybase.us/2010/03/a160t-hummingbird-unmanned-helicopter-proves-resupply-capability-for-u-s-marines/ (accessed 28 December 2011).

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K-MAX helicopter to deliver 3,500 pounds of food and supplies from Camp Dwyer, Afghanistan, to Combat Outpost Payne in Helmand province.[20] This platform and capability are in accordance with the Army's Logistics Innovation Agency's desire to develop unmanned cargo aircraft within the next 7-10 years, with an emphasis placed on the autonomy in its development.[21]

U.S. Air Force

At the outset of the Global War on Terrorism (GWOT), the UAS became the weapon of choice. The U.S. Air Force's *Unmanned Aircraft Systems Flight Plan 2009-2047* envisions a networked family of UASs. These next generation UASs will operate autonomously and provide an exponentially improved degree of operational capabilities which will be managed by the designated Joint Force Air Component Commander (JFACC), a role traditionally carried out by the USAF. These systems will consist of a common airframe and will perform varied tasks traditionally executed by manned platforms, such as attacking enemy air defenses, operating as an airborne warning and control aircraft (AWACs), and long-range bombers. Ultimately, the end state will be to reduce the logistical footprint and requirements of fixed wing formations (see figure 2).

[20]James K. Sanborn, "UAV delivers cargo in first warzone run," *Marine Corps Times*, 31 December 2011, http://www.marinecorpstimes.com/news/2011/12/marine-uav-delivers-cargo-in-first-warzone-run-123111/ (accessed 1 January 2012).

[21]Michael Hoffman, "Army seeks industry help in developing unmanned cargo aircraft," *Army Times*, 19 December 2011, 30.

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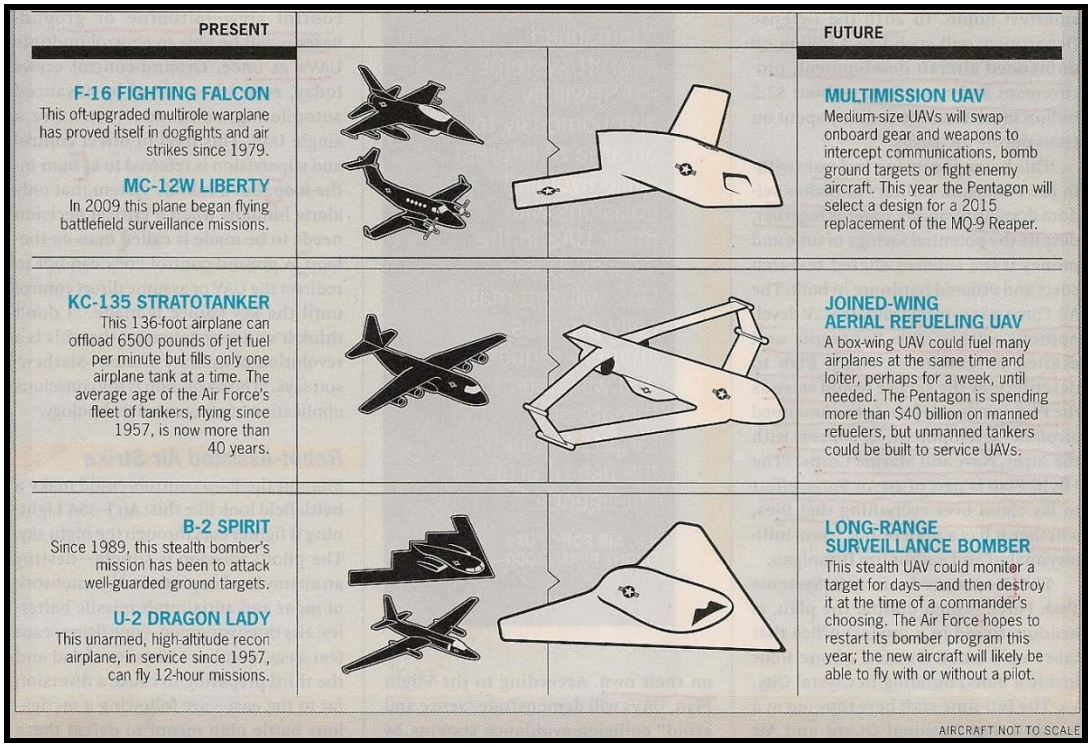


Figure 2. Non-DoD Manned and Unmanned UAV concept comparison

Source: Popular Mechanics, "Air Strike 2025, The Radical Plan to Reinvent the Air Force," March 2010, 59.

The U.S. Air Force's (USAF) vision for medium sized UASs (MQ-M) by 2020 is designed on a common platform and will contain an enhanced autonomous networked system. The MQ-M will evolve from the current medium-sized unmanned aircraft, Predator and Reaper, and it includes three phases of development, MQ-Ma, MQ-Mb, and MQ-Mc. In the first phase, the MQ-Ma's will be designed as a networked all weather platform supporting electronic warfare (EW), Close Air Support (CAS), Strike, and multi-intelligence (multi-INT) ISR missions. Additionally, the MQ-Ma allows for the flexibility to be controlled from mobile ground control stations. In the second phase, the MQ-Mb will merge capabilities from the MQ-9 Reaper and MQ-Ma in order to provide a

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wider spectrum of capabilities, which include Suppression of Enemy Air Defenses (SEAD) , Air Interdiction (AI), Special Operations (SOF) ISR, and the ability to conduct unmanned air refuel (see figure 3).[22]

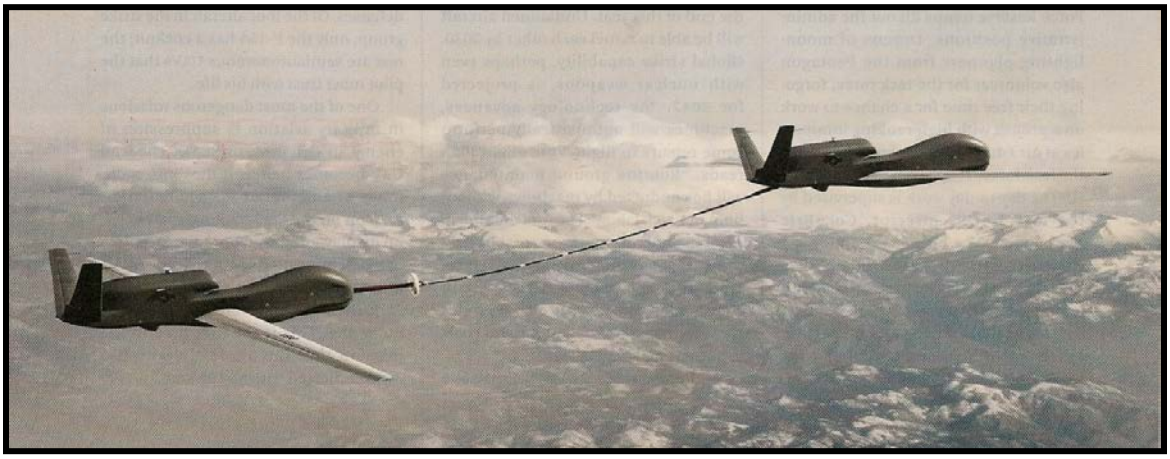


Figure 3. MQ-1 Predator in-flight refuel exercises circa 2007

Source: Popular Mechanics "Air Strike 2025, The Radical Plan to Reinvent the Air Force," March 2010, 59.

The advanced autonomous MQ-Mb will utilize SWARM technology which will allow multiple MQ-Mb aircraft to cooperatively operate at the control of a single pilot.[23]

[22]United States Air Force, *United States Air Force Unmanned Aircraft Systems Flight Plan: 2009-2047* (Washington, DC: Government Printing Office, 18 May 2009), 39.

[23]On 18 August 2011, Boeing announced the successful autonomous communications and operation of dissimilar unmanned aerial vehicles (UAV), which communicated using a Mobile Ad Hoc Network and swarm technology developed by Johns Hopkins University Applied Physics Laboratory. Swarm technology is similar to how insects communicate and perform tasks as an intelligent group. The UAVs worked together to search the test area through self-generating waypoints and terrain mapping, while simultaneously sending information to teams on the ground,

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Finally, the MQ-Mc will possess the full spectrum of capabilities to assume manned system capabilities, such as Defensive Counter Air (DCA), Strategic Attack, Missile Defense and SEAD.

The U.S. Air Force vision for large-sized UASs (MQ-L) by 2020 will leverage autonomous capabilities and will also undergo three phases of development. In the first phase, the MQ-La will incorporate high resolution imaging Synthetic Aperture Radar (SAR) and Ground Moving Target Indicator (GMTI) capabilities, advanced signal intelligence (SIGINT) capabilities, and will operate in conjunction with the RQ-4 Global Hawk in multi-INT ISR missions. Furthermore, the USAF will design these platforms to replace manned battle management command and control (BMC2) platforms such as Joint Surveillance and Target Attack Radar System (JSTARs) and Airborne Warning and Control System (AWACS). Second phase, an all-weather MQ-Lb will be a multi-mission endurance aircraft providing ISR, EW, BMC2, and lift capabilities. In the third phase, the MQ-Lc will serve as the foundation for all missions requiring a large aircraft platform, such as air mobility, airlift, air refueling, EW, multi-INT ISR, Strategic Attack, Global Strike, CAS, and Air Interdiction operations.[24]

In summary, the USAF UAS Road Map supports the 2020 JTF essential tasks of providing operational reach and establishing operational access throughout its operations. The ability to accomplish these tasks with the projected unmanned systems in lieu of manned systems is in accordance with responsibilities outlined in JP 3-33, *Joint Task*

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http://uavbusinessreview.com/2011/08/26/boeingswarmtechnology (accessed on 15 November 2011).

[24]United States Air Force, *United States Air Force Unmanned Aircraft Systems Flight Plan*, 39.

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Force Headquarters (see figure 4). Additionally, the JFACC is further responsible for ensuring that all of the elements in the Theater Air-Ground System (TAGS) are in place prior to the commencing of joint operations.[25]

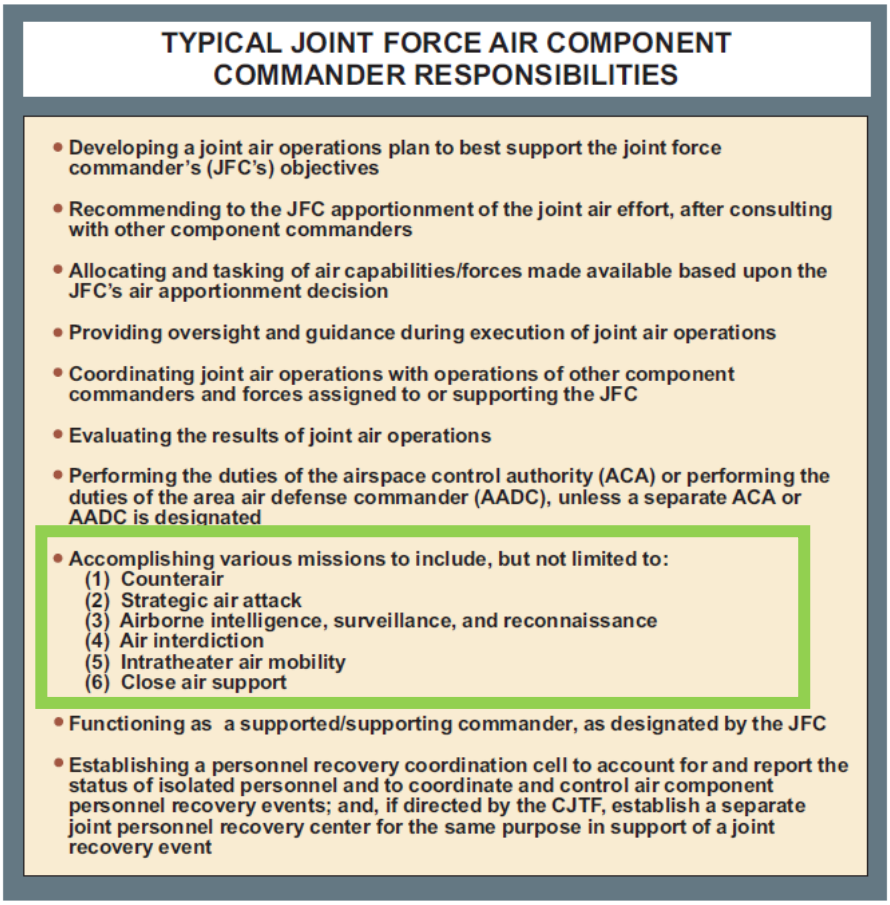


Figure 4. Typical JFACC Responsibilities

Source: Chairman, Joint Chiefs of Staff, Joint Publication (JP) 3-33, *Joint Task Force Headquarters* (Washington, DC: Government Printing Office, 6 February 2007), III-5.

[25]When all elements of the USAF Theater Air Control System (TACS), Army Air-Ground System (AAGS), Marine Air Command and Control System (MACCS), and Navy Tactical Air Control system (NTACS) integrate, the entire system is labeled the Theater Air-Ground System (TAGS), JP 3-03, *Joint Interdiction*, 14 October 2011, IV-4.

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U.S. Navy

The U.S. Navy (USN) is engaged in several major programs in support of UMS development and integration, such as the Littoral Combat Ship (LCS) as a command and control center for unmanned surface and undersea vehicles (USV/UUV), a vertical take-off unmanned air vehicle squadron (VTUAV), and the unmanned carrier-launched airborne surveillance and strike demonstration (UCLASS-D). The former Chief of Naval Operations (CNO) Admiral (Ret.) Gary Roughead stated that unmanned systems will be the future for the US Navy.[26] These unmanned systems are essential in supporting the Navy's global strategic presence mission, intelligence gathering, and extending the U.S. Navy's sea lines of communication (SLOCs). Furthermore, these unmanned systems will mitigate dangerous missions, such as conducting operations in the Arctic regions and mitigating anti-access/area-denial (A2/AD) threats.

In support of UMS integration, the U.S. Navy has designated the Littoral Combat Ship (LCS) to serve as a control center for both Unmanned Underwater Vehicles (UUV) and Unmanned Surface Vehicles (USV). The LCS is configured for various mission modules such as, anti-submarine warfare, mine countermeasures, anti-surface warfare, ISR, maritime intercept, and logistics. Several of these mission modules will be executed utilizing unmanned systems such as the Modular Unmanned Surface Craft Littoral, an ISR platform providing real time monitoring of vessels and personnel along waterways and shorelines.[27] An example of unmanned mine clearing operations, the U.S. Navy

[26]Carlo Munoz, "CNO Bets on Underwater Drones for Future Fleet," *AolDefense*., 19 August 2011, http://defense.aol.com/ (accessed 10 November 2011).

[27]P. W. Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century* (New York: Penguin Press, 2009), 225.

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fielded the AN/WLD-1 RMS Remote Mine Hunting System, a three-foot-long robot that can detect mines underwater and carries a sensor payload that allows it to identify entities in the surrounding waters. In a mine-clearing operation in the port of Um Quasar, Iraq (2003), it cleared a square-mile area of mines within 16 hours; compared to the 21 days it would have taken USN divers to accomplish the same mission.[28]

In support of the vertical take-off unmanned air vehicle squadron (VTUAV) concept, the USN has conducted trial runs of the MQ-8 Fire Scout, an unmanned helicopter which is expected to dramatically cut the Navy's kill chain (the time it takes to identify, track and eventually engage an enemy target). The MQ-8 Fire Scout can neutralize or destroy fleets of small, fast moving boats used by drug smugglers and pirates. [29] The U.S. Navy recently conducted MH-60R Sea Hawk trials with the MQ-8 Fire Scout in order to extend the command and control (C2) and range of the MQ-8 Fire Scout.[30] This capability will allow for the coverage of thousands of miles of ocean determined to support wide area security operations (see figure 5).

[28]"Military Increasingly Looking to Robots to Clear Waterways of Dangerous Mines," July 27, 2007, http://www1.whdh.com/news/articles/national/MI56402/ (accessed 27 November 2011).

[29]Carlo Munoz, "Navy Arms Its First Unmanned Vehicle, Fire Scout," AolDefense, 9 November 2011, http://defense.aol.com/ (accessed 20 November 2011).

[30]Carlo Munoz, "Navy tries MH-60 Seahawks with unmanned helos," AolDefense, 9 November 2011 http://defense.aol.com/ (accessed 12 November 2011).

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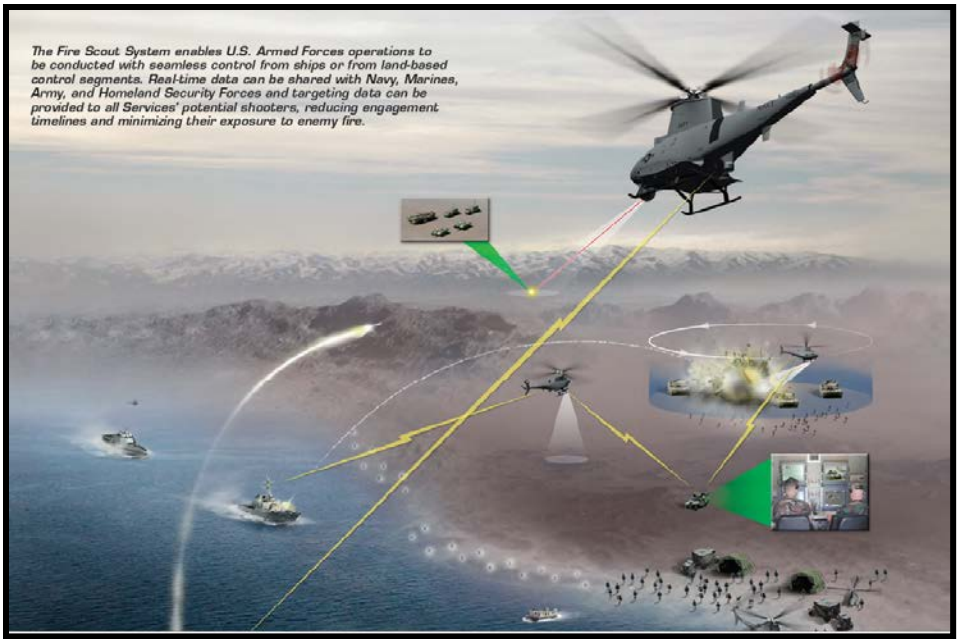


Figure 5. MQ-8 Fire Scout Unmanned Helicopter

Source: Northrop Grumman Corporation (2011).

The U.S. Navy's Unmanned Combat Air System Carrier Demonstration (UCAS-D) complies with the joint platforms envisioned in the 2006 QDR and has strategic deployment considerations.[31] The U.S. Navy is utilizing the UCAS-D to demonstrate the suitability of an UCAS Air Wing capable of operating in an unrefueled combat radius of 2,100 nautical miles (nm), exceeding current manned capabilities. Furthermore, with autonomous aerial refueling capabilities, loiter time for an UCAS/X-47B is 50 to 100

[31]"future joint air platforms with greater range (independent reach), greater persistence (ability to loiter over the target area), improved stealth (ability to survive in contested airspace), and improved networking (ability to operate as part of a joint multidimensional network) . . . the final Report of the 2006 QDR directed the Department of the Navy (DoN) to "develop an unmanned longer-range carrier-based aircraft capable of being air-refueled to provide greater standoff capability, to expand payload and launch options, and to increase naval reach and persistence . . . to field a low-observable unmanned combat air system (UCAS) that is capable of operating safely off of a carrier deck, and over longer combat ranges than contemporary manned carrier-based aircraft."

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hours (five to ten times longer than a manned aircraft). The UCAS/X-47B can conduct (without refueling) surveillance-strike combat air patrols at ranges out to 2,100 nm, with the capacity of a 4,500 pound weapon payload. In a strictly combat radius comparison, an F-35B Lighting II can operate within a radius of 485nm; F/A-18A-D Hornet within 500nm; AV-8B Harrier II within 300 nautical miles.[32] The U.S. Navy's UCAS-D will allow a dispersed UCAS aircraft carrier force to exert combat power over a significant area not achievable with manned aircraft and mitigate anti-area/area denial (A2/AD) threats (see figure 6).[33]

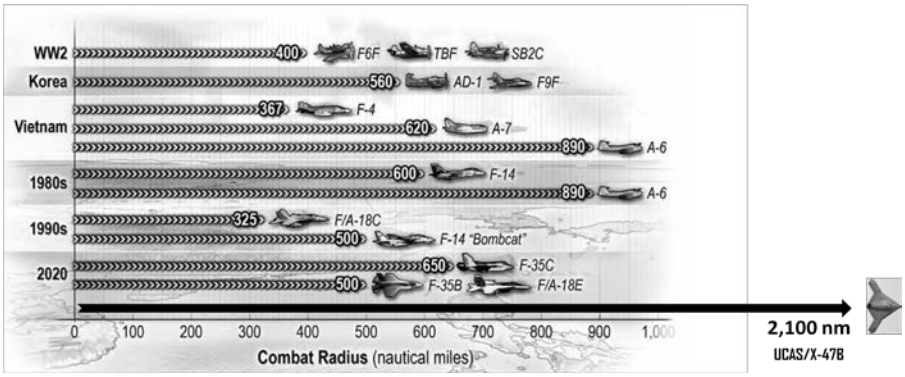


Figure 6. USN Air Carrier Wing Reach

Source: Created by author using data from Mark A. Gunziger, *Sustaining America's Strategic Advantage in Long-Range Strike* (Washington, DC: Center for Strategic and Budgetary Assessments, 2010), 67.

[32]Department of the Navy and United States Marine Corps, *Fiscal Year 2011 Marine Aviation Plan* (Washington, DC: Government Printing Offices, 16 September 2010), Section 17, Platform Quick Reference "Quad" Charts.

[33]Thomas P. Erhard, PhD and Robert O. Work, *Range, Persistence, Stealth, and Networking: The Case for a Carrier-Based Unmanned Combat Air System* (Washington, DC: Center for Strategic and Budgetary Assessments, 2008), 2009.

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The U.S. Navy's emphasis on unmanned systems supports the 2020 JTF essential tasks of providing operational reach and establishing operational access throughout its operations. The ability to accomplish these tasks depends upon revolutionary unmanned systems in lieu of manned systems. Furthermore, with these unmanned capabilities, a U.S. Navy Numbered Fleet will garner further consideration to be designated as JTF HQ, as recently demonstrated in Operation Odyssey Dawn, which will be further discussed in this thesis.

U.S. Army

The *2009 Robotics Strategy White Paper* prepared by the Army Capabilities Integration (ARCIC) Center and Tank-Automotive Research and Development Engineering Center (TARDEC) focuses on the US Army's path forward in the procurement and employment of robots (also referred to as robotics).[34] The Army's use of robots, primarily to support EOD operations in Iraq and Afghanistan demonstrated the ability of unmanned systems to assist Soldiers in a wide range of mission support capabilities. The *2009 Robotics Strategy White Paper* highlights three critical opportunities for further development and procurement of unmanned systems. First, robotics reduces risks to Soldiers; second, robotics enabled platforms will reduce Soldier workloads; and third, robotics enables entirely new capabilities for extended range or stand-off reconnaissance operations. Additionally, the white paper identified and

[34]Department of the Army. *2009 Robotics Strategy White Paper*, prepared by the Army Capabilities Integration Center and Tank-Automotive Research and Development Engineering Center Robotics Initiative (Washington, DC, 19 March 2009).

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evaluated the feasibility of unmanned systems conducting and/or assisting with 32 tasks in the Universal Joint Task List (see Appendix A).

The *2009 Robotics Strategy White Paper* also recognizes and supports the four mission areas highlighted in the 2007 Office Secretary of Defense (OSD) Unmanned Systems Roadmap, (1) ISR - the number one operational commander priority, (2) target identification and designation - the ability to positively identify and precisely locate military targets in real-time, (3) conduct counter-mine warfare - Improvised Explosive Devices (IEDs) resulted in the number one cause of casualties in Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF), and (4) chemical, biological, radiological, nuclear, explosive reconnaissance - the ability to detect chemical, biological, radiological, nuclear, and explosive agents and to operate in these contaminated areas.

In addition to robotics and unmanned ground vehicle (UGV) development, the U.S. Army has engaged in manned-unmanned (MUM) trials, integrating UAVs with manned platforms, such as the AH-64D Longbow Block III attack helicopter (also known as the Apache). In a recent MUM proof of concept trial, Lockheed Martin outfitted the AH-64D Longbow Block III, with an Unmanned Aerial Systems Tactical Common Data Link Assembly (UTA).[35] The trial successfully demonstrated the Apache's ability to control the payload and flight of an MQ-1C Grey Eagle UAV in flight, validating the UTA's design in which "all goals of this phase of UTA testing were completed with 100 percent success."[36] The UTA control system will allow the Apache pilot to control the

[35]Lockheed Martin, LONGBOW UTA, http://www.f-16.biz/us/products/longbow_uta.html (accessed 12 March 2012).

[36]Lockheed Martin, "LONGBOW LLC's Data Link Controls UAS from Apache Block III Attack Helicopter for the First Time," http://www.lockheedmartin.com/

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flight path, weapons system and sensors on the MQ-1C Grey Eagle UAV, initially serving as a forward remote sensor in hostile environments (see figure 7).



Figure 7. Apache Block III with a Gray Eagle UAV (MUM concept)

Source: Defense Update, http://defense-update.com/20111109_apache-block-iii-controls-a-gray-eagle-uav-demonstrating-advanced-manned-unmanned-operations.html (accessed 10 December 2011).

In exploring the capabilities of utilizing unmanned helicopters, the 2010 Army Expeditionary Warrior Experiment (AEWE) validated that the MQ-8 Fire Scout's ability to provide the following capabilities: (1) support unmanned small unit resupply (2) provide the autonomous capability to transport and emplace unmanned ground vehicles/unattended ground sensors into the battlefield, (3) provide dedicated network communications relay, (4) ability to land/takeoff from unimproved surfaces, and (5)

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us/news/press-releases/2011/november/LONGBOWLLCsDataLinkContro.html (accessed 12 March 2012).

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enhance situational awareness through persistent stare capabilities.[37] The AEWE is managed by the Maneuver Battle Lab at Fort Benning, in coordination with TRADOC Army Capabilities Integration Center (ARCIC) allowing for network-enabled small units to experiment in a live field environment with emerging technologies and concepts of operation.

The U.S. Army's emphasis on UMSs (UAVs, robots, and UGVs) will support the four mission areas previously outlined in the 2007 Office Secretary of Defense (OSD) Unmanned Systems Roadmap. The U.S. Army leveraging these UMS capabilities in lieu of manned systems will support the 2020 JTF essential tasks of providing operational reach and establishing operational access throughout its operations. Furthermore, UMSs fully support Army Operating Concept (AOC) constructs; combined arms maneuver (CAM) and wide-area security (WAS).

> Army forces conduct combined arms maneuver to gain physical, temporal, and psychological advantages over enemy organizations . . . Army forces integrate the combat power resident in the Army's six war fighting functions . . . to defeat enemies and seize, retain, and exploit the initiative.
>
> Army forces conduct wide area security to consolidate gains, stabilize environments, and ensure freedom of movement and action. Wide area security operations protect forces, populations, infrastructures, and activities.
>
> Army forces capable of combined arms maneuver and wide area security operations are an essential component of the joint force's ability to achieve or facilitate the achievement of strategic and policy goals.[38]

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[37]Northrop Grumman, "Facts: Northrop Grumman Proves Value of Vertical Unmanned Systems at Army Expeditionary Warrior Experiment," www.northrop grumman.com/media (accessed 14 April 2012).

[38]Department of the Army. TRADOC Pam 525-3-1: *The Army Operating Concept-2016-2020* (Washington, DC: Government Printing Office, 2010), iii.

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U.S. Marine Corps

The *Marine Corps Vision and Strategy 2025* serves as the strategic planning document encompassing its legislated role, functions, and composition in order to conduct operations against hybrid threats in complex environments.[39] The supporting operating concepts outlined in this document establish its role as an expeditionary fighting force capable of operating in diverse operating environments. Furthermore, the Marine Corps will be able to lead joint operations and accomplish its missions with Marine Air-Ground Task Force (MAGTF) incorporating manned and unmanned platforms to support combined maneuvers.[40]

The DOTMLPF impact for the Marine Corps is on its: (1) Operating Force Structure; which recognizes the application of unmanned systems across the MAGTF, (2) on the Command Element (CE), which will need to provide persistent ISR in a complex operational environment, and (3) on the Ground Combat Element (GCE), which is tasked to enhance the maneuver capabilities of Marine ground forces within in a complex urban environment.[41]

The *USMC Vision and Strategy 2025* further requires: (1) continuous, all weather, precision fires, (2) the ability to rapidly and precisely engage asymmetric targets of

[39]Department of the Navy and United States Marine Corps, *USMC Vision and Strategy 2025* (Washington, DC: Government Printing Press, 2).

[40]Ibid., 3.

[41]Ibid., 20.

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opportunity, and (3) that the Aviation Combat Element (ACE) integrate UASs in order to expand the force-multiplying capabilities inherent in unmanned systems.[42]

The *Marine Corps Unmanned Aircraft System (UAS) Plan* recognizes the capabilities of UASs in lieu of manned aircraft throughout the MAGTF. The key enhancements are ISR, C2, Strike, EW, and combat logistics. The initial organizational change to the MAGTF is the establishment of the Marine Unmanned Aerial Vehicle Squadrons (VMU). Additionally, the Marine Corps will integrate various UAS platforms, such as: (1) small UAS (SUAS), such as the RQ-11 Raven, (2) small tactical UAS (STUAS), such as the Scan Eagle system, (3) Marine Corps Tactical UAS (MCTUAS), currently supported by the RQ-7B Shadow, and (4) future Group-4 MCTUAS, capable of Strike, ISR, and EW capabilities.[43] The FY16 end state is that the MAGTF will employ UASs in order to enhance its operational capabilities. Additionally, it will integrate UAS cargo platforms currently being utilized in Afghanistan, to support and execute unmanned logistical support requirements.

North Atlantic Treaty Organization (NATO)

> The globalization and the boom of information, computing, networking, satellite and precision technologies all have tremendous implications for the defense and security sector. The extensive use of modern technologies in the offensive campaigns in Kosovo, Afghanistan and Iraq enabled the military to

[42]Ibid., 21.

[43]Department of the Navy and United States Marine Corps, *FY 2011 Marine Aviation Plan* (Washington, DC: Government Printing Office, 16 September 2010), 6-2.

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> achieve an unprecedented operational tempo and precision, and to win wars in the course of several weeks, instead of years.[44]

The NATO Defense Security Committee published a report authored by Pierre Claude Nolin (Canada), *Transforming the Future of Warfare: Network-Enabled Capabilities and Unmanned Systems*, focusing on network-enabled capabilities (NEC) and unmanned systems to assume missions in lieu of personnel or manned platforms in future conflict scenarios.[45]

> An information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision-makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization. In essence, [network-centric warfare] translates information superiority into combat power.[46]

The report asserts that NEC and unmanned systems are different technological development programs; however, "emerging drone technology is a physical extension of NEC and those NEC C4ISTAR systems will increasingly depend on Unmanned Aerial Vehicles (UAVs) as a tool to collect intelligence and reconnaissance data and even to

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[44]NATO Parliamentary Assembly, Pierre Claude Nolin (Canada), General Rapporteur, 175 STC 07 E bis -*Transforming the Future of Warfare: Network-Enabled Capabilities and Unmanned Systems*. 2007 Annual Session, I-1.

[45]The Defense and Security Committee (DSC) examine ongoing operations, partnerships and programs to find how NATO can continually improve its effectiveness as an ally. The DSC focus: (1) military effectiveness, (2) interoperability, (3) defense transformation, (4) defense budgets, (5) organization of NATO military structure, (5) operational relations with other international organizations, particularly the European Union, and (6) progress of candidate and partner countries in meeting standards for integration into NATO operations and partnerships, i.e. STANAG 4856.

[46]NATO Parliamentary Assembly, Pierre Claude Nolin (Canada), General Rapporteur, 175 STC 07 E bis -*Transforming the Future of Warfare: Network-Enabled Capabilities and Unmanned Systems*. 2007 Annual Session, II-A-4.

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attack targets."[47] The inherent benefits of NEC enabled unmanned systems are the reduction of Soldiers and increased survivability. Additionally, the report recognizes the inherent benefits outlined in DoD roadmaps, such as: (1) reduction of personnel/logistical footprints within the area of operation, (2) assumption of the 3D (dull-dirty-dangerous) missions, (3) the use of ground or underwater drones in demining operations. It further proposes a price incentive comparison. A F-16 fighter aircraft costs $30 million; a MQ-9 Reaper with a similar payload capacity costs approximately $7 million. Moreover, a UCAV could be a cheaper alternative to manned fighter programs. One F-35 Joint Strike Fighter costs $100 million; an F-22 Raptor $200 million, while the estimated costs of X-45 UCAV is $40 million.[48] Additionally, UAS upgrades are flexible and can be tailored to meet emerging threats. In contrast, manned systems place "very strict limitations on the size, shape, speed, altitude and many other technical characteristics of an aircraft. Without these limitations, engineers can create machines that would change our understanding of what an aircraft can do and it could look like."[49] This NATO report further highlights two points: (1) the extent of UMS proliferation, which extends to 32 countries, developing more than 250 different UAV models, (2) UMS customers encompass, Europe, Middle East, North Africa and Asia, which are expected to capture nearly 40 percent of the global market.[50]

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[47]Ibid., III-A-38.

[48]Ibid., 8.

[49]Ibid., 9.

[50]Ibid.

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DoD Publications

The purpose of reviewing DoD Joint publications is to analyze the doctrinal guidance on establishing a JTF and determine if the 2020 JTF will be postured to integrate and execute operations utilizing unmanned systems.

JP-1, *Doctrine for the Armed Forces of the United States* outlines the fundamental principles that guide the employment of US military forces in a Joint environment. It states that: (1) the strategic security environment is extremely fluid and that the Joint Force must be prepared to address emerging peer competitors and hybrid threats, (2) it will operate under the concept of Unified Action (UA), which refers to the synchronization, coordination, and/or integration of the activities of governmental and non-governmental entities to achieve unity of effort. Furthermore, UA demands maximum interoperability between all forces, units, and systems in order to operate together effectively across the spectrum of operations.[51]

JP 3-0, *Joint Operations*, provides the JTF guidance on planning, preparing, executing, and assessing joint military operations. It outlines six basic Joint functions which are common to most joint operations: (1) command and control, (2) intelligence, (3) fires, (4) movement and maneuver, (5) protection, and (6) sustainment. Furthermore, it addresses (a) organizing for joint operations, (b) organizing the joint force, and (c)

[51]Chairman, Joint Chiefs of Staff, Joint Publication (JP) 1, *Doctrine for the Armed Forces of the United States* (Washington, DC: Government Printing Office, March 2007, Incorporating Change 1, March 2009).

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conducting joint operations across the range of military operations, which includes the phasing of a joint operation.[52]

JP 3-33, *Joint Task Force Headquarters* (JTF HQ), outlines the formation and employment of a JTF HQ to command and control joint operations. It also outlines the JTF HQ organization and staffing and duties and responsibilities of the directorates, for the purpose of this thesis, the author will primarily focus on the J2 (Intelligence), J3 (Operations), and J4 (Logistics) and further describes the JTF functional commands; Joint Forces Air Component Commander (JFACC), Joint Forces Land Component Commander (JFLCC), Joint Forces Maritime Commander (JFMCC), and the Joint Forces Special Operations Commander (JFSOC).[53]

JP 5-0, *Joint Operation Planning*, forms the core of joint doctrine for joint operation planning throughout the range of military operations. It outlines: (1) the role of joint operation planning, (2) strategic direction and joint operation planning, (3) operational art and operational design, and (4) the joint operation planning process (JOPP).[54]

Additional Joint Publications relevant to JTF operations and to the discussion of UMS integration are: (1) JP 3-30, *Command & Control for Joint Air Operations*, (2) JP 3-31, *Command & Control for Joint Land Operations*, and (3) JP 3-32, *Command &*

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[52]Chairman, Joint Chiefs of Staff. Joint Publication (JP) 3-0, *Joint Operations* (Washington, DC: Government Printing Office, 11 August 2011).

[53]Chairman, Joint Chiefs of Staff, Joint Publication (JP) 3-33, *Joint Task Force* H*eadquarters* (Washington, DC: Government Printing Office, 16 February 2007).

[54]Chairman, Joint Chiefs of Staff, Joint Publication (JP) 5-0, *Joint Operations Planning* (Washington, DC: Government Printing Office, 11 August 2011).

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Control for Joint Maritime Operations. Together, these set forth the doctrine for joint operations to their respective functional components; to include interagency and multinational operations. For example, JP 3-30 outlines the responsibilities for the JFACC such as command and control of joint air operations across the range of military operations. The UMS operational considerations for the JFACC where highlighted in the Joint Capability Area (JCA) discussion and further refined in the USAF *Unmanned Aircraft Systems Flight Plan 2009-2040*, which envisions a networked family of UASs. These next generation UASs will operate autonomously and provide an exponential degree of operational capabilities which will be managed by the designated Joint Force Air Component Commander (JFACC).

The discussion regarding the perceived future hybrid threat operating environment, from both DoD and academic institutions, has been clearly defined and adopted. *Training Circular 7-100, Hybrid Threat*, describes the hybrid threat and outlines the manner in which this future threat may operationally organize against US forces and allows for further discussion in the integration of UMSs to mitigate threats in this operating environment in lieu of manned platforms and/or personnel.

> Hybrid threats (HT) are innovative, adaptive, globally connected, networked, and can possess a wide range of technologies, including the possibility of weapons of mass destruction (see figure 8). Hybrid Threat (HT) strategy is multi-dimensional conducted in four strategic-level courses of action, (1) strategic operations aim is to preclude the JTF from intervening in the HT area of operation/influence,(2) regional operations-actions against regional adversaries and internal threats,(3) transition operations- HT continues to pursue its regional goals while dealing with the development of outside intervention with the potential for overmatching the HT's capabilities, and(4) adaptive operations-

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actions to preserve the HT's power and apply it in adaptive ways against overmatching opponents.[55]

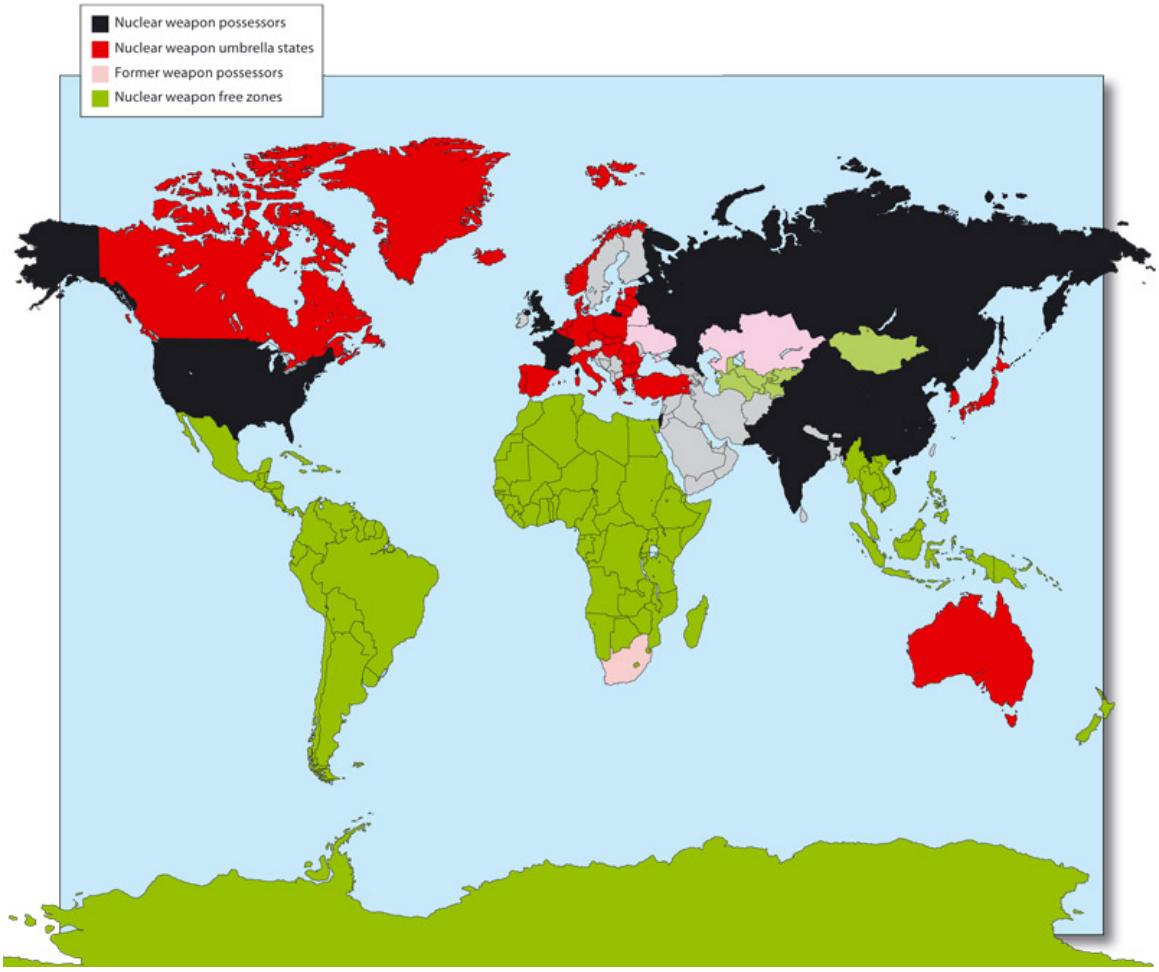


Figure 8. WMD proliferation map

Source: The International Campaign to Abolish Nuclear Weapons, http://www.icanw.org/nuclear-map/ (accessed 15 December 2011).

[55]Department of the Army, Training Circular 7-100, *Hybrid Threat* (Washington, DC: Government Printing Office, 29 November 2010), 1-1. (Headquarters, U.S. Army Training and Doctrine Command (TRADOC) is the proponent for this TC. The preparing agency is the Contemporary Operational Environment and Threat Integration Directorate (CTID), TRADOC G-2 Intelligence Support Activity (TRISA) –Threats).

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The foreseeable WMD/CBRNE planning considerations for the 2020 JTF are: (1) proliferation of nuclear weapons; (2) neighboring nuclear armed states in conflict, such as Pakistan/India or North Korea/Japan; (3) conducting operations in a CBRNE contaminated environment, such as in the event of a nuclear reactor meltdown. The WMD/CBRNE scenario will require remote engagement with platforms possessing increased standoff capabilities, a dispersion of forces, and persistent ISR and Strike capabilities. In this scenario, the U.S. Naval forces will be forced to operate from dispersed platforms; U.S. Army and USMC ground forces will be restricted from establishing Intermediate Staging bases (ISBs) and operating within a land based area of operation. The U.S. Air Force, in support of ISR and Strike missions, will be forced to rely on UAVs to mitigate the residual effects of CBRNE agents for an indefinite period of amount of time. The impact of a WMD/CBRNE operating environment to the 2020 JTF is the emphasis on utilizing UMSs throughout the air, land, and sea domains in lieu of manned systems or personnel in order to accomplish its mission. (see Annex A).

Academic Publications

The two prolific academic writers on robotics/unmanned systems and their impact on future military operations are Dr. Robert Finklestein and P.W. Singer. In "*Robotics in Future Warfare*" Dr. Finklestein, President of Robotic Technology Inc, focuses on his rationale for robots in future warfare. The focus is on the "three D's"; dirty, dull, and dangerous operations that robots can assume. Furthermore, those robots are expendable, maneuverable, have a faster response time, indefatigable, autonomous, and incorporate

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emerging technology which is a far superior option than human Soldiers.[56] In *Wired for War - The Robotics Revolution and Conflict in the 21st Century*, P.W. Singer, Director of the 21st Century Defense Initiative at Brookings Institute, focuses on the ongoing robotic revolution within the Department of Defense and its implications for 21st century warfare, the "dawn of robotic warfare." He further highlighted in his book that with the end of Operation Desert Shield/Storm (ODS) military leaders assumed that the public's tolerance of Vietnam level casualties had dramatically diminished, leading Major General (Retired) Robert H. Scales to state that in the new era of warfare that "dead Soldiers are America's most vulnerable center of gravity."[57] Furthermore, U.S. State Senator John Warner (Virginia), former Senate Armed Services Committee Chairman, went on record to state that "in my judgment this country will never again permit the armed forces to be engaged in conflicts which inflict the level of casualties we have seen historically… so what do you do? You move toward the unmanned type of military vehicle to carry out missions which are high risk in nature." [58]

In November 2011, the Brookings Institute chaired a panel "The Future of Land Wars: Intense, High-Tech, Urban, Coastal" with current and retired Army officers and professional analysts which provide relevant insights for future UMS procurement and employment considerations. Colonel (COL) Gian Gentile, United States Military

[56]Dr. Robert Finklestein, "Robotics in Future Warfare" (presented to the Panel on Robotics and Contemporary/Future Warfare Conference on the Strategic Implications of Emerging Technologies, US Army War College Strategic Studies Institute, 14-16 April 2009).

[57]Singer, *Wired for War*, 59.

[58]Ibid., 60.

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Academy (USMA) history professor, stated that "we should absolutely avoid building a future ground force optimized for wars like Iraq and Afghanistan … future land battlefields demand a ground force built around the pillars of firepower, protection and mobility, moreover, this future ground force needs to be able to move and fight in dispersed, distributed operations."[59] His insight(s) were further expanded on by Lieutenant General (LTG) (retired) Dave Barno, a Senior Fellow for the Center for a New American Security, stating that the " typical land battlefield of 2021 will be a complex, often urbanized environment where battles are often fought inside the dense urban sprawl that increasingly proliferates along the edges of the world's great cities …. enabling small units to reliably leverage networked technology for access to fires, to employ unmanned and robotic adjuncts and operate mobile fighting systems will be a key sector for investment" (see figure 9).[60]

[59]David Axe, "The Future of Land Wars: Intense, High-Tech, Urban, Coastal," 30 November 2011, http://defense.aol.com/2011/11/30/the-future-of-land-wars-intense-high-tech-urban-coastal/ (accessed 15 December 2011).

[60]Ibid.

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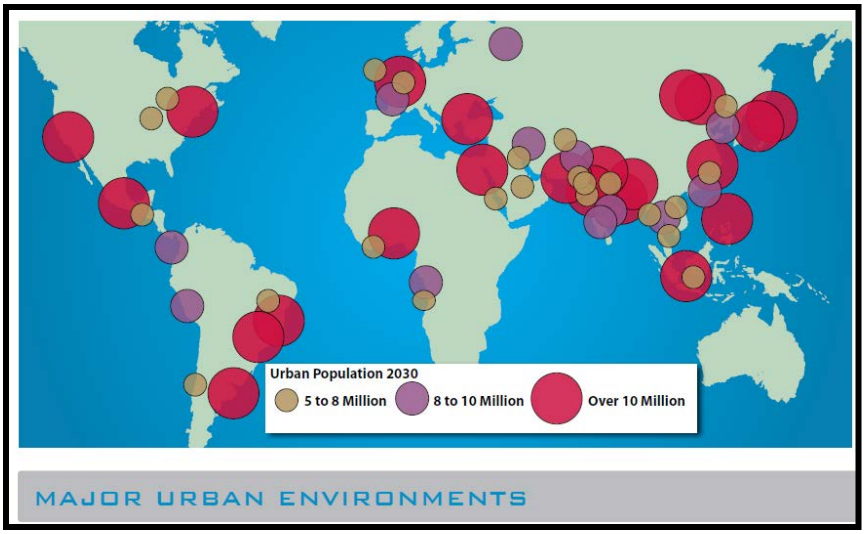


Figure 9. Urban population centers (2030)

Source: Joint Operating Environment (JOE) 2010, 57.

Lastly, P. W. Singer, stated that "more than 40 percent of the world's population already lives in cities with populations of more than 1 million . . . the megacity, an urban agglomeration of more than 10 million people . . . there are 22 such megacities, the majority in the developing countries of Asia, Africa and Latin America. By 2025, there will be another 30 or more . . . megaslums that house millions of young, urban poor--the angry losers of globalization."[61]

Foreign UMS Capabilities Considerations

The rise of the People's Republic of China (PRC) as a major international actor stands out as a defining feature in the 21st century strategic landscape.[62] The People's

[61]Axe.

[62]Department of Defense, Office of the Secretary of Defense, Annual Report to Congress - Military and Security Developments Involving the People's Republic of China, 2011, I.

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Liberation Army (PLA) strategic focus is to compete equally with the US military in certain areas, such as submarine warfare, space, and cyber warfare. In December 2011, China placed in operation a satellite navigation service that is designed to provide an alternative to the U.S. Global Positioning System (GPS), which will assist the Chinese military to identify, track and strike U.S. ships in the region in the event of armed conflict.[63] The Beidou Navigation Satellite System provides initial positioning, navigation and timing services to China and its surrounding areas.[64] According to the assessment of Professor Tan Kaijia, a weaponry expert with the PLA's National Defense University, "China has made substantial progress in intelligent control systems, precise measuring-controlling systems and computer information processing for military uses."[65]

The development and manufacture of Chinese of unmanned systems over the past 30 years have been often based on U.S. UAV/UCAV concepts (see table 2).

[63]Jeremy Page, "China Launches Own Global Positioning System," *The Wall Street Journal* – Asia Technology, 27 December 2011, http://online.wsj.com/article/SB10001424052970203479104577123600791556284.html#ixzz1hlsK5e1W (accessed 27 December 2011).

[64]Ibid.

[65]UAVs in active service reveal China's growing interest in military robots, Defense Professionals, 2 October 2009, http://www.defpro.com/news/details/10219/ (accessed 27 December 2011).

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Table 2. Chinese UAV/UCAV Development

Chinese UMS[66]		US equivalent	Industry	Date displayed
WuZhen-5	UAV	AQM-34N Fire-Bee	Beijing University of Aeronautics & Astronautics	1981/1999
ASN-206/207	UAV.	MQ-1 Predator	Xi'an ASN Technology Group Company	1996
WuZhen-2000	UAV	RQ-4 Global Hawk	Guizhou Aviation Industry Group	2000 Zhuhai Air Show
HARPY	UAV	TBD	Israel Aerospace Industries (IAI)	O/A 2000
ANJIAN "Dark Sword"	UCAV	TBD/X-47B	UNK	2006 Zhuhai Air Show.
Xianglong "Sour Dragon"	UAV	RQ-4 Global Hawk	Chengdu Aircraft	2006 Zhuhai Air Show (China)
Yilong	UAS	MQ-1 Predator	UNK	2008 Zhuhai Air Show
CH-3	UCAV	X-47B	China Aerospace S &T Corporation	2008 Zhuhai Air Show

Source: Created by author with information gathered from Defense Professionals website, http://www.defpro.com/news/details/10219/ (accessed 27 December 2011).

[66]Ibid.

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In addition, China has developed anti-access capabilities such as over-the horizon (OTH) radars that can locate and fix U.S. Navy Carrier Strike Groups (see figure 10). This comprehensive development of Chinese anti-access/area-denial (A2/AD) capabilities will mitigate traditional U.S. power projection capabilities such as uncontested deployment of ground forces, aircraft formations in regional airbases, and the uncontested employment of combat aircraft to support ground operations.

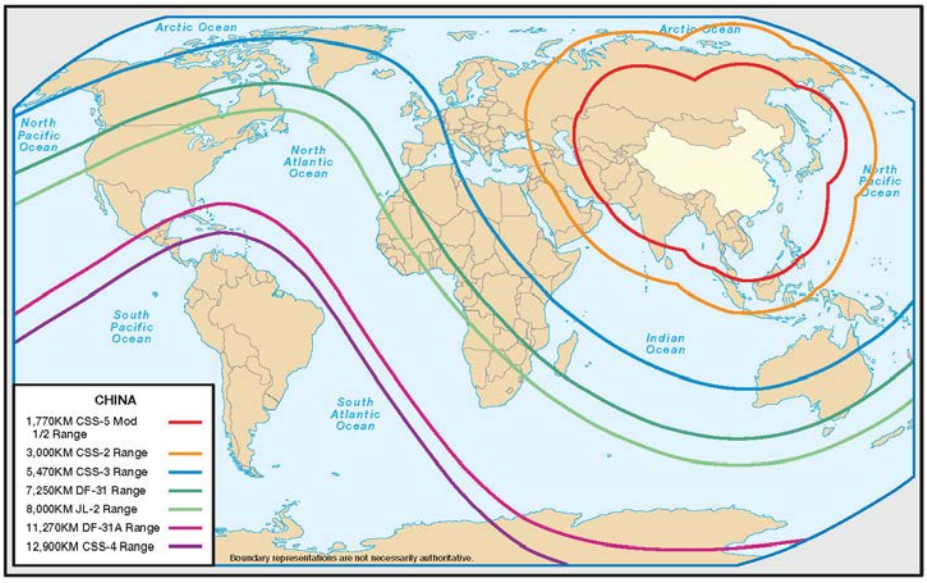


Figure 10. Chinese Medium and ICBM ranges.

Source: Department of Defense, "Military Power of the People's Republic of China 2007" (Report to Congress Pursuant to the National Defense Authorization Act Fiscal Year 2000, Washington, DC), 19.

In respect to the current OEF operating environment it is relevant to recognize Pakistan's availability, and procurement of UMS, primarily UAVs. Pakistan at the outset of the U.S. Global War on Terrorism (GWOT) requested and was denied UMS platforms

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by the United States. Therefore, Pakistan engaged in procuring UAV concepts and systems, both domestically and on the international market.

Pakistan entered into a deal with the Italian firm, Selex-Galileo, in order to produce UAV's at their Kamra Air Weapons Complex. The Pakistan Navy acquired rotorcraft drones from foreign sources. The Pakistani Army has pursued partnerships with China, and local manufacturers to continue to develop more advanced platforms within the country.[67] For example, the Burraq is a high endurance/long range (HE/LR) over the horizon armed UCAV aircraft that is being developed in partnership with China (includes weapons development, control systems development, propulsion, airframe, ground control stations).[68]

UMS Commercial Proliferation

> Unmanned aerial vehicles (UAVs) represent one of the brightest, fastest-growing segments in the aerospace and defense industry . . . move beyond strategic reconnaissance and surveillance and into roles previously filled by manned jet fighter aircraft, combat helicopters, and even special operations forces on the ground . . . will provide battlefield situational awareness, fire support from the air, covert surveillance, and applications no one has thought of yet.[69]

The proliferation of UMS has led to the establishment of multinational organizations such as the Association for Unmanned Vehicle Systems International

[67]"Say hello to Pakistan's first domestically produced armed drone: The Burraq UCAV," 5 December 2011, http://www.techlahore.com/2011/12/04/say-hello-to-pakistans-first-domestically-produced-armed-drone-the-burraq-ucav/ (accessed 15 December 2011).

[68]Ibid.

[69]Military and Aerospace Executive Briefing: Unmanned aircraft applications proliferate, and represent one of the few growing markets in an otherwise-shrinking defense budget, http://www.militaryaerospace.com/executive-briefings/2011/unmanned-aircraft-applications-proliferate.whitepaperpdf.render.pdf. (accessed 14 April 2012).

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AUVSI).[70] In recognition of the impact within the aerospace and defense industry, the AUVSI's Unmanned Systems North America 2012 Symposium at Mandalay Bay Resort & Casino, Las Vegas, Nevada, will feature the latest issues, trends and developments impacting the unmanned systems and robotics community.[71]

In respect to U.S. Defense firms, they have until recently been restricted from generating UAV export revenue due to the Missile Technology Control Regime (MTCR) Category I export control restrictions.[72] These restrictions strongly discourage export of such platforms to Asia and the Middle East. These markets are serviced by foreign UAV manufacturers and exporters such as Israel, Singapore, and South Africa. In response, American UAV manufacturers redesigned their existing military platforms to fall under the far less restrictive MTCR Category II. General Atomics, focusing in Asia and the Middle East, introduced the Predator XP, designed for overseas buyers. In Asia, General Atomics continues to prioritize Predator B sales to Australia, Japan, and South Korea.

Notes on Methodology

The purpose of this section is to highlight the research methodology that will be used to answer the primary research question: Will the 2020 JTF be postured to utilize

[70]The Association for Unmanned Vehicle Systems International (AUVSI) is the world's largest non-profit organization dedicated to the advancement of unmanned systems and robotics–represents 7,000 members and more than 500 corporate members from 60 allied countries involved in the fields of government, industry and academia, at www.auvsi.org.

[71]AUVSI homepage, http://www.auvsishow.org/auvsi12/public/enter.aspx (accessed 1 April 2012).

[72]Eddie Walsh, "Predator Maker Redesigns UAV To Boost Exports," *AolDefense*, 15 November 2011, http://defense.aol.com/2011/11/15/predator-maker-redesigns-uav-to-boost-exports/ (accessed 1 December 2011).

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mandated unmanned systems? In chapter 1 the secondary research questions were identified. In chapter 2 the literature associated with the primary and secondary research questions was discussed. The author's intent is to provide a definitive answer for the secondary research questions, within the limitations outlined in chapter 1. Additionally, it's feasible that simply generating a discussion from the secondary research questions to gain an understanding its relevance to the primary research question may be all that is required. With this intent, conclusions will be drawn for each secondary research question. Therefore, a description of the methodology to be used will follow the following framework.

SRQ #1: What future training will be required for the JTF to employ UMSs? The purpose of this question is to gain an understanding and identify future training requirements for the JTF to employ UMS. In order to generate UMS training requirements, DoD in conjunction with the Services must understand the capabilities of UMS and how they will integrate and support operational reach and provide operational access in the JTF area of operations (JOA). These future training requirements will be outlined in chapter 4–conclusions.

SRQ #2: How will the incorporation of robust UMS capability impact the organization of a JTF in 2020? The purpose of this question is to gain an understanding (or identify) the impact on the organization of a JTF with the integration of revolutionary unmanned systems. In order to generate JTF task organization analysis, DoD in conjunction with the Services must understand the capabilities of UMS and what capabilities can be accomplished by UMS in lieu of manned systems.

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Conclusions and Recommendations

In chapter 3, preliminary conclusions will be provided for the secondary research questions; chapter 4 will provide a final conclusion for each secondary research question and the primary research question. Table 3, provides a reference chart of the research methodology.

Table 3. Research Methodology

SRQ	Purpose	Ends	Ways	Means
1. What future training will be required for the JTF to employ UMSs?	Gain an understanding of anticipated future UMS capabilities & required staff training	Training requirements & principal staff directorates identified	Examine Service & Functional Component Commander mission requirements	Review Joint publications; UMS academic publications; Service specific UMS roadmaps; JTF case studies
2. How will the incorporation of robust UMS capability impact the organization of a JTF in 2020?	Identify mission requirements for the JTF and staff directorates in which UMS can be employed in lieu of manned platforms	JTF task organization recommended	Examine Functional Component Commander mission requirements	Review Joint publications; UMS academic publications; Service specific UMS roadmaps; JTF case studies

Source: Created by author.

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CHAPTER 3

ANALYSIS

The purpose of chapter 3 is to present the findings of the research in order to answer the primary research question: Will the 2020 JTF be postured to utilize mandated unmanned systems? As discussed in Chapter 2, JP 3-33, Joint Task Force Headquarters, outlines the doctrinal framework to establish a JTF HQ and its Functional Component Commands. The understanding of the capabilities, duties, and responsibilities of the staff functions and commands will facilitate the analysis of UMS integration in its operations.

Functional Component Commands

A functional component command is composed of forces of two or more DoD Services in which the Service component commander with the preponderance of forces is designated as the functional component commander (see table 4).

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Table 4. Functional Component Command Considerations

	JTF HQ	JFACC	JFLCC	JFMCC	JFSOC
USA	X		X		X
USN	X	X		X	X
USAF	X	X			X
USMC	X	X	X	X	X

Source: Created by author using data from Chairman, Joint Chiefs of Staff, Joint Publication (JP) 3-33, *Joint Task Force Headquarters* (Washington, DC: Government Printing Office, 16 February 2007).

Joint Forces Air Component Commander (JFACC)

A JFACC will be designated based on having the preponderance of air assets and the ability to effectively plan, task, and control joint air operations. The responsibilities of the JFACC include, planning, coordinating, and monitoring joint air operations and the allocation and tasking of joint air operations forces.[73] The operational consideration is the integration of UMSs described in Chapter 2 (UAVs will be predominate in the JFACC)

[73]Chairman, Joint Chiefs of Staff, Joint Publication (JP) 3-33, *Joint Task Force Headquarters* (Washington, DC: Government Printing Office, 16 February 2007), III-5.

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throughout the JFACC subordinate division in lieu of manned systems; primarily the Combat Operations and ISR Division (see figure 11).

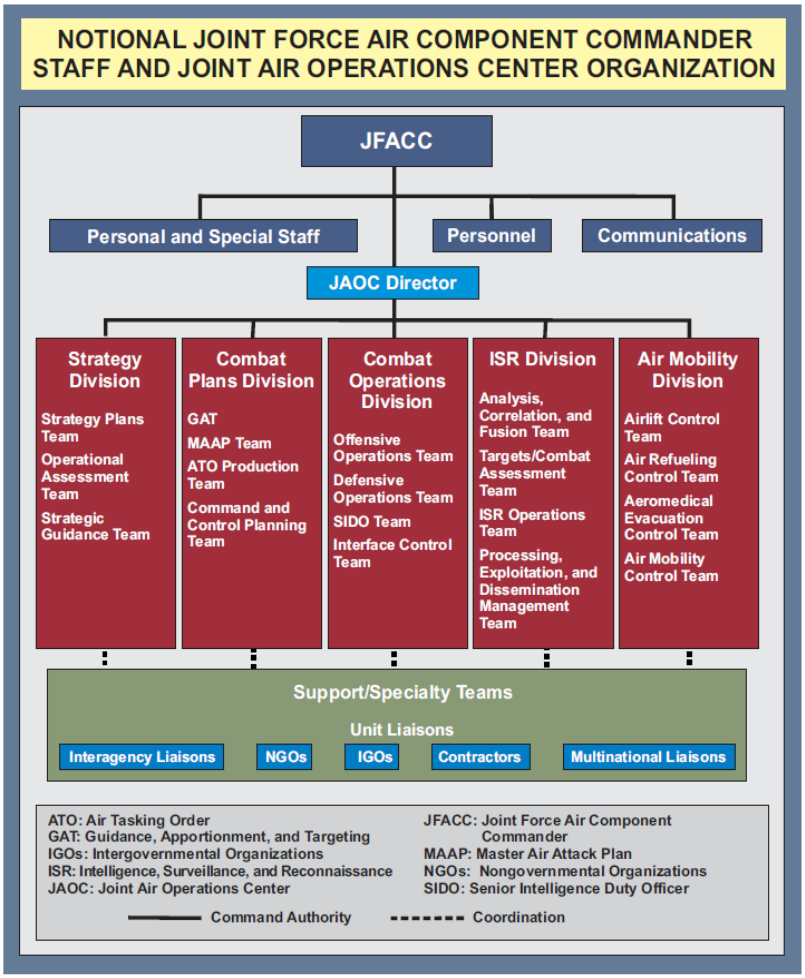


Figure 11. Notional JFACC Composition

Source: Chairman, Joint Chiefs of Staff, Joint Publication (JP) 3-33, *Joint Task Force Headquarters* (Washington, DC: Government Printing Office, 16 February 2007), III-6.

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Joint Forces Land Component Commander (JFLCC)

The designation of a JFLCC typically occurs when forces of more than one Service component participate in a land operation and the CJTF determines that doing this will achieve unity of command and effort among land forces.[74] The essential planning consideration for a JFLCC is the availability of ports of debarkation and the mutual support possible between land forces. A JFLCC can consist of an Army corps or MAGTF (see Table 2). The operational consideration is the integration of UMSs described in Chapter 2 (UGVs, UGSs, and UAVs) throughout JFLCC operations in lieu of manned systems and/or personnel.

Joint Forces Maritime Component Commander (JFMCC)

The essential task of a JFMCC is to command and control joint maritime operations. These forces, generally, consist of ship formations, marines and Special Operation Forces (SOF). Typical JMFCC missions include: sea control, maritime power projection, deterrence, strategic sealift, forward maritime presence, and sea basing operations.[75] The operational consideration is the integration of UMSs described in chapter 2 (USVs, UUVs, UAVs) throughout JFMCC operations in lieu of manned systems and/or personnel.

Joint Forces Special Operations Commander (JFSOC)

The JFSOC generally will be the commander with the preponderance of SOF and appropriate command and control structure to conduct operations. Additionally, the

[74]Chairman, Joint Chiefs of Staff, Joint Publication (JP) 3-33, III-7.

[75]Ibid., III-9.

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JFSOC may establish a joint special operations air component commander (JSOACC) responsible for planning and executing joint special operations air activities. This includes the responsibility to coordinate, allocate, task, control, and support the assigned and attached joint special operations aviation assets.[76] The operational consideration is the integration of UMSs described in Chapter 2 (USVs, UUVs, UAVs, UGVs, and UGSs) throughout JFSOC operations in lieu of manned systems and/or personnel.

Joint Task Force Directorates

The operational considerations of UMS integration does not solely rest on the Services as they execute their missions as a functional component command, but, also to the JTF staff. As discussed in chapter 1, the 2020 JTF will be required to leverage cutting-edge information technologies to ensure a secure and collaborative command and control network. These requirements will generate training requirements for the staff to plan and execute operations with UMSs in lieu of manned platforms. A key impact will be on the JTF Chief of Staff (COS) who serves as the key staff integrator. The COS is responsible for the establishment and management of staff processes and procedures that support the JFC decision making process.[77]

The impact to the JTF J2 will be on the Joint Intelligence Support Element (JISE). The JISE is the hub of intelligence activity in the Joint Area of Operations (JOA) which requires persistent awareness and is characterized by net-centric and fused operations. Therefore, the impending UMS training requirements support battle space awareness

[76]Chairman, Joint Chiefs of Staff, Joint Publication (JP) 3-33, III-11.

[77]Ibid., II-8.

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(BA) and the Tasking, Production, Exploitation, and Dissemination (TPED) process to translate sensor data into a common picture becomes apparent. Furthermore, the projected UMS platforms with their requirement to operate with full autonomy will extend their BA persistence capabilities from days to weeks across all of the domains.

The impact to the J3 will be to support and execute Force Application (FA) missions which are focused on maneuver and engagement. The Joint Operations Center serves as the focal point for all operational matters and the current operations (CUOPS) element is staffed by J-3 air, land, maritime, and special operations watch officers. The projected UMS platforms will be able to assume air, ground, and sea operations in lieu of manned platforms and/or personnel. Additionally, the J3 (Operations Directorate) will need to leverage UMS protection platforms that will assist in FORCEPRO tasks, such as FOB security, obstacle construction/breach, sophisticated explosive ordnance disposal, and casualty extraction and evacuation. The J-4 provides the foundation of combat power, by air, land, and sea. Additionally, the J-4 must understand the capabilities of all UMS mobility assets as they become available throughout sustainment and operations. The discussions of the UMS capabilities across the services support these requirements and require successful integration in order to support the JFC's decision making process and execution of its assigned missions.

Case Studies

> Historically, creating a joint task force (JTF) has come with its share of forming and planning difficulties . Typically, a Service two or three-star headquarters will be designated as the JTF for a crisis or contingency and will receive augmentation from the Services to fill the capability gaps within the JTF. Most situations require JTFs to be established rapidly, and the lag time in

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> receiving augmentation, coupled with the inexperience of augmentees in joint operations, has proven an ineffective and unsuccessful model.[78]

The first case study for this thesis is the designation of the V Corps HQ as Combined Joint Task Force-7 (CJTF-7) for Operation Iraqi Freedom (OIF I/II- June 2003-May 2004). The overall analysis of CJTF-7 is outside the scope of this thesis; the intent is to: (1) analyze the doctrinal guidance that was followed in establishing CJTF-7 in the dominant operating environment for DoD and the Services at the time, and (2) to determine if the lessons observed allow for future considerations in establishing a JTF under a similar operating environment utilizing unmanned systems in lieu of manned systems and/or personnel. Additionally, the JTF Odyssey Dawn (JTF OD) case study will highlight future considerations for integrating and operating from a mobile C2 platform with unmanned systems in lieu of manned systems.

CJTF-7 Background

In April 2003, the commanding general of 1st Armored Division (1AD), Major General (MG) Ricardo Sanchez was designated the commander of V Corps (Germany) and promoted to Lieutenant General (LTG), concurrently while deploying his division (1AD) from Germany to Kuwait. At this point the Combined Forces Land Component (CFLCC) HQ had been designated the responsibility for Phase IV (establish security) operations. On 17 May, V Corps was officially notified of its designation as a CJTF with

[78]Walter E. Carter, Jr, "The Joint Enabling Capabilities Command: A Rarity within the Conventional Force," *Joint Forces Quarterly* 64 (January 2012): 19.

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a Relief in Place/Transfer of Authority (RIP/TOA) set for 15 June 2003, less than 30 days to prepare for assuming responsibility for all operations in Iraq.[79]

Challenges

The immediate challenges faced by CJTF-7 were to support operations at the tactical, operational and theater strategic level. It was unable to initially do so, due to it being grossly understaffed and lacking strategic communications and capability. The end result, was that it took six to eight months for CJTF -7 to become fully operational and capable (FOC); which was roughly at the 75 percent completion date of its 12 month rotation. In COL (R) Mansoor's assessment "CJTF-7 lacked the link between the strategic ends and tactical means that would ensure a successful outcome."[80] For the foreseeable hybrid-threat environment, six to eight months to become FOC will result in mission failure.

Analysis

For the 2020 JTF assigned to a similar operating environment, UMSs will provide strategic communications, C2, and ISR throughout the phasing of operations; Phase 0 (shape), Phase I (deter), Phase II (seize the initiative), and Phase III (dominate), which will exploit the initiative and dictate the operational tempo. The follow on phases, Phase IV (establish security) and Phase V (enable civil authority) can incorporate UMSs with

[79]Donald P. Wright, *The United States Army in Operation Iraqi Freedom, May 2003-January 2005: On Point II: Transition to the New Campaign*; *With the Contemporary Operating Study Team* (Washington, DC: Government Printing Office, June 2008).

[80]Peter R. Mansoor, *Baghdad at Sunrise: A Brigade Commander's War in Iraq*. (New Haven: Yale University Press, 2008), 109.

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land forces, providing capabilities normally performed by manned platforms or personnel.

The second case study for this thesis is the designation of the U.S. Navy 6th Fleet as the HQ for JTF Odyssey Dawn in support of operations in Libya.

JTF Odyssey Dawn (Libya) Background

In March 2011, U.S. Africa Command (USAFRICOM) established Joint Task Force Odyssey Dawn (JTF OD) under the command of Admiral Samuel Locklear III, commander of U.S. Naval Forces Europe – Africa, to support United Nations Security Council Resolutions (UNSCRs) 1970 and 1973. The JTF mission was to (1) provide humanitarian assistance, (2) support noncombatant evacuation (NEO) operations, (3) enforcement of a maritime exclusion zone and (4) enforcement of a no-fly zone within the JOA Libya.[81] In the span of three weeks, JTF OD conducted a coalition air campaign against Libya's integrated air defense systems and halted Libyan government forces from advancing against rebel-held population centers. On March 31, JTF OD transferred command and control of the operation to NATO; re-designated as Operation Unified Protector.

Challenges

The JTF was composed of U.S. personnel and foreign liaison officers with additional augmentation with a Joint Deployable Team (JDT) provided by the United States Transportation Command (USTRANSCOM) Joint Enabling Capabilities

[81]JTF Odyssey Dawn website, http://www.naveur-navaf.navy.mil/odysseydawn/index.html (accessed 10 March 2012).

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Command (JECC). The JTF OD staff was headquarted and certified aboard the USN 6th Fleet Command and Control ship the USS Mount Whitney (LCC/JCC 20). The JTF consisted of a JFMCC, JFACC, and JFSOC. A JFLCC was not established. However, a USMC battalion deployed as an Air Contingency Battalion (ACB) to serve as a Battalion Landing Team for the 26th Marine Expeditionary Unit (MEU) in the event landing forces were required throughout JOA Libya. In the conduct of an after action review (AAR) the inclusion of a designated JFLCC was deemed essential for mission planning and force employment.

> JTFs should consider the composition of the adversary when forming its own structure, even if ground troops are not employed on the friendly side. Filling every key position of a JTF staff will enhance understanding of the operational environment and can multiply the effects and outcomes of the planning process and subsequent operation execution. In future operations where U.S. ground forces are not employed, consideration of a JFLCC team to conduct planning and provide input covering some or all of the functions is essential.[82]

Analysis

The JTF OD mission merits further evaluation of future missions that can be assumed by unmanned systems in lieu of manned systems, such as strike coordination and reconnaissance, defined as a mission flown for the purpose of detecting targets and coordinating or performing attack or reconnaissance on those targets (also known as

[82]Gregory K. James, Larry Holcomb, and Chad T. Manske, "Joint Task Force Odyssey Dawn: A Model for Joint Experience, Training, and Education," *Joint Forces Quarterly* 64 (January 2012): 26.

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SCAR see table 5).[83] Furthermore, UMSs support all the steps of the Dynamic Targeting Steps, such as find, fix, track, target, engage, and assess.[84]

Table 5. JTF OD Manned- Unmanned Mission Matrix

Task	Manned Platform	UAS	USV	UUV	UGV
Destroy shoreline defenses	X	X (SCAR)	X		
Interdict military ground convoy	X	X (SCAR)			X
Destroy hardened positions	X	X (SCAR)	X		X
Conduct EW	X	X (MQ-M/L)			
Maritime Search and Rescue	X	X	X	X	
Destroy surface ship (s)	X	X (SCAR)	X	X	
Provide SA/C2	X	X (BAMS)	X		X
WMD-E[85]	X	X	X		X

Source: Created by Author

[83]Headquarters, Department of the Army. Field Manual (FM) 3-60.2. *Multi-Service Tactics, Techniques, and Procedures for Strike Coordination and Reconnaissance* (Washington, DC: Government Printing Office, November 2008).

[84]Ibid., 31.

[85]Weapons of Mass Destruction-Elimination (WMD-E) was not a specified task for JTF OD, the implied planning consideration becomes apparent with presence of the Rabta chemical weapons facility, which was estimated to contain 23T of mustard gas and 1,300T of precursor chemicals. WMD elimination operations are actions to systematically locate, characterize, secure, disable, or destroy WMD programs and related capabilities (ATTP 3-11, M*ulti-Service Tactics, Techniques, and Procedures for Weapons of Mass Destruction Elimination Operations*, 10 December 2010, 1-1).

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In summary and comparison, CJTF-7 faced the challenges of (1) unclear mission focus, (2) conflict in levels of authority, (3) inadequate staff augmentation, (4) lack of strategic communications, and (5) an estimated six to seven months for the CJTF to become fully operational & capable (FOC). In comparison, JTF OD provided a mobile platform with (1) mission focus, (2) levels of authority clearly established, (3) critical staff was augmented by the JECC, (4) strategic communications was provided by the JCSE, and (5) the JTF was FOC and completed all assigned tasks within a three week period.

From Major Combat Ops Risk	To Platforms	Acceptable Level of Risk
Indirect fires vs.	UA	High
	Fighter/attack fixed wing	Medium
	Manned rotary wing	Low
	Tanker/airlift/civilian	Low
UA vs.	UA	High
	Fighter/attack fixed wing	Medium
	Manned rotary wing	Medium
	Tanker/airlift/civilian	Low
Fighter/attack fixed wing vs.	UA	Medium
	Fighter/attack fixed wing	Medium
	Manned rotary wing	Low
	Tanker/airlift/civilian	Low
Manned rotary wing vs.	UA	Medium
	Fighter/attack fixed wing	Low
	Manned rotary wing	Medium
Tanker/airlift/civilian vs.	UA	Low
	Fighter/attack fixed wing	Low
	Manned rotary wing	Low
	Tanker/airlift/civilian	Low

Figure 12. Notional Risk Chart for the employment of UMS
Source: Department of the Air Force, Air Force Doctrine Document 3-52, *Air Space Control* (Maxwell AFB, AL: Government Printing Office, 2 February 2011), 55.

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CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The purpose of Chapter 4 is to answer the primary research question; will the 2020 JTF be postured to utilize mandated unmanned systems? In order to answer this question, two secondary research questions have been analyzed.

UMSs have provided great capability throughout operations in OEF /OIF and are being designed to provide exponentially greater capabilities within the next 8-10 years that will dramatically impact the way the 2020 JTF executes its missions (see table 6). This thesis did not cover the broad spectrum of UMS development which ranges from nanotechnology (machines that are the size of a hummingbird, or smaller) utilizing SWARM technology to unmanned submarines. This thesis only covered the time period from the present to the year 2020, a period of eight years. The Service UMS Roadmaps extend beyond 2030 and to speculate about the capabilities that will become available in the next 18 years is beyond the scope of this thesis. Furthermore, excluded were numerous academic institutions, such as the Stanford Research Institute (Robotics and Artificial Intelligence Center), Florida Institute for Human and Machine Cognition, and QinetiQ that actively engage with DoD R&D and continue to expand on the estimated 7,000 unmanned/robot systems that are being utilized throughout the Global War on Terrorism.

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Table 6. UMS Technology Roadmap (2012-2020)

		2012	2020	
Interoperability	Technology	Common Data links & Encryption	Common data standards across all services and platforms	Synergistic operation through the exchange, interpretation and action on data from coalition systems
	Capability	Common ground stations	Common autonomy capabilities across platforms	
Autonomy	Technology	Multi-sensor data fusion	Intelligent control	Force structure reduction and full, reliable autonomous control during complex mission sets
	Capability	Environmental understanding and adaptation	Autonomous collaboration	
Airspace Integration	Technology	Ground based Sense and Avoid	Airborne Sense and Avoid	UAS unfettered access to national and international airspace
	Capability	Missions in low density airspace	Dynamic operations for Medium and Large UAS	
Training	Technology	High Fidelity Simulators/Trainers	Universal Ground Control Station	TBD
	Capability	Manned/Unmanned Teaming	Universal Pilots and Operators	
Manned-Unmanned Teaming	Technology	UAV FMV and target data to manned aircraft	Cognitive machine learning	TBD
	Capability	MUMT-2 (air to air to ground)	Unmanned scout and attack	

Source: Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036* (Washington, DC: Government Printing Office, October 2010), 89.

The impact for DoD and pertinent for this thesis is how will these revolutionary systems impact the DOTMLPF process, more specifically the 2020 JTF. At which echelon will there be a centralized entity to integrate these unmanned systems and operational capabilities for the 2020 JTF? Will these occur at the Geographic Combat Commander (GCC) level, or with the Service Component Commands who will then

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advise the GCC upon establishing a JTF? With the consensus that the future operating environment will be hybrid, which includes A2/AD threats, the emphasis for establishing a fully operational and capable (FOC) based on the JTF OD model, mitigating the CJTF-7 operational challenges, becomes a further opportunity for Senior leadership to consider: "jointness is not automatic; it must be continually updated through joint integrated joint force development activities to provide relevant capabilities that are responsive to the security environment."[86]

The establishment of a UMS consolidated proponency within an appropriate CJCS directorate, such as the J7/ Joint Force Development and Integration (JFDID) division should be considered. The JFDID serves as the primary agent for developing and monitoring the implementation plans for joint experimentation and concept development.[87] Additionally, the USSTRATCOM Joint Functional Component Command for Intelligence, Surveillance and Reconnaissance (JFCC-ISR) merits consideration. The JFCC-ISR is responsible for aligning processing, exploitation, and dissemination (PED) capacity with ISR allocation to provide enablers necessary to deliver intelligence to combatant command. This recommendation is based on that all UMSs primarily serve as an ISR platform which can be re-configured to strike platforms.

All leaders and organizations that can directly impact UMS integration must support a culture of innovation, emphasizing the capabilities provided by these unmanned

[86]Joint Forces Quarterly, "Joint Doctrine Update," *JFQ* 64 (1st Quarter 2012): 148.

[87]The author makes this recommendation based on the availability of unclassified sources. A discussion on the dissolution and capabilities of U.S. Joint Forces Command is outside the scope of this thesis.

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systems throughout their formations. Therefore, the author offers a relevant outline from General (retired) Don A. Starry who found himself in a similar period of transformation, which required him to "bring clearly a focused intellectual activity in the matter of any change."[88] In this case, the integration and employment of UMSs in lieu of manned systems or personnel throughout military operations.

1. There must be an institution or mechanism to identify the need for change.
2. There must be a spokesperson for change.
3. The spokesperson must build consensus amongst a wide audience.
4. There must continuity among the architects of change.
5. Changes proposed must be subjected to trials to determine their relevance.

All of the above have been presented throughout this thesis. For example, the mechanism for change has been identified as the FY2001 NDAA. The spokesman for change has been identified as academic writers and organizations, such as P.W. Singer and the AUVSI. The spokesman who must build consensus is present within the U.S. Congress, such as Congressman Howard P. "Buck" McKeon (R-CA), Chairman of the Congressional Unmanned Systems Caucus (CUSC), which recognizes the overwhelming value of unmanned systems in the scientific, intelligence, law enforcement, and homeland security communities.[89] Additionally, consensus is needed within the U.S. House Robotics Caucus which focuses on: (1) educating members of Congress and

[88]GEN (R) Don A. Starry, "To Change an Army," *Military Review* 63, no. 3 (March 1983): 20-27. This article is adapted from an address made by GEN Starry, 10 June 1982, to the US Army War College Committee on a Theory of Combat, Carlisle Barracks, PA. CGSC Copyright Registration #11-270 C/E.

[89]Congressional Unmanned Systems Caucus (CUSC), http://uavc.mckeon.house.gov/.

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congressional staff on current & future research and development, and utilization initiatives and (2) ensure that the nation remains globally competitive as the robotics industry expands and further affects the way we live our lives.[90] The continuity amongst the architects of change is reflected in the Services UMS roadmaps, many of which extend well beyond the timeline discussed in this thesis. Finally, the changes proposed must be subjected to trials to determine that their relevance is present in the DoD R&D directorates and amongst the commercial industry trials/programs that have been highlighted in this thesis.

Secondary research question conclusions

SRQ #1: What future training will be required for the JTF to employ UMSs?

In the DOTMLPF analysis process, *training* examines how we prepare our forces to fight and determine methods of improvement to offset war fighting capability gaps. It addresses the following questions: (1) is the issue caused by lack of or inadequate training? (2) does training exist which addresses the issue? and (3) do personnel affected by the issue have access to training?

Analysis of these questions reveals that the Services each participate in collective training throughout their respective training centers. The U.S. Army Combat Training Centers (CTC) offer the opportunity to fully integrate the UMS platforms outlined in this thesis to support the Army's Operating Concept; specifically, combined arms maneuver and wide-area security (CAM/WAS). Additionally, the Joint Multinational Readiness

[90]U.S. House Robotics Caucus, http://www.roboticscaucus.org/.

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Center (JMRC) in Grafenwoehr, Germany allows for the integration of U.S. and Coalition UMS programs and training.

The U.S. Navy's participation in a fleet exercise/joint task force exercise (FLEETEX/JTFEX) requires that it integrate all its forces in a multi-dimensional, multi-threat environment, in which UMS can range from UAVs, USVs, UUVs, and UGSs. In this respect, a JTFEX allows all participants to train with emerging systems and technology, such as UMS.

The U.S. Air Force engages in counter-UAV(C-UAV) scenarios, such as, Black Dart, Blue Knight, and Red Flag. The purpose of Black Dart is to determine DoD's ability to detect and counter enemy UAS systems in flight.[91] The purpose of Blue Knight is to simulate air to air combat between UAVs, which due to the proliferation of UAVs is a realistic expectation in the near future and an operational concern for the 2020 JTF.[92] The feasibility of Red Flag exercises extends to training USAF pilots in fighter interdiction, attack, defense suppression, airlift, air refueling, and reconnaissance.[93] The majority of these missions have been determined capable of being assumed by UAVs by the USAF *Unmanned Aircraft Systems Flight Plan 2009-2047* in lieu of manned systems.

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[91]Holly Jordan, "AFRL, ASC team demonstrate Black Dart technology," posted 16 October 2006 and updated 14 December 2006, http://www.wpafb.af.mil/news/story.asp?id=123034602 (accessed 20 February 2012).

[92]Sgt. Josh LeCappelain (USA), "Blue Knight 2010 demonstration concludes in Nevada," http://www.jfcom.mil/newslink/storyarchive/2010/pa112210.html (accessed 20 February 2012).

[93]414th Combat Training Squadron, "Red Flag," http://www.nellis.af.mil/library/flyingoperations.asp (accessed 22 February 2012).

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In respect to the case studies and for future JTF operational considerations, a critical component for JTF OD was provided by the Joint Enabling Capabilities Command (JECC/USTRANSCOM). The JECC is a collection of high-demand joint capabilities ready to immediately support joint force commander requirements worldwide. The JECC provides mission-tailored, ready joint capability packages to Combatant Commanders in order to facilitate the rapid establishment of Joint Force Headquarters and to fulfill Global Response Force Execution and Bridge Joint Operational requirements.[94]

The two critical enablers provided by the JECC were a Joint Deployable Team (JDT) consisting of experienced joint planners in planning and execution of the full range of joint military operations. Additionally, they provided expertise in operations, plans, knowledge management, intelligence, and logistics. Second, a Joint Communications Support Element (JCSE) delivered secure, reliable, and scalable command, control, communications, and computer (C4) capabilities to JFC's, U.S. Special Operations Command, and other agencies. The JSCE provided essential C4 support, ranging from small mobile teams to full-sized JTF headquarters that immediately establish and then expanded the communications capability of a JTF headquarters. Furthermore, the JCSE can access the full range of DoD and commercial networks.[95]

SRQ #2: How will the incorporation of robust UMS capability impact the organization of a JTF in 2020?

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[94]Department of the Army, United States Transportation Command, JECC, http://www.transcom.mil/jecc/ (accessed 5 February 2012).

[95]Ibid.

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In the DOTMLPF analysis process, *organization* examines how we are organized to fight and if there is a better organizational structure or capability that can be developed to solve a capability gap. It addresses the following questions: (1) where is the problem occurring?, (2) what is the mission focus of those organizations?, and (3) are Senior leaders aware of the issues?

Analysis of this question reveals that the Services are incorporating the organizational changes to incorporate UMS with the end state to reduce personnel/logistical footprints and exponentially enhance its operational capabilities. The USAF has established a robust Remote Piloted Aircraft (RAP) program for its officers, to include a career field and UAV formations. The USN is engaged in UMS programs that have strategic implications, such as strategic forward presence. The United States Marine Corps is restructuring their MAGTF to incorporate UMSs. The U.S. Army is primarily focusing on UGVs and UAVs to support future land operations. The challenge for Senior leaders, both military and civilian, is the integration of UMSs and its reduced personnel footprint to support the 2020 JTF. The experience of a JTF HQ taking almost eight months to become fully operational& capable (FOC) is not an option. The capabilities of UMS have the ability to reduce the length of operations from months to weeks.

Answer to the Primary Research Question

So, will the 2020 JTF be postured to utilize revolutionary unmanned systems? At this time all available information to the author indicates that the 2020 JTF will have the basic organizational framework to incorporate unmanned systems. Additionally, the services have initiated the organizational changes to integrate UMSs with the understanding that an end state is for these systems to reduce the personnel and logistical

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footprints throughout military operations. However, at this time, unclassified sources have not provided a definitive answer to the integration of UMSs to support the 2020 JTF. The CJCS has directed the Services with a specified and essential task; the 2020 JTF will be required to leverage cutting-edge information technologies to ensure a secure and collaborative C2 network in an operational environment encompassing hybrid threats, A2/AD threats, and the proliferation of advanced unmanned systems. The CJTF -7 case study highlighted lessons observed that cannot be repeated in establishing a JTF in the future operating environment in order to accomplish the specified task(s) outlined by the CJCS. Additionally, the JTF OD case study highlights the future considerations of integrating UMS to accomplish missions traditionally executed by manned platforms and/or personnel.

Recommendations

The 2020 JTF will be postured to utilize revolutionary unmanned systems, if the following recommendations are implemented:

1. Establish a Joint UMS Directorate to assist combat commanders in the integration and training of a JTF utilizing the aforementioned UMSs. Additionally, this UMS directorate would establish an UMS Lexicon that would provide a common language and end the debate of how to properly classify an UMS platform, for example is a Reaper an UAV or UAS? The current ALFUS document provides a starting point on codifying a DoD UMS Lexicon which can be adopted by other government, civilian, and academic organizations.

2. Services must continue to leverage their respective training centers and exercises to fully exploit the incorporation of UMSs throughout their operations and

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provide recommendations to the CJCS on how to best integrate UMS platforms and formations within the 2020 JTF. For example, the U.S. Army is currently conducting discussions on the future task organization of its Battlefield Surveillance Brigade (BfSB) which provides ISR to the supported Division commander and higher echelons. The ability to integrate UAS, UGV and UGS (Unattended Ground Sensors) will exponentially increase the ISR capabilities for the commander while reducing the personnel and logistical requirements; to include mitigate AD/A2 threats.

3. DoD must encourage a culture of innovation with specific emphasis on UMS throughout all of its echelons. As UMSs continue to develop it capacity for autonomy and replace manned systems and personnel, leaders must consider the new tactical and operational capabilities these systems provide. It can be argued that at the tactical level, U.S. Service members readily adapt, however, military organizations as a whole are often deliberate to accept change due to the invested time and resources in supporting their respective Services strategic considerations. Additionally, DoD must encourage institutional training on UMS which can dissuade potential Service hindrance to change and allow for discourse amongst leaders regarding the impact of UMS integration into their respective Services and for the 2020 JTF.

4. DoD expands the capabilities of organizations, such as the JECC, to train Joint officers on the incorporation and execution of staff processes utilizing UMSs. The notional JTF HQ structure will likely remain the same; however, as UMSs reduce mission accomplishment from months to weeks, the feasibility of an organization such as the JECC becomes apparent. An end state for UMS incorporation throughout the Services is the reduction of personnel/formation footprint throughout its operations.

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Therefore, DoD must continue to support UMS development, and specific to this thesis to ensure that the 2020 JTF is postured to integrate and accomplish its essential tasks utilizing unmanned systems in lieu of manned platforms.

Recommendations for further research

While the aforementioned recommendations are of most importance, there continues to be room for further discussion and analysis on this ever-evolving topic. These topics and areas for further research include (1) UMSs impacts all three levels of war, (2) the Services doctrinal framework, (3) continuing impact to the DOTMLPF process, and (4) impact on Joint, Interagency, Intergovernmental, and Multinational (JIIM) planning considerations and integration.

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GLOSSARY

Air interdiction. Air operations conducted to divert, disrupt, delay, or destroy the enemy's military surface capabilities before it can be brought to bear effectively against friendly forces, or to otherwise achieve objectives that are conducted at such distances from friendly forces that detailed integration of each air mission with the fire and movement of friendly forces is not required (Joint Publication 3 -03, Joint Interdiction, 14 OCT 2011, GL-4).

Cognizance Levels or Levels of Cognizance. The levels of what a UMS can know or understand based on its sensory processing capability: Level 1. Data or observed data, initially processed forms after measured by sensors. Level 2. Information, further processed, refined and structured data that is human understandable. Level 3. Intelligence, knowledge, combat and actionable information. Further processed for particular mission needs. Directly linked to tactical behaviors.

Common Operational Picture (COP). A single identical display of relevant information shared by more than one command; to facilitate collaborative planning and situational awareness.

Cooperative Engagement. A method of engagement for destroying enemy forces, employing sensors and shooters not resident on the same platform.

Controlling Element. The part of a UMS that provides a method for a human to control it remotely.

Information Superiority. Information, information processing, and communications networks are at the core of every military activity. The development of a concept labeled *the global information grid* (GIG) will provide the network-centric environment required to achieve this goal. Interoperability is the foundation of effective joint, multinational, and interagency operations, a mandate for the joint force of 2020 especially in terms of communications, common logistics items, and information sharing. Information systems and equipment that enable a common relevant operational picture must work from shared networks.

Markers. (physical or electronic). A visual or electronic aid used to mark a designated point for such tactical purposes as route following, determination of bearings, courses, or location, and key items or points of interest, including landmine markers, minefields markers, and area NBC decontamination markers.

Material Solution. Correction of a deficiency, satisfaction of a capability gap, or incorporation of new technology that results in the development, acquisition, procurement, or fielding of a new item (including ships, tanks, self-propelled weapons, aircraft, etc., and related software, spares, repair parts, and support equipment, but excluding real property, installations, and utilities) necessary to equip, operate, maintain, and support military activities without disruption as to

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its application for administrative or combat purposes. In the case of family of systems and system of systems approaches, an individual materiel solution may not fully satisfy a necessary capability gap on its own.

Non-materiel solution. Changes in doctrine, organization, training, materiel, leadership and education, personnel, facilities, or policy (including all human systems integration domains) to satisfy identified functional capabilities. The materiel portion is restricted to commercial or non-developmental items, which may be purchased commercially, or by purchasing more systems from an existing materiel program. The materiel portion must comply with all acquisition policies.

Operator Control Unit (OCU). Also referred to as operator control interface (OCI) or human interaction control unit. The computer(s), accessories, and data link equipment that an operator uses to control, communicate with, receive data and information from, and plan missions.

Precision Engagement. The effects based engagement that is relevant to all types of operations. Its success depends on in-depth analysis to identify and locate critical nodes and targets. The pivotal characteristic of precision engagement is the linking of sensors, delivery systems, and effects.

Point and Shoot. A subset of cooperative engagement that allows a soldier or platform to designate a target for lethal engagement by another platform. The information is immediately displayed on the COP. Point and Shoot implies the immediacy of effects and generally occurs within the same echelon.

Remotely Guided. An unmanned system requiring continuous input for mission performance is considered remotely guided. The control input may originate from any source outside of the unmanned system itself. This mode includes remote control and teleoperation.

Sensor to Shooter. The information link from a target acquisition capability to the weapons platform(s) that engage(s) the target.

Standoff. Detection or lethality efforts intended to suppress an enemy threat from a position outside the range of the enemy threat.

Unattended Ground sensors (UGS). Small, low cost, robust sensors, capable of operating in the field for extended periods of time (30 days or more). They will consist of modular groups of sensors utilizing tailorable ground sensing technologies, such as seismic, magnetic, infrared, acoustic, radio frequency, and CBRN detection, and other advanced sensing capabilities. UGSs self-organize into a networked sensor array (sensor web) by locating the most efficient gateways for transmission of information.

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APPENDIX A

Universal Joint Task List (UJTL) UMS feasibility evaluation matrix

		Schedule	Cost	Complexity	Total	Feasible within next five years (2015)	Schedule	Cost	Complexity
L1-A	**UJTL Logistics (Tasks determined to be executed by an unmanned system)**								
L1-B	Surface cargo transport and delivery of equipment and supplies using logistics convoys	3	3	3	9	Yes	3 = Low (3-5 years)	3 = Low (< $500K)	3 = Low
L2	Aerial cargo transport and delivery of equipment and supplies using pods	2	3	3	8	Yes	2 = Mid (3-5 years)	3 = Low (< $500K)	3 = Low
L3-A	Cargo packaging and palletizing	2	3	3	8	Yes	2 = Mid (3-5 years)	3 = Low (< $500K)	3 = Low
L3-B	Pick-taped warehousing: Inventory management, prioritization, retrieval and preparation for movement	2	3	3	8	Yes	2 = Mid (3-5 years)	3 = Low (< $500K)	3 = Low
L4	Loose binning: warehousing: Inventory management, prioritization, retrieval and preparation for movement	1	2	2	5	No	1 = High (> 5 years)	2 = Mid ($1-$10M)	2 = Mid
L5	Reflecting (wholesale and retail)	2	1	3	6	Yes	2 = Mid (3-5 years)	1 = High (> $10M)	3 = Low
L6-A	Crane and lift operations	3	3	3	9	Yes	3 = Low (0-2 years)	1 = High (> $10M)	3 = Low
L6-B	Indoor yard lift and short movement operations	2	1	2	5	No	2 = Mid (3-5 years)	1 = High (> $10M)	2 = Mid
L7-A	Outdoor yard lift and short movement operations	2	2	2	6	Yes	2 = Mid (3-5 years)	2 = Mid ($1-$10M)	2 = Mid
L7-B	New design for waterborne discharge of equipment ship to shore	1	1	1	3	No	1 = High (> 5 years)	1 = High (> $10M)	1 = High
L8	Retrofit for waterborne discharge of equipment ship to shore	1	1	2	4	No	1 = High (> 5 years)	1 = High (> $10M)	2 = Mid
L9	Robotic re-arming	2	1	1	4	No	2 = Mid (3-5 years)	1 = High (> $10M)	1 = High
S1-A	**Soldier Sustainability: Improved Soldier Strength and Endurance and Transport of Dismounted Maneuver (Tasks designated to be executed by an unmanned system)**	**Schedule**	**Cost**	**Complexity**	**Total**	**Feasible within next five years (2015)**	**Schedule**	**Cost**	**Complexity**
S1-B	Provide unarmed perimeter security of military installations/airfields, ammunition storage areas, chemical weapons storage areas: CONUS, unarmed, static	3	3	3	9	Yes	3 = Low (0-2 years)	3 = Low (< $500K)	3 = Low
S1-C	Provide armed perimeter security of military installations/airfields, ammunition storage areas, chemical weapons storage areas: FOB exterior, armed, static	2	2	3	7	Yes	2 = Mid (3-5 years)	2 = Mid ($1-$10M)	3 = Low
S1-D	Provide perimeter security of military installations/airfields, ammunition storage areas, chemical weapons storage areas: FOB exterior, armed, mobile	3	3	3	9	Yes	1 = High (> 5 years)	1 = High (> $10M)	1 = High
S2-A	Remotely scan personnel and vehicles entering restricted areas: fixed at Entry Control Point	2	2	2	6	Yes	3 = Low (0-2 years)	3 = Low (< $500K)	3 = Low
S2-B	Remotely scan personnel and vehicles entering restricted areas: mobile	3	3	3	9	Yes	3 = Low (0-2 years)	3 = Low (< $500K)	3 = Low
S3	Detect, identifies, assess, report, and provide warning, in event of a hazardous spill	2	2	3	7	Yes	2 = Mid (3-5 years)	3 = Low (< $500K)	3 = Low
S4	Remove and clean up hazardous materials from contaminated areas	3	2	3	8	Yes	2 = Mid (3-5 years)	2 = Mid ($1-$10M)	3 = Low
S5	Casualty Evacuation	2	2	3	7	Yes	3 = Low (0-2 years)	2 = Mid ($1-$10M)	3 = Low
E1-A	**UJTL Engineering (Tasks determined to be executed by an unmanned system)**	**Schedule**	**Cost**	**Complexity**	**Total**	**Feasible within next five years (2015)**	**Schedule**	**Cost**	**Complexity**
E1-B	Conduct terrain recon for trafficability and location of barriers/obstacles/mines: Remote control and tele-operation	3	1	3	7	Yes	3 = Low (0-2 years)	2 = Mid ($1-$10M)	3 = Low
E1-C	Conduct terrain recon for trafficability and location of barriers/obstacles/mines: Fully autonomous	3	1	3	7	No	3 = Low (0-2 years)	2 = Mid ($1-$10M)	3 = Low
E2-A	Overcome and report obstacles: Remote control and tele-operation	3	2	3	8	Yes	3 = High (0-2 years)	2 = Mid ($1-$10M)	3 = Mid
E2-B	Overcome and report obstacles: Fully autonomous	1	1	2	4	No	1 = High (> 5 years)	1 = High (> $10M)	2 = Mid
E3-A	Conduct breach operations: suppress, obscure, and secure breach lanes: remote control and tele-operation	3	2	3	8	Yes	3 = Low (0-2 years)	2 = Mid ($1-$10M)	3 = Low
E3-B	Conduct breach operations: suppress, obscure, and secure breach lanes: Fully autonomous	1	1	2	4	No	1 = High (> 5 years)	1 = High (> $10M)	2 = Mid
E4-A	Move and emplace material, construct obstacles, establish security: Remote control and tele-operation	2	2	3	7	Yes	2 = Mid (3-5 years)	2 = Mid ($1-$10M)	3 = Low
E4-B	Move and emplace material, construct obstacles, establish security: Fully autonomous	2	2	3	7	Yes	2 = Mid (3-5 years)	2 = Mid ($1-$10M)	3 = Low
E5	Mark, record and report obstacles	2	2	3	7	Yes	2 = Mid (3-5 years)	2 = Mid ($1-$10M)	3 = Low
E6-A	Conduct firefighting operations: Remote control and tele-operation	2	1	3	6	Yes	2 = Mid (3-5 years)	1 = High (> $10M)	3 = Low
E6-B	Conduct firefighting operations: Fully autonomous	1	2	2	5	No	1 = High (> 5 years)	2 = Mid ($1-$10M)	3 = Low
E7-A	Earthmoving for airfields, FOBs etc: RC Remote control and tele-operation	3	2	3	8	Yes	3 = Low (0-2 years)	2 = Mid ($1-$10M)	3 = Low
E7-B	Earthmoving for airfields, FOBs etc: Fully autonomous	3	2	3	8	Yes	3 = Low (0-2 years)	2 = Mid ($1-$10M)	3 = Low
E8-A	Detection and removal of explosives, surface and sub surface on land or water: Remote control and tele-operation	2	2	2	6	Yes	2 = Mid (3-5 years)	2 = Mid ($1-$10M)	2 = Mid
E8-B	Detection and removal of explosives, surface and sub surface on land or water: Fully autonomous	1	2	2	5	No	1 = High (> 5 years)	2 = Mid ($1-$10M)	2 = Mid
M1-A	**UJTL Medical (Tasks designated to be executed by an unmanned system)**	**Schedule**	**Cost**	**Complexity**	**Total**	**Feasible within next five years (2015)**	**Schedule**	**Cost**	**Complexity**
M1-B	Conduct pharmacy operations: CONUS	3	3	3	9	Yes	3 = Low (0-2 years)	3 = Low (< $500K)	3 = Low
M2-B	Conduct pharmacy operations: FOB	3	2	3	8	Yes	2 = Mid (3-5 years)	2 = Mid ($1-$10M)	3 = Low
M2-B	Perform telemedicine: Vital signs	3	1	2	6	Yes	3 = Low (0-2 years)	3 = Low (< $500K)	3 = Low
M2-B	Perform telemedicine: Non-vital signs	3	1	2	6	Yes	3 = Low (0-2 years)	3 = Low (< $500K)	3 = Low
M3-1	Perform battlefield tele-operated surgery	1	1	3	5	No	1 = High (> 5 years)	1 = High (> $10M)	3 = Low
M4	Recover battlefield casualties	3	2	3	8	Yes	3 = Low (0-2 years)	2 = Mid ($1-$10M)	3 = Low
M5-3	Disposal of medical waste	2	2	3	7	Yes	2 = Mid (3-5 years)	2 = Mid ($1-$10M)	3 = Low
M6-1	**UJTL Maintenance (Tasks designated to be executed by an unmanned system)**	**Schedule**	**Cost**	**Complexity**	**Total**	**Feasible within next five years (2015)**	**Schedule**	**Cost**	**Complexity**
MA1	Maintenance on vehicles and equipment	2	2	3	7	Yes	2 = Mid (3-5 years)	2 = Mid ($1-$10M)	3 = Mid
MA2	Perform diagnostic checks/PMCS on vehicles and equipment	2	2	3	7	Yes	3 = Mid (3-5 years)	2 = Mid ($1-$10M)	3 = Mid
MA3-A	Perform vehicle recovery/wrecker functions: tele-operated	3	2	3	8	Yes	3 = Low (0-2 years)	2 = Mid ($1-$10M)	3 = Low
MA3-B	Perform vehicle recovery/wrecker functions: fully autonomous	1	1	3	5	No	1 = High (> 5 years)	1 = High (> $10M)	3 = Low
MA5-A	Perform maintenance: tele-operation	1	2	2	5	No	1 = High (> 5 years)	2 = Mid ($1-$10M)	2 = Mid
MA5-B	Perform maintenance: fully autonomous	1	2	2	5	No	1 = High (> 5 years)	2 = Mid ($1-$10M)	2 = Mid
MA6-A	Perform advanced manufacturing, turning and welding	2	2	2	6	Yes	2 = Mid (3-5 years)	2 = Mid ($1-$10M)	2 = Mid
MA6-B	Perform advanced manufacturing: metal lithography	1	1	2	4	No	1 = High (> 5 years)	1 = High (> $10M)	2 = Mid

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APPENDIX B

Interoperability across UMS Domains Vignette, 2030s Scenario

1. a. A former Soviet-era, *Akula* class, nuclear-powered attack submarine sails out of a rouge state undetected by reconnaissance satellites and detected by a US Navy underwater surveillance grid, triggering an unmanned underwater vehicle (UUV) to deploy and tether itself to the submarine.

1. b. Every three hours the UUV transmits a low-power position report which is received by an orbiting communications relay, the Baton One, an EQ-25 (UAS) operating at 75,000 ft. The EQ-25 is an extreme-endurance UAS, capable of operating for two months on station without refueling.

1. c. By the third day of sail, the submarine is heading toward the mid-Pacific and the Hawaiian Islands. The decision is made to deploy a naval anti-submarine warfare (ASW) ship to intercept and track the submarine. The following day, the submarine reverses course and the ASW ship turns for Pearl Harbor.

1. d. A Broad Area Maritime Surveillance (BAMS) UAS, MQ-4C, is launched from Guam to in order to track the beacon. Autonomously descending with its internal airborne sense and avoid (ABSAA) system the BAMS UAS is able to visually acquire the UUV, detached from the submarine. The submarine's position and intent are now unknown.

1. e. Ten days later, seismic disturbances are detected 150 miles southeast of Anchorage, Alaska. An interagency DoD/homeland defense reconnaissance UAS is launched and detects a radiation plume. The UAS maps the plume as it begins spreading over the sound, and a U.S. Coast Guard offshore patrol cutter employs its unmanned helicopter to drop buoys with CBRN sensors to measure fallout levels. The plume begins to spread over the sound and threatens the city of Valdez. The port of Valdez, the largest indigenous source of oil for the United States, is effectively under quarantine.

1. f. Due to the growing contamination of the local environment, disaster response officials request US military unmanned CBRNE support. The amphibious transport dock ship USS *New York* anchors near an entrance to Prince William Sound and begins

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operations with its unmanned surface vehicles (USVs) and MQ-8 Fire Scout unmanned helicopters. An EQ-25 orbit is established over the Sound to ensure long term, high-volume communication capability in the high-latitude, mountainous region. The EQ-25 UAS is capable of handling all the theater data relay requirements.

1. g. A USV proceeds to the focus of contamination and lowers a tethered remotely operated vehicle (ROV) to conduct an underwater search for the source and finds the open hull of the *Akula* class submarine. The ROV places temperature gradient sensors on the hull and inserts gamma sensors into the exposed submarine compartments.

1. h. The radiation plume has now encompassed the evacuated town of Valdez, and MQ-8 Fire Scout fly repeated sorties to the town, dock, and terminal areas to deploy unmanned ground vehicles (UGVs) with sensors and collect samples for analysis.

1. i. With conditions deteriorating, two unmanned Homeland Defense CBRN barges fitted with cranes, containers, and remote controls arrive from Seattle. Over the next two weeks, ROVs equipped with cutting torches, grappling fixtures, and operating from USVs, one remotely operated submersible barge is able to work around the clock and recover the exposed fuel sources and to isolate them in specially designed containers. A second barge similarly retrieves sections of the crippled submarine. Both barges operate with a high degree of autonomy, limiting exposure of personnel to the radioactive contamination.

1. j. The UGVs continue monitoring contamination levels and collecting samples, but now also start conducting decontamination of the oil terminal control station and the local power and water facilities. Highly contaminated soil is placed into steel drums, and larger UGVs are used to dig pits and bury contaminated building and pipeline materials.

1. k. Advanced sensor technology and control logic allows the UGVs to operate around the clock with human operators serving solely in a monitoring function. USVs are used to collect carcasses floating in the Sound and bring them to shore for disposal. UASs fly continuously at low altitude to monitor and map the declining radiation contours, at medium altitude to map cleanup operations, and at high altitude to relay control commands and data from the nearly one hundred unmanned vehicles at work.

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1. l. Decontamination, refueling, and repair shops have been established in nearby Cordova to service the vehicles and aircraft and on the USS *New York* to service the boats and submersibles, thereby, conducting the largest demonstration of interoperability between air, ground, and maritime unmanned systems.[96]

[96]This vignette offers an example of the increased capability and flexibility inherent in unmanned systems as DoD continues to field unmanned technologies and integrate resulting systems into its existing force structure. Adopted from the U.S Department of Defense, *The Unmanned Systems Integrated Roadmap*, *FY 2011 -2036,* 6.

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U.S. Unmanned Aerial Systems

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Summary

Unmanned aerial systems comprise a rapidly growing portion of the military budget, and have been a long-term interest of Congress. At times, Congress has encouraged the development of such systems; in other instances, it has attempted to rein in or better organize the Department of Defense's efforts.

Unmanned aircraft are commonly called unmanned aerial vehicles (UAVs), and when combined with ground control stations and data links, form UAS, or unmanned aerial systems.

The use of UAS in conflicts such as Kosovo, Iraq, and Afghanistan, and humanitarian relief operations such as Haiti, revealed the advantages and disadvantages provided by unmanned aircraft. Long considered experimental in military operations, UAS are now making national headlines as they are used in ways normally reserved for manned aircraft. Conventional wisdom states that UAS offer two main advantages over manned aircraft: they are considered more cost-effective, and they minimize the risk to a pilot's life. For these reasons and others, DOD's unmanned aircraft inventory increased more than 40-fold from 2002 to 2010.

UAVs range from the size of an insect to that of a commercial airliner. DOD currently possesses five UAVs in large numbers: the Air Force's Predator, Reaper, and Global Hawk, and the Army's Hunter and Shadow. Other key UAV developmental efforts include the Air Force's RQ-170 Sentinel, the Navy's Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS), MQ-8 Fire Scout, and Broad Area Maritime Surveillance (BAMS) UAV, and the Marine Corps's Small Tactical Unmanned Aerial System.

In the past, tension existed between the services' efforts to acquire UAS and congressional initiatives to encourage a consolidated DOD approach. Some observers argue that the result has been a less than stellar track record for UAS programs. However, reflecting the growing awareness and support in Congress and the Department of Defense for UAS, investments in unmanned aerial vehicles have been increasing every year. DOD spending on UAS has increased from $284 million in FY2000 to $3.3 billion in FY2010.

Congressional considerations include the proper pace, scope, and management of DOD UAS procurement; appropriate investment priorities for UAS versus manned aircraft; UAS future roles and applications; legal issues arising from the use of UAS; issues of operational control and data management; personnel issues; industrial base issues; and technology proliferation.

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Background

Since 1917, United States military services have researched and employed unmanned aerial vehicles (UAVs).[1] Over that time, they have been called drones, robot planes, pilotless aircraft, RPVs (remotely piloted vehicles), RPAs (remotely piloted aircraft) and other terms describing aircraft that fly under control with no person aboard.[2] They are most often called UAVs, and when combined with ground control stations and data links, form UAS, or unmanned aerial systems.

The Department of Defense (DOD) defines UAVs as powered, aerial vehicles that do not carry a human operator, use aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, and artillery projectiles are not considered UAVs by the DOD definition.[3] UAVs are either described as a single air vehicle (with associated surveillance sensors), or a UAV system (UAS), which usually consists of three to six air vehicles, a ground control station, and support equipment.

Although only recently procured in significant numbers by the United States, UAS were first tested during World War I, although not used in combat by the United States during that war. Indeed, it was not until the Vietnam War that the U.S. employed UAS such as the AQM-34 Firebee in a combat role. The Firebee exemplifies the versatility of UAS—initially flown in the 1950s as an aerial gunnery target and then in the 60s as an intelligence-collection drone, it was modified to deliver payloads and flew its first flight test as an armed UAV in 2002.[4]

The military use of UAS in conflicts such as Kosovo (1999), Iraq (since 2003), and Afghanistan (since 2001) has illustrated the advantages and disadvantages of unmanned aircraft. UAS regularly make national headlines as they perform tasks historically performed by manned aircraft. UAS are thought to offer two main advantages over manned aircraft: they eliminate the risk to a pilot's life, and their aeronautical capabilities, such as endurance, are not bound by human limitations. UAS also protect the lives of pilots by performing those dull, dirty, or dangerous missions that do not require a pilot in the cockpit. UAS may also be cheaper to procure and operate than manned aircraft. However, the lower procurement cost of UAS can be weighed against their greater proclivity to crash, while the minimized risk to onboard crew can be weighed against the complications and hazards inherent in flying unmanned vehicles in airspace shared with manned assets.

UAS use has increased for a number of reasons. Advanced navigation and communications technologies were not available just a few years ago, and increases in military communications satellite bandwidth have made remote operation of UAS more practical. The nature of the Iraq and Afghanistan wars has also increased the demand for UAS, as identification of and strikes against targets hiding among civilian populations required persistent surveillance and prompt

[1] National Museum of the U.S. Air Force, *Kettering Aerial Torpedo "Bug,"* http://www.nationalmuseum.af.mil/factsheets/factsheet.asp?id=320.

[2] Drones differ from RPVs in that they are designed to fly autonomously.

[3] Joint Publication 1-02, "DOD Dictionary of Military and Associated Terms."

[4] Jefferson Morris, "Northrop Grumman Modifies BQM-34 Firebee To Drop Payloads," *Aerospace Daily*, January 22, 2003.

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strike capability, to minimize collateral damage. Further, UAS provide an asymmetrical—and comparatively invulnerable—technical advantage in these conflicts.

For many years, the Israeli Air Force led the world in developing UAS and tactics. U.S. observers noticed Israel's successful use of UAS during operations in Lebanon in 1982, encouraging then-Navy Secretary John Lehman to acquire a UAS capability for the Navy. Interest also grew in other parts of the Pentagon, and the Reagan Administration's FY1987 budget requested notably higher levels of UAS funding.[5] This marked the transition of UAS in the United States from experimental projects to acquisition programs.

Initial U.S. capabilities came from platforms acquired from Israel. One such UAS, Pioneer, emerged as a useful source of intelligence at the tactical level during Operation Desert Storm, when Pioneer was used by Navy battleships to locate Iraqi targets for its 16-inch guns. Gulf War experience demonstrated the potential value of UAS, and the Air Force's Predator was placed on a fast track, quickly adding new capabilities.[6] Debuting in the Balkans conflict, the Predator performed surveillance missions such as monitoring area roads for weapons movements and conducting battle damage assessment. Operations in Iraq and Afghanistan have featured the Air Force's Global Hawk, as well as adding a new mission that allows the Predator to live up to its name—armed reconnaissance.

Reflecting a growing awareness and support for UAS, Congress has increased investment in unmanned aerial vehicles annually. The FY2001 investment in UAS was approximately $667 million. For FY2012, DOD has asked for $3.9 billion in procurement and development funding with much more planned for the outyears.[7] DOD's inventory of unmanned aircraft increased from 167 to nearly 7,500 from 2002 to 2010.[8]

DOD's UAS research and development (R&D) funding has also grown, for a variety of reasons: UAS are considered a growth industry, many UAS are relatively inexpensive to produce and new technology in miniaturization has helped accelerate the development of many UAS types.

Congress has approached UAS development with strong encouragement tempered with concern. Notably, in 2000, Congress set the goal of making "one-third of the aircraft in the operational deep strike force aircraft fleet" unmanned.[9] Congress has also directed the formation of joint program offices to ensure commonality among the services' UAS programs. Following expressed concern that DOD's "growing enthusiasm may well lead to a situation in which there is no clear

[5] For more on the early history of UAV use, CRS Report 93-686F, *Intelligence Technology in the Post-Cold War Era: The Role of Unmanned Aerial Vehicles (UAVs)*, by Richard A. Best, Jr., 1993, available from author on request. Other useful sources include two papers by Thomas P. Ehrhard: "Unmanned Aerial Vehicles in the United States Armed Services: A Comparative Study of Weapon System Innovation" (Ph.D. dissertation, The Johns Hopkins University, 2000); and *Air Force UAVs: The Secret History*, Mitchell Institute, July 2010.

[6] Jim Garamone, "From U.S. Civil War To Afghanistan: A Short History Of UAVs," *American Forces Information Service*, April 16, 2002.

[7] Office of the Under Secretary of Defense (Comptroller)/CFO, *Program Acquisition Costs by Weapon System*, February 2011, p. 1-1.

[8] Ed Wolski, *Unmanned Aircraft Systems*, OUSD (AT&L) Unmanned Warfare, briefing, January 9, 2009, p. 6. Dyke Weatherington, *Current and Future Potential for Unmanned Aircraft Systems*, OUSD (AT&L) Unmanned Warfare, briefing, December 15, 2010. (Hereinafter "Weatherington brief.")

[9] P.L. 106-398, "Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001," section 220.

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path toward the future of UAS," Congress also required DOD to submit a UAS roadmap.[10] In some instances, Congress has chastened DOD for what it saw as a leisurely rate of UAS acquisition and encouraged it to speed up this pace, or speed up the incorporation of certain capabilities. For example, an 1996, the House Armed Services Committee (HASC) supported legislation directing DOD to weaponize both the Predator and Hunter, but DOD opposed the initiative.[11]

Although this report focuses on the military uses of UAS, Congress's interest in UAS extends beyond the defense committees, as UAS capabilities have also led to their use in missions outside the military. The Department of Homeland Security operates UAS to help patrol U.S. borders, and Congress has questioned the efficacy of such operations.[12] Further, the use of UAS in a variety of roles, but particularly as platforms for delivering lethal force, raise a number of legal issues of interest to Congress.

Why Does the Military Want UAS?

> In today's military, unmanned systems are highly desired by combatant commanders for their versatility and persistence. By performing tasks such as surveillance; signals intelligence (SIGINT); precision target designation; mine detection; and chemical, biological, radiological, nuclear (CBRN) reconnaissance, unmanned systems have made key contributions to the Global War on Terror.[13]

To be sure, manned systems could accomplish many if not all of the same goals. But "unmanned systems reduce the risk to our warfighters by providing a sophisticated stand-off capability that supports intelligence, command and control, targeting, and weapons delivery. These systems also improve situational awareness and reduce many of the emotional hazards inherent in air and ground combat, thus decreasing the likelihood of causing civilian noncombatant casualties."[14] "UAVs have gained favor as ways to reduce risk to combat troops, the cost of hardware and the reaction time in a surgical strike"[15] and "to conduct missions in areas that are difficult to access or otherwise considered too high-risk for manned aircraft or personnel on the ground."[16]

[10] U.S. Congress, 2d Session, House of Representatives, Committee on Appropriations, Department of Defense Appropriations Bill for Fiscal Year 2003, H.Rept. 107-532, p.207.

[11] Hearing of the Tactical Air and Land Forces Subcommittee of the House Armed Services Committee. "Fiscal Year 2004 Budget Request for Unmanned Combat Aerial Vehicles and Unmanned Aerial Vehicle Programs." March 26, 2003.

[12] For more information on DHS UAV operations, see CRS Report RS21698, *Homeland Security: Unmanned Aerial Vehicles and Border Surveillance*, by Chad C. Haddal and Jeremiah Gertler.

[13] Department of Defense, *FY2009–2034 Unmanned Systems Integrated Roadmap* (2009), p. xiii.

[14] Stockdale Center on Ethical Leadership, U.S. Naval Academy, "New Warriors and New Weapons: The Ethical Ramifications of Emerging Military Technologies," Report of the 2010 McCain Conference, Annapolis, MD, April 23, 2010, http://www.usna.edu/Ethics/mccain.htm.

[15] Scott Hamilton, "Here's a Thought: The Pentagon Wants 'Thinking' Drones," *National Defense*, February 2011.

[16] U.S. Customs and Border Protection, "UAS Overview," August 31, 2010, http://www.cbp.gov/xp/cgov/border_security/air_marine/uas_program/uasoverview.xml.

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As a result, "The number of platforms in this category—R/MQ-4 Global Hawk-class, MQ-9 Reaper, and MQ-1 Predator-class unmanned aircraft systems (UAS)—will grow from approximately 340 in FY 2012 to approximately 650 in FY 2021."[17]

Some in the military also tout UAS's reduced cost of acquisition and operation when compared to manned platforms. However, the Congressional Budget Office cautions that savings cannot be taken for granted:

> Unmanned aircraft systems are usually less expensive than manned aircraft. Initial concepts envisioned very low-cost, essentially expendable aircraft. As of 2011, however, whether substantially lower costs will be realized is unclear. Although a pilot may not be on board, the advanced sensors carried by unmanned aircraft systems are very expensive and cannot be viewed as expendable ... Moreover, excessively high losses of aircraft can negate cost advantages by requiring the services to purchase large numbers of replacement aircraft.[18]

What Missions Do UAS Currently Perform?

Intelligence, Surveillance and Reconnaissance

Intelligence gathering is UAS' traditional mission. In the 1960s, autonomous drones were used for reconnaissance in the Vietnam War and on strategic reconnaissance missions over denied areas. Early modern controllable UAS were used to loft cameras to allow units in the field to observe opposing forces beyond direct line of sight. Subsequently, longer-endurance systems introduced the ability to maintain surveillance on distant and moving targets.

Strike

The first UAS were essentially unpiloted bombs, designed to fly in a particular direction until the fuel ran out, at which point the entire aircraft would plunge to the ground. Today, some UAS carry precision-guided weapons to attack ground targets, and more are being weaponized, although this is still adding strike capability to systems originally designed for reconnaissance.

A separate class of UAS is being designed from the ground up to carry out combat missions. Called unmanned combat air vehicles, or UCAVs, these systems feature greater payload, speed, and stealth than current UAS.

[17] Department of Defense, *Aircraft Procurement Plan, Fiscal Years (FY) 2012-2041*, Washington, DC, March 2011, http://www.airforce-magazine.com/SiteCollectionDocuments/Reports/2011/May%202011/Day25/AircraftProctPlan2012-2041_052511.pdf.

[18] Congressional Budget Office, *Policy Options for Unmanned Aircraft Systems*, Publication 4083, Washington, DC, June 2011, p. 31.

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What Other Missions Might UAS Undertake in the Future?

Resupply

The Navy is investigating how UAS could deliver cargo to ships at sea,[19] and the Marine Corps has awarded contracts to two firms to demonstrate how UAS might resupply units in Afghanistan.[20]

Combat Search and Rescue

Early research is underway to develop the capability for an unmanned system to locate and possibly evacuate personnel behind enemy lines.

Refueling

Large UAS could eventually take on the aerial refueling task now performed by KC-10 and KC-135 tanker aircraft. Tanker flight profiles are relatively benign compared to many others, and they tend to operate far from enemy air defenses. Except for operating the refueling boom (to refuel Air Force aircraft), the refueling crew's primary job is to keep the aircraft flying straight, level, and at a steady speed. In July, 2010, the Defense Advanced Research Projects Agency awarded a contract to demonstrate refueling by Global Hawk UAVs,[21] [22] and a March, 2011 test demonstrated the Global Hawk's ability to receive refueling autonomously.[23] The Global Hawk's 2001 trans-oceanic flights (from the United States to Australia and from the United States to Portugal) demonstrate the ability of current UAVs to fly missions analogous to aerial refueling missions. This same technology could allow UAVs to refuel manned aircraft. The second X-47B will be equipped to demonstrate refueling.[24]

Air Combat

A more difficult future task could be air-to-air combat. Although UAS offensive operations to date have focused on ground targets, UCAVs are being designed to carry air-to-air weapons and other systems that may allow them to undertake air superiority missions. DOD is experimenting with outfitting today's UAVs with the sensors and weapons required to conduct such a mission. In fact, a Predator has reportedly already engaged in air to-air combat with an Iraqi fighter aircraft. In March, 2003 it was reported that a Predator launched a Stinger air-to-air missile at an Iraqi

[19] Dan Taylor, "ONR Meets With Industry For Long-Term Cargo UAS Program In Mid-2010s," *Inside the Navy*, July 26, 2010.

[20] Gayle Putrich, "USMC splits unmanned cargo resupply contract," *FlightGlobal.com*, December 2, 2010.

[21] W.J. Hennigan, "Northrop Grumman Wins Contract To Turn Unmanned Spy Plane Into Refueling Tanker," *Los Angeles Times*, July 2, 2010.

[22] W. J. Hennigan, "Northrop Grumman Wins Contract To Turn Unmanned Spy Plane Into Refueling Tanker," *Los Angeles Times*, July 2, 2010; Graham Warwick, "Global Hawk To Demonstrate Autonomous Air Refueling," *Aerospace Daily*, July 2, 2010.

[23] Graham Warwick, "Flight Paves Way For Global Hawk Autonomous Aerial Refueling," *Aerospace Daily*, March 10, 2011.

[24] Carlo Munoz, "After Successful First Flight, Navy Plans For Next Stage of UCAS-D Development," *Defense Daily*, February 8, 2011.

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MiG before the Iraqi aircraft shot it down.[25] While this operational encounter may be a "baby step" on the way toward an aerial combat capability, newer UAS such as the X-47B, Avenger, and Phantom Ray are not being designed with acknowledged air-to-air capability.

In short, UAS are expected to take on every type of mission currently flown by manned aircraft.

Why Are There So Many Different UAS?

Although UAS have a long history, only in the last 10-15 years have advances in navigation, communications, materials, and other technologies made a variety of current UAS missions possible. UAS are therefore still in a period of innovation, both in their design and how they are operated. This can be seen as analogous to military aircraft in the 1930s and 1940s, when technologies and doctrines evolved at a rapid rate to exploit the new technology, and also to the early Jet Age, when the military acquired many different models of aircraft with varying capabilities before settling on a force made up of large numbers of relatively few models based on lessons learned.

Also, the period of UAS innovation has coincided with ongoing US combat operations in Iraq, Afghanistan, and elsewhere. Demand for UAS capabilities in the field is essentially unconstrained.[26] As new systems and capabilities have emerged, the availability of urgent-needs funding has allowed commanders to bring the latest technology into theater without lengthy procurement processes. Thus, instead of traditional competitions in which systems may be tested against each other in advance of operations, new UAS have been deployed directly to the field, where U.S. forces are able to experiment with and exploit their capabilities. The combination of funding, demand, and technological innovation has resulted in DOD acquiring a multiplicity of systems without significant effort to reduce the number of systems or consolidate functions across services.

> For example, the Office of the Secretary of Defense (OSD) is concerned that the Army and Air Force are unnecessarily developing two different electro-optical and infrared sensor payloads for Sky Warrior and Predator when a common payload could be achieved—currently the basic sensors are 80 percent common and manufactured by the same contractor. However, according to Army officials, the Air Force sensor is more expensive and has capabilities, such as high-definition video, for which the Army has no requirements. Therefore, the Army does not believe a fully common solution is warranted. [27]

It should be noted that the number of systems acquired does not correspond to the number of unique platforms. By installing different sensors, a mostly-common airframe can be made to serve the requirements of multiple services. The General Atomics I-GNAT developed into the Air Force Predator and Reaper, which served as the basis for the Army Gray Eagle and DHS's Predator optimized for marine environments; Northrop Grumman's Air Force Global Hawk became, with different equipment, the Navy's Broad Area Maritime Surveillance (BAMS) system.

[25] David Fulghum. "Predator's Progress." *Aviation Week & Space Technology*. March 3, 2003.

[26] CRS interview with LtGen. David Deptula, Air Force Deputy Chief of Staff for Intelligence, Surveillance, and Reconnaissance, February 3, 2010.

[27] U.S. Government Accountability Office, *Defense Acquisitions: Opportunities Exist to Achieve Greater Commonality and Efficiencies among Unmanned Aircraft Systems*, 09-520, July 2009, page 4.

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This is not to say that the resulting systems are the same. Due to different requirements and payloads, a BAMS, for example, costs almost twice as much as a Global Hawk. This commonality may, however, provide an argument for those who advocate greater jointness in UAS development.

Does the Department of Defense Have an Integrated UAS Development Policy?

In September, 2007, the Secretary of Defense ordered creation of a UAS Task Force within the office of the Under Secretary of Defense for Acquisition, Technology and Logistics.[28] [29] The Task Force's charter gives it the responsibility to coordinate UAS requirements among the services, "promot[e] the development and fielding of interoperable systems and networks," and to "[s]hape DoD UAS acquisition programs to prioritize joint solutions." The charter does not give the Task Force the authority to terminate redundant programs nor compel their consolidation. Thus, development of UAS in DOD can be said to be federated, but not integrated.

DOD also issues a biannual roadmap indicating what technologies and capabilities it expects to see in future systems, and attempting to project the requirements for broad UAS capabilities 25 years into the future.[30] Development of UAS is still carried out by individual military services.

UAS programs range from the combat tested—Pioneer, Hunter, Predator and Global Hawk—to the not yet tested—the Air Force and Navy's Unmanned Combat Air Vehicles. Sizes and ranges of UAVs also vary greatly: the 8-inch-long Wasp Micro UAV has a combat radius of 5 nautical miles, while the 44-foot-long Global Hawk (the size of a medium sized corporate jet) has a combat radius of 5,400 nm.[31]

Table 1 outlines the total UAV inventory.[32] When compared to the inventory of February 2003, which only included five major platforms and an inventory of 163 unmanned aircraft, the acceleration and expansion becomes clear. The 7454 UAVs include many 2nd generation derivatives, such as Predator B and BAMS, and some non-traditional vehicles, such as gMAV and T-Hawk.

[28] Under Secretary of Defense (Acquisition, Technology and Logistics), *Department of Defense Report to Congress on Addressing Challenges for Unmanned Aircraft Systems*, September 2010.

[29] Creation of the UAS Task Force was a compromise outcome. DOD had sought to designate a single executive agent to oversee UAS development across the Department. The Air Force actively sought the role, but other services did not support their bid.

[30] See, for example, Department of Defense, *FY2009–2034 Unmanned Systems Integrated Roadmap* (2009).

[31] For a more comprehensive treatment of these UAV programs, see the "Current DOD UAV Programs" section below.

[32] Note that these inventories do not include small UAVs, micro UAVs or lighter-than-air platforms.

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Table 1. DOD UAS Platforms

Name	Vehicles	Ground Control Stations	Employing Service(s)	Capability/Mission
RQ-4A Global Hawk/BAMS-D Block 10	9	3	USAF/Navy	ISR/Maritime Domain Awareness (Navy)
RQ-4B Global Hawk Block 20/30	15	3	USAF	ISR
RQ-4B Global Hawk Block 40	1	1	USAF	ISR/Battle Management Command & Control
MQ-9 Reaper	54	61[a]	USAF	ISR/Reconnaissance, Surveillance, and Target Acquisition/EW/Precision Strike/Force Protection
MQ-1A/B Predator	161	61[a]	USAF	ISR/Reconnaissance, Surveillance, and Target Acquisition/Precision Strike/ Force Protection (MQ-1C Only-C3/LG)
MQ-1 Warrior/MQ-1C Gray Eagle	26	24	Army	ISR/Reconnaissance, Surveillance, and Target Acquisition/Precision Strike/ Force Protection (MQ-1C Only-C3/LG)
UCAS-D	2	0	Navy	Demonstration Only
MQ-8B Fire Scout VTUAV	9	7	Navy	ISR/Reconnaissance, Surveillance, and Target Acquisition/Anti-Submarine Warfare/ASUW/MIW/OMCM
MQ-5 Hunter	25	16	Army	ISR/Reconnaissance, Surveillance, and Target Acquisition/Battle Damage Assessment
RQ-7 Shadow	364	262	Army/USMC/SOCOM	ISR/Reconnaissance, Surveillance, and Target Acquisition/Battle Damage Assessment
A160T Hummingbird	8	3	SOCOM/DARPA/Army	Demonstration
STUAS	0	0	Navy/USMC	ISR/Explosive Ordnance Disposal/Force Protection
ScanEagle	122	39	Navy /SOCOM	ISR/Reconnaissance, Surveillance, and Target Acquisition/Force Protection
RQ-11 Raven	5346	3291	Army/Navy/SOCOM	ISR/Reconnaissance, Surveillance, and Target Acquisition
Wasp	916	323	USMC/ SOCOM	ISR/Reconnaissance, Surveillance, and Target Acquisition
SUAS AECV Puma	39	26	SOCOM	ISR/Reconnaissance, Surveillance, and Target Acquisition
gMAV / T-Hawk	377	194	Army (gMAV) Navy (T-Hawk)	ISR/Reconnaissance, Surveillance, and Target Acquisition/Explosive Ordnance Disposal

Source: Weatherington brief.

Note: For comparison purposes, table does not include mini/small, micro, or lighter-than-air UAS.

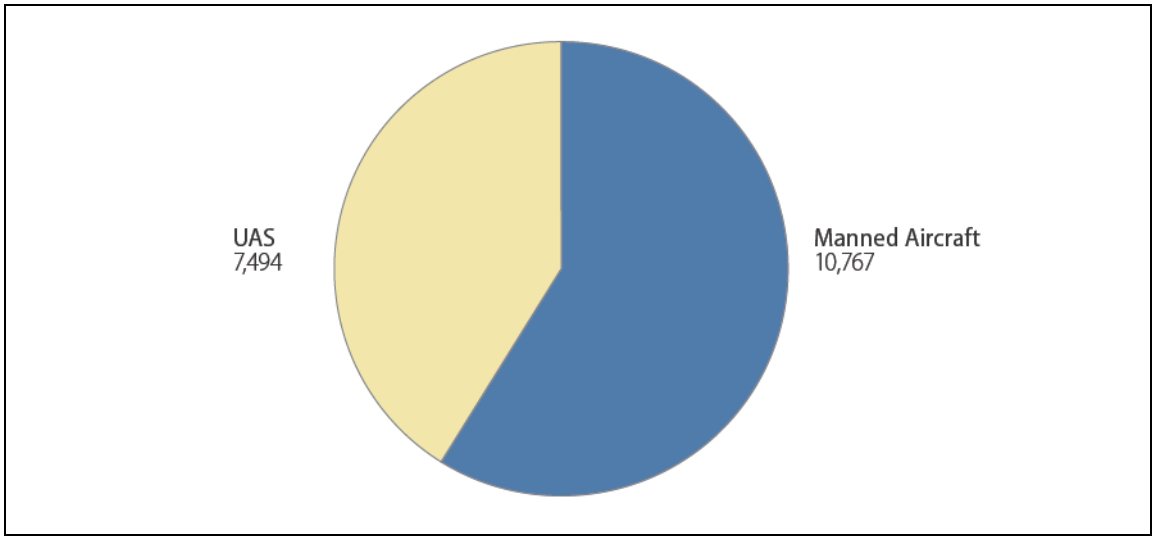
a. MQ-1 and MQ-9 use the same GCS.

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The increase in DOD's UAV inventory appears largely due to the rising demand for UAVs to branch out from the typical intelligence, surveillance and reconnaissance (ISR) applications and conduct a wider variety of missions. Predator B and Reaper are equipped with a strike capability, and many Predator As have been modified to carry weapons. Additionally, mine detection, border patrol, medical resupply, and force perimeter protection are increasingly considered as roles for UAS.

In order to understand fully the pace and scope of UAS acquisition, a comparison between manned aircraft inventories and unmanned inventories may prove to be a useful tool. **Figure 2** shows the ratio of manned to unmanned aircraft. Due to the recent acceleration in UAS production and drawdowns in manned aircraft, manned aircraft have gone from 95% of all DOD aircraft in 2005 to 69% today. Previously described as complements to, or augmentation of, manned aircraft, user demand and budgetary push have increasingly promoted UAS into a principal role.

Figure 1. Manned Aircraft Inventory vs. UAS Inventory



Source: The Military Balance 2010; Weatherington brief.

A significant Congressional boost to UAS acquisition came in the conference report for the National Defense Authorization Act for Fiscal Year 2001, which expressed Congress's desire that "within ten years, one-third of U.S. military operational deep strike aircraft will be unmanned."[33] This goal was seen at the time as very challenging, because DOD had no unmanned deep strike aircraft.

Subsequently, the Fiscal 2007 Defense Authorization Act required the Secretary of Defense to "develop a policy, to be applicable throughout the Department of Defense, on research, development, test and evaluation, procurement, and operation of unmanned systems." The policy was required to include, among other elements, "A preference for unmanned systems in acquisition programs for new systems, including a requirement under any such program for the

[33] H.Rept. 106-945, U.S. Congress, Enactment of Provisions of H.R. 5408, the Floyd D. Spence National Defense Authorization Act For Fiscal Year 2001, Conference report to accompany H.R. 4205, 106th Cong., 2nd sess., October 6, 2000, section 220.

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development of a manned system for a certification that an unmanned system is incapable of meeting program requirements."[34] Thus, Congress changed the default assumption of new systems; instead of seeking unmanned systems to accomplish the same tasks as manned equivalents, unmanned systems would be developed to accomplish military tasks unless there was some need that the systems be manned.

UAS Management Issues

In addition to establishing acquisition pace, and scope of application, one significant Congressional task may be to determine whether DOD's administrative processes and lines of authority within the acquisition process are effective for UAS development and acquisition. The management of DOD's development and acquisition programs received heightened attention in recent Congresses. Given that UAS are acquired by all four of the military services and the U.S. Special Operations Command, and that UAS acquisition is accelerating, (for a growing list of applications), it appears that great potential exists for duplication of effort. This leads many to call for centralization of UAS acquisition authority, to ensure unity of effort and inhibit wasteful duplication. On the other hand, if UAS efforts are too centralized, some fear that competition and innovation may be repressed.

Cost Management Issues

Once viewed as a cheap alternative to manned aircraft, or even a "poor man's air force," some UAS are beginning to rival manned aircraft in cost. According to DOD's most recent estimate, the Global Hawk program will cost $13.9 billion to purchase 54 aircraft; a program acquisition unit cost of $211 million per UAV.[35] The program has twice triggered Nunn-McCurdy breaches, which require DOD to notify Congress when cost growth on a major acquisition program reaches 15%.[36] In 2005, development cost overruns led to an average unit cost growth of 18% per airframe and prompted appropriators to voice their concern (H.R. 2863, H.Rept. 109-119, p. 174). In April, 2011, a reduction in the number of Global Hawk Block 40 aircraft requested in the FY2012 budget from 22 to 11 caused overall Global Hawk unit prices to increase by 11%, again triggering Nunn-McCurdy.

> [T]he RQ-4 Global Hawk surveillance drone, by Northrop Grumman [NOC] has been criticized by the Air Force for higher than expected cost growth. [Under Secretary of Defense Ashton] Carter said that program is "on a path to being unaffordable" and will be studied in detail to determine what is causing the suspected inefficiencies.[37]

Much UAS cost growth appears to spring from factors that have also affected manned aircraft programs, such as "requirements creep" and inconsistent management practices. Global Hawk

[34] P.L. 109-364, *John Warner National Defense Authorization Act for Fiscal Year 2007*, section 941.

[35] OSD (AT&L), *Selected Acquisition Report (SAR): RQ-4A/B UAS Global Hawk*, December 31, 2010. Costs are expressed in constant 2002 dollars.

[36] The Nunn-McCurdy provision requires DOD to notify Congress when cost growth on a major acquisition program reaches 15%. If the cost growth hits 25%, Nunn-McCurdy requires DOD to justify continuing the program based on three main criteria: its importance to U.S. national security; the lack of a viable alternative; and evidence that the problems that led to the cost growth are under control. For more information, see CRS Report R41293, *The Nunn-McCurdy Act: Background, Analysis, and Issues for Congress* , by Moshe Schwartz.

[37] Marina Malenic, "Pentagon Unveils Belt-Tightening Plan For Acquisition Programs," *Defense Daily*, June 29, 2010.

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costs, for example, have been driven up by adding multiple sensors, which themselves increase cost, but also require larger wings and more powerful engines to carry the increased weight, which also increases cost. Although originally intended to carry one primary sensor at a time, DOD changed the requirement so that Global Hawk is to carry two or more primary sensors—which has increased the UAS's price.[38]

Global Hawk is not the only example of requirements creep. Originally considered a relatively modest UAS, the Joint Unmanned Combat Air System (J-UCAS) evolved into a large, long range aircraft with a heavy payload, which increased cost. J-UCAS was canceled in 2006.

Organizational Management issues

The frequent change and realignment of DOD's organizations with a role in UAS development illustrates the difficulties of establishing a comprehensive UAS management system. Over the years, management of UAS programs has gone full circle from the military services, to a Navy-run Joint Program Office (JPO), to the Defense Airborne Reconnaissance Office (DARO) and then back to the services, under the auspices of OSD. The JPO was established in 1988, but met criticism in Congress.

The JPO was replaced by the Defense Airborne Reconnaissance Office (DARO), created in 1993 to more effectively manage DOD's disparate airborne reconnaissance programs, including UAS. DARO was disbanded in 1998, amid criticism of problems, redesigns, and accidents with the family of systems that it was formed to develop.[39] It is unclear whether this criticism was completely legitimate, or whether it was generated by advocates of manned aviation, who sought to protect these established programs.

Since DARO's demise, no single organization has managed DOD UAS efforts. General oversight authority resides within the Office of the Assistant Secretary of Defense for Command, Control, Communications and Intelligence (OASD(C3I)), while the military services manage program development and acquisition.

In an effort to increase joint coordination of UAS programs operated by the services, OSD established the Joint UAV Planning Task Force in 2001. The task force, which falls under the authority of the Pentagon's acquisition chief (Under Secretary of Defense for Acquisition, Technology and Logistics), works to help standardize payload development, establish uniform interfaces, and promote a common vision for future UAS-related efforts. Subsequently, the Joint UAV Planning Task Force has been promoted to the top rung on the UAS management ladder.

> In lieu of creating an executive agent for UAS, the Deputy Secretary of Defense (DepSecDef) directed the formation of a UAS Task Force (TF). The TF was directed to identify to the Deputy Advisory Working Group (DAWG) and, where appropriate, assign lead organizations for issues related to the acquisition and management of UAS including interoperability, civil airspace integration, frequency spectrum and bandwidth utilization, ground stations, and airframe payload and sensor management.[40]

[38] For more information, see CRS Report RL30727, *Airborne Intelligence, Surveillance, and Reconnaissance (ISR): The U-2 Aircraft and Global Hawk UAV Programs*, by Richard A. Best Jr. and Christopher Bolkcom.

[39] Bill Sweetman. "DARO Leaves A Solid Legacy," *Journal of Electronic Defense*, June 1998, p.43.

[40] Under Secretary of Defense (Acquisition, Technology and Logistics), *Department of Defense Report to Congress on* (continued...)

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In order to help a common UAS vision become a reality, the task force, through the OSD, published three UAS Roadmaps in April 2001, December 2002, and August 2005. A more recent UAS roadmap was published in April 2009 as part of a DOD integrated roadmap that also included unmanned systems for ground and sea warfare.

In March 2005 testimony to the House Armed Services Subcommittee on Tactical Air and Land Forces, the GAO criticized DOD for the lack of an " ... oversight body to guide UAV development efforts and related investment decisions," which ultimately does not allow DOD " ... to make sound program decisions or establish funding priorities."[41] From the testimony, it would appear that the GAO envisioned a central authority or body to satisfy this role.

In what appeared to be a move toward further management restructuring, reports in 2005 indicated that OSD was considering appointing one of the services as the executive agent and coordinator for UAS programs, a role the Air Force actively pursued.[42] However, later that year the JROC announced that DOD had abandoned the notion of an executive agent in favor of two smaller organizations focusing on interoperability.[43] The first, entitled the Joint UAV Overarching Integrated Product Team (OIPT), provides a forum for identification and problem solving of major interoperability and standardization issues between the services.[44] A complementary Joint UAV Center of Excellence coordinates with the OIPT to improve interoperability and enhance UAS applications through the examination of sensor technologies, UAS intelligence collection assets, system technologies, training and tactics.[45]

That command arrangement was revised in 2007, when the Deputy Secretary of Defense directed the formation of a UAS Task Force.[46] The task force was directed to, "where appropriate, assign lead organizations for issues related to the acquisition and management of UAS including interoperability, civil airspace integration, frequency spectrum and bandwidth utilization, ground stations, and airframe payload and sensor management."[47] That arrangement remains in place today.

UAS and Investment Priorities

All four military services, the U.S. Special Operations Command (SOCOM), and the U.S. Coast Guard are developing and fielding UAS. Developing a coordinated, DOD-wide UAS investment strategy appears key to ensuring duplication is avoided, and scarce resources are maximized. As

(...continued)

Addressing Challenges for Unmanned Aircraft Systems, September 2010.

[41] Sharon Pickup and Michael J. Sullivan, written testimony before the House Armed Services subcommittee on Tactical Air and Land Forces. "Unmanned Aerial Vehicles Improved Strategic and Acquisition Planning Can Help Address Emerging Challenges." Government Accountability Office. GAO-05-395T. March 9, 2005, p. 1.

[42] John A. Tirpak. "The UAV Skirmishes." Air Force Magazine. June 2005, pg. 11.

[43] "JROC Cans UAV Executive Agent Idea, Back Joint Excellence Center." *Inside the Pentagon*. June 30, 2005.

[44] Office of Assistant Secretary of Defense for Public Affairs, "Joint Unmanned Aerial Vehicle Team, Center of Excellence Announced." July 8, 2005.

[45] Ibid.

[46] Office of the Secretary of Defense, *Deputy Secretary of Defense Memorandum, "Unmanned Aircraft Systems (UAS),"* September 13, 2007.

[47] Under Secretary of Defense (Acquisition, Technology and Logistics) , *Department of Defense Report to Congress on Addressing Challenges for Unmanned Aircraft Systems*, September 2010.

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part of its defense oversight role, Congress is positioned to arbitrate between competing UAS investments, or impact DOD's overarching investment plan. Several relevant questions seem apparent: How is UAS cost quantified? What is the most effective balance in spending between UAS and manned aircraft? How should DOD, Congress and the UAS manufacturers balance cost with capability? Finally, what areas of investment are the most important to maximize UAS capabilities?

When compared to other aircraft, the cost of an individual remotely piloted vehicle can be misleading. UAVs operate as part of a system, which generally consists of a ground control station, a ground crew including remote pilots and sensor operators, communication links and often multiple air vehicles. Unlike a manned aircraft such as an F-16, these supporting elements are a requisite for the vehicle's flight.[48] Consequently, analysts comparing UAV costs to manned aircraft may need to consider the cost of the supporting elements and operational infrastructure that make up the complete unmanned aviation system.

Monitoring or evaluating UAS costs can also be complicated by budgeting conventions. While UAVs can be found in the "Aircraft Procurement, Air Force" account in that service's budget request documentation, the Army includes its UAS funding requests in "Other Procurement, Army." This account contains a broad range of dissimilar items. Also, because most UAS conduct Intelligence, Surveillance and Reconnaissance missions, some portion of their costs are covered in the Intelligence budget rather than the DOD budget, which complicates building a complete picture of cost.

Once an adequate and uniform cost comparison mechanism or definition has been established, the next step for Congress may be to identify an appropriate balance in spending between UAS and manned aircraft. If the upward trend in UAS funding continues through 2013, as shown in **Figure 3**, DOD is projected to have spent upwards of $26 billion on procurement, RDT&E, operations and maintenance for UAS from 2001-2013. This number far exceeds the $3.9 billion spent on UAS from 1988-2000.

Table 2. FY2011-FY2013 President's Budget for UAS

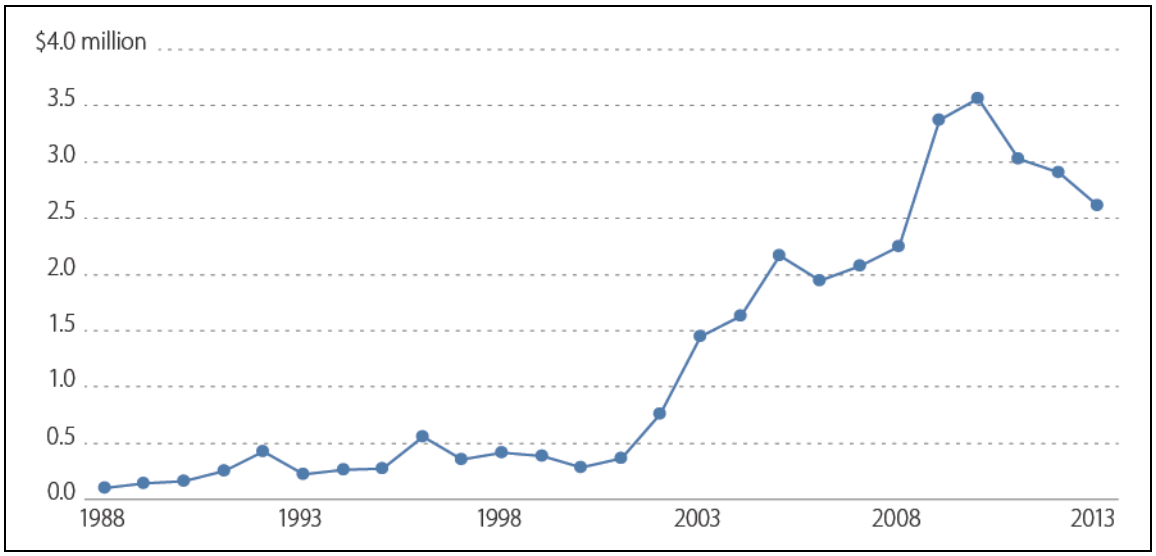
	FY11	FY12	FY13
RDT&E	$1076.4	$894.0	$719.5
PROC	$1704.7	$1734.3	$1576.2
O&M	$249.0	$274.9	$320.2
TOTAL	$3,030.1	$2,903.2	$2,615.9

Source: DOD FY2009–2034 Unmanned Systems Integrated Roadmap, April, 2009, page 4.

[48] Manned aircraft like the F-16 do require radar operators and air traffic controllers in order to maximize their performance, yet these are not required for flight. An F-16 needs a pilot in the cockpit and little else. UAVs, with the exception of the few autonomous flight models, require constant intervention and control from a ground crew. The probability that an F-16 could sustain flight without communication from its ground crew is relatively high, whereas the lack of communication between the ground operators and the UAV yields a low probability of sustained flight.

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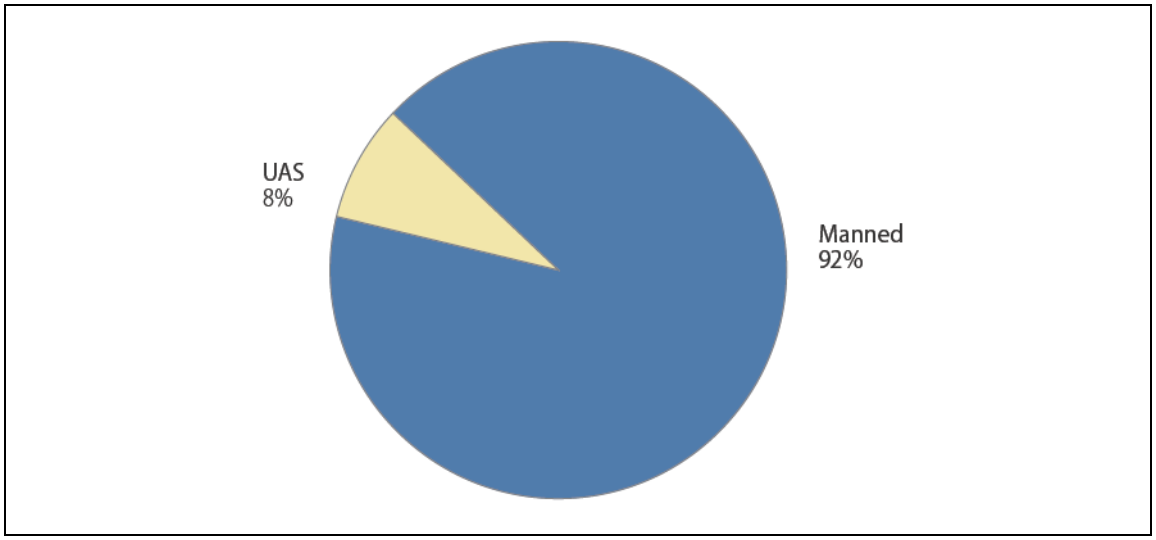
Figure 2. UAS budgets, 1988-2013



Source: OSD, UAS Roadmap 2005-2030, August 2005, p.37 and DOD FY2009–2034 Unmanned Systems Integrated Roadmap, April, 2009, Page 4.

Figure 3 demonstrates the total funding for UAS as a percentage of the total military aviation funding. As the pie chart shows, despite the recent acquisition of many UAS, such systems represent only 8% of all military aviation procurement funding.

Figure 3. Manned vs. Unmanned Aircraft Procurement Budget (FY2011)



Source: DOD UAS Roadmap 2009-2030; FY2011 DOD justification books for procurement of manned aircraft. Does not include small UAVs, micro-UAVs or lighter-than-air platforms.

Cost savings have long been touted by UAS advocates as one of the advantages offered by unmanned aircraft over manned aircraft. However, critics point out that the acquisition cost savings are often negligible if one considers that money saved by not having a pilot in the cockpit must be applied to the "ground cockpit" of the UAS aircrew operating the UAV from the ground control station. Another cost question concerns personnel. Do UAS "pilots" cost less to train and

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keep proficient than pilots of manned aircraft?[49] So although the air vehicle might be cheaper than a manned aircraft, the UAV system as a whole is not always less expensive.[50] Additionally, UAS have a higher attrition rate and lower reliability rate than manned aircraft, which means that the operation and maintenance costs can be higher. On the other hand, UAS ground control stations are capable of simultaneously flying multiple UAVs, somewhat restoring the advantage in cost to the unmanned system. Congress has noted that, "while the acquisition per unit cost may be relatively small, in the aggregate, the acquisition cost rivals the investment in other larger weapon systems."[51]

At what threshold does an "expendable" UAV cost too much to lose? Sensors have consistently increased the cost of the air vehicle, according to Former Air Force Secretary James Roche.[52] The inexpensive design of small UAV air vehicles like the Desert Hawk and Dragon Eye are dwarfed by the cost of the lightweight electro-optical/infrared cameras that make up their payloads. On the other end of the size spectrum, the RQ-4B second generation Global Hawk's sensor payload represents approximately 54% of the vehicle's flyaway cost, which does not include the cost of the increased wingspan that shoulders the extra 1000 pounds of sensor suites.[53] These costs are increasing due to the basic law of supply and demand. Growing demand, matched with a lack of commercial sensor equivalents, means that UAS sensor producers face little competition, which would help keep costs down.

Growing sensor costs have prompted some observers to recommend equipping UAVs with self-protection devices, suggesting those UAVs are no longer considered expendable. Consequently, two schools of thought exist for employing UAVs in ways that could help balance cost with capability. One is to field many smaller, less expensive and less capable UAVs controlled through a highly interconnected communications network.[54] One example of this investment approach was included in the Army's developmental Future Combat System, which intended to link several relatively inexpensive UAVs like the Raven, the Shadow and the Fire Scout with 18 other weapons platforms. None of these UAVs could individually shoulder all of the air duties required by the system, yet the robust communications network was expected to distribute the mission duties to allow each platform to provide its specialized task.[55]

A second approach advocates fielding fewer, more expensive and more capable UAVs that are less networked with other systems, such as the autonomous Global Hawk. The Global Hawk serves as a high altitude, "all-in-one" surveillance platform capable of staying aloft for days at a time, yet does not operate in concert with any of its fellow UAV peers. Since 2003, programs at both ends of this spectrum have experienced delays and a reduction in funding. The Army's

[49] For more on personnel issues, see "Recruitment and Retention" section below.

[50] As an example, a Predator air vehicle costs $4.5 million, while the Predator system, including four air vehicles and control equipment, costs over $20 million.

[51] U.S. Congress, 107th Congress, 2nd Session, House of Representatives, Bob Stump National Defense Authorization Act for Fiscal Year 2003, H.Rept. 107-436, p.243.

[52] U.S. Congress, 107th Congress, 2nd Session, Senate, Committee on Armed Services, "Department of Defense Policies and Programs to Transform the Armed Forces to Meet the Challenges of the 21st Century," Senate Hearing 107-771, April 9, 2002, p.124.

[53] More information on the second generation RQ-4B and its difference from the RQ-4A is included in "Current DOD UAV Programs," below. Also, please see OSD, *UAS Roadmap 2005-2030*. August 2005, Appendix B, p. B-1.

[54] Some have referred to this option as the "swarming UAV" concept.

[55] See CRS Report RL32888, *Army Future Combat System (FCS) "Spin-Outs" and Ground Combat Vehicle (GCV): Background and Issues for Congress*, by Andrew Feickert and Nathan J. Lucas.

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Future Combat System has experienced delays due to significant management and technology issues. Similarly, the highly capable Global Hawk has risen in cost and been the target of funding cuts.[56]

Finally, what areas of investment will yield the maximum effectiveness out of these UAS? Four specific issues stand out as the most pressing: interoperability, reliability, force multiplication/autonomy, and engine systems.

Interoperability

UAS development has been marked by the slow advancement of interoperability. The future plans for UAS use within the framework of larger battlefield operations and more interconnected and potentially joint-service combat systems require UAS to communicate seamlessly between each other and numerous different ground components, and to also be compatible with diverse ground control systems. The lack of interconnectivity at these levels has often complicated missions to the point of reducing their effectiveness, as Dyke Weatherington, head of DOD's UAS planning taskforce, noted; "There have been cases where a service's UAV, if it could have gotten data to another service, another component, it may have provided better situational awareness on a specific threat in a specific area that might have resulted in different measures being taken."[57]

Advancing the interoperability of UAS has been a critical part of the OSD's investment plans. The Department of Defense has pushed forward with the establishment of communication between similar UAS to help facilitate interoperability among four system elements:[58]

- First, DOD hopes to integrate an adequate interface for situational awareness, which will relay the objective, position, payload composition, service operator and mission tasking procedure to other unmanned aircraft and potentially to ground elements.
- Second, a payload interface will allow the coherent transfer of surveillance data.
- Third, the weapons interface will constitute a separate transfer medium by which operators can coordinate these platform's offensive capabilities.
- Finally, the air vehicle control interface will enable navigation and positioning from the ground with respect to other aircraft.

Although the framework for these categories of interoperability has been established, the technology has been slow to catch up. The House of Representatives version of the FY2006 Defense Authorization Act (H.R. 1815, H.Rept. 109-89) took a major step to encourage inter-platform communication. The members of the House Armed Services Committee included a clause that called for the requirement of all tactical unmanned aerial vehicles throughout the services to be equipped with the Tactical Common Data Link, which has become the services' standardized communication tool for providing "critical wideband data link required for real-time situational awareness, as well as real time sensor and targeting data to tactical commanders."[59] If

[56] See the "Current DOD UAV Programs" section for more information about the Global Hawk and J-UCAS programs.

[57] Michael Peck, "Pentagon Setting Guidelines For Aircraft Interoperability," *National Defense*, July 2004, p. 47.

[58] Four categories as outlined by Dyke Weatherington and reported by Michael Peck. "Pentagon Setting Guidelines For Aircraft Interoperability," *National Defense*, July 2004, p. 47.

[59] For text of congressional clause see National Defense Authorization Act for Fiscal Year 2006, Report of the House (continued...)

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UAS are to achieve the level of interoperability envisioned by the OSD, the services and industry will likely need to keep focused on achieving the Common Data Link communications system goal and invest appropriately to facilitate an expedited and efficient development process.

The finite bandwidth that currently exists for all military aircraft, and the resulting competition for existing bandwidth, may render the expansion of UAS applications infeasible and leave many platforms grounded. Ultimately, the requirement for bandwidth grows with every war the U.S. fights.[60] The increased use of UAS in Iraq and Afghanistan indicates that remotely piloted platforms' mass consumption of bandwidth will require a more robust information transfer system in the coming years.

One approach to alleviating the bandwidth concern was the Transformational Satellite Communications (TSAT) project. DOD intended to use that laser and satellite communications system to provide U.S. armed forces with an unlimited and uninhibited ability to send and receive messages and critical information around the world without data traffic jams.[61] However, the TSAT project was canceled in 2009. As another interim option, DOD has testified that a more autonomous UAV would require less bandwidth, since more data are processed on board and less data are being moved.[62] However, it is unclear that autonomy will actually decrease bandwidth requirements since the transmission of data from the UAV's sensors drives the demand for bandwidth. As an example, a single Global Hawk, already an autonomous UAV, "requires 500Mbps bandwidth—which equates to 500 percent of the total bandwidth of the entire U.S. military used during the 1991 Gulf War."[63]

Another approach to alleviating the bandwidth problem is allowing UAVs to be operated from a manned stand-off aircraft such as a command and control aircraft with line of sight to the UAV. Stationing the mission control element of the UAV system in another aircraft instead of on the ground would reduce the reliance on satellites for beyond-line-of-sight communication, simplifying command and control. Experimentation is currently ongoing in this area, with the first step being controlling the UAV's sensor payload from an airborne platform.

Reliability/Safety

A 2010 media study reported that "Thirty-eight Predator and Reaper drones have crashed during combat missions in Afghanistan and Iraq, and nine more during training on bases in the U.S.—

(...continued)

of Representatives' Committee on Armed Services, H.Rept. 109-89, Section 141 of Legislative Provisions, May 20, 2005. For citation of TCDL purpose, see "Tactical Common Data Link (TCDL) Overview." BAE Systems, http://www.cnir.na.baesystems.com/cnir_tcdl_overview.htm. 2005.

[60] Bandwidth is the amount of data that can be transmitted over a communications link in a fixed amount of time.

[61] Sandra Erwin. "Multibillion-Dollar 'Internet in the Sky' Could Help Ease Bandwidth Crunch." National Defense. June 2005, p. 24.

[62] Hearing of the Tactical Air and Land Forces Subcommittee of the House Armed Services Committee. "Fiscal Year 2004 Budget Request for Unmanned Combat Aerial Vehicles and Unmanned Aerial Vehicle Programs." March 26, 2003.

[63] Department of the Navy Chief Information Officer Spectrum/Telecommunications Team, "Transformational Communications," *CHIPS*, January-March 2005.

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with each crash costing between $3.7 million and $5 million. Altogether, the Air Force says there have been 79 drone accidents costing at least $1 million each."[64]

In 2004 the Defense Science Board indicated that relatively high UAV mishap rates might impede the widespread fielding of UAVs.[65] Although most UAV accidents have been attributed to human error,[66] investment in reliability upgrades appears to be another high priority for UAS. The 2005 UAS Roadmap indicated that UAV mishap rates appeared to be much higher than the mishap rates of many manned aircraft. **Table 3** shows the number of Class A Mishap per 100,000 hours of major UAVs and comparable manned aircraft as of 2005.[67]

Table 3. Selected Mishap Rates, 2005

(per 100,000 hrs)

Vehicle Type	Class A Mishaps
UAV	
Predator	20
Hunter	47
Global Hawk	88
Pioneer	281
Shadow	191
Manned	
U-2	6.8
F-16	4.1

Source: DOD's UAS Roadmap 2005-2030, p. 75.

However, "(a)ccident rates per 100,000 hours dropped to 7.5 for the Predator and 16.4 for the Reaper last year (2009), according to the Air Force. The Predator rate is comparable to that of the F-16 fighter at the same stage, Air Force officers say, and just under the 8.2 rate for small, single-engine private airplanes flown in the U.S."[68]

[64] David Zucchino, "War zone drone crashes add up," *Los Angeles Times*, July 6, 2010.

[65] Defense Science Board. "Defense Science Board Study on Unmanned Aerial Vehicles and Uninhabited Combat Aerial Vehicles." Office of the Undersecretary of Defense for Acquisitions, Technology, and Logistics. February 2004, p.vii-viii.

[66] A 2005 study cited human operational or maintenance mistakes as causing 68% of UAV accidents. William T. Thompson, Major Anthony P. Tvaryanas, and Stefan H. Constable, *U.S. Military Unmanned Aerial Vehicle Mishaps: Assessment of the Role of Human Factors Using Human Factors Analysis and Classification System (HFACS)*, U.S. Air Force, 311th Human Systems Wing, HSW-PE-BR-TR-2005-0001, Brooks City-Base, TX, March 2005.

[67] Note that Class A mishaps, according to the Army Safety Center, are considered to be damage costs of $1,000,000 or more and/or destruction of aircraft, missile or spacecraft and/or fatality or permanent total disability. Similar definitions for the Air Force, Navy and Marine Corps can be found at their respective safety center websites. Also note the performance capabilities of the manned versus unmanned vary greatly and may have an impact on the mishap rate. Finally, note that the definition of a Class A mishap is not indexed for inflation, so the actual damage need to reach $1 million in cost effectively declines each year.

[68] David Zucchino, "War zone drone crashes add up," *Los Angeles Times*, July 6, 2010.

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In its 2004 study, the Defense Science Board (DSB) notes that manned aircraft over the past five decades have moved from a relatively high mishap rate to relatively low rates through advancements in system design, weather durability improvements and reliability upgrades.[69] It should be pointed out, however, that the UAS, with the exception of Predator, have total flight times that are significantly less the than the 100,000 hours used to calculate the mishap rate. Most aircraft tend to have a much higher mishap rate in their first 50,000 hours of flight than their second 50,000 hours of flight. Further, some of the UAS in **Table 3** have flown numerous missions while still under development. Predator and Global Hawk, for instance, entered combat well prior to their planned initial operational capability (2005 for Predator, and 2011 for Global Hawk.) It may be unfair to compare the mishap rates of developmental UAS with manned aircraft that have completed development and been modernized and refined over decades of use.

The DSB report also suggests that nominal upgrades and investment—arguing even that many UAS will need little change—could produce substantial reductions in the UAV mishap rates. The 2005 UAS Roadmap proposes investments into emerging technologies, such as self-repairing "smart" flight control systems, auto take-off and recovery instruments, and heavy fuel engines, to enhance reliability.[70] Also the incorporation of advanced materials—such as high temperature components, light-weight structures, shape memory alloys and cold weather tolerance designs that include significant de-icing properties—will also be expected to improve the survivability of UAS in adverse environments.[71]

Force Multiplication/Autonomy

One of the most attractive and innovative technological priorities for UAS is to enable one ground operator to pilot several UAVs at once. Currently most UAS require at least two ground operators; one to pilot the vehicle and another to control the sensors. The end goal for UAS manufactures and users is to reduce the 2:1 operator-vehicle ratio and eventually elevate the autonomy and interoperability of UAS to the point where two or more vehicles can be controlled by one operator. If this technological feat is achieved, the advantage of UAS as a force-multiplier on the battlefield could provide a dramatic change in combat capability.

The process of achieving this goal may require significant time and investments. As the 2005 UAS Roadmap notes, "Getting groups of UA to team (or swarm) in order to accomplish an objective will require significant investment in control technologies" with specific reference to distributed control technologies.[72] Considering the two operator system currently in place for most UAS, the logical approach to reaching this technological advancement is to first invest in the autonomous flight capabilities of the UAVs, so as to reduce the workload for the complete UAS. The Global Hawk and the Scan Eagle possess significant automated flight capabilities, but their degree of actual flight autonomy can be debated due to the UAV's need for continuous operator intervention in poor weather conditions. The OSD quantifies the degree of UAV autonomy on a scale of one to ten; **Table 4** shows the OSD's Autonomous Capability Levels for UAVs.

[69] Defense Science Board. "Defense Science Board Study on Unmanned Aerial Vehicles and Uninhabited Combat Aerial Vehicles." Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics. February 2004, p. viii.

[70] OSD. *UAS Roadmap 2005-2030*, August 2005, p. H-8 and H-9.

[71] Ibid.

[72] OSD. *UAS Roadmap 2005-2030*, August 2005, p. D-7.

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Table 4. Autonomous Capability Levels (ACL)

Level	Capability
10	Fully Autonomous Swarms
9	Group Strategic Goals
8	Distributed Controls
7	Group Tactical Goal
6	Group Tactical Replan
5	Group Coordination
4	Onboard Route Replan
3	Adapt to Failures & Flight Conditions
2	Real Time Health/Diagnosis
1	Remotely Guided

Source: Data taken from DOD's UAS Roadmap 2005-2030, p. D-10.

In order for UAVs to achieve maximum use when being controlled by a single pilot, the UAV ACL must achieve a level of at least eight. Currently, the Global Hawk, which is considered by many the most autonomous UAV currently in service, maintains an ACL of approximately 2.5. FAA and the UAS industry are working with the Department of Defense in order to facilitate the universal development of "see and avoid" technology that would allow a UAV to operate autonomously and avoid approaching aircraft, potentially increasing the standard ACL for UAS to four. Additionally, inter-UAS communication and the coordination associated with interoperability must match the autonomous flight abilities. Full automation of sensor capabilities would enable the lone operator to control a network of intelligence collecting drones.

The first steps towards the "one-operator-per-several-UAVs" advancement are already underway.In 2005, the Air Force evaluated a Predator upgrade that allowed one operator to control the flight plan of four Predator UAVs during an exercise in which one UAV engaged a target and the other three hovered nearby on standby status. [73] The next step is to consolidate the tasks of the four mission payload operators, each manning the sensors or weapons system on the four Predators, into one or fewer operators.

Engine Systems

Another technology under development is fuel cell-generated electric power. Supporters of fuel cells note that these devices could double the efficiency of mid-sized UAS and could reduce the aircrafts' acoustic and thermal signatures, effectively making them more difficult to detect and target.[74] Air Combat Command is sponsoring the project with the goal to use the fuel cells in many of its smaller UAS, and the Air Force Research Laboratory flight tested a fuel cell-powered

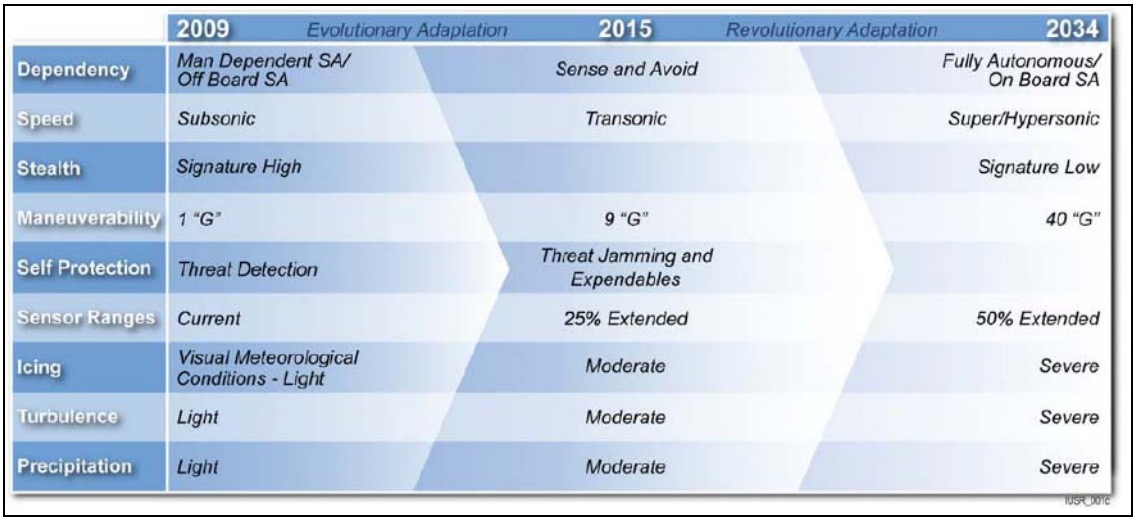
[73] "Predators Fly First Four-Ship Sortie." Air Force Print News. September 26, 2005.

[74] Libby John. "Fuel Cell Project Could Help Make UAVs Less Detectable, More Efficient." *Inside the Air Force.* September 23, 2005.

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Puma UAV in 2007. "With a power system using a chemical hydride fuel, the UAV demonstrated flight endurance of more than 7 hr., versus 2.5 hr. for the standard Puma."[75] [76]

Figure 4. UAS Technology Futures



Source: DOD FY2009–2034 Unmanned Systems Integrated Roadmap, April, 2009, Page 30.

Note: SA is "situational awareness," although in this context "Sense and Avoid" capability is also an appropriate fit for the acronym.

Some key technologies that will enable future UAS include:

> lightweight, long endurance battery and/or alternative power technology, effective bandwidth management/data compression tools, stealth capability and collaborative or teaming technologies that will allow UAS to operate in concert with each other and with manned aircraft. A critical enabler allowing UAS access to U.S. National and ICAO airspace will be a robust on-board sense and avoid technology. The ability of UAS to operate in airspace shared with civil manned aircraft will be critical for future peacetime training and operations. There is also a need for open architecture systems that will allow competition among many different commercial UAS and ground control systems allowing DoD to "mix and match" the best of all possible systems on the market. Technology enablers in propulsion systems coupled with greater energy efficiency of payloads are required to extend loiter time and expand the missions of UAS to include Electronic Attack and directed energy.[77]

Duplication of Capability

Congress may ask if the production of different UAS with relatively similar performance capabilities constitutes unnecessary duplication. Critics of expanded UAS roles often argue that the production of similar platforms is unnecessary, considering that a consolidated inventory—

[75] David Eshel, "Mini-UAVs rack up big gains," *Defense Technology International*, May 15, 2008.

[76] Fuel cell technology has already been tested on other types of aircraft:."German Aerospace Centre has converted an Antares 20E, the DLR-H2, to fly with a fuel cell. Boeing has also flown a Dimona motor glider with an electric motor powered by a fuel cell. And United Technologies, which makes Sikorsky helicopters, has flown a large model electric-helicopter powered by a hydrogen fuel cell." "Electric planes: High voltage," *The Economist*, June 10, 2010.

[77] DOD FY2009–2034 Unmanned Systems Integrated Roadmap, April, 2009, pp. 48-49.

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hypothetically consisting of only the RQ-4B Global Hawk, the RQ/MQ-1 Predator and the RQ-7 Shadow—could perform and fulfill the same duties as the expanded inventory.

According to GAO, for example,

> Although several unmanned aircraft programs have achieved airframe commonality, service-driven acquisition processes and ineffective collaboration are key factors that have inhibited commonality among subsystems, payloads, and ground control stations. For example, the Army chose to develop a new sensor payload for its Sky Warrior,[78] despite the fact that the sensor currently used on the Air Force's Predator is comparable and manufactured by the same contractor. To support their respective requirements, the services also make resource allocation decisions independently. DOD officials have not quantified the potential costs or benefits of pursuing various alternatives, including common systems. To maximize acquisition resources and meet increased demand, Congress and DOD have increasingly pushed for more commonality among unmanned aircraft systems. [79]

Table 5 shows a comparison of the performance specifications of UAS with electro-optical and infra-red sensors. The chart indicates that a majority of such UAS feature an endurance of 5 to 24 hours, an altitude of 10,000 - 25,000 ft, max speeds between 105 and 125 knots and radiuses of 100 to 150 nm.

Table 5. ISR UAS with E-O/IR Sensors

	Vehicle Endurance (hrs) Max	Altitude (ft) Max	Speed (kt)	Range (nm)	Additional Sensor	User
Eagle Eye	5.5	20000	210	110	MMR	Coast Guard
Grey Eagle	26	25000	120	150	None	Army
Maverick	7	10300	118	175	None	SOCOM
MQ-1	24	25000	118	500	SAR	AF
MQ-5B	18	18000	106	144	None	Army
RQ-4A	32	65000	350	5400	SAR/MTI	AF
RQ-4B	28	60000	340	5400	SAR/MTI, SIGINT	AF
RQ-5A	12	15000	106	144	None	Army
RQ-7A	5	14000	110	68	None	Army
RQ-7B	7	15000	105	68	None	Army
RQ-8	6	20000	125	150	LDFR	Army/Navy

Source: OSD. 2005-2030 UAS Roadmap. August 2005, pp. 4-25.

The 2011 program acquisition unit cost for the MQ-9 Reaper is $28.4 million, just over half the $55 million estimate for the F-16 Falcon.[80] A simple payload comparison shows that the F-16 can

[78] Sky Warrior is now Grey Eagle.

[79] U.S. Government Accountability Office, *Defense Acquisitions: Opportunities Exist to Achieve Greater Commonality and Efficiencies among Unmanned Aircraft Systems*, GAO-09-520, July 2009.

[80] Reaper cost from Office of the Secretary of Defense (Acquisition, Technology & Logistics), *Selected Acquisition* (continued...)

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carry approximately four times the payload of the Reaper (10,750 lbs vs. 2,500 lbs).[81] Further, the F-16 is a versatile combat aircraft that can be used to perform many missions that the Reaper cannot. This may suggest that using manned aircraft for air-to-ground combat may generally prove more cost effective than using UAS, and that the UAS's unique combat capabilities may be most valued in niche circumstances, such as when manned aircraft would be in extreme danger.

Other Potential Missions

Other missions for which UAS appear useful, or are being considered in the near-term, include electronic attack (also called stand-off jamming, or escort jamming), and psychological operations, such as dropping leaflets. UAS such as the Army's Shadow have been evaluated for their capability to deliver critical medical supplies needed on the battlefield.

While UAS use in foreign theaters is well established, one of the most commonly discussed new mission areas for UAS is homeland defense and homeland security. The Coast Guard and U.S. Border Patrol already employ UAS such as the Eagle Eye and Predator to watch coastal waters, patrol the nation's borders, and protect major oil and gas pipelines.

It appears that interest is growing in using UAS for a variety of domestic, and often non-defense roles. Long-duration law enforcement surveillance, a task performed by manned aircraft during the October 2002 sniper incident near Washington, D.C. is one example. The U.S. Department of Transportation has studied possible security roles for UAS, such as following trucks with hazardous cargo, while the Energy Department has been developing high-altitude instruments to measure radiation in the atmosphere.[82] UAS might also be used in sparsely populated areas of the western United States to search for forest fires. Following the wide-spread destruction of Hurricane Katrina, some suggest that a UAS like Global Hawk could play roles in "consequence management" and relief efforts.[83] Also, UAS advocates note that countries like South Korea and Japan have used UAS for decades for crop dusting and other agricultural purposes.[84]

> Historically, UAS were predominately operated by DoD in support of combat operations in military controlled airspace; however, UAS support to civil authorities (JTF Katrina in 2005, U.S. Border surveillance, and fire suppression) continues to expand. This expansion, coupled with the requirement to train and operate DoD and [other government agency] assets,

(...continued)

Report: MQ-9 UAS Reaper, RCS: DD-A&T(Q&A)823-424, Washington, DC, December 30, 2010., p. 69. F-16 cost from Air Force reporting referenced in U.S. Government Accountability Office, *Tactical Aircraft: Air Force Fighter Reports Generally Addressed Congressional Mandates, but Reflected Dated Plans and Guidance, and Limited Analyses*, GAO-11-323R, February 24, 2011, p. 9.

[81] Payload based on the maneuvering capability of an F-16 flying at 9 g with a center fuel tank , see Jane's All the World Aircraft 2005-2006. 96th edition, edited by Paul Jackson, p. 728. OSD. *UAS Roadmap 2005-2030.* August, 2005, Section 2, p.10.

[82] National Journal's Congress Daily. "Pilotless Aircraft Makers Seek Role For Domestic Uses," December 17, 2002.

[83] Martin Matishak, "Global Hawk Could Perform Multiple Tasks in Relief Efforts, Study Finds," *Inside the Air Force*, September 23, 2005.

[84] See, for example Statement of Christopher Bolkcom, Analyst in National Defense Congressional Research Service. Before the Senate Governmental Affairs Committee, Subcommittee on International Security, Proliferation, and Federal Services. Hearing On Cruise Missile Proliferation. June 11, 2002. http://hsgac.senate.gov/061102bolkcom.pdf

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> highlights the need for routine access to the [national airspace system] outside of restricted and warning areas, over land and water. [85]

Heavier-than-air UAS may not always be the preferred platforms for these new roles and applications. Other options could include manned aircraft, blimps, and space satellites.[86] Each platform offers both advantages and disadvantages. Manned aircraft provide a flexible platform, but risk a pilot's life. Some of the country's largest defense contractors are competing to develop unmanned blimps that may be capable of floating months at a time at an altitude of 70,000 feet and carrying 4,000 pounds of payload. OSD's UAS Roadmap includes a section on lighter-than-air blimps and tethered "aerostat" platforms, which OSD indicates to be important for a variety of roles, including psychological operations, spotting incoming enemy missiles and border monitoring. Furthermore, these platforms could provide services equivalent to many border surveillance UAS, but their decreased dependency on fuel could reduce operations costs. One drawback to these lighter-than-air platforms is their lack of maneuverability and speed relative to UAVs like the Global Hawk; their long persistence once on station may be somewhat offset by the time required for them to relocate in response to new taskings. Nonetheless, many major UAS manufacturers are preparing—and, in some cases, testing—lighter-than-air systems that could carry out a variety of missions for homeland security.[87]

Space satellites offer many benefits; they are thought to be relatively invulnerable to attack, and field many advanced capabilities. However, tasking the satellites can be cumbersome, especially with competing national priorities. The limited number of systems can only serve so many customers at one time. Additionally, some satellites lack the loitering capability of UAS, only passing over the same spot on Earth about once every three days. Due to the high costs of space launches, UAVs like Global Hawk are being considered for communication relays as substitutes for low-orbiting satellite constellations.[88]

The Issue of Airspace

Not all of these new UAS applications are uncontroversial or easily implemented. UAS advocates state that in order for UAS to take an active role in homeland security, law enforcement, aerial surveying, crop dusting, and other proposed civilian uses, Federal Aviation Administration (FAA) regulations and UAS flight requirements must approach a common ground. According to FAA spokesman William Shumann, the primary challenge in finding this common ground is "to develop vehicles that meet FAA safety requirements if they want to fly in crowded airspace." [89] The August 2003 announcement that the FAA had granted the Air Force a certificate of authorization for national airspace operation signified the first steps in the reconciliation of these discrepancies.[90] Upgrading UAS collision avoidance capabilities, often referred to as "sense and avoid" technology, appears to be a critical part in the next step of reaching the UAS-airspace

[85] Department of Defense, *FY2009–2034 Unmanned Systems Integrated Roadmap* (2009), p. 91.

[86] For more information on blimps (airships) and aerostats, see CRS Report RS21886, *Potential Military Use of Airships and Aerostats*, by Christopher Bolkcom.

[87] Bob Cox, "The blimp is back," *Sky Talk blog/Dallas Star-Telegram*, July 27, 2011.

[88] David Fulghum. "Air Force Chief Predicts Growth of UAV Use By Military," *Aviation Week and Space Technology*. March 17, 2003.

[89] Greta Wodele, "Firms to showcase unmanned planes for Border Patrol," *National Journal's Technology Daily*, Aug. 11, 2003.

[90] Sue Baker. "FAA Authorizes Global Hawk Flights." Aeronautical Systems Center Public Affairs. August 21, 2003.

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common ground. The FAA's Unmanned Aircraft Systems Working Group is working with the Department of Defense to facilitate safe UAS operations and the adequacy of flight requirements.[91]

The schedule for integrating UAS into the national airspace remains contentious. Industry has expressed frustration at not being able to test new UAS from their own test facilities due to airspace restrictions. Also:

> DOD has pioneered UAS applications for wartime use and, in 2007, was the major user of UAS, primarily for ongoing conflicts in Iraq and Afghanistan. While many of DOD's UAS operations currently take place outside the United States, DOD needs access to the national airspace system for UAS to, among other things, transit from their home bases for training in restricted military airspace or for transit to overseas deployment locations.[92]

In November 2009, Secretary of the Air Force Michael Donley and FAA Administrator Randy Babbitt co-moderated an industry forum on UAS in the national airspace system. At that event, Administrator Babbitt said:

> In order for us to get to the place where the UAS can become a viable, accepted part of the national airspace system, we have to make sure that sense-and-avoid is more than a given—it must be a guarantee.
>
> Without a pilot who can look and scan to the left and the right—just the way you and I do when we're backing out of a parking space—there's a perceived level of risk that the American public isn't ready for.[93]

The issue of when and how UAS will be allowed to operate in U.S. airspace continues to evolve, and continues to be of interest to Congress. The House passed a proposed FAA reauthorization bill in 2011 which "includes a provision requiring FAA to develop a comprehensive plan within nine months of enactment to safely integrate commercial unmanned aircraft systems (UASs) in the national airspace system. The bill further specifies that this integration is to be completed as soon as possible, but not later than September 30, 2012, and authorizes such sums as may be necessary to carry out the implementation plan."[94] A companion Senate bill "includes a provision requiring FAA to develop a plan for accelerating the integration of UASs into the National Airspace System within one year of enactment." More detailed information on this issue can be found in CRS Report R41798, *Federal Aviation Administration (FAA) Reauthorization: An Overview of Legislative Action in the 112th Congress*.

Recruitment and Retention

The defining characteristic of UAS is that they are "unmanned" or "unpiloted." However, this may be a misnomer.

[91] "UAV Sense-And-Avoid Technologies Not Just A Military Concern." *Defense Daily*. August 2, 2005.

[92] U.S. Government Accountability Office, *Unmanned Aircraft Systems: Federal Actions Needed to Ensure Safety and Expand Their Potential Uses within the National Airspace System*, GAO-80-511, May 2008, p. 9.

[93] "FAA: Drones Not Ready for Prime Time," *Aviation Today*, December 7, 2009.

[94] CRS Report R41798, *Federal Aviation Administration (FAA) Reauthorization: An Overview of Legislative Action in the 112th Congress*, coordinated by Bart Elias.

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> "There's nothing unmanned about them," [former Air Force Lt Gen David] Deptula said. It can take as many as 170 persons to launch, fly, and maintain such an aircraft as well as to process and disseminate its ISR products. [95]

Recruitment and retention is a perennial congressional issue that may be receiving increased attention due to the operational stresses associated with the ongoing efforts to counter terrorism. What impact might wide spread deployment of UAS have on military personnel? If UAS are introduced into the force in large numbers, might personnel issues arise?

It has not always been easy for the aviation culture to adapt to flying aircraft from the ground. The Air Force has realized the retention implications of requiring rated pilots to fly their UAS,[96] and has offered enticements such as plum assignments after flying the UAS, and allowing pilots to keep up their manned flying hours during their UAS tour of duty.

Historically, many believed that as more UAS were fielded, recruitment and retention would suffer because those inclined to join the military would prefer to fly manned aircraft instead of unmanned aircraft. This may be the case in some instances. The future impact of DOD's UAS programs on recruitment, however, is more complicated than this argument suggests.

The recruitment and retention situation varies among the services and for different types of personnel. The Air Force and Navy are actively trying to reduce their number of uniformed personnel. Thus, possible reduced enlistments due to increased UAS use might not have the anticipated negative impact.[97]

A central question related to the potential impact of increased UAS employment on personnel is "what qualifications are required to operate UAS?" Currently, the Air Force requires Predator and Global Hawk operators to be pilot-rated officers. Other services do not require that status for their UAS operators. This means that, in the other services, there is no competition between manned and unmanned aircraft for potentially scarce pilots.

Many people enlist in military service with no desire, or intention to fly manned aircraft. Some wish to fly, but lack physical qualifications, such as good eyesight. The increased fielding of UAS may encourage some to enlist because it offers them an opportunity to "fly" that they may not have had otherwise. Further, those inclined to fly manned aircraft may not be as disinclined to fly UAS as was believed in the past. Flying armed UAS may be more appealing to these personnel than is flying non-armed UAS. Also, flying UAS may be an attractive compromise for certain personnel. While it may not confer all the excitement of flying a manned aircraft, it also avoids many of the hardships (e.g. arduous deployments and potential harm). The Air Force believes that flying UAS from control stations in the United States will be attractive to some in the reserve component who may be disinclined to experience an active duty lifestyle consistent with flying manned aircraft. Also, not all UAS compete with manned aircraft for pilots. Those UAS that are pre-programmed and operate autonomously (like Global Hawk) do not require a pilot, unlike the Predator and other remotely piloted aircraft.

[95] John A. Tirpak, "The RPA Boom," *Air Force*, August 2010.

[96] Currently the Air Force is the only service to require rated pilots to fly their UAVs.

[97] For more information on recruitment issues see CRS Report RL32965, *Recruiting and Retention: An Overview of FY2009 and FY2010 Results for Active and Reserve Component Enlisted Personnel*, by Lawrence Kapp.

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The Air Force maintains that their UAS are more technologically and operationally sophisticated than other UAS, and a trained pilot is required to employ these UAS most effectively. As UAS autonomy, or command and control matures, or if personnel issues for the Air Force become more troublesome, it, or Congress, may decide to review the policy of requiring pilot-rated officers to operate UAS.[98]

Increased employment of UAS could potentially boost enlistment in other specialties, if they are perceived as being effective in their missions. If, for example, those inclined to enlist in infantry positions perceive UAS to offer improved force protection and CAS capabilities over today's manned aircraft, these potential recruits may have fewer qualms about the potential hazards of combat.

Industrial Base Considerations

Defense industrial base issues perennially confront Congress. Is U.S. industry becoming too dependent on foreign suppliers? Do foreign competitors get government subsidies that put U.S. firms at a competitive disadvantage? Should Congress take steps to encourage or discourage defense industry consolidation? Should Congress take steps to promote competition in the defense industrial base? Should Congress takes steps to protect U.S. defense industries in order to safeguard technologies or processes critical to national defense?[99] It appears that DOD's pursuit of UAS presents several interrelated issues relevant to the defense industrial base.

Some commentators argue that increasing acquisition of UAS may take funds from manned aircraft programs, and the technical expertise required to design and perhaps build manned combat aircraft could erode. Many observers point out that the ability to produce world class combat aircraft is a distinct U.S. comparative advantage, and should be guarded closely. Others disagree that the pursuit of UAS could harm the industrial base. They argue that the F-35 Joint Strike Fighter (JSF) is likely to be the last manned tactical fighter, and that the industrial base is naturally evolving toward the skills and processes required to make increasingly advanced UAS.

Those who fear manned industrial base atrophy argue that the future of UAS is overrated, and that demand will continue for tactical manned aircraft in the post-JSF timeframe. In their eyes, crucial skills and technologies could thus be lost by concentrating only on unmanned aircraft design, possibly causing U.S. dominance in tactical aircraft design to wane. These proponents point out that UAS have been around for almost a century, yet only recently became operationally effective, and are not likely to replace manned aircraft in the near future.[100]

Others disagree, and believe that critical manned aircraft design skills are not jeopardized by increased pursuit of UAS because there is considerable commonality between manned and unmanned combat aircraft. Except for the obvious lack of a cockpit, unmanned combat aircraft may require stealthy airframes, advanced avionics, and high performance engines just like

[98] LtGen Dave Deptula, *The Way Ahead: Remotely Piloted Aircraft in the United States Air Force*, U.S. Air Force, undated briefing, http://www.daytonregion.com/pdf/UAV_Rountable_5.pdf.

[99] See, for example, CRS Report RL31236, *The Berry Amendment: Requiring Defense Procurement to Come from Domestic Sources*, by Valerie Bailey Grasso.

[100] For more information on the arguments for and against future demand of tactical aircraft, see CRS Report RL31360, *Joint Strike Fighter (JSF): Potential National Security Questions Pertaining to a Single Production Line*, by Christopher Bolkcom and Daniel H. Else.

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manned combat aircraft. Also, major defense contractors have already begun to shift to unmanned aircraft design in order to stay competitive. This is because UAS are beginning to play a prominent role in warfare, as seen in Operations Enduring Freedom and Iraqi Freedom. The same skills and technologies required for building manned aircraft will likely lend themselves to unmanned aviation design as well. Companies that have lost out in recent aviation contracts, such as Boeing and the JSF in 2001, are looking towards unmanned bombers and fighters as prospects for growth. Were Boeing to design manned aircraft in the future, the critical skills needed would still be present, according to this argument. Boeing acquired UAS maker Insitu in 2008.[101] Northrop Grumman Corp., as another example, has created a new business unit to aggressively pursue UAS contracts, and acquired Scaled Composites in 2007 in part for UAS design expertise.[102]

Others would argue that maintaining a healthy U.S. defense industrial base depends, in part, on how well U.S. firms compete for the global UAS market. One survey finds that in 2011, there are 680 different UAS programs world wide, up from 195 in 2005. [103] [104] Another estimates that global UAS expenditures will double from $1.7 billion in 2011 to $3.5 billion in 2020.[105] The global market for combat aircraft alone, at approximately $15.8 billion in 2011, dwarfs the UAS market. But the rate of growth is projected to be much slower, peaking at approximately $21 billion in 2017, and dropping to approximately $19 billion in 2020.[106] Thus, some would argue that much new business is likely to be generated in the UAS market, and if U.S. companies fail to capture this market share, European, Russian, Israeli, Chinese, or South African companies will. From this perspective, capturing this new business, and nurturing industrial expertise in UAS challenge areas (e.g. autonomous flight, control of multiple vehicles, command and control, communications bandwidth) would be an effective way to keep U.S. industry competitive and healthy.

As U.S. companies compete for business in a growing international UAS marketplace, concerns about the proliferation of these systems may grow. Are steps required—and if so, what might they be—to control the spread of UAS? As part of its defense and foreign policy oversight, Congress may examine whether a balance must be struck between supporting legitimate U.S. exports and curbing the spread of UAS technologies to dangerous groups or countries.

Congressional Considerations

Advances in UAS technology and their expanding role in national security lead to a number of possible questions for Congressional consideration. They may include:

[101] Andy Pasztor, "Boeing Aims For Slice Of Fighter-Jet Contract Awarded to Lockheed, But Blow Still Stings," *The Wall Street Journal*, October 29, 2001.

[102] David Fulghum, "New Northrop Grumman Unit Focuses on Unmanned Aircraft," *Aviation Week & Space Technology,* April 30, 2001.

[103] J.R. Wilson, "2011 Worldwide UAV Roundup," *Aerospace America*, March 2011.

[104] "Unmanned Aerial Vehicles Directory," *Flight International*, June 21-27, 2005.

[105] "Unmanned Aerial Vehicles Market Overview," World Missiles Briefing, Teal Group Inc., Fairfax, VA, January 2011.

[106] "Fighter/Attack Aircraft Market Overview," World Military & Civil Aircraft Briefing, Teal Group Inc., Fairfax, VA, February 2011.

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Funding

Should Congress increase, reduce, or approve DOD's proposed overall funding level for UAS?

Budget impact: How might an increased reliance on UAS affect future DOD funding needs? Would it permit a net reduction in DOD funding requirements for performing a given set of missions, and if so, by how much?

Trade-Offs

If funding constraints require choices to be made among DOD UAS programs, what are some of the key potential choices? Choices may include whether to reduce the number of UAS programs, buy fewer UAS overall, defer purchase of more sophisticated UAS, or other choices.

Measures of Effectiveness

How should the effectiveness of UAS be evaluated? Number of aircraft procured? Number of UAS tracks supported? Area under surveillance by UAS? Suppression or elimination of a particular threat or category of threats?

Pace of Effort

In terms of developing, procuring, and integrating UAS into their operations, are DOD and the services moving too slowly, too quickly, or at about the right speed? Are the services adequately implementing their UAS road maps? Should the current requirement for issuing road maps every two years be changed, and if so, how? Can a standard metric be established to determine the optimal pace?

Management

Who should manage the development and procurement of DOD UAS? Should management of at least some of these programs be centralized? If so, where in DOD should the central authority reside?

Air Force Chief of Staff General Norton Schwartz made the case that "Ideally, what you want to do is have the U.S. government together in a way that allows us to get the best capability… An example is BAMS and Global Hawk. Why should the Navy and Air Force have two separate depots, ground stations and training pipelines for what is essentially the same airplane with a different sensor? I think there is lots of opportunity for both of us to make better uses of resources."[107]

[107] David A. Fulghum, "USAF Chief Considers F-35 And F-22 Replacement," *Aerospace Daily*, November 25, 2010.

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Operators

Are current service policies regarding who can operate a UAS satisfactory? If not, how should they be changed? Should there be a uniform, DOD-wide policy? Should DOD consider using a mix of uniformed and civilian personnel for operating UAS, particularly those that are not used for firing weapons (somewhat similar to how Military Sealift Command ships are operated by a mix of uniformed and civilian personnel)? What would be the potential advantages and disadvantages of such an arrangement for operating UAS? What is an appropriate role for contractors in operating military UAS?

R&D Priorities

What new UAS capabilities are most needed? Should priority be given to incremental increases in capability versus ambitious technological leaps? What is the importance of maintaining the U.S. technological lead in UAS?

Development Facilities

Are current FAA limits on DOD access to domestic U.S. flight facilities for developing UAS hindering the development of DOD UAS? What are the relevant factors and capabilities involved, and do they make a persuasive case for the change or retention of current limits?

Other Issues

In recent years, the pace of UAS development has accelerated, and the scope of UAS missions and applications has expanded. How should these efforts be managed so that they are cost-efficient, effective, and interoperable? In its eagerness to deploy UAS, does DOD risk duplication of effort between various programs? Are DOD UAS acquisition plans responsive to congressional direction? Are UAS being developed fast enough? Are they being developed too fast? Has DOD developed an appropriate plan and structure for incorporating UAS into future military capabilities?

Investment priorities could change as the introduction of UAS into the U.S. inventory shifts the balance between manned and unmanned capabilities. Congress, as part of its defense oversight responsibilities, may assess DOD's current UAS efforts to verify that they match up with new investment goals and strategies. Conventional wisdom states that UAS are cheap, or cost-effective. Is this true today? How do UAS costs compare to manned aircraft costs?

In Summation

UAS have traditionally been used for reconnaissance and surveillance, but today they are being employed in roles and applications that their designers never envisioned. The unanticipated flexibility and capability of UAS have led some analysts to suggest that more, if not most, of the missions currently undertaken by manned aircraft could be turned over to unmanned aerial platforms, and that manned and unmanned aircraft could operate together. Future Congresses may have to contemplate the replacement of a significant portion of the manned aircraft fleet with unmanned aircraft.

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Current Major DOD UAS Programs

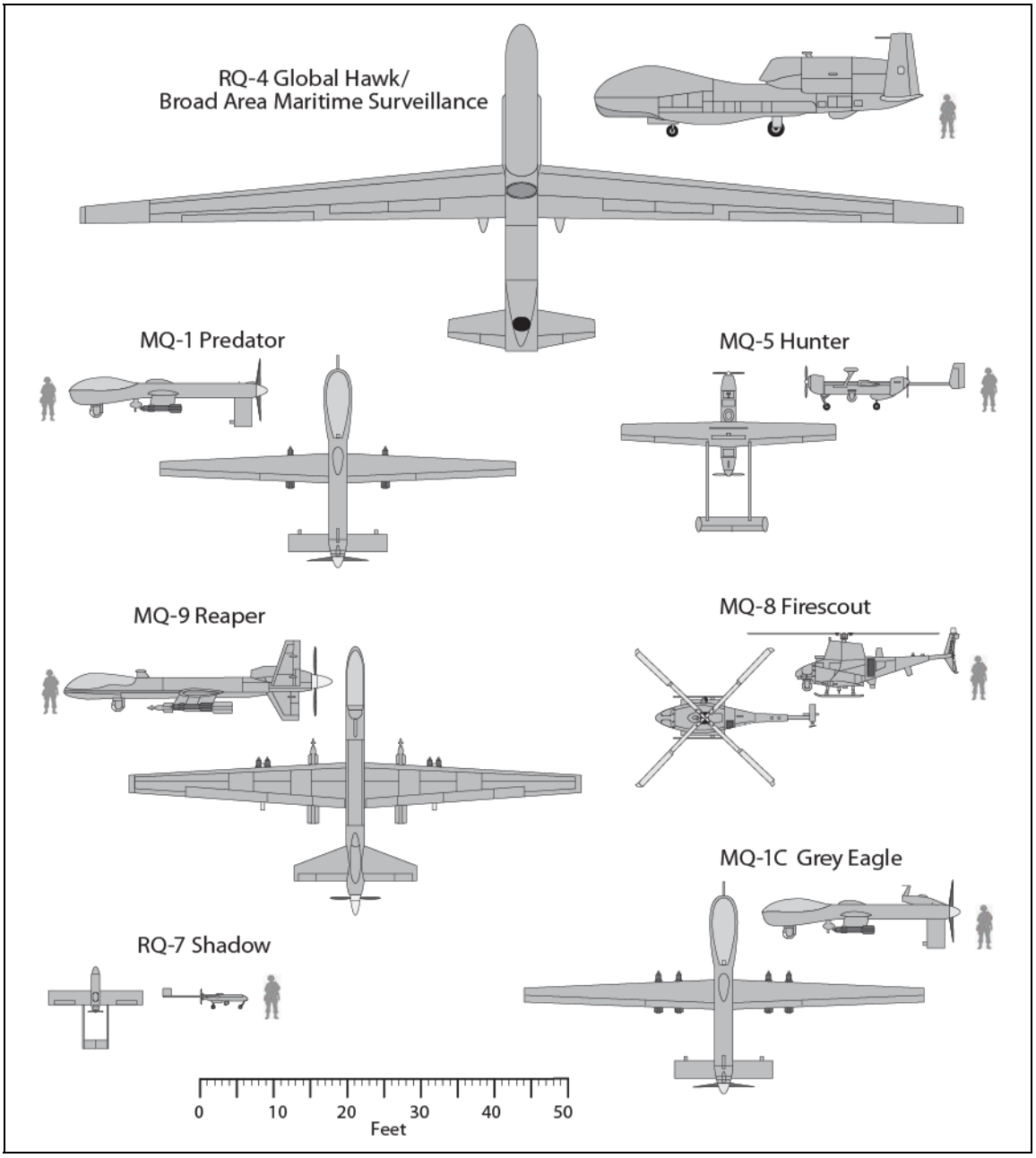
This section addresses the program status and funding of some of the most prominent UAS programs being pursued by DOD, and most likely to compete for congressional attention. This section does not attempt to provide a comprehensive survey of all UAS programs, nor to develop a classification system for different types of UAS (e.g. operational vs. developmental, single mission vs. multi mission, long range vs. short range). One exception is a short subsection below titled "Small UAVs." The UAVs described in this section are distinguished from the proceeding UAVs by being man-portable and of short range and loiter time. These smaller UAVs are not currently, and are unlikely to be, weaponized. The Services do not provide as detailed cost and budget documentation for these UAVs as they do for major UAS programs. Individually, these UAVs appear very popular with ground forces, yet do not necessarily demand as much congressional attention as larger UAS programs like Predator or Global Hawk. As a whole, however, these small, man-portable UAVs appear likely to increasingly compete with major UAS programs for congressional attention and funding.

Table 6. Characteristics of Selected Tactical and Theater-Level Unmanned Aircraft

System	Length (ft)	Wingspan (ft)	Gross weight (lbs)	Payload capacity (lbs)	Endurance (hours)	Maximum altitude (ft)
Predator	27	55	2,250	450	24+	25,000
Grey Eagle	28	56	3,200	800	40	25,000
Reaper	36	66	10,500	3,750	24	50,000
Shadow	11	14	375	60	6	15,000
Fire Scout	23	28	3,150	600	6+	20,000
Global Hawk	48	131	32,250	3,000	28	60,000
BAMS	48	131	32,250	3,200	34+	60,000

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Figure 5. U.S. Medium-Sized and Large Unmanned Aircraft Systems



Source: Congressional Budget Office, *Policy Options for Unmanned Aircraft Systems*, Publication 4083, Washington, DC, June 2011.

Notes: All aircraft are drawn to the same scale. The silhouette figure is a 6-foot-tall soldier, also drawn to scale.

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Table 7. Acquisition Cost of Medium-Sized and Large Unmanned Aircraft Systems Under the Department of Defense's 2012 Plan

(Millions of 2011 dollars)

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total, 2011-2020
Air Force											
RQ-4 Global Hawk	1,200	1,060	890	790	810	710	1,160	530	80	60	7,290
MQ-1 Predator	30	10	10	10	[a]	[a]	[a]	[a]	[a]	[a]	60
MQ-9 Reaper	1,700	1,550	1,740	1,440	1,350	1,150	1,060[b]	1,040[b]	1,030[b]	1,010[b]	13,070
Army											
MQ-1C Grey Eagle	870	1,060	1,040	740	220	90	[a]	[a]	[a]	[a]	4,020
RQ-7 Shadow	610	250	270	200	300	280	[a]	[a]	[a]	[a]	1,910
Navy and Marine Corps											
RQ-4 Broad Area Maritime Surveillance	530	560	760	880	900	1,010	1,230	1,260	1,130	1,130	9,390
MQ-8 Fire Scout	60	70	60	80	80	90	130	160	150	150	1,030
RQ-7 Shadow	90	10	10	10	[a]	[a]	[a]	[a]	[a]	[a]	120
All services											
	5,090	4,570	4,780	4,150	3,660	3,330	3,580	2,990	2,390	2,350	36,890

Source: Congressional Budget Office based on data from the Department of Defense's budget request for 2012, Selected Acquisition Reports for December 2010, and Aircraft Procurement Plan: Fiscal Years 2012-2041 (submitted with the 2012 budget, March 2011).

Notes: Acquisition cost includes the cost of procuring air vehicles, sensors, and grounds stations, plus the cost for research. development, test, and evaluation. The services' cost data have been adjusted using CBO's projection of inflation and rounded to the nearest $10 million.

a. The Department of Defense has no plans to acquire or modify the specified system in these years.

b. The cost is for the follow-on aircraft the Air Force plans to acquire instead of the Reaper.

MQ-1 Predator

Through its high profile use in Iraq and Afghanistan and its multi-mission capabilities, the MQ-1 Predator has become the Department of Defense's most recognizable UAS. Developed by General Atomics Aeronautical Systems in San Diego, CA, the Predator has helped to define the modern role of UAS with its integrated surveillance payload and armament capabilities. Consequently, Predator has enjoyed accelerated development schedules as well as increased

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procurement funding. The wide employment of the MQ-1 has also facilitated the development of other closely related UAS (described below) designed for a variety of missions.

System Characteristics. Predator is a medium-altitude, long-endurance UAS. At 27 feet long, 7 feet high and with a 48 foot wingspan, it has long, thin wings and a tail like an inverted "V". The Predator typically operates at 10,000 to 15,000 feet to get the best imagery from its video cameras, although it has the ability to reach a maximum altitude of 25,000 feet. Each vehicle can remain on station, over 500 nautical miles away from its base, for 24 hours before returning home. The Air Force's Predator fleet is operated by the 15th and 17th Reconnaissance Squadrons out of Creech Air Force Base, NV; the 11th Reconnaissance Squadron provides training. A second control station has been established at Whiteman AFB, MO.[108] Further, "[t]here are plans to set up Predator operations at bases in Arizona, California, New York, North Dakota, and Texas."[109] The Air Force has about 175 Predators;[110] the CIA reportedly owns and operates several Predators as well.

Mission and Payload. The Predator's primary function is reconnaissance and target acquisition of potential ground targets. To accomplish this mission, the Predator is outfitted with a 450-lb surveillance payload, which includes two electro-optical (E-O) cameras and one infrared (IR) camera for use at night. These cameras are housed in a ball-shaped turret that can be easily seen underneath the vehicle's nose. The Predator is also equipped with a Multi-Spectral Targeting System (MTS) sensor ball which adds a laser designator to the E-O/IR payload that allows the Predator to track moving targets. Additionally, the Predator's payload includes a synthetic aperture radar (SAR), which enables the UAS to "see" through inclement weather. The Predator's satellite communications provide for beyond line-of-sight operations. In 2001, as a secondary function, the Predator was outfitted with the ability to carry two Hellfire missiles. Previously, the Predator identified a target and relayed the coordinates to a manned aircraft, which then engaged the target. The addition of this anti-tank ordinance enables the UAS to launch a precision attack on a time sensitive target with a minimized "sensor-to-shoot" time cycle. Consequently, the Air Force changed the Predator's military designation from RQ-1B (reconnaissance unmanned) to the MQ-1 (multi-mission unmanned).[111] The air vehicle launches and lands like a regular aircraft, but is controlled by a pilot on the ground using a joystick.

MQ-1C Grey Eagle

A slightly larger, longer-endurance version of the Predator, the Army's MQ-1C Grey Eagle entered low-rate initial production on March 29, 2010.[112] The Grey Eagle can remain aloft for 36 hour, 12 hours longer than its Air Force sibling.

An Army platoon operates four (4) aircraft with electro-optical/infrared and/or laser rangefinder/designator payloads, communications relay equipment, and up to four Hellfire

[108] Phillip O'Connor, "Drones seeking terrorists guided from Missouri air base," *St. Louis Post-Dispatch*, May 10, 2011.

[109] P.W. Singer, *Wired for War* (New York: The Penguin Press, 2009), p. 33.

[110] Congressional Budget Office, *Policy Options for Unmanned Aircraft Systems*, Pub. No. 4083, June 2011, p. 5.

[111] Glenn W. Goodman, Jr., "UAVs Come of Age," *The ISR Journal*, July 2002, p. 24.

[112] Department of Defense, *Selected Acquisition Report (SAR), MQ-1C UAS Gray (sic) Eagle*, DD-A&T(Q&A)823-420, Washington, DC, December 31, 2010.

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missiles. Each platoon includes two ground control stations, two ground data terminals, one satellite communication ground data terminal, one portable ground control station, one portable ground data terminal, an automated takeoff and landing system, two tactical automatic landing systems, and ground support equipment. In total, the program will be 124 aircraft, plus 21 attrition aircraft and seven schoolhouse aircraft, for a total of 152 aircraft. The average procurement unit cost of a Grey Eagle system is $114.1 million.[113]

MQ-9 Reaper

The MQ-9 Reaper, formerly the "Predator B," is General Atomics' follow on to the MQ-1. The Reaper is a medium-to-high altitude, long endurance Predator optimized for surveillance, target acquisition and armed engagement. While the Reaper borrows from the overall design of the Predator, the Reaper is 13 feet longer and carries a 16-foot-longer wingspan. It also features a 900hp turboprop engine, which is significantly more powerful than the Predator's 115hp engine. These upgrades allow the Reaper to reach a maximum altitude of 50,000 feet, a maximum speed of 225 knots, a maximum endurance of 32 hours and a maximum range of 2000 nautical miles.[114] However, the feature that most differentiates Reaper from its predecessor is its ordinance capacity. While the Predator is outfitted to carry two 100-pound Hellfire missiles, the Reaper now can carry as many as 16 Hellfires, equivalent to the Army's Apache helicopter, or a mix of 500-pound weapons and Small Diameter Bombs.

As of February 4, 2011, General Atomics Aeronautical Systems had delivered 65 of 399 planned Reapers, 43 of which are operationally active.[115]

The MQ-9 is operated by the 17th Reconnaissance Squadron and the 42nd Attack Squadron, both at Creech Air Force Base, Nevada, and the 29th Attack Squadron at Holloman AFB, New Mexico. [116]

Program Status. Predator–family UAS are operated as part of a system, which consists of four air vehicles, a ground control station, and a primary satellite link. The unit cost in FY2009 for one Predator system was approximately $20 million,[117] while the average procurement unit cost for a Reaper system was $26.8 million.[118]

[113] Ibid.

[114] OSD, *UAS Roadmap 2005-2030*, August 2005, p. 10.

[115] Department of Defense, *Selected Acquisition Report (SAR), MQ-9 UAS Reaper*, DD-A&T(Q&A)823-424, Washington, DC, December 31, 2010.

[116] U.S. Air Force, *Fact Sheet: MQ-9 Reaper*, August 18, 2010.

[117] U.S. Air Force, *Fact Sheet: MQ-1 Predator*, July 20, 2010.

[118] Department of Defense, *Selected Acquisition Report (SAR), MQ-9 UAS Reaper*, DD-A&T(Q&A)823-424, Washington, DC, December 31, 2010.

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Table 8. Predator and Reaper Combined Funding

($ in Millions)

		Procurement	RDT&E
FY11			
Request	62 air vehicles	1600.0	
	Mods	31.8	
Appropriations Conference	12 air vehicles	176.6	83.2
	Mods	31.8	
FY12			
Request	9 air vehicles	125.5	61
	Mods	30.2	

RQ-4 Global Hawk

Northrop Grumman's RQ-4 Global Hawk has gained distinction as the largest and most expensive UAS currently in operation for the Department of Defense. Global Hawk incorporates a diverse surveillance payload with performance capabilities that rival or exceed most manned spy planes. However, Pentagon officials and members of Congress have become increasingly concerned with the program's burgeoning cost, which resulted in Nunn-McCurdy breaches in April 2005, and April 2011.[119] Also, the RQ-4B Block 30 was deemed "not operationally suitable" due to "low air vehicle reliability" by the office of Operational Test and Evaluation in May 2011.[120] [121]

System Characteristics. At 44 feet long and weighing 26,750 lbs, Global Hawk is about as large as a medium sized corporate jet. Global Hawk flies at nearly twice the altitude of commercial airliners and can stay aloft at 65,000 feet for as long as 35 hours. It can fly to a target area 5,400 nautical miles away, loiter at 60,000 feet while monitoring an area the size of that state of Illinois for 24 hours, and then return. Global Hawk was originally designed to be an autonomous drone capable of taking off, flying, and landing on pre-programmed inputs to the UAV's flight computer. Air Force operators have found, however, that the UAS requires frequent intervention by remote operators.[122] The RQ-4B resembles the RQ-4A, yet features a significantly larger airframe. In designing the B-model, Northrop Grumman increased the Global Hawk's length from 44 feet to 48 feet and its wingspan from 116 feet to 132 feet. The expanded size enables the RQ-4B to carry an extra 1000 lbs. of surveillance payload.

[119] Amy Butler, "USAF Declares Second Major Global Hawk Cost Breach," Aerospace Daily, April 13, 2011. The 2005 breach stemmed from costs in transitioning from the Block 10 Global Hawk to the larger Block 30; the 2011 breach was attributed primarily to reduced procurement quantities rather than issues with the program.

[120] J. Michael Gilmore, *RQ-4B Global Hawk Block 30* , OSD Director, Operational Test and Evaluation, Operational Test and Evaluation Report, May 2011.

[121] John T. Bennett, "Pentagon testers slam aerial spy drone as unfit for operations," *The Hill*, June 7, 2011.

[122] Jeff Morrison, "USAF No Longer Viewing Global Hawk As An Autonomous System, Official Says," *Aerospace Daily*, December 3rd, 2005.

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Mission and Payload. The Global Hawk UAS has been called "the theater commander's around-the-clock, low-hanging (surveillance) satellite."[123] The UAS provides a long-dwell presence over the battlespace, giving military commanders a persistent source of high quality imagery that has proven valuable in surveillance and interdiction operations. The RQ-4A's current imagery payload consists of a 2,000-lb integrated suite of sensors much larger than those found on the Predator. These sensors include an all-weather SAR with Moving Target Indicator (MTI) capability, an E-O digital camera and an IR sensor. As the result of a January 2002 Air Force requirements summit, Northrop Grumman expanded its payload to make it a multi-intelligence air vehicle. The subsequent incarnation, the RQ-4B, is outfitted with an open-system architecture that enables the vehicle to carry multiple payloads, such as signals intelligence (SIGINT) and electronic intelligence (ELINT) sensors. Furthermore, the classified Multi-Platform Radar Technology Insertion Program (MP-RTIP) payload will be added in order to increase radar capabilities. These new sensor packages will enable operators to eavesdrop on radio transmissions or to identify enemy radar from extremely high altitudes. Future plans include adding hyper-spectral sensors for increased imagery precision and incorporating laser communications to expand information transfer capabilities.[124] The end goal is to field a UAS that will work with space-based sensors to create a "staring net" that will prevent enemies from establishing a tactical surprise.[125] In August of 2003, the Federal Aviation Administration granted the Global Hawk authorization to fly in U.S. civilian airspace, which further expanded the system's mission potential.[126] This distinction, in combination with the diverse surveillance capabilities, has led many officials outside the Pentagon to consider the Global Hawk an attractive candidate for anti-drug smuggling and Coast Guard operations.[127]

Program Status. Developed by Northrop Grumman Corporation of Palmdale, CA, Global Hawk entered low-rate-initial-production in February 2002. The Air Force has stated that it intends to acquire 51 Global Hawks, at an expected cost of $6.6 billion for development and procurement costs. As of November 2009, the Air Force possessed 7 RQ-4A s and 3 RQ-4Bs. [128] Another 32 Global Hawks had been authorized and appropriated through FY2011. [129] According to the most recent Selected Acquisition Report, the current average procurement unit cost for the Global Hawk has reached $140.9 million in current dollars.[130]

In April 2005, the Air Force reported to Congress that the program had overrun by 18% as a result of an "increasing aircraft capacity to accommodate requirements for a more sophisticated, integrated imagery and signals intelligence senor suite".[131] A Government Accountability Office report in December 2004 noted that the program had increased by nearly $900 million since 2001 and recommended delaying the purchase of future Global Hawks until an appropriate

[123] Glenn W. Goodman, Jr., "UAVs Come Of Age," *The ISR Journal*, July 2002.

[124] David A. Fulghum, "Global Hawk Shows Off Updated Package of Sensors," *Aviation Week & Space Technology,* September 08, 2003.

[125] Ibid.

[126] Sue Baker, "FAA Authorizes Global Hawk Flights," Aeronautical Systems Center Public Affairs, August 21, 2003.

[127] Ron Laurenzo, "Global Hawk Scouts Ahead for Other UAVs," *Defense Week*, September 2, 2003.

[128] U.S. Air Force, *Fact Sheet: RQ-4 Global Hawk*, November 19, 2009.

[129] Department of Defense, *Department of Defense Fiscal Year 2012 Budget Estimates, Aircraft Procurement, Air Force*, February 2011.

[130] OSD, *Selected Acquisition Report,* December 31, 2010, p. 29.

[131] James R. Asker, "Global Hawk 18% Over Budget," *Aviation Week & Space Technology*, April 25, 2005.

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development strategy could be implemented.[132] The rising costs of the UAV and accusations of Air Force mismanagement have caused concern among many in Congress and in the Pentagon as well as facilitating an overall debate on the Air Force's development strategy.[133]

Following a 2010 Defense Acquisition Board review of the Global Hawk program,

> Air Force acquisition executive David Van Buren told reporters that he is "not happy" with the pace of the program, both on the government and the contractor side. Chief Pentagon arms buyer Ashton Carter also criticized the program, saying that it was "on a path to being unaffordable."[134]

In April, 2011, a reduction in the number of Global Hawk Block 40 aircraft requested in the FY2012 budget from 22 to 11 caused overall Global Hawk unit prices to increase by 11%, again triggering Nunn-McCurdy.[135]

In its markup of the Fiscal 2011 defense authorization bill, the House Armed Services Committee expressed concern "that differing, evolving service unique requirements, coupled with Global Hawk UAS vanishing vendor issues, are resulting in a divergence in each service's basic goal of maximum system commonality and interoperability, particularly with regard to the communications systems." The bill report directs the Under Secretary of Defense for Acquisition, Technology and Logistics to certify and provide written notification to the congressional defense committees by March 31, 2011, that he has reviewed the communications requirements and acquisition strategies for both Global Hawk and BAMS. The subcommittee wants assurance that the requirements for each service's communications systems have been validated and that the acquisition strategy for each system "achieves the greatest possible commonality and represents the most cost effective option" for each program.[136]

A May 20, 2011 report from the Air Force Operational Test and Evaluation Center found the Global Hawk Block 20/30 to be "effective with significant limitations ... not suitable and partially mission capable." The report cited "lackluster performance of the EISS imagery collector and ASIP sigint collectors at range" rather than issues with the Global Hawk airframe itself.[137]

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[132] United States Government Accountability Office, GAO-05-6 *Unmanned Aerial Vehicles[:] Changes in Global Hawk's Acquisition Strategy Are Needed to Reduce Program Risks,* November 2004, p. 3-4.

[133] See H.Rept. 109-89. House Armed Service Committee "National Defense Authorization Act for the Fiscal Year 2006." May 20, 2005, p. 91.

[134] Marina Malenic, "Air Force, Navy Pledge Greater Global Hawk-BAMS Cooperation," *Defense Daily*, July 2, 2010.

[135] The Nunn-McCurdy provision requires DOD to notify Congress when cost growth on a major acquisition program reaches 15%. If the cost growth hits 25%, Nunn-McCurdy requires DOD to justify continuing the program based on three main criteria: its importance to U.S. national security; the lack of a viable alternative; and evidence that the problems that led to the cost growth are under control. For more information, see CRS Report R41293, *The Nunn-McCurdy Act: Background, Analysis, and Issues for Congress* , by Moshe Schwartz.

[136] U.S. Congress, House Committee on Armed Services, *National Defense Authorization Act for Fiscal Year 2011*, Report to accompany H.R. 5136, 111th Cong., May 21, 2010, H.Rept. 111-491, p. 178.

[137] Amy Butler, "Poor Testing Results Latest Hurdle for Global Hawk," *Aviation Week/Ares blog*, June 3, 2011.

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Table 9. Global Hawk Funding

($ in Millions)

	Quantity	Procurement	RDT&E	Advance Procurement
FY11				
Request	4	649.6	251.3	90.2
Authorization Conference[a]	N/A	N/A	N/A	N/A
Appropriations Conference	4	503.0	220.3	72.3
FY12				
Request	3	323.9		71.5

a. As passed, H.R. 6523, the Ike Skelton National Defense Authorization Act For Fiscal Year 2011, did not include program-level detail, so no amounts were specified for these program elements.

BAMS

The Navy's Broad Area Maritime Surveillance system is based on the Global Hawk Block 20 airframe but with significantly different sensors from its Air Force kin. This, coupled with a smaller fleet size, results in a higher unit cost. "The air service's drone costs $27.6 million per copy, compared to an expected $55 million per BAMS UAV, including its sensors and communications suite... At 68 aircraft, the BAMS fleet will be the world's largest purchase of long-endurance marinized UAVs."[138]

System Characteristics and Mission. "BAMS ... provides persistent maritime intelligence, surveillance, and reconnaissance data collection and dissemination capability to the Maritime Patrol and Reconnaissance Force. The MQ-4C BAMS UAS is a multi-mission system to support strike, signals intelligence, and communications relay as an adjunct to the MMA/P-3 community to enhance manpower, training and maintenance efficiencies worldwide."[139]

"The RQ-4 ... features sensors designed to provide near worldwide coverage through a network of five orbits inside and outside continental United States, with sufficient air vehicles to remain airborne for 24 hours a day, 7 days a week, out to ranges of 2000 nautical miles. Onboard sensors will provide detection, classification, tracking and identification of maritime targets and include maritime radar, electro-optical/infra-red and Electronic Support Measures systems. Additionally, the RQ-4 will have a communications relay capability designed to link dispersed forces in the theater of operations and serve as a node in the Navy's FORCEnet strategy."[140]

[138] Gayle S. Putrich, "Northrop selected to build BAMS drone," *Navy Times*, April 22, 2008.

[139] Northrop Grumman, "MQ-4C BAMS UAS," press release, http://www.as.northropgrumman.com/products/bams/index.html.

[140] Department of Defense, *Department of Defense Fiscal Year 2012 Budget Estimates, Research, Development, Test & Evaluation, Navy*, Budget Activity 7, February 2011.

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"The drones ... will collect information on enemies, do battle-damage assessments, conduct port surveillance and provide support to Navy forces at sea. Each aircraft is expected to serve for 20 years." [141]

Program Status. The Administration's FY2012 budget request documents place Milestone C for BAMS in the 3rd quarter of FY2013, with initial operational capability in the 1st quarter of 2016. "Since Milestone B for the Navy BAMS UAS program, identifying opportunities for the RQ-4-based BAMS and Global-Hawk programs has been a significant interest item for the UAS TF and has been well documented within the Department." [142] In one effort to integrate development, on June 12, 2010, the Navy and Air Force concluded a Memorandum of Agreement (MOA) regarding their Global Hawk and BAMS programs, which use a common airframe. "Shared basing, maintenance, command and control, training, logistics and data exploitation are areas that could be ripe for efficiencies, says Lt. Gen David Deptula, Air Force deputy chief of staff for intelligence, surveillance and reconnaissance… Also, a single pilot and maintenance training program is being established at Beale AFB, Calif., for both fleets."[143] However, issues still exist over common control stations and whether one service's pilots should be able to operate the other service's aircraft.

MQ-8B Fire Scout

Now in deployment, the Fire Scout was initially designed as the Navy's choice for an unmanned helicopter capable of reconnaissance, situational awareness and precise targeting.[144] Although the Navy canceled production of the Fire Scout in 2001, Northrop Grumman's vertical take-off UAV was rejuvenated by the Army in 2003, when the Army designated the Fire Scout as the interim Class IV UAV for the future combat system. The Army's interest spurred renewed Navy funding for the MQ-8, making the Fire Scout DOD's first joint UAS helicopter.

System Characteristics and Mission. Northrop Grumman based the design of the Fire Scout on a commercial helicopter. The RQ-8B model added a four-blade rotor to reduce the aircraft's acoustic signature.[145] With a basic 127-lb. payload, the Fire Scout can stay aloft for up to 9.5 hours; with the full-capacity sensor payload, endurance diminishes to roughly six hours. Fire Scout possesses autonomous flight capabilities. The surveillance payload consists of a laser designator and range finder, an IR camera and a multi-color EO camera, which when adjusted with specific filters could provide mine-detection capabilities.[146] Fire Scout also currently possesses line-of-sight communication data links. Initial tests of an armed Fire Scout were conducted in 2005, and the Navy expects to add "either Raytheon's Griffin or BAE's Advanced Precision Kill Weapon System" small missiles to currently deployed Fire Scouts soon.[147]

[141] Gayle S. Putrich, "Northrop selected to build BAMS drone," *Navy Times*, April 22, 2008.

[142] Under Secretary of Defense (Acquisition, Technology and Logistics), *Department of Defense Report to Congress on Addressing Challenges for Unmanned Aircraft Systems*, September 2010.

[143] Amy Butler, "U.S. Navy/Air Force UAV Agreement Raises Questions," *Aerospace Daily*, July 6, 2010.

[144] "RQ-8A Fire Scout, Vertical Take Off and Landing Tactical Unmanned Aerial Vehicle (VTUAV)," GlobalSecurity.org, http://www.globalsecurity.org/intell/systems/vtuav.htm, April 26th, 2004.

[145] David A. Fulghum, "Army Adopts Northrop Grumman's Helicopter UAV," *Aviation Week & Space Technology*, October 20th, 2003.

[146] Northrop Grumman Corp. Press Release, "Northrop Grumman's Next-Generation Fire Scout UAV on Track," June 23rd, 2005.

[147] Joshua Stewart, "Navy plans to arm Fire Scout UAV with missiles," *Navy Times*, August 18, 2011.

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Discussions of future missions have also covered border patrol, search and rescue operations, medical resupply and submarine spotting operations.

Program Status. Six production MQ-8 air vehicles have been delivered to date.[148] The Pentagon's 2009 UAS Roadmap estimates a future inventory of 131 RQ-8Bs for the Navy to support the Littoral Combat Ship class of surface vessels.[149] [150] The Army had intended to use the Fire Scout as the interim brigade-level UAV for its Future Combat System program,[151] but canceled its participation in January, 2010.[152]

A Fire Scout attracted media attention in August, 2010, when it flew through Washington, D.C. airspace after losing its control link. "A half-hour later, Navy spokesmen said, operators re-established control and the drone landed safely."[153]

FIRE-X/MQ-8C

The FIRE-X project, recently designated MQ-8C but continuing the Fire Scout name, is a developmental effort to adapt the Fire Scout software and navigation systems to a full-size standard helicopter. The Navy "is to award Northrop Grumman a contract to supply 28 MQ-8C Fire Scout ... to be fielded by the first quarter of 2014 to meet an urgent operational requirement."[154]

> Fire Scout can fly for 8 hours with a maximum range of 618 nautical miles? Well, Fire-X will fly for 15, with a max range of 1227. Fire Scout tops out at 100 knots? Fire-X can speed by at 140. Fire-X will carry a load of 3200 lbs. to Fire Scout's 1242. All this talk from a drone helicopter that just took its first flight in December.... Fire-X isn't going to be a big departure from Fire Scout, though. The BRITE STAR II and other radars will remain on board, as will its software for relaying information to a ship.[155]

RQ-170 Sentinel

Although publicly acknowledged to exist, most information about the Lockheed Martin RQ-170 Sentinel is classified. First photographed in the skies over Afghanistan, but also reportedly in operation from South Korea,[156] the RQ-170 is a tailless "flying wing" stealthier than other current

[148] Department of the Navy, *Fiscal Year (FY) 2012 Budget Estimates, MQ-8 UAV*, February 2011.

[149] Northrop Grumman Corp. Press Release, "Northrop Grumman's Next-Generation Fire Scout UAV on Track," June 23rd, 2005.

[150] *FY2009–2034 Unmanned Systems Integrated Roadmap*, p. 66.

[151] The Army intended to field four different classes of UAVs as part of its Future Combat System (FCS): Class I for platoons, Class II for companies, Class III for battalions, and Class IV for brigades. See CRS Report RL32888, *Army Future Combat System (FCS) "Spin-Outs" and Ground Combat Vehicle (GCV): Background and Issues for Congress*, by Andrew Feickert and Nathan J. Lucas, for more information.

[152] April M. Havens, "U.S. Army wants to cancel Fire Scouts (sic) program," *The Mississippi Press*, January 15, 2010, As presented on http://www.gulflive.com.

[153] Elisabeth Bumiller, "Navy Drone Violated Washington Airspace," *The New York Times*, August 26, 2010.

[154] Graham Warwick, "U.S. Navy Goes Ahead With Bell 407-Based Fire Scout UAV," *Aerospace Daily*, September 8, 2011.

[155] Spencer Ackerman, "Navy Upgrades Its Spying, Drug-Sniffing Robot Copter," *Wired.com/Danger Room blog*, April 11, 2011.

[156] Bill Sweetman, "Beast Sighted In Korea," *Aviation Week/Ares blog*, February 16, 2010.

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US UAS. An RQ-170 was reported to have performed surveillance and data relay related to the operation against Osama bin Laden's compound on May 1, 2011. The government of Iran claimed on December 2, 2011 to be in possession of an intact RQ-170 following its incursion into Iranian airspace.

System Characteristics. Built by Lockheed Martin, the RQ-170 has a wingspan of about 65 feet and is powered by a single jet engine. It appears to have two sensor bays (or satellite dish enclosures) on the upper wing surface. Although an inherently low-observable blended wing/fuselage design like the B-2, the RQ-170's conventional inlet, exhaust, and landing gear doors suggest a design not fully optimized for stealth.[157]

Potential Mission and Payload. "The RQ-170 will directly support combatant commander needs for intelligence, surveillance and reconnaissance to locate targets."[158]

Program Status. "The RQ-170 is a low observable unmanned aircraft system (UAS) being developed, tested and fielded by the Air Force."[159] No further official status is available.

Other Current UAS Programs

RQ-5A Hunter / MQ-5B Hunter II

Originally co-developed by Israel Aircraft Industries and TRW (now owned by Northrop Grumman) for a joint U.S. Army/Navy/Marine Corps short range UAS, the Hunter system found a home as one of the Army's principal unmanned platforms. The service has deployed the RQ-5A for tactical ISR in support of numerous ground operations around the world. At one time, the Army planned to acquire 52 Hunter integrated systems of eight air vehicles apiece, but the Hunter program experienced some turbulence. The Army canceled full-rate-production of the RQ-5A in 1996, but continued to use the seven systems already produced. It acquired 18 MQ-5B Hunter IIs through low-rate-initial-production in FY2004 and FY2005. The MQ-5B's design includes longer endurance and the capability to be outfitted with anti-tank munitions. Both variants are currently operated by the 224th Military Intelligence Battalion out of Fort Stewart, GA; by the 15th Military Intelligence Battalion out of Ft. Hood, TX; and by 1st Military Intelligence Battalion out of Hohenfels, Germany.

System Characteristics. The RQ-5A can fly at altitudes up to 15,000 feet, reach speeds of 106 knots, and spend up to 12 hours in the air. Weighing 1,600 lbs, it has an operating radius of 144 nautical miles. The MQ-5B includes an elongated wingspan of 34.3 feet up from 29.2 feet of the RQ-5A and a more powerful engine, which allows the Hunter II to stay airborne for three extra hours and to reach altitudes of 18,000 feet.[160] The Hunter system consists of eight aircraft, ground control systems and support devices, and launch/recovery equipment. In FY2004, the final year of Hunter procurement, a Hunter system cost $26.5 million.

[157] U.S. Air Force, *Fact Sheet: RQ-170 Sentinel*, December 2, 2010. and CRS analysis of available RQ-170 photography.

[158] U.S. Air Force, *Fact Sheet: RQ-170 Sentinel*, December 2, 2010.

[159] Ibid.

[160] OSD, *UAS Roadmap 2005-2030*, August 2005, p. 7

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Mission and Payload. The Army has mostly used the Hunter system for short and medium range surveillance and reconnaissance. More recently, however, the Army expanded the Hunter's missions, including weaponization for tactical reconnaissance/strike operations with the GBU-44/B Viper Strike precision guided munition, which can designate targets either from the munition's laser, from another aerial platform or from a ground system. This weapon makes the Hunter the Army's first armed UAS. "Also, in 2004, the Department of Homeland Security, Customs and Border Protection Bureau, and Office of Air and Marine utilized Hunter under a trial program for border patrol duties. During this program, the Hunter flew 329 flight hours, resulting in 556 detections."[161]

Program Status. The Army halted Hunter production in 2005. As of May 2011, 45 Hunter UAVs were still in operation and periodically receiving upgrades and modifications. In August, 2005, the Army awarded General Atomics' Warrior UAS (which later became Grey Eagle) the contract for the Extended Range-Multi Purpose UAS program over the Hunter II.[162]

RQ-7 Shadow

The RQ-7 Shadow found a home when the Army, after a two decade search for a suitable system, selected AAI's close range surveillance platform for its tactical unmanned aerial vehicle (TUAV) program. Originally, the Army, in conjunction with the Navy explored several different UAVs for the TUAV program, including the now-cancelled RQ-6 Outrider system. However, in 1997 after the Navy pursued other alternatives, the Army opted for the low cost, simple design of the RQ-7 Shadow 200. Having reached full production capacity and an IOC in 2002, the Shadow has become the primary airborne ISR tool of numerous Army units around the world and is expected to remain in service through the decade.

The Administration's FY2011 budget request did not include funding for Shadow aircraft, although it did include continued RDT&E funding for Shadow.[163]

System Characteristics. Built by AAI Corporation (now owned by Textron), the Shadow is 11 feet long with a wingspan of 13 feet. It has a range of 68 nautical miles, a distance picked to match typical Army brigade operations, and average flight duration of five hours. Although the Shadow can reach a maximum altitude of 14,000 feet, its optimum level is 8,000 feet. The Shadow is catapulted from a rail-launcher, and recovered with the aid of arresting gear. The UAS also possesses automatic takeoff and landing capabilities. The upgraded version, the RQ-7B Shadow, features a 16 inch greater wingspan and larger fuel capacity allowing for an extra two hours of flight endurance.

Mission and Payload. The Shadow provides real-time reconnaissance, surveillance and target acquisition information to the Army at the brigade level. A potential mission for the Shadow is the perilous job of medical resupply. The Army is considering expanding the UAS's traditional missions to include a medical role, where several crucial items such as blood, vaccines and fluid

[161] Kari Hawkins, "Pioneer platform soars to battlefield success," *www.army.mil*, May 19, 2011.

[162] Jefferson Morris, "Army More Than Doubles Expected Order for ERMP with General Atomics Win," *Aerospace Daily & Defense Report,* August 10th, 2005.

[163] Todd Harrison, *Analysis of the FY 2011 Defense Budget* (Washington, DC: Center for Strategic & Budgetary Assessments, 2010), p. 38.

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infusion systems could be delivered to troops via parachute.[164] For surveillance purposes, the Shadow's 60-pound payload consists of an E-O/IR sensor turret which produces day or night video, and can relay data to a ground station in real-time via a line-of-sight data link. As part of the Army's Future Combat System plans, the Shadow will be outfitted with the Tactical Common Data Link currently in development to network the UAS with battalion commanders, ground units and other air vehicles.[165] The Marine Corps is considering how to arm Shadow.[166]

Program Status. The Army and Marine Corps currently maintain an inventory of 364 Shadow UAVs.[167] The program cost for a Shadow UAV system—which includes four vehicles, ground control equipment, launch and recovery devices, remote video terminals, and High Mobility Multipurpose Wheeled Vehicles for transportation-reached $11.1 million in current year dollars for FY2008.[168] The Army procured 102 systems through 2009.[169] In FY2012, the Army requested $25 million for 20 Shadow aircraft to replace combat losses, and approximately $200 million for payload upgrades.

"Small UAVs"

RQ-14 Dragon Eye

AeroVironment's Dragon Eye is a backpack-carried, battery-operated UAV employed by the Marines at the company level and below for reconnaissance, surveillance and target acquisition. Dragon Eye features a 3.8 ft. rectangular wing, twin propellers and two cameras ports each capable of supporting day-light electro-optical cameras, low-light TV cameras, and infrared cameras. The compact and lightweight design of the UAV allows an operational endurance of 45 minutes and can travel as far as two and a half nautical miles from the operator. Low-rate-initial-production of 40 aircraft began in 2001. After a 2003 operational assessment, the Marine Corps awarded AeroVironment a contract to deliver approximately 300 systems of full-rate-production Dragon Eyes.[170] However, that contract was later revised to acquire Raven UAS instead. One Dragon Eye system consists of three air vehicles and one ground station. The final Marine Corps procurement budget request in FY2006 anticipated the current unit cost per Dragon Eye system as $154,000.[171]

[164] Erin Q. Winograd, "Army Eyes Shadow UAVs Potential For Medical Resupply Missions," *InsideDefense.com*, December 20, 2002, p.14.

[165] "Upgraded Shadow UAV Rolls Off Production Line," *Defense Today*, August 5, 2004.

[166] Paul McCleary, "Marines Want a Big Bang From a Small Package," *Aviation Week/Ares blog*, October 26, 2010.

[167] OSD, *UAS Roadmap 2005-2030*, August 2005, p. 8.

[168] Department of the Army, Army Procurement OPA 02: Communications and Electronics FY2009, February 2008, TUAS (B00301), Item No. 61, p. 18 of 23.

[169] Department of the Army, *Committee Staff Procurement Backup Book, Fiscal Year 2012 Budget Estimate, Aircraft Procurement, Army, RQ-7 UAV MODS*, Washington, DC, February 2011, p. 1 of 10.

[170] Peter La Franchi, "Directory: Unmanned Air Vehicles," *Flight International*, June 21st, 2005, p. 56.

[171] Department of the Navy, FY2006-FY2007 Budget Estimate - Marine Corps Procurement, February 2005, BLI No. 474700, Item 44, p. 20 of 22.

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FQM-151 Pointer

Although procurement of this early UAS began in 1990, the electric-powered Pointer has seen service in Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF). Pointer is a short range reconnaissance and battlefield surveillance UAV developed by AeroVironment. Its flight endurance (two hours) is greater than most similar small UAVs, in part due to its relatively large, 9-foot wingspan. That wingspan decreases portability of the 8.5-pound Pointer, and as a result, transportation of a Pointer system (two air vehicles and a ground control unit) requires two personnel. Although superseded by the Raven (below), Pointer remains a valued short range ISR asset for the Air Force and Special Operations Command.

RQ-11 Raven

Engineered from the basic design of the Pointer, the Raven is two-thirds the size and weight of its predecessor, with a much smaller control station, making the system man-portable.[172] "The RQ-11A is essentially a down-sized FQM-151 *Pointer*, but thanks to improved technology can carry the same navigation system, control equipment, and payload."[173] The Raven provides Army and SOCOM personnel with "over-the-hill" reconnaissance, sniper spotting and surveillance scouting of intended convoy routes. The electric motor initiates flight once hand-launched by a running start from the ground operator. The vehicle is powered by an electric battery that needs to be recharged after 90 minutes, but deployed soldiers are equipped with four auxiliary batteries that can be easily charged using the 28 volt DC outlet in a Humvee. The vehicle lands via a controlled crash in which the camera separates from the body, which is composed of Kevlar plating for extra protection. Like the Pointer, the Raven can carry either an IR or an E-O camera and transmits real-time images to its ground operators. The relatively simple system allows soldiers to be trained in-theater in a matter of days. Raven systems can either be deployed in three aircraft or two-aircraft configurations. "Raven was adopted as the US Army's standardised short range UAV system in 2004 with a total of 2469 air vehicles (including older RQ-11A series models) in operational service by mid 2007."[174] "The US Army has an ongoing acquisition objective for about 2,200 Raven systems and has taken delivery of more than 1,300 to date."[175] A three-aircraft system costs approximately $167,000.[176]

ScanEagle

Developed by the Insitu Group (owned by Boeing) as a "launch-and-forget" UAV, the ScanEagle autonomously flies to points of interest selected by a ground operator.[177] The ScanEagle has gained notice for its long endurance capabilities and relative low cost. The gasoline-powered UAV features narrow 10 foot wings that allow the 40 lb. vehicle to reach altitudes as high as 19,000 feet, distances of more than 60 nautical miles and a flight endurance of almost 20 hours.

[172] Peter La Franchi, "Directory: Unmanned Air Vehicles," *Flight International*, June 21st, 2005, p. 57.

[173] Andreas Parsch, "AeroVironment RQ-11 Raven," *Directory of U.S. Military Rockets and Missiles*, September 12, 2006.

[174] "UAV Directory - Aircraft Specification AeroVironment - RQ-11A Raven," *FlightGlobal.com*, (2011).

[175] "UAV Directory - Aircraft Specification AeroVironment - RQ-11B Raven," *FlightGlobal.com*, (2011).

[176] The FY2012 budget request includes $70.8 million for 424 systems and supporting equipment. Department of Defense, *Department of Defense Fiscal Year 2012 Budget Estimates, Aircraft Procurement, Army*, February 2011.

[177] Jim Garamone, "ScanEagle Proves Worth in Fallujah Fight," *American Forces Press Service*, January 11th, 2005.

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Using an inertially stabilized camera turret carrying both electro-optical and infrared sensors, ScanEagle currently provides Marine Corps units in Iraq with force-protection ISR and is also used by Special Operations Command. ScanEagle operations began in 2004,[178] and continue today. Although ScanEagle was expected to cost about $100,000 per copy, the Navy and SOCOM have contracted for operations instead of procurement, with Boeing providing ISR services utilizing ScanEagle under a fee-for-service arrangement.[179]

ScanEagle is also in use by non-military organizations for surveillance purposes including tracking whale migrations.[180]

Small Tactical Unmanned Aerial System (STUAS)

In July 2010, the Department of the Navy awarded Insitu a two-year, $43.7 million contract for the design, development, integration, and test of the Small Tactical Unmanned Aircraft System (STUAS) for use by the Navy and Marine Corps to provide persistent maritime and land-based tactical reconnaissance, surveillance, and target acquisition (RSTA) data collection and dissemination. "For the USMC, STUAS will provide the Marine Expeditionary Force and subordinate commands (divisions and regiments) a dedicated ISR system capable of delivering intelligence products directly to the tactical commander in real time. For the Navy, STUAS will provide persistent RSTA support for tactical maneuver decisions and unit-level force defense/force protection for Navy ships, Marine Corps land forces, and Navy Special Warfare Units." [181]

Payloads include day/night video cameras, an infrared marker, and a laser range finder, among others. STUAS can be launched and recovered from an unimproved expeditionary/urban environment, as well as from the deck of Navy ships.[182]

STUAS uses Insitu's Integrator airframe, which uses common launch, control, and recovery equipment with ScanEagle. STUAS has a takeoff weight of up to 125 pounds with a range of 50 nautical miles. However, STUAS will be procured and operated by the services rather than operated on a fee-for-service basis because "the Scan Eagle's current fee-for-service contract limits the way the UAS is deployed ... with Boeing/Insitu employees usually operating the aircraft in the field due to liability issues." Procuring the system will allow the services to train their own operators. Initial operating capability is expected in the fourth quarter of FY2013. [183]

[178] Insitu, "Backgrounder: ScanEagle® Unmanned Aircraft System," press release, September 22, 2011, http://www.boeing.com/bds/mediakit/2011/ausa/pdf/bkgd_scaneagle.pdf.

[179] See, inter alia, Boeing, "Boeing Awarded Navy Contract for ScanEagle Services," press release, June 6, 2008, http://www.boeing.com/news/releases/2008/q2/080606a_nr.html and Insitu, "Boeing Wins $250M Special Ops Contract for ScanEagle ISR Services," press release, May 22, 2009, http://www.insitu.com/print.cfm?cid=3774.

[180] Boeing, " From saving soldiers to saving whales," undated press release, http://www.boeing.com.au/ViewContent.do?id=61784&aContent=ScanEagle.

[181] Naval Air Systems Command, *Aircraft and Weapons: Small Tactical Unmanned Aircraft System*, http://www.navair.navy.mil/index.cfm?fuseaction=home.display&key=4043B5FA-7056-4A3A-B038-C60B21641288.

[182] Ibid.

[183] Gayle Putrich, "Insitu wins long-awaited US Navy STUAS deal," *FlightGlobal.com*, July 30, 2010.

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Future UAS

Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS)

In the mid 1990s, the Pentagon began developing a UAS designed primarily for combat missions. The result was two separate Unmanned Aerial Combat Vehicles (UCAV) programs, the Air Force's UCAV and the Navy's UCAV-N demonstrator program. The Air Force favored Boeing's X-45 for its program, while Northrop Grumman's X-47 Pegasus and Boeing's X-46 competed for the Navy's project. However, in June 2003, the Pentagon merged the two programs in order to establish the Joint Unmanned Combat Air System (J-UCAS) project under the management of the Defense Advanced Research Projects Agency (DARPA). The objective of the J-UCAS merger was to create a flexible offensive network in which the air and ground elements are adapted to meet specific combat mission.[184] As part of Program Budget Decision (PBD) 753 in December 2004, DARPA was ordered to transfer administration of the J-UCAS resources to Air Force.[185] J-UCAS was cancelled in 2006. The total money spent on the J-UCAS/UCAV program, which reached more than $1.45 billion in RDT&E funding, made it one of the most expensive UAS ventures undertaken by DOD.

Subsequently, in May, 2010, the Navy issued a Request for Information for a carrier-borne UCAV called UCLASS,

> seeking ideas on a stealthy strike/surveillance platform that could operate alongside manned aircraft as part of a carrier air wing by the end of 2018. The notional system would comprise four to six aircraft capable of autonomous operation from Nimitz- and Ford-class carriers, with an unrefueled endurance of 11-14 hours and the capability for both hose-and-drogue and boom-and-probe aerial refueling. [186]

Another significant attribute of UCLASS is that—unlike most current UAS that are designed to operate only in permissive or lightly defended environments—UCLASS "must be capable of operating in hostile airspace, which means the aircraft design must feature low-observable traits."[187] Navy Secretary Ray Mabus said that "The notion here is that—just like the F-35 carrier version—it is going to be stealthy. It is going to be low observable," he says. "And, if you are going to integrate an airplane into the carrier air wing, it should be able to go into contested airspace."[188]

The Navy has awarded UCLASS concept study contracts to Boeing, General Atomics Aeronautical Systems, Lockheed Martin, and Northrop Grumman.[189] The UCLASS request for proposal is expected in fall 2011.[190]

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[184] OSD, *UAS Roadmap 2005-2030*, August 2005, p. 11.

[185] OSD, *Program Budget Decision 753,* December 23, 2004, p. 9.

[186] Graham Warwick, "Predator C Flexes its Sea Legs," *Aviation Week/Ares blog*, May 3, 2010.

[187] Amy Butler, "Mabus: Uclass Must Operate In Contested Airspace," *Aerospace Daily*, April 6, 2011.

[188] Ibid.

[189] Carlo Munoz, "Navy Awards Multiple Contracts For UCLASS Development," *Defense Daily*, June 27, 2011.

[190] Amy Butler, "Mabus: Uclass Must Operate In Contested Airspace," *Aerospace Daily*, April 6, 2011.

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Likely UCLASS contenders include the following:

X-47B

Northrop Grumman's X-47B, an advanced version of the X-47A UCAV-N contender, is nearly 36 feet long, with a wingspan of 62 feet. The increased wingspan in combination with the Pratt & Whitney F100-220U turbojet engine may allow X-47B an endurance of nine hours and range of 1,600 nautical miles. The X-47B features folding wing-tips that cut down on size, making it more suitable for storage aboard an aircraft carrier.[191]

Phantom Ray

System Characteristics. 36 feet long with a wingspan of 50 feet; single GE F404-102D engine. The X-45C was expected to achieve speeds of 450 knots and altitudes of 40,000 feet, with a flight duration of up to seven hours and a range of 1,200 nautical miles.

Program Status. First flown on May 27, 2011, Phantom Ray is a development of Boeing's X-45C J-UCAS contender. Although it is a company-funded one-off demonstrator, it is expected to contend for the Navy's UCLASS program.

Avenger/Sea Avenger

General Atomics is currently developing a third generation Predator that uses a turbojet engine to fly long endurance, high altitude surveillance missions. The Avenger (formerly "Predator C") will reportedly use the fuselage of the Reaper, but will be similar to Northrop Grumman's Global Hawk in payload capacity and flight performance. General Atomics confirmed its offer of the "Sea Avenger" variant for the UCLASS competition in 2010.[192]

> With a 41-foot long fuselage and 66-foot wingspan, the Avenger is capable of staying in the air for up to 20 hours, and operating at up to 50,000 feet. Powered by a 4,800-lb. thrust Pratt & Whitney PW545B jet engine, it can fly at over 400 knots—50 percent faster than the turboprop-powered Reaper unmanned plane, and more than three times as quick as the Predator.
>
> General Atomics says the first Avenger is now flying two to three times a week.... A second and third Avenger are now in production. It'll be a little longer than the first—44 feet—and able to haul a 6,000 pound payload. That's a 50 percent improvement over what the Reaper can carry.[193]

Lockheed is also reported to be interested in entering an RQ-170 variant in the UCLASS competition.[194]

[191] "UCAVs and Future Military Aeronautics." *Military Technology*, June 2005, p. 100.

[192] Graham Warwick, "Predator C Flexes its Sea Legs," *Aviation Week/Ares blog*, May 3, 2010.

[193] Noah Shachtman, "Killer Drones Get Stealthy," *Wired.com/Danger Room blog*, July 19, 2010.

[194] Amy Butler, "Mabus: Uclass Must Operate In Contested Airspace," *Aerospace Daily*, April 6, 2011.

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High Altitude Long Endurance Systems

Tactical UAS, ranging from Raven to Reaper, have become familiar, and the prototypes of combat UAS like UCLASS are already in the air. But a new class of UAS is under development that would move beyond the endurance and range of Global Hawk to provide much more persistent platforms for ISR, data relay, and other purposes. Among these HALE, for high altitude long endurance systems, are:

Phantom Eye

Proposed by the Boeing Phantom Works, Phantom Eye would use hydrogen-fueled automobile engines to carry a 3,000-pound payload for ten days.[195] A 150-foot wingspan demonstrator version hopes to achieve "up to four days of endurance at 65,000 ft." with a first flight in autumn 2011.[196]

Orion

In 2009, Aurora Flight Sciences unveiled the Orion, which would use hydrogen-fueled diesel engines to carry a 2,600-pound payload at 30,000 feet, or a 1,000-pound payload for ten days at 15,000-20,000 feet.[197] [198] Its demonstrator version is designed to reach five-day endurance with the same payload.[199] Orion is part of a system called MAGIC, an acronym for Medium-Altitude Global ISR and Communications, being developed by under a $4.7-million contract from the Air Force Research Laboratory.[200]

Global Observer

A third hydrogen-powered HALE contender, AeroVironment's Global Observer "can fly as high as 65,000 feet for five to seven days while carrying a 400-pound payload."[201] It is optimized for "persistent communications and remote sensing."[202] Global Observer flew for the first time in 2010, but the first test aircraft crashed in April, 2011.

Airships

Several firms (Lockheed Martin, MAV6, Northrop Grumman, and others) are developing unmanned airships for long- to extremely-long endurance missions. "In comparison with unmanned fixed-wing aircraft, such as the Global Hawk or Reaper, an airship ... would have a

[195] "U-2 Option," *Defense Daily*, April 25, 2011.

[196] Graham Warwick, "Phantom Eye UAV Readied For Hydrogen Flights," *Aerospace Daily*, September 26, 2011.

[197] Marcus Weisgerber, "USAF Seeks Endurance-Payload Sweet Spot," August 29, 2011.

[198] Graham Warwick, "Orion UAS To Demo 120-hr. Endurance," *AviationWeek.com*, September 20, 2010.

[199] Graham Warwick, "Aurora Unveils Orion Persistent UAV," *Aerospace Daily*, September 16, 2009.

[200] Richard Whittle, "Gorgon Stare Broadens UAV Surveillance," *Defense Technology International*, November 3, 2010.

[201] Marcus Weisgerber, "USAF Seeks Endurance-Payload Sweet Spot," August 29, 2011.

[202] AeroVironment, "Stratospheric Persistent UAS: Global Observer," undated press release, http://www.avinc.com/uas/stratospheric/global_observer/.

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similar payload and substantially longer endurance but considerably slower cruise speed."[203] The Army's High Altitude Airship program "has the long-term objective of building an airship capable of carrying a 2,000-pound payload and generating 15 kilowatts of power (to run the payload and aircraft systems) at 65,000 feet for more than 30 days."[204]

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The author is indebted to his predecessor, the late Christopher Bolkcom, and to Harlan Geer for some portions of this work.

[203] Congressional Budget Office, *Recent Development Efforts for Military Airships*, Pub. No. 4239, Washington, DC, November 2011.

[204] Ibid. For more information on lighter-than-air platforms, see CRS Report RS21886, *Potential Military Use of Airships and Aerostats*, by Christopher Bolkcom.

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Army PM UAS Spectrum Update

David Milburn
Sigmatech Contractor
Spectrum Manager
Unmanned Aircraft Systems
Project Office

PACOM 2012

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Army Unmanned Aircraft Systems

Corps Level

Corps Level reconnaissance, surveillance, target acquisition, and battle damage assessment

Division Level

Provide dedicated mission configured, UAV support to the Combat Aviation Brigade, Division Fires and Battlefield Surveillance Brigades, Brigade Combat Teams (BCTs), and other Army and Joint Force units based upon Division Commander's priorities

Brigade Level

Provide Army Brigade Commanders with tactical level reconnaissance, surveillance, target acquisition, and battle damage assessment

Battalion Level

Provides the small unit the organic capability to perform Beyond Visual Line-Of-Sight (BLOS) Reconnaissance, Surveillance, and Target Acquisition (RSTA)

FOCUS OF ARMY UAS:

- ~~Strategic~~
- Operational
- Tactical

Hunter
MQ-5B



Gray Eagle
MQ-1C



Shadow
RQ-7B



Raven RQ-11B

Puma RQ-20A



Universal Ground Control Station

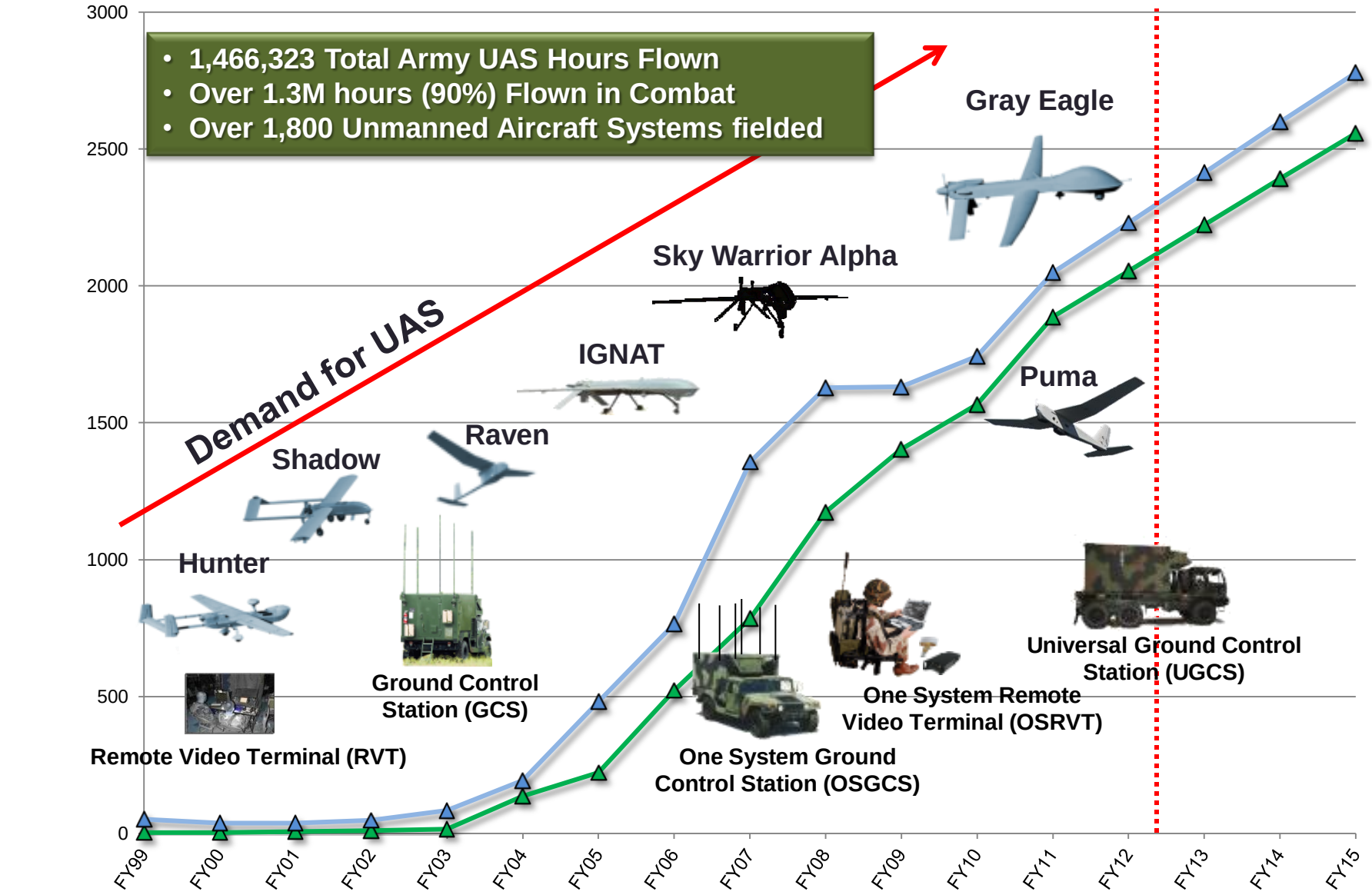


One System Remote Video Terminal



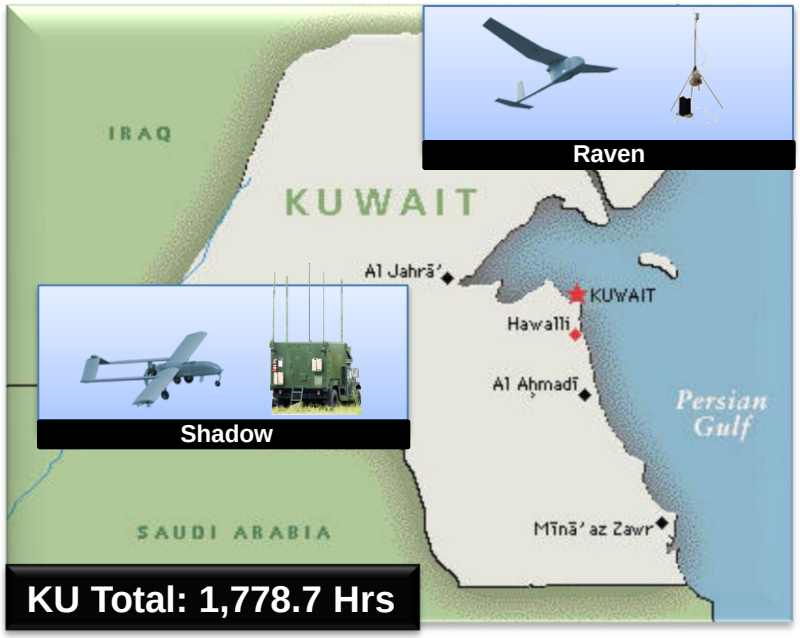
Army UAS Demand

- 1,466,323 Total Army UAS Hours Flown
- Over 1.3M hours (90%) Flown in Combat
- Over 1,800 Unmanned Aircraft Systems fielded

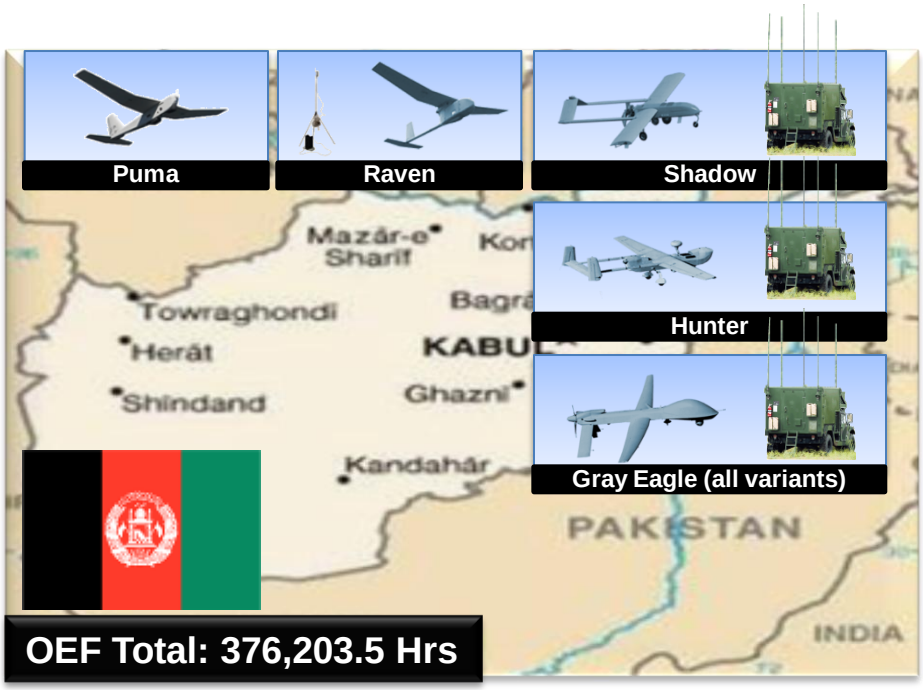


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Supporting the Soldier Current Systems



KU Total: 1,778.7 Hrs



OEF Total: 376,203.5 Hrs

Total UAS OIF/OND Hours (EOM 15 Dec 2012)
991,966.7

Field Support Representatives in Country

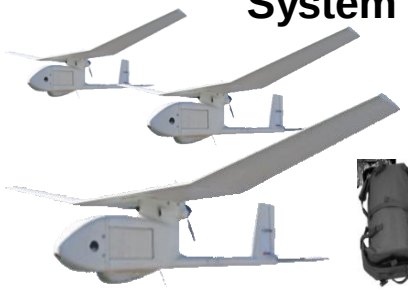
Total Hours Flown : 1,526,064.6 Hrs

OND/KU/OEF Hours Flown: 1,368,909.3 Hrs

90% Combat Hours Flown

System Overview: RQ-11B Raven

System Configuration


Aircraft (3 each)


Aircraft Transport


Hand Controller




GCS & RVT with Battery and Case


EO Sensors


EO/IR/LI Gimbaled Payloads


RSTA Kit


Field Repair Kit

Characteristics/Description

Wing Span	4.6 ft
Air Vehicle Weight	4.4 lbs
Range	10+ km
Airspeed	27-60 mph
Altitude	>300 AGL
Endurance	90 min Lithium
Data Link	Digital Data Link; AES-128 encryption
Payload	Current fixed sensors: • Electro-optical day camera (side and front: 2592x1944 pixels); 3X Zoom; 5 Megapixel • IR (320x240) with Laser Illuminator (25 ft IR spot marking capability) Combined EO/IR/LI gimbaled sensors: • Electro-optical day camera (5MP-2592x1944 pixels); IR (640 x 480); Laser Illuminator
GCS	- 14 lbs (with RSTA laptop)

Purpose

Provides the small unit with an increased situational awareness and force protection by providing expanded reconnaissance and surveillance coverage of maneuver areas.

Characteristics

- Rapidly deployed/hand-launched
- SAASM GPS
- Semi-autonomous operations and tele-operations
- In-flight re-tasking
- Commanded auto-loiter at sensor point of interest
- Executes lost link recovery procedures
- Flight termination to pre-planned point
- Decentralized planning and execution
- Common mission planning (AMPS/Falcon View)

Status

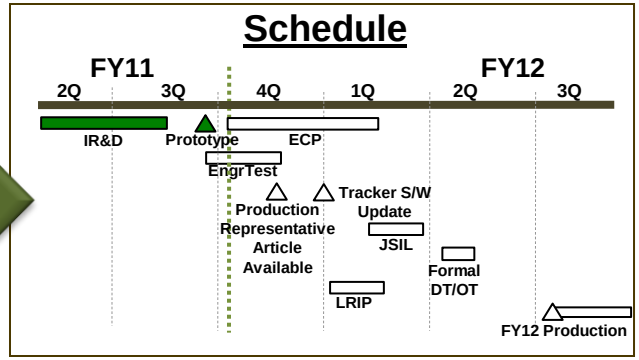
- RQ-11B; ACAT III POR – MDA is MG Crosby
- Production buyout of 2358 systems (FY15)
- Raven Surge on schedule
- Gimbaled Payload production begins 3QFY12
- All DDL retrofit kits procured
- Working CPD actions with TCM

RAVEN Gimbaled Payload

- Response to user requests
- Fits standard DDL Raven with S/W upgrade
- Full gimbal; stow on landing; ruggedized for nose impact
- Sized to accommodate other camera options such as SWIR
- Combined EO/IR/LI Sensors
  - 5MP EO (Same as Puma)
  - 640 x 480 IR (Same as Puma)
  - Laser Illuminator (Same as Raven)
- 3Q FY11 prototyping
- 3Q FY12 production



- Prototypes undergoing flight and qualification testing
- Low rate production planned Fall 2011
- Priority to OEF units





Latest Technology into the Fight

System Overview: RQ-20A Puma AECV



InfiniSpin Payload (3 each)



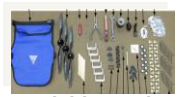


AECV Aircraft (3 each)





GCS & RVT with Battery and Case
(Same as Raven)



Field Repair Kit



RSTA Kit

Additionally:
- Cables
- Batteries
- Chargers

Characteristics/Description

Wing Span	9.16 ft
Air Vehicle Weight	12.9 lbs (with payload)
Range	10KM (Omni); 20KM (Patch Antenna)
Airspeed	23-41 mph
Altitude	>500 AGL
Endurance	120 minutes
Data Link	Digital Data Link; AES-128 encryption
Payload	- InfiniSpin (Dual mounted/fully gimbaled) - Electro-optical day camera (side and front: 2592x1944 pixels); 3X Zoom; 5 Megapixel - IR (640 x 480) with Laser Illuminator (25 ft IR spot marking capability)
GCS	- 14 lbs (with RSTA laptop)

Purpose

Provides the small unit with an increased situational awareness and force protection by providing expanded reconnaissance and surveillance coverage of maneuver areas.

Characteristics

- Rapidly deployed/hand-launched
- SAASM GPS
- Combined EO/IR/LI fully gimbaled payload
- Target tracking
- Follow-me mode for mobile operations
- In-flight re-tasking
- Executes lost link recovery procedures
- Flight termination to pre-planned point
- Common mission planning (AMPS/Falcon View)

Status

- Non-POR
- Procured under 2 JUONS—288 total systems (includes systems inherited from REF)
- Uses same controller as Raven
- All systems for theater use and training

Spectrum

J/F-12 09670 (check HNSWDO)

- **M1- 1625-1725 MHz DDVL 4M68G7W or 1M56G7W**
- **M2- 1755-1850 MHz DDVL 30 FPS or 15 FPS**

J/F-12 07160

- **216-216.1 MHz Falcon Tracking/Recovery system 10K0P0N**

J/F-12-TBD

- **1090 MHz TICK—No interrogation-periodic transmit**

Spectrum Reallocation

Losing the Lower 25 MHz of the band

- **RAVEN—PUMA– WASP--ACTS**
  - **Can we find a way to compress operations in 5 years, prior to relocating to 2025-2110 MHz in 10 years?**
  - **If asked to vacate the lower 25 MHz indefinitely:**
    - **Can operations be compressed into the upper 70 MHz?**
- **Other 1755 – 1850 MHz Band systems**
  - **Can the other system operations be compressed?**
  - **What combinations of compressed operations can coexist in the upper 70 MHz indefinitely?**
  - **What combinations of compression and relocation are necessary to vacate the lower 25 MHz?**

Spectrum Reallocation Issues

Primary concerns: Deconfliction

Small Unmanned Aircraft Systems vs. Air Combat Telemetry Systems

SUAS- 2 Watts	**vs.**	**ACTS 100 Watts**
SUAS- 25 km normal radius	**vs.**	**ACTS 200 km normal radius**

Primary Concerns: Operational

Small Unmanned Aircraft Systems- normally 10 channels for close use

IF we lose the lower 25 MHz:

1) **loss of 3 usable channels**
2) **loss of more channels due to other systems who have to share spectrum, ie; National Training Center's GSM system**
3) **Operational Impact: UNKNOWN- Mission Dependant**

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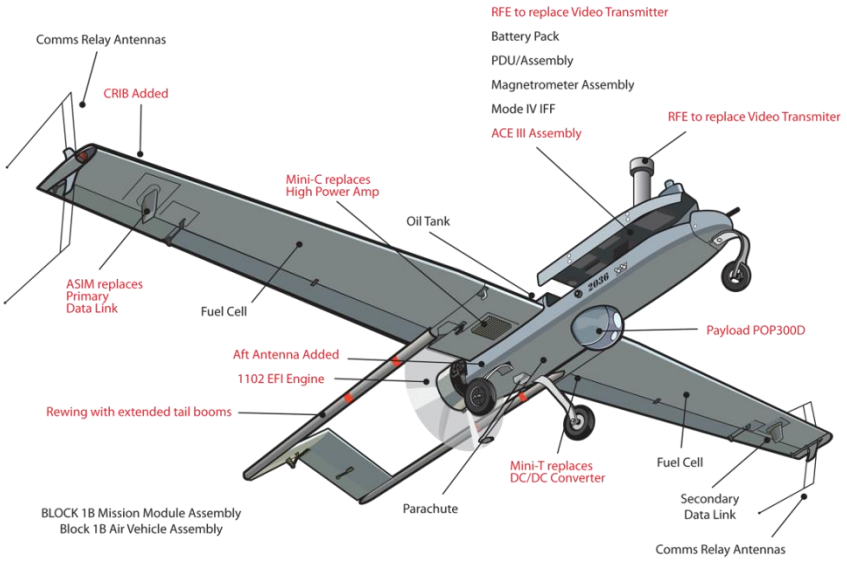
Spectrum Reallocation: When?

- **<u>Spectrum Re-allocation for M1755-M1850 Status</u>**

  Commerce Department officials said they wouldn't make a formal recommendation to the FCC about auctioning the airwaves to wireless carriers until government and industry users reach some sort of agreement on how to share the airwaves.

  (as of 3/30/2012)

System Overview: RQ-7B Shadow®



Capabilities

- System consists of **four Air Vehicles, two Ground Control Stations, one rail launcher, and 8 HMMWVs**
- **9 hour endurance**
- EO/IR Laser Designator Payload (**Full Motion Video**)
- Capable of launch and land in remote locations ("soccer field")
- SINCGARS Communications Relay
- 38 HP, 38 pound engine
- 18,000 ft MSL ceiling (supports operations in **Afghanistan** Mountains)
- Type 1 **Encryption** - Tactical Common Data Link

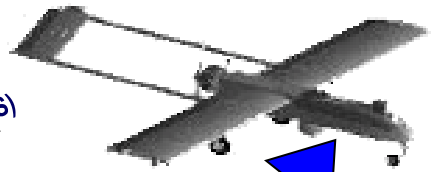
Quantity/Cost

- **Manufacturer: AAI Corporation,** Hunt Valley, MD
- **ACAT II** Program that is now conducting sustainment/upgrades
- **APO: 102** (All systems have been procured; currently fielding system 98)
- **AAO: 115;** There is one Shadow Platoon per BCT, and one in 8 Special Forces Groups; BfSBs and Fires Brigades are not resourced

Current Distribution of Systems (102)

Organization	Systems
Army BCTs	74 (46, 28)
SFGs	8 (6, 2)
GOCO	5 (1 Tng)
Training/Other	9 (+2 NGB Trng)
TCDL, FS CAB, TAFT, Aust	2, 2, 1, 1
Marine Corps, FMS	13, 2

C Band



FM Video G4.4 – G4.95 (CONUS) and G5.25 – G5.85 (OCONUS)

Primary C^2 M2400 – M2485

Secondary C^2 M340 – M380

TALS Transponder

35 GHz

34.93 GHz

FM Video G4.4 – G4.95 (CONUS) and G5.25 – G5.85 (OCONUS)

Primary C2 M2400 – M2485

Secondary C^2 M340 – M400

To GCS

Ground Data Terminal (GDT)

2 GDT per TUAV System

TALS Interrogator

Track System

Only 1 station (GDT or PGDT) can be in active control of a single TUAV at any time. Any other ground terminal may monitor any TUAV in LOS at any time.

OR

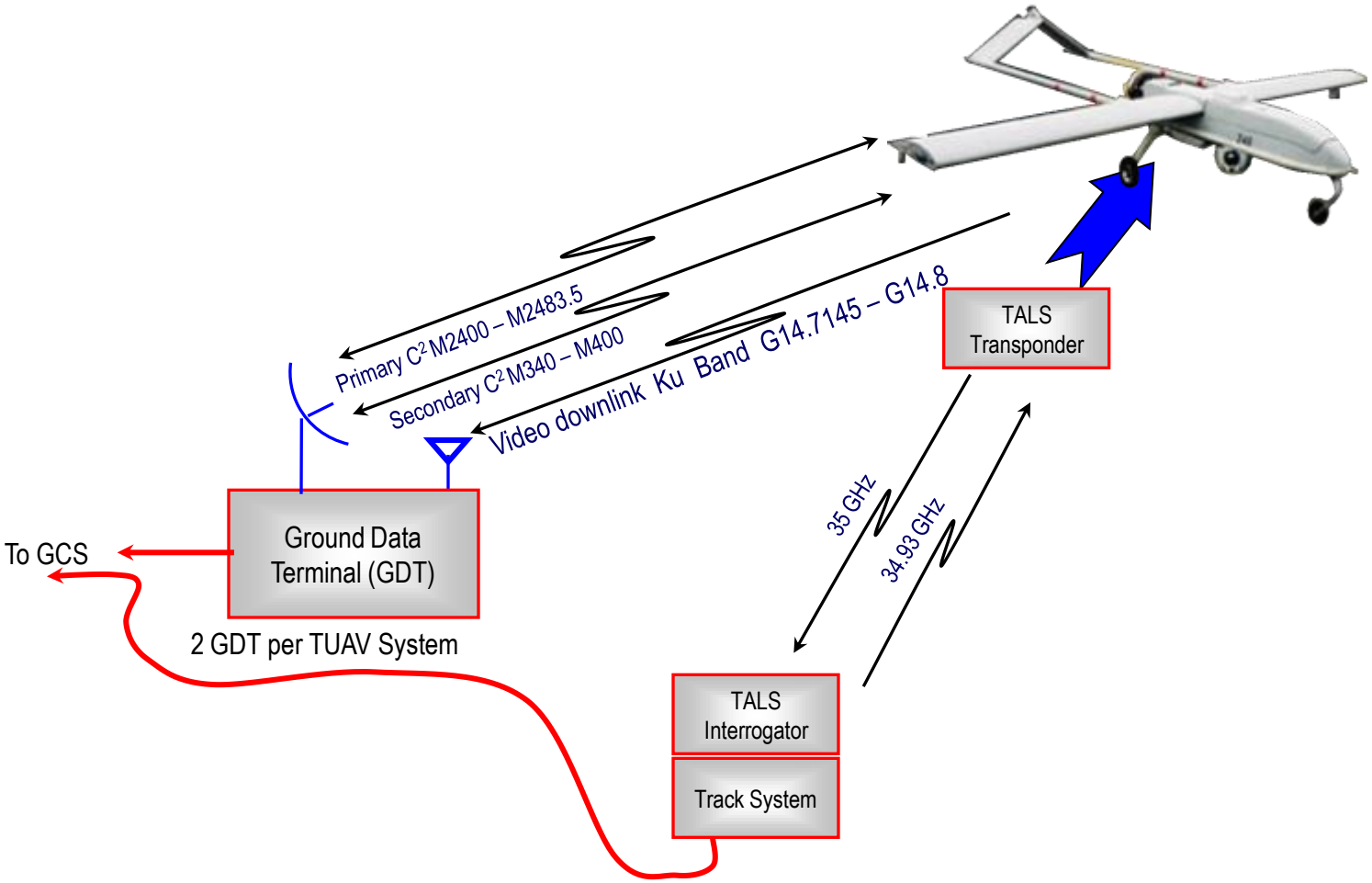
To PGCS

Portable Ground Data Terminal (PGDT)

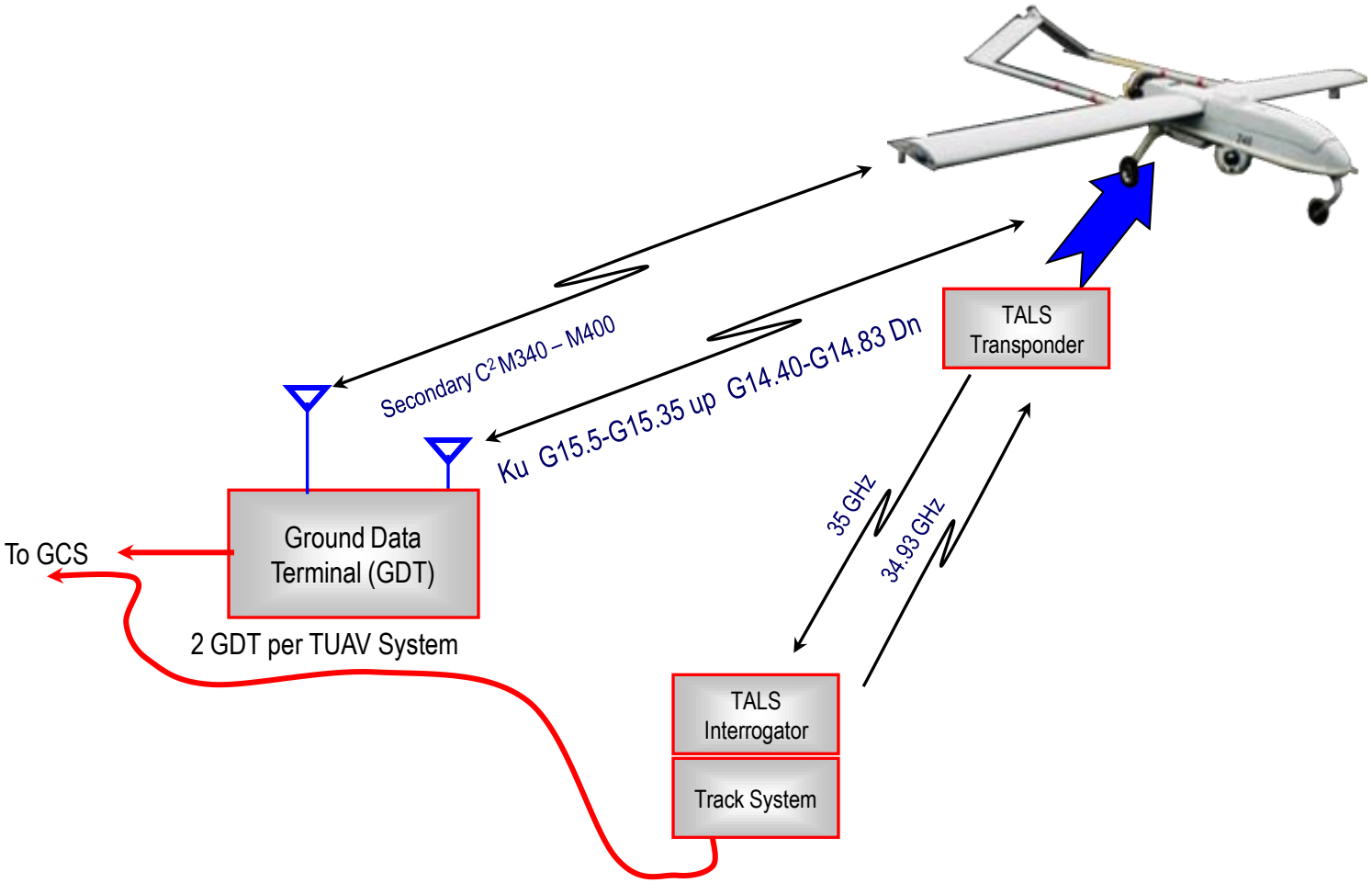
1 PGDT per TUAV System

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Tactical Interim Encryption System



Tactical Common Data Link



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Differences of Legacy & TCDL

Legacy (or pre-TCDL) Shadow

- Redundant C2 links, 52 bytes @16 Hz
  - Primary link = 2.40 to 2.48 GHz
  - Secondary Link = 340 to 400 MHz
- Video, ~ Analog RS-170
  - CONUS = 4.90 to 4.95 GHz
  - OCONUS = 5.25 to 5.85 GHz

TCDL

- Combines primary C2 & payload into one link
- Ku Band
  - 10.7 Mbps waveform (10.5 down, .2 up)
  - BE CDL (4.0 Mbps, 4.0 down, .5 up)
  - 2.0 Mbps (2.0 down, .2 up)
- Keeps UHF secondary link

System Overview: MQ-5B Hunter

Mission

Unmanned Aircraft System providing 24/7 SIGINT, Intelligence, Surveillance and Reconnaissance to the three Aerial Exploitation Battalions (AEB). Command and Control Via OSGCS and C-Band or TCDL.



History/Present

- **Only UAS fielded at the AEBs (CORPS level).**
- **Peacetime Operations Based OMA**
  - **4 systems fielded (1st MI, 224th, A15th MI, UASTB)**
  - **MTOE of 5 aircraft, Soldiers and 5 embedded CLS**
  - **Interoperability**
  - **Peacetime sustainment to include Depot, supply support, storage, engineering, spares, CLS, CM, Product Assurance and Program Management**
- **Valid Requirement – Directed Requirement**
- **Current direction is to keep Hunter operational until 2022**

Characteristics/Description

Wing Span	34.25 Ft
Max GTOW	1950 Lbs
Range	200Km LOS
Airspeed	62kts cruise/ 110 kts dash
Altitude	18,000 Ft DA
Operational Endurance	20 Hours payload dependent
Weapon	Equipped with Hardpoints
Launch/Recovery	Unapproved runway 1600 ft
Propulsion	HFE

Fleet Status

- **14 supporting OEF**
- **3 Schoolhouse (Ft. Huachuca) UASTB**
- **6 Supporting Capability Base Rotation**
- **2 Supporting engineering and safety of flight testing**
- **8 In Reset and in various stages of repair/acceptance**
- **12 TCDL aircraft in various stages of acceptance/ production**
- **Utilizes the OSGCS and transitioning to UGCS**
- **C-Band and TCDL Datalink**

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HUNTER Frequencies

- **<u>Legacy C band. J/F-12 06601</u>**

  14 preset Primary/6 Backup selectable frequency sets- 1 uplink+1backup+1 OSRVT(downlink only)

- **Tactical Common Data Link(TCDL) Ku Band.**

  1 Primary Link

  1 Backup Link

  1 Link-One System Remote Video Terminals(OSRVT)

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System Overview: MQ-1C Gray Eagle

Mission: Provides the Division Commander a responsive, agile, and flexible capability to perform RSTA, Communications Relay, Manned-Unmanned Teaming and Target Attack Capability



Characteristics/Description

Wing Span	56 Ft 3 in
Max GTOW	3,600 lbs
Range with Relay/SATCOM	>500/1200 km
Max Airspeed	150 kts
Altitude	>25,000 Ft
Endurance	Up to 24 hours
Weapon	Up to 4 HELLFIRE Missiles
Runway (Improved Surface)	4,500 ft max length required

Mission Requirements

- Deployed and integrated with the Combat Aviation Brigade (CAB)
- Immediately responsive RSTA to the Division Commander
- Two simultaneous payloads (EO/IR, Laser Designator, SAR, Communications Relay) and weapons
- "Always on" Medium Communications Relay (SINCGARS, ELPRS)
- Tactical Common Data Link (TCDL) & SATCOM Communications
- Heavy Fuel Engine

Company Set of Equipment

- 12 Multi-Purpose Aircraft (6 w/SATCOM)
- 6 Ground Control Stations
- 3 Portable Ground Control Stations
- 6 Tactical Common Data Link (TCDL) Ground Data Terminals
- 2 TCDL Portable Ground Data Terminals
- 3 Ground SATCOM system
- 6 Automatic Takeoff and Landing Systems
- Payloads
  - Electro Optic/Infrared (EO/IR)
  - Synthetic Aperture Radar's (SAR) / Ground Moving Target Indicator (GMTI)
  - SIGINT
  - WIN-T Communications Payload (WCP)
- Ground Support Equipment

Gray Eagle System Characteristics

Company Equip Set

(3 Balanced Platoons)



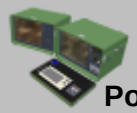
12 Unmanned Aircraft



6 Control Stations



9 TCDL GDT



3 Portable GCS



3 SATCOM GDT



6 TALS

Transition plan to Ka SATCOM

Datalinks SATCOM & TCDL

- Ku Band SATCOM with migration to Ka Band NLT FY13
- Increased LOS datalink range over legacy C-band
- Increased bandwidth: TCDL 274 mbs/SATCOM 50 mbs



30" SATCOM





TCDL Antennas

Transition plan to JTRS

Standard Equipment Package

Comms Relay Package-Medium

- Single Channel Comms Relay
- Secure Digital Communications



SINCGARS (x2)



APX-118 IFF



ARC-231

Additional Capabilities

- Airframe
  - 3,600 lb GTOW with 2.0l engine
  - Designed for take-off and landing distance of 4,500 feet
- Near all weather capability
  - Wing De-icing capability allows flight through light icing conditions
  - 20 knot crosswind landing capability
- Redundant Avionics
  - Redundant flight controls
  - Triple-Redundant flight processors
  - Redundant I/O & Power Bus
- Dual Automatic Take-off & Landing (ATLS)
  - Differential GPS
  - Back-up TALS (same as Shadow UAS system)
- Multiple hard points for weapons and external stores
  - (4 x on wings, 1 x center lower fuselage)
- Multiple Payload Bays
  - (2 x Forward Bays, 1 x Aft Bay)

Transition plan for WIN-T & SIGINT

Payloads



EO/IR/LD



SAR/GMTI

SIGINT

HD/TLA

WIN-T/JTRS



HELLFIRE Missiles

- Up to 4 HELLFIRE Missiles
- Current: HELLFIRE II UAS Variant Missiles
- Future: Transition to AGM-114R & JAGM

Heavy Fuel Engine



- Diesel JP-8
- Reduced logistics due to common fuel
- 2.0 l Engine Provides:
  - Increased climb rates
  - Faster dash speeds
  - Increased fuel efficiency

The System is much more than just an Aircraft

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Gray Eagle RF Spectrum Requirements

System Component	Frequencies Used	Manufacturer	Quantity	Location	J/F-12 Number
H-764 Embedded GPS/INS (EGI)	S-Band 1575.42 MHz (L1) 1227.60 MHz (L2)	Honeywell / Trimble	1	Aircraft	J/F-12 7666
GS511 INS/GPS	S-Band 1575.42 MHz (L1) 1227.60 MHz (L2)	Athena	2	Aircraft	No DD 1494
AN/ARC-231 RT-1808 VHF/UHF Radio	VHF / UHF 30 MHz min 512 MHz max	Raytheon	1	Aircraft	J/F-12 7987
AN/APX-118(V) or 123 IFF Transponder	RX 920 to 1266MHz TX 1090 +- 0.1MHz	BAE Systems	1	Aircraft	J/F-12 07902/2 J/F-12 09691/2
TALS AS - Aircraft System	RX 34.78 to 35.08GHz TX 34.85 to 35.15GHz	Sierra Nevada Corporation (SNC)	1	Aircraft (Wing)	J/F-12 06982
TALS TS - Ground Unit	RX 34.85 to 35.15GHz TX 34.78 to 35.08GHz	Sierra Nevada Corporation (SNC)	2	Runway	J/F-12 06982

Gray Eagle RF Spectrum Requirements

System Component	Frequencies Used	Manufacturer	Quantity	Location	J/F-12 Number
LOS Modem Assembly (MA) Data Link	14.40 to 14.83GHz 15.15 to 15.35GHz	L-3 Comm	2 2	Aircraft GDT	J/F-12 09711
SATCOM Modem Assembly (SMA) Data Link	RX 10.95 to 12.75GHz TX 13.75 to 14.5GHz	L-3 Comm	2 2	Aircraft GDT	J/F-12 9711
ME- 406 Emergency Locator Transponder	121.5 MHz Guard Freq 406.028 MHz Guard Freq	Artex	1	Aircraft	J/F-12 07477
Remote Link Module (RLM) With SecNet 11	S Band 2400-24835 MHz	Harris	3	The RLM links TALS and METS data with the GCS	J/F 12/7603

Gray Eagle RF Spectrum Requirements

System Component	Frequencies Used	Manufacturer	Quantity	Location	J/F-12 Number
Electro-Optical / Infra-red / Laser Range Finder / Laser Designator (EO/IR/LRF/LD)	3um to 5um LRF 1.063um to 1.065um LD	Raytheon	1	Aircraft (Payload)	No J/F Required
LYNXII Synthetic Aperture Radar / Ground Moving Target Indicator (SAR / GMTI) or STARLite	4-inch Resolution: 15.2 to 18.2 GHz 6-inch resolution: 15.4 to 17.3 GHz	General Atomics Photonics	1	Aircraft (Payload)	J/F-12 7993 J/F-12 9722
War-fighter Information Network – Tactical (WIN-T) Communications Payload (WCP)	TBD	General Dynamics			TBD
AN/ARC-201D SINCGARS Radio	VHF 30 MHz min 88 MHz max	ITT Corporation	2	Aircraft	J/F-12 04967/6

Gray Eagle RF Spectrum Requirements

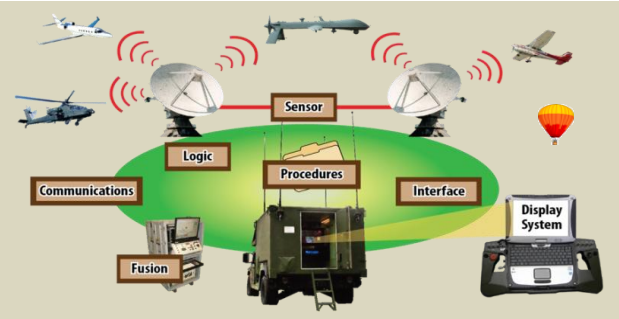
System Component	Frequencies Used	Manufacturer	Quantity	Location	J/F-12 Number
AN/VRC-103 Receiver Transmitter RT-1796 (P) PRC-117F (C) (CCI)	VHF / UHF 30 MHz min 512 MHz max	Harris	2	OSGCS	J/F-12 07852
MIDS LVD(2) Link 16 Terminal	960 to 1215 MHz	ViaSat	1	OSGCS	J/F-12 4413/4
Blue Force Tracker (BFT) Satellite Transceiver	RX 1525 to 1559 MHz TX 1626.5 to 1660.5 MHz	Comtech Mobile DataCom	1	OSGCS	J/F12 7778
AN/PRC-148(V)1 Handheld	UHF / VHF 30 MHz min 512 Mhz max	THALES	2	OSGCS	J/F-12 07365/4
AN/PRC-152(V)1 Handheld	UHF / VHF 30 MHz min 512 Mhz max	Harris	2	UGCS	J/F-12/09317

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Ground Based Sense and Avoid System Description

Mission

Ground Based Sense and Avoid (GBSAA) will provide Unmanned Aircraft Systems (UAS) with the capability to "see and avoid" other aircraft in the National Airspace System. GBSAA eliminates the need for visual observers and provides the ability to test and train at night.



History/Present

- First historic night flights in the NAS with a Sense and Avoid system occurred the week of 27 April 2011 at El Mirage, CA (ELMO) with Army GBSAA/Gray Eagle.
- Army has transitioned test activities from ELMO to Dugway Proving Ground to facilitate accelerated fielding schedules
  - Testing in restricted airspace (no FAA oversight necessary).
  - Testbed currently operates with existing radar systems (Range/ATC) with plans to install two 3D radar in Spring 2012
- As OSD Task Force GBSAA Lead, working with the tri-services to develop Common GBSAA requirements that support cost leveraging and mission needs for all

GBSAA System Description

Key Building Blocks

- Commonality
- Interoperability
- Expandability
- Safety/ System Confidence
- Early Capability (Now)
- Baseline System (prototypes)

- GBSAA provides the necessary intelligence to the UAS to mitigate or provide an alternate means of compliance to the FAA "see and avoid" regulations (FAR Part 91.113)
- GBSAA system includes all available sensor data, correlation, fusion, communications, networks, logic, procedures and user interfaces

Path Forward

- Army continues to serve as GBSAA lead developer , as designated by the OSD UAS Task Force, with the following goals:
  - Interoperability across services and platforms
  - Expeditious NAS access with easy capability growth
- GBSAA has received POM funding in FY 13-15 to support fielding to five Gray Eagle sites.
- Interoperability and Technology demos utilizing the DPG testbed currently planned for Summer 2012
  - Live/Virtual/Distributed tests demonstrating interoperability of system components to support Common GBSAA requirements development among the tri-services

GBSAA Frequency Usage

- **Radar is AN/TPQ-50(modified) but still fits into same 1494 specifications**
- **J/F-12 09652 1215-1390 MHz**

  4M80Q3N & 2M77Q3N PEP: 2560 W
- **Assignments at Dugway Proving Grounds- 2 Systems**
- **Working site locations and frequencies for all Gray Eagle fielding sites. Fort Hood, Stewart, Bragg, Campbell, & Riley**
- **Possible conflicts: fielding of AN/TPQ-50 to tactical units on same installation.**

Issues

- **IFF- Aims Certification Testing-seems to be constant changes in procedure to obtain assignment**
- **Last Minute requirements from Higher Headquarters**
- **Requestors not realizing lead times for assignment**
- **Contingency discussions overseas lead to “need now” reactions by leadership**
- **Obtaining “official” DD-1494 approval for devices**
- **Quantities of systems to operate simultaneously**
- **More than one PM working on same platform at the same location(ie: A-160)- confusing when AFMO gets multiple requests**

Unmanned Aircraft Systems Project Office
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QUESTIONS

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The U.S. Department of Defense (DoD) faces a tightening budget in the coming years. Despite the lean budget years, unmanned aircraft systems (UAS) are expected to be a priority. Secretary of Defense Leon Panetta has pledged to maintain or even increase spending in critical mission areas, such as cyber offense and defense, special operations forces, and UAS (Shanker and Bumiller 2011). Due to their usefulness for intelligence collection in irregular warfare (IW) and counterinsurgency (COIN), UAS were quickly fielded and sent to theater without analysis of how their intelligence sensors complemented each other (Isherwood 2011). There are ways for DoD to improve the methods of employment and the integration of multi-intelligence capabilities on assets to better leverage the systems it currently owns. The general aim of this research is to explore an area in which DoD can operate ?smarter? with its proliferating UAS fleet. Specifically, this research investigates how DoD can better leverage UAS and improve multi-intelligence capabilities by expanding its geolocation capacity through the use of time/frequency-difference-ofarrival (T/FDOA) geolocation on UAS. The research sheds light on important questions that need to be answered before investing in T/FDOA-capable UAS. I first demonstrate the potential of T/FDOA geolocation in the context of how we use UAS today. I then show what some of the ?costs? of adding a T/FDOA geolocation capability to UAS might be. Finally, I explore how T/FDOA geolocation could improve multi-intelligence operations.

15. SUBJECT TERMS

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DISSERTATION

Expanding the Use of Time/Frequency Difference of Arrival Geolocation in the Department of Defense

Kimberly N. Hale

This document was submitted as a dissertation in September 2012 in partial fulfillment of the requirements of the doctoral degree in public policy analysis at the Pardee RAND Graduate School. The faculty committee that supervised and approved the dissertation consisted of Brien Alkire (Chair), Carl Rhodes, and Sherrill Lingel.



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Abstract[1]

The U.S. Department of Defense (DoD) faces a tightening budget in the coming years. Despite the lean budget years, unmanned aircraft systems (UAS) are expected to be a priority. Secretary of Defense Leon Panetta has pledged to maintain or even increase spending in critical mission areas, such as cyber offense and defense, special operations forces, and UAS (Shanker and Bumiller 2011). Due to their usefulness for intelligence collection in irregular warfare (IW) and counterinsurgency (COIN), UAS were quickly fielded and sent to theater without analysis of how their intelligence sensors complemented each other (Isherwood 2011). There are ways for DoD to improve the methods of employment and the integration of multi-intelligence capabilities on assets to better leverage the systems it currently owns.

The general aim of this research is to explore an area in which DoD can operate "smarter" with its proliferating UAS fleet. Specifically, this research investigates how DoD can better leverage UAS and improve multi-intelligence capabilities by expanding its geolocation capacity through the use of time/frequency-difference-of-arrival (T/FDOA) geolocation on UAS. The research sheds light on important questions that need to be answered before investing in T/FDOA-capable UAS. I first demonstrate the potential of T/FDOA geolocation in the context of how we use UAS today. I then show what some of the "costs" of adding a T/FDOA geolocation capability to UAS might be. Finally, I explore how T/FDOA geolocation could improve multi-intelligence operations.

[1] This manuscript was formatted assuming that the reader would have access to a color copy. Interested readers who obtain a copy that is difficult to read may contact the author at hale.kimberly@gmail.com for a color copy.

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Summary

The U.S. Department of Defense (DoD) faces a tightening budget in the coming years. Despite the lean budget years, unmanned aircraft systems (UAS) are expected to be a priority. Secretary of Defense Leon Panetta has pledged to maintain or even increase spending in critical mission areas, such as cyber offense and defense, special operations forces, and UAS (Shanker and Bumiller 2011). Due to their usefulness for intelligence collection in irregular warfare (IW) and counterinsurgency (COIN), UAS were quickly fielded and sent to theater without analysis of how their intelligence sensors complemented each other (Isherwood 2011). There are ways for DoD to improve the methods of employment and the integration of multi-intelligence capabilities on assets to better leverage the systems it currently owns.

The general aim of this research is to identify and explore an area in which DoD can operate "smarter" with its proliferating UAS fleet by leveraging geolocation. Geolocation is the identification of the physical location of an object. Specifically, this research investigates how DoD can better leverage UAS and improve multi-intelligence capabilities by expanding its geolocation capacity through the use of time/frequency-difference-of-arrival (T/FDOA) geolocation on UAS.

I focused on the geolocation of radio frequency (RF) emitters used in a military context. There are several different techniques to geolocate an emitter. This research investigates the use of T/FDOA geolocation on UAS and sheds light on important questions that need to be answered before investing in a T/FDOA capability for UAS.

To perform this research, I created a tool to estimate the accuracy of T/FDOA geolocation to quantify its effectiveness. The T/FDOA Accuracy Estimation Model takes a scenario for geolocation and estimates the accuracy of the cooperative T/FDOA technique, including the impact of various sources of errors. Quantifying the effectiveness of T/FDOA geolocation allows this research to answer the proposed research questions. Beyond the analysis in this dissertation, the tool

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would be useful for assessing the dominant factors in T/FDOA geolocation accuracy, which can inform decisions on choosing aircraft orbit geometries to optimize performance, technology investment decisions, and comparisons of the performance of T/FDOA with alternative geolocation techniques for specific applications.

I first demonstrate the potential of T/FDOA geolocation in the context of how we use UAS today to show what a signals intelligence (SIGINT) system capable of T/FDOA would add. I contrast the T/FDOA technique with direction finding, which is the common geolocation technique used in the military today. T/FDOA geolocation is useful against many targets, particularly those in an IW/COIN environment that are difficult to geolocate using direction finding. Two of the major drawbacks to T/FDOA are the need for multiple platforms and the sensitivity to geometry. The drawbacks do not hinder employment of T/FDOA as a secondary capability on UAS.

I then show some of the requirements of adding a T/FDOA geolocation capability to UAS. Small changes are necessary to implement T/FDOA on UAS. The technology for T/FDOA-capable sensors already exists, and many UAS are nearly equipped to be capable. Today, one of the largest drivers of manpower for UAS is the processing, exploitation, and dissemination (PED) needed to turn the data collected into actionable intelligence. The manpower and cost implications appear to be small compared with the requirements to PED other sensors.

Finally, I explore how T/FDOA geolocation could improve multi-intelligence operations. Adding a SIGINT with T/FDOA capability to UAS instantly increases our ability to provide more information about targets by layering complementing intelligence, surveillance, and reconnaissance (ISR) sensors. T/FDOA geolocation provides high-accuracy geolocation very quickly, reducing the time delay between intelligence types and the area that a second intelligence, such as full-motion video (FMV), would need to search. For command, control, and communication (C3), the emerging ISR mission type orders (MTO) concept meets the C3 needs for T/FDOA geolocation in complex operating environments.

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ABBREVIATIONS

AOA	angle of arrival
AT3	Advanced Tactical Targeting Technologies
BAMS	Broad Area Maritime Surveillance
C2	command and control
C3	command, control, and communication
CAN	correlation analyst
CAOC	Combined Air Operations Center
CAP	combat air patrol
CEP	circular error probable
CONOPs	concept of operations
DARPA	Defense Advanced Research Projects Agency
DART	DCGS Analysis and Reporting Team
DCGS	Distributed Common Ground System
DIRLAUTH	direct liaison authority
DoD	U.S. Department of Defense
EIRP	effective isotropic radiated power
EO	electro-optical
FDOA	frequency difference of arrival
FMV	full-motion video
GEOINT	geospatial intelligence
GMTI	ground moving target indicator
HF	high frequency
HUMINT	human intelligence
HTS R7	Harm Targeting System Revision 7
IA	imagery analyst
IED	improvised explosive device
IMINT	imagery intelligence
IMS	imagery mission supervisor
INS	Inertial Navigation System
IR	infrared
IRE	Imagery Report Editor
ISR	intelligence, surveillance, and reconnaissance

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ISRD	ISR Division
JTIDS	Joint Tactical Information Distribution System
LOB	line of bearing
MASINT	measurement and signature intelligence
MOC	mission operations commander
MP	mission planner
MSA	multi-source analyst
MTO	mission type order
NASIC	National Air and Space Intelligence Center
NIB	non-interference basis
OSINT	open-source intelligence
PLLS	Precision Location and Strike System
SAM	surface-to-air missile
SAR	synthetic aperture radar
SATCOM	satellite communication
SIDO	senior intelligence duty officer
UHF	ultra high frequency
PED	processing, exploitation, and dissemination
QDR	Quadrennial Defense Review
RF	Radio Frequency
SATCOM	satellite communication
SIGINT	signals intelligence
SWAP	size, weight, and power
SNR	signal-to-noise ratio
TDOA	time difference of arrival
UAS	unmanned aircraft systems
VHF	very high frequency

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1. Introduction

Problem Statement

The U.S. Department of Defense (DoD) faces steep budget declines over the next decade. Military acquisition and research, development, test, and evaluation will likely be the hardest hit by spending cuts (Eaglen and Nguyen 2011). Despite the lean budget years, unmanned aircraft systems (UAS) are expected to be a priority. Secretary of Defense Leon Panetta has pledged to keep the spending constant or even increase spending in critical mission areas, such as cyber offense and defense, special operations forces, and UAS (Shanker and Bumiller 2011). As part of the plus-up to fight the wars in Afghanistan and Iraq, DoD invested heavily in UAS for intelligence, surveillance, and reconnaissance (ISR). The result was quickly fielding and sending to theater complex systems. The UAS inventory surged from 163 in February 2003 to over 6,000 today (Bone and Bolkcom 2003; Kempinski 2011). These UAS were rapidly amassed and employed, with very little analysis of how the different ISR sensors complemented each other (Isherwood 2011). There are ways for DoD to improve the methods used to employ UAS and the integration of multi-intelligence capabilities on assets to better leverage the systems it currently owns. The general aim of this research is to identify and explore one area in which DoD can operate "smarter" with its proliferating UAS fleet by leveraging geolocation. Geolocation is the identification of the physical location of an object. This research focuses on a method of employment coupled with small technological changes that can significantly improve the geolocation capabilities of DoD.

Specifically, this research investigates how DoD can better leverage UAS and improve multi-intelligence capabilities by expanding its geolocation capacity through the use of time/frequency-difference-of-arrival (T/FDOA) geolocation on unmanned assets. This advancement in geolocation would improve several aspects of ISR. It would increase the hunting ability for UAS, which are often termed hunter-killer platforms, potentially shortening the kill chain. Focusing on ISR,

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improved geolocation would enable better cross-cueing between platforms or self-cueing on multi-intelligence platforms, creating a richer intelligence picture. Incorporating T/FDOA geolocation would require changes. A new concept of operation (CONOP) needs to be developed for the execution of T/FDOA from ISR platforms and the incorporation of multi-intelligence sources. Payload modifications, though hypothesized to be modest, need to be quantified. The impacts on the processing, exploitation, and dissemination (PED) process also need to be evaluated to determine the efficacy of this concept. This research is intended to inform DoD policy by showing that an expanded use of T/FDOA geolocation on UAS would improve multi-intelligence capabilities.

MOTIVATION AND BACKGROUND

The 2010 Quadrennial Defense Review (QDR) stresses the importance of increased ISR to support the warfighter. The QDR articulates several priorities involving the growth of ISR, including expansions of the "intelligence, analysis, and targeting capacity" and of "unmanned aircraft systems for ISR" (Department of Defense 2010). The *Unmanned Systems Integrated Roadmap FY2009-2034*, published by the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, outlines priorities for future investment in unmanned systems and echoes similar themes. The top two priorities for future investments in UAS are improvements in reconnaissance and surveillance, particularly multi-intelligence capable platforms, and improvements in target identification and designation, including the ability to precisely geolocate military targets in real time (Under Secretary of Defense for Acquisition, Technology, and Logistics 2009).

Geolocation is the identification of the physical location of objects on the earth. The term is used to refer to both the action of locating and the results of the localization. There are numerous ways to accomplish geolocation. This research focuses on the geolocation of radio frequency (RF) emitters used in a military context. Geolocation of RF emitters is critical to a wide variety of military applications. In conflicts, geolocation is vital for both targeting and situational awareness. RF emitters of interest range from elements of an integrated

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air defense system and communications nodes in a major combat operation to insurgents communicating with push-to-talk radios. A key difference in military geolocation is the non-cooperation of targets. An enemy usually attempts to disguise emissions using evasive techniques that complicate geolocation. For example, the time of transmission might not be known. The military uses signals intelligence (SIGINT) to take advantage of the electromagnetic emissions intercepted from targets. These electromagnetic emissions can provide information on the intention, capabilities, or location of adversary forces (AFDD 2-0).

Many intelligence tasks depend on geolocation; however, each task does not require the same level of accuracy. Table 1.1 summarizes specific intelligence tasks requiring geolocation, comments on the value of geolocation, and gives an idea of the accuracy needed. Although these accuracies are intended to be ballpark figures, they highlight the need for significant accuracy for certain tasks, such as precision location.

Table 1.1
Geolocation Contribution to Intelligence Tasks

Objective	**Value**	**Accuracy Needed**
Weapon sensor location (self-protection)	Allows threats to be avoided or negated through jamming	Low ($5km^2$)
Emitter differentiation	Allows sorting by location for separation of threats for identification processing	
Enemy asset location	Allows narrowed reconnaissance search	Medium ($1km^2$)
Electronic order of battle	Locate emitter types associated with specific weapons/ units. Provides information on enemy strength, deployment, etc.	
Weapon sensor location	Allows threat to be avoided by other friendly forces	
Precision target location	Allows direct attack	High ($100m^2$)

SOURCE: Table adapted from Adamy, D. (2001). EW 101. Boston, Artech House. p. 144.

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There are several techniques currently used to geolocate an RF emitter. These techniques include using the angle of arrival (AOA) of the emission, using coherent time-difference-of-arrival (TDOA) at a single platform, using non-coherent TDOA for the emission to multiple receivers, and using the frequency-difference-of-arrival (FDOA) for the emission to multiple receivers. Each of the techniques depends on precise measurements. Errors in the accuracy of the measurements impact the accuracy of geolocation, resulting in some amount of error inherent in the geolocation.

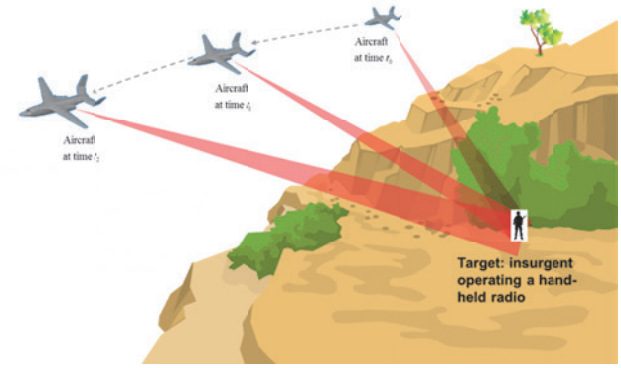
The errors involved and the impact on the accuracy of the geolocation depend on the technique used. These errors include such things as positioning errors (how well the aircraft knows its own position), signal measurement errors (how well the receiver can capture the received signal), and noise inherent in the signal. To reduce error, techniques can be combined and used together, for example T/FDOA geolocation leverages both TDOA and FDOA to determine position more accurately. Regardless of the system used, the geolocation accuracy is dependent on the accuracy of the chosen technique and how the SIGINT system is designed to minimize error (Adamy 2001).

The military traditionally uses direction finding, also known as triangulation, to fix the position of an emitter using specialized manned aircraft. In direction finding, an aircraft would measure the AOA at multiple locations along a baseline to create lines of bearing (LOBs) between the receiver and the emitter. Two or more LOBs enable the emitter to be fixed at the intersection of these different LOBs. Figure 1.1 depicts a pictorial of direction finding. Single-receiver direction finding requires one receiver to measure the signal at one position and then move and re-measure the same signal. Multi-receiver direction finding requires at least two geographically separated receivers collecting LOBs on the same target. There are many algorithms available to calculate the emitter location. These range from plotting LOBs on a common map to calculations based on statistical techniques such as least-squares error estimation and the discrete probability density method (Poisel 2005).

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There are limitations to direction finding. It requires a directional antenna, which can be bulky and expensive. The accuracy of direction finding can be severely hampered by the duration of the emission as well as target movement. Cooperative T/FDOA geolocation is not subject to these limitations.

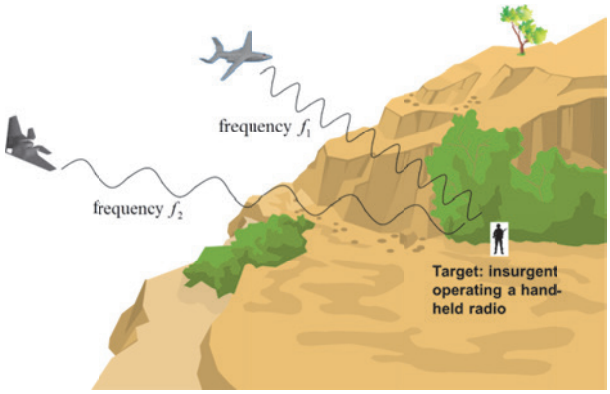
Figure 1.1
Aircraft Calculates LOBs along a Baseline



Cooperative T/FDOA is the combination of two techniques that enable receivers to quickly geolocate a signal. For both TDOA and FDOA, at least two receivers are needed to calculate a difference of arrival. In TDOA, the difference in the time that a signal arrives at the two receivers is proportional to the difference in the ranges of the two receivers from the target. One TDOA measurement provides a contour in the shape of a hyperbola of potential positions of the signal. In FDOA, the difference in the frequency of arrival is proportional to the difference in the frequencies measured by the two receivers. Figure 1.2 shows a pictorial of FDOA. One FDOA measurement provides a contour of potential sources of the signal. When the contours of potential sources of the signal (one from TDOA and one from FDOA) are intersected, the position of the source of the signal is at the intersection.

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Figure 1.2
Signal May Have a Frequency Difference



TDOA and FDOA are straightforward to describe mathematically. The equations for TDOA and FDOA are described by position, velocity, and signal characteristics. Let τ denote a TDOA measurement and ϕ denote a FDOA measurement. Let $v \in \mathbf{R}^n$ and $w \in \mathbf{R}^n$ denote the positions of the pair of receivers in n-space. Similarly, let $\bar{v} \in \mathbf{R}^n$ and $\bar{w} \in \mathbf{R}^n$ denote the corresponding velocities of the pair of receivers. Let c denote the speed of light and f denote the center frequency of the emitter. The equations to calculate TDOA and FDOA are as follows[2]:

TDOA equation: $$\tau = \frac{1}{c}\left(\|v-x\| - \|w-x\|\right)$$

FDOA equation: $$\phi = \frac{f}{c}\left(\bar{v}^T \frac{(v-x)}{\|v-x\|} - \bar{w}^T \frac{(w-x)}{\|w-x\|}\right).$$

Finding the emitter source using T/FDOA is not as easy to describe mathematically, due to errors causing inconsistent measurements of TDOA and FDOA. The T/FDOA Accuracy Estimation Tool, developed as part of this dissertation, simulates the various errors that impact T/FDOA geolocation and predicts the accuracy that could be expected from a T/FDOA geolocation given a specific application. This tool is used throughout the analysis and is explained in detail in Chapter Two.

[2] For more information on TDOA and FDOA equations, see Stewart (1997).

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Direction finding and T/FDOA are difficult to directly compare. The accuracy of each technique is dependent on the specific application, and so it is more useful to contrast the advantages and limitations of each technique. Table 1.2 shows advantages and limitations for direction finding with a single receiver, direction finding with multiple geographically separated receivers, and T/FDOA.

Table 1.2
Summary of Pros and Cons of Geolocation Techniques

	Direction Finding (Single Receiver)	Direction Finding (Multi-Receiver)	T/FDOA
Requires directional antenna	Yes	Yes (on each platform)	No
Signals of interest	Low power, high frequency	Low power, high frequency	Low power, low frequency
Time needed for geolocation	2-3 minutes	Nearly instantaneous	Nearly instantaneous
Requires multiple aircraft	No	Yes	Yes
Sensitive to target movement	Yes	No	No
Sensitive to geometry	No	Yes	Yes

Adding a T/FDOA geolocation capability to UAS would increase both the capacity and capability for geolocation. Today, the number of large UAS owned by the Air Force is on par with the number of manned

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ISR/command and control (C2) platforms. Placing T/FDOA geolocation on these UAS would more than double the number of collectors capable of geolocation.[3] The UAS inventory is also expected to increase in the coming years, potentially bringing the number of group 4/5 UAS to over 500 for the Air Force and Navy alone. Using T/FDOA geolocation would also expand the overall capability for geolocation. Signals that are difficult to geolocate with direction finding for a variety of reasons, such as length of emission, range from collector, and the frequency used, can be located with good accuracy using T/FDOA geolocation. The techniques are contrasted in more depth in Chapter Three.

The expansion of capability and capacity would benefit several aspects of ISR. Higher-accuracy geolocation yields better intelligence. T/FDOA geolocation is able to achieve high enough accuracy to be targetable. Targetable accuracy geolocation determined by a multi-role UAS, such as an armed MQ-9 Reaper, could shorten the sensor-to-shooter timeline. Geolocation is also very useful for cross-cueing. Today, we use UAS predominantly for their FMV sensors. Unfortunately an FMV sensor has a limited field of view, often compared to looking through a soda straw. SIGINT has a much wider field of view, potentially only limited by the line of sight to the radar horizon. A geolocation tip on a known adversary frequency could be used to cue an FMV sensor to identify and perhaps neutralize the target. The increase in geolocation capacity equates to more information about targets that might not have been captured previously. More and better quality geolocation that is catalogued would have impacts on the later phases of PED, such as forensics. Forensics draws together intelligence derived from multiple sources to provide an in-depth analysis. An example of forensics would be an analysis of a roadside bomb explosion. The analysis would pull all available intelligence to try to determine details about the incident, such as when the bomb was placed, when it was detonated, etc. If catalogued, the expanded collection and geolocation from using

[3]As of Jan 2012, the number of manned ISR/C2 assets (U-2, MC-12, E-3B, E-4B, E-8C, RC-135B/S/U/V/WH, EC-130) was 145 aircraft (according to fact sheets on www.af.mil). The number of large (group 4/5) multi-role/ISR UAS is approximately 180 aircraft (according to the Aircraft Procurement Plan FY2012-2041).

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T/FDOA on UAS could increase the available information for forensic analysis.

T/FDOA Implementation in the Military

For several decades, the military invested in technologies to improve geolocation through the implementation of T/FDOA geolocation, although to date this technology has not been incorporated on UAS. The Precision Location and Strike System (PLSS) was one of the first efforts to use TDOA geolocation. Throughout the 1970s, this program attempted to quickly triangulate hostile emitters with high enough accuracy to target with weapons using a combination of TDOA and other techniques (U.S. Congress Office of Technology Assessment 1987). It utilized three aircraft collecting electronic intelligence data. These data were then relayed to a ground station that used TDOA, direction of arrival, and distance measuring equipment to fix the position of the target. The Air Force spent millions of dollars on the development of PLSS, but the project never succeeded because of technical challenges (Pocock 2008).

The advent of GPS, improvements in computer processing power, and higher-bandwidth communications since the early 1990s enabled more recent attempts to use T/FDOA geolocation for near-real-time precision location of hostile emitters from the air. In 1991, the Army upgraded its Guardrail Common Sensor system to have a limited TDOA capability that depended on an initial cue.[4] In 1997, the Defense Advanced Research Projects Agency (DARPA) began work on Advanced Tactical Targeting Technologies (AT3), the first system designed and built to fully employ T/FDOA geolocation. DARPA's goal was to develop and demonstrate the enabling technologies for a cost-effective, tactical targeting system for the lethal suppression of enemy air defenses. The idea was to generate and distribute highly precise location of radars within seconds using T/FDOA geolocation. Emitter collection packages would be hosted on combat aircraft, obviating the need for any dedicated collection platforms. Instead, collection would be opportunistic, with

[4] Subsequent upgrades to the Guardrail system added a true T/FDOA capability.

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minimal pre-coordination required. The DARPA system has been incorporated in the F-16 HARM Targeting System, greatly improving the ability of F-16 Block 50s to quickly locate and engage an emitting target (Cote 2010). Another program, Net-Centric Collaborative Targeting (NCCT), greatly expanded the geolocation capabilities of manned ISR assets. Integrated on assets such as the RC-135, RC-130, EC-130, U-2, and EP-3, NCCT allows separate sensors to cooperatively geolocate a target (Anonymous 2008). To date, such technologies are not incorporated on unmanned ISR assets, such as MQ-9 Reapers or MQ-1C Grey Eagles.

Academic research on T/FDOA geolocation centers on methods of estimation and the impact of errors on accuracy. Chestnut (1982) determined relationships between errors in measurement and geolocation accuracy. Bardelli, Haworth, and Smith (1995) found that the Cramér-Rao lower bounds on T/FDOA measurement are typically so small[5] that positioning errors and other measurement errors predominate. Musicki and Koch (2008) devised a method to estimate emitter location accuracy using T/FDOA and compared it with geolocation results from a direction finding approach. Musicki, Kaune, and Koch (2010) proposed a method for recursive tracking of a mobile emitter using T/FDOA. This research expands on academic literature by examining important questions that need to be answered before investing in T/FDOA-capable UAS.

Much of the academic research on geolocation with UAS focuses on using autonomous, often small UAS that cooperate as a swarm (Okello 2006; Marsh, Gossink et al. 2007; Scerri, Glinton et al. 2007; Liang and Liang 2011). These works highlight advantages of small UAS, including their lower cost and higher mobility. Although small UAS have some characteristics that lend themselves to being used for geolocation, larger UAS provide a significant opportunity to leverage T/FDOA geolocation. This research focuses on larger UAS. Group 4/5 UAS, defined as UAS that have a gross weight of larger than 1,320 lbs, show potential for hosting a T/FDOA capability. Some examples of these UAS include the Army's MQ-1C Grey Eagle, the Air Force's MQ-9 Reaper, and

[5] A Cramér-Rao lower bound gives a lower bound on the variance of any unbiased estimator.

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the Navy's MQ-4C BAMS. These UAS have characteristics that make them a logical choice for integrating a T/FDOA geolocation capability. Their large size gives them the payload capacity needed to host multiple sensors. Their long endurance and employment altitude allow for long collection times over significant geographic areas. The large and growing inventory of group 4/5 UAS provides the required ability to mass numbers of equipped platforms over one geographic area.

RESEARCH QUESTIONS

The chapters that follow each focus on one question to inform the overall recommendation of integrating T/FDOA geolocation on UAS platforms to expand the geolocation capacity and increase multi-intelligence capabilities. The analysis leverages mathematical modeling techniques and geospatial analysis to answer the following research questions:

1. When would T/FDOA geolocation be useful on UAS?
2. What is needed to use T/FDOA geolocation on UAS?
3. How can T/FDOA geolocation be leveraged in multi-intelligence operations on UAS?

Each research question is divided into several tasks that help to answer the questions.

The first research question focuses on whether T/FDOA geolocation would be useful if we were to add the capability to UAS operating today. Specifically, I am interested in whether T/FDOA would fill a gap and be a practical capability on UAS. The accuracy of geolocation of a signal is dependent on the method of geolocation used, the characteristics of the scenario, and the signals of interest. Direction finding is a common geolocation technique used today. T/FDOA geolocation offers distinct advantages over direction finding. First, I explore these advantages using a simple model of direction finding to contrast the two techniques. This model is described in Appendix A. Two major drawbacks of T/FDOA geolocation are that it requires multiple equipped platforms and that the geolocation accuracy is extremely sensitive to the geometry of the receiver platforms in relation to the target emitter. Today, multi-intelligence capable platforms are tasked

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with one intelligence priority (e.g., signals intelligence-prime), and the orbit flown is optimized for that mission. I examine the impact of these orbit geometries on the expected accuracy given different intelligence priorities using the T/FDOA Accuracy Estimation Tool. For T/FDOA geolocation, the multiple equipped platforms must be operating within line of sight of the same target. Using a combination of geospatial analysis and the T/FDOA Accuracy Estimation Tool, I analyze the line of sight coverage overlap and the resulting accuracy available for specific targets in the current operating environment.

Any modification to how a mission is accomplished will have ramifications and cost implications in other areas. The second research question investigates some of these implications. Before T/FDOA is implemented, the requisite hardware and software modifications to platforms need to be determined. I research DARPA's AT3 program as an example of successful T/FDOA geolocation implementation. An addition of T/FDOA capability will likely impact the already manpower constrained processing, exploitation, dissemination (PED) enterprise. I examine the workload for T/FDOA PED. Then, using the current PED operations conducted by the Distributed Common Ground Systems (DCGS) as a baseline, I determine whether the workload requires additional personnel and calculate the total additional personnel burden. As mentioned in the introduction, fiscal constraints faced by DoD will be severe in the coming years. To recommend using T/FDOA in this climate, an understanding of what the potential cost implications for T/FDOA is necessary. I estimate the cost implications of the additional personnel.

Most UAS are equipped with several different types of sensors. DoD would like to capitalize on these multi-intelligence capable platforms to collect more complete information on targets and use one intelligence collection to cue another intelligence collection. The third research question explores how T/FDOA can improve multi-intelligence operations. T/FDOA geolocation can provide highly accurate

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geolocation within seconds.[6] This combination of accuracy and speed can in turn aid in multi-intelligence collection through improved cueing. The time burden of T/FDOA geolocation is impacted by the command, control, and communication (C3) channels used to pass the geolocation from the analysis source to the warfighter. Today's C3 channels were designed to pass geolocation from manned intelligence platforms, commonly using direction finding, where timeliness is not as important. I examine the kind of C3 needed to enable multi-intelligence cross-cueing.

The research outlined above sheds light on important questions that need to be answered before investing in T/FDOA-capable UAS. The first research question demonstrates the potential of T/FDOA geolocation in the context of how we use UAS today. The second question shows what some of the "costs" of adding a T/FDOA geolocation capability to UAS might be. The third question explores how T/FDOA geolocation could improve multi-intelligence cueing. Each research question helps to inform the overall policy recommendation of better leveraging UAS and improving multi-intelligence capabilities through the use of T/FDOA geolocation.

ORGANIZATION OF THE DISSERTATION

Chapter Two presents the T/FDOA Accuracy Estimation Tool that will be used throughout the analysis. Chapter Three discusses when T/FDOA would be useful in the context of today's operations. Chapter Four examines what is needed to use T/FDOA geolocation focusing on the requisite system modifications and the impacts on the PED enterprise. Chapter Five shows how T/FDOA geolocation could be leveraged in multi-intelligence operations. Chapter Six summarizes the conclusions and policy recommendation. Several appendixes are included to provide further information on the models used and results summarized in the body of the dissertation.

[6] An example error ellipse with good geometry would give in a semi-major axis of 37m and a semi-minor axis of 19m, resulting in an area of 2,210m. See Chapter Two for more examples.

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2. T/FDOA Accuracy Estimation Model

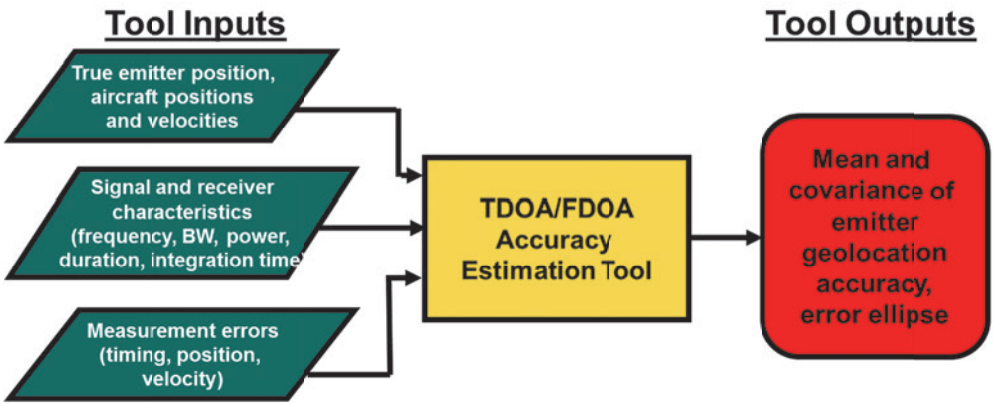
The T/FDOA Accuracy Estimation Model takes a scenario for geolocation and estimates the accuracy of the cooperative T/FDOA technique, including the impact of various sources of errors. The tool improves on other tools to estimate the accuracy of T/FDOA in the literature by including errors in the measurement of the aircraft state vector. The tool was needed to evaluate the accuracy of T/FDOA as a means of quantifying the benefits of T/FDOA geolocation for this dissertation. Beyond this research, the simulation provides a useful tool for assessing the dominant factors in T/FDOA geolocation accuracy that can inform decisions on choosing aircraft orbit geometries to optimize performance, technology investment decisions, and comparisons of the performance of T/FDOA with alternative geolocation techniques for specific applications.

There are several methods to solve for TDOA and FDOA in the academic literature. Ho and Chan (1993) show how to estimate position at the intersection of two or more hyperbolae using TDOA measurements. Chestnut (1982) derives formulas for cooperative T/FDOA. Ren, Fowler, and Wu (2009) use the Gauss-Newton method for non-linear least-squares to estimate the emitter location using cooperative T/FDOA. Prior work on the estimation of accuracy for cooperative T/FDOA takes into account the precision for the measurement of time difference and frequency difference known as Cramér-Rao lower bounds. Bardelli, Haworth, and Smith (1995) found that the Cramér-Rao lower bounds on TDOA and FDOA are often so small that equipment errors predominate. Equipment errors in the aircraft state vector, such as error in the estimation of position and speed by the platforms conducting the geolocation, have been noted but not explicitly included in previous research. The T/FDOA Accuracy Estimation Model expands on previous research by including measurement errors of the aircraft state vector as well as the traditional Cramér-Rao lower bounds on the measurement of TDOA and FDOA.

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Geolocation using T/FDOA is a complex function of geometry, signal characteristics, and navigational precision. Due to measurement errors and noise, there are limitations on how well an emitter can be geolocated. I use a simulation-based approach to determine the accuracy with which an emitter's position can be geolocated using cooperative T/FDOA. An outline of the inputs and outputs of the T/FDOA Accuracy Estimation Model is show in Figure 2.1.

Figure 2.1
Graphic Depiction of Tool Inputs and Outputs



For each run, I use non-linear least-squares optimization to determine the emitter position most consistent with the simulated measurements. In formulating the least-squares for TDOA and FDOA equations, it is apparent that both functions are not convex, resulting in a non-convex optimization problem. For a non-convex optimization, a good initial estimate is required. I use the true emitter position as an initial estimate to mitigate the possibility of non-convergence.[7] The least-squares fit is also non-linear. I use the Gauss-Newton Method with an approximation of the Hessian for the non-linear least-squares optimization.[8] I then calculate statistics for the distribution of the

[7] The non-convex nature of the problem causes global techniques to fail. Using the true emitter position as the initial estimate guards against non-convergence. The optimization may still fail, and the tool notifies the user of instances of non-convergence.

[8] The Gauss-Newton method is a standard optimization technique for non-linear least-squares optimization. It avoids the direct computation of the Hessian by approximating it, and the approximation improves as

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estimated positions. I use the sample covariance matrix to determine an error ellipse. The output of the tool is this error ellipse.

MEASUREMENT AND SOURCES OF ERROR

The equations for TDOA and FDOA are described by position, velocity, and signal characteristics. Let τ denote a TDOA measurement and ϕ denote a FDOA measurement. Let $v \in \mathbf{R}^n$ and $w \in \mathbf{R}^n$ denote the positions of the pair of receivers. Similarly, let $\overline{v} \in \mathbf{R}^n$ and $\overline{w} \in \mathbf{R}^n$ denote the corresponding velocities of the pair of receivers. Let c denote the speed of light and f denote the center frequency of the emitter. The equations to calculate TDOA and FDOA are as follows:

TDOA equation: $$\tau = \frac{1}{c}\left(\|v-x\| - \|w-x\|\right)$$

FDOA equation: $$\phi = \frac{f}{c}\left(\overline{v}^T \frac{(v-x)}{\|v-x\|} - \overline{w}^T \frac{(w-x)}{\|w-x\|}\right).$$

As noted in Okello (2006), T/FDOA geolocation requires precise data on the distance between each sensor and a precise clock to synchronize the timing of measurements. Due to measurement errors, TDOA and FDOA measurements are rarely consistent, meaning that an exact solution that satisfies both the TDOA and FDOA equations rarely exists. Our model considers several different sources of error. Consistent with other works, these measurement errors are assumed to be zero-mean Gaussian (Musicki and Koch, 2008). There is error inherent in a receiver's ability to measure its own position and velocity, σ_p and σ_v, respectively. The measurement of TDOA and FDOA each introduce errors due to noise in the receivers, σ_τ and σ_φ. TDOA measurement also includes clock synchronization error, σ_T. The errors and their values are listed in Table 2.1.

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one approaches convergence. Also, the approximation is always positive definite, which ensures we obtain a descent direction, even for a non-convex problem such as this.

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Table 2.1
Data for Error Model

Error	Value of Error
σ_p	Default is 10.2 m, based on GPS P(Y) code error
σ_v	Default is 5 cm/s, based on typical error for GPS or low grade IMU
$\sigma_\tau \geq \frac{1}{2\pi B_{rms}\sqrt{BTS_e}}$	I use Cramér-Rao lower bounds (Musicki, Kaune et al. 2010)
$\sigma_\phi \geq \frac{1}{2\pi T_{rms}\sqrt{BTS_e}}$	I use Cramér-Rao lower bounds (Musicki, Kaune et al. 2010)
$\sigma_T = 100\times10^{-9}$ sec	Default is times the worst-case GPS satellite clock error.

PROBLEM FORMULATION

I formulate the problem as a non-linear least-squares optimization problem to find the emitter position that minimizes the deviation from zero for every T/FDOA measurement. I first fit a least-squares optimization to the T/FDOA equations. I want to find the emitter position that is most consistent in the least-squares sense; that is, the emitter position that minimizes the sum of the squared residuals. Let τ_i denote the i^{th} TDOA measurement for $i=1,\cdots,m$. Similarly, let ϕ_i denote the i^{th} FDOA measurement for $i=1,\cdots,m$. Let $v_i \in \mathbf{R}^n$ and $w_i \in \mathbf{R}^n$ denote the positions of the i^{th} unique pair of receivers for $i=1,\cdots,m$. Similarly, let $\overline{v}_i \in \mathbf{R}^n$ and $\overline{w}_i \in \mathbf{R}^n$ denote the corresponding velocities of the i^{th} unique pair of receivers. Let c denote the speed of light and f denote the frequency of the emitter. Then x^* is given by:

$$x^* = \underset{x\in\mathbf{R}^n}{\arg\min} \left\| \begin{matrix} \|v_1 - x\| - \|w_1 - x\| - c\tau_1 \\ \|v_2 - x\| - \|w_2 - x\| - c\tau_2 \\ \vdots \\ \|v_m - x\| - \|w_m - x\| - c\tau_m \\ \overline{v}_1^{\,T}\dfrac{(v_1 - x)}{\|v_1 - x\|} - \overline{w}_1^{\,T}\dfrac{(w_1 - x)}{\|w_1 - x\|} - \dfrac{c}{f}\phi_1 \\ \overline{v}_2^{\,T}\dfrac{(v_2 - x)}{\|v_2 - x\|} - \overline{w}_2^{\,T}\dfrac{(w_2 - x)}{\|w_2 - x\|} - \dfrac{c}{f}\phi_2 \\ \vdots \\ \overline{v}_m^{\,T}\dfrac{(v_m - x)}{\|v_m - x\|} - \overline{w}_m^{\,T}\dfrac{(w_m - x)}{\|w_m - x\|} - \dfrac{c}{f}\phi_m \end{matrix} \right\|^2 .$$

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This is a non-convex optimization problem. I can show that a least-squares fit is non-convex through counter examples. If a function were convex, then the entire function would lie on or below a line segment connecting any two points on the function. Mathematically, this is stated as:

$$g(ax+(1-a)y) \le ag(x)+(1-a)g(y), \text{ for any } 0 \le a \le 1 .$$

The function for the normalized TDOA fit would be:

$$g(x)=\left(\|v-x\|-\|w-x\|-c\tau\right)^2 .$$

Let $v=2, w=-1,$ and $c\tau=1.5$. I can then check the convexity for this example by graphing. The graph on the left in Figure 2.2 shows clearly that the least-squares fit to TDOA is not convex. Similarly, the function for the normalized FDOA fit would be:

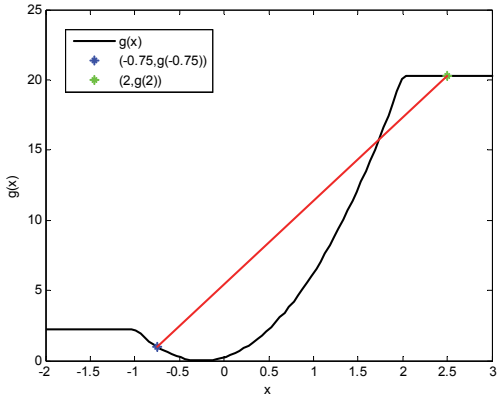
$$g(x)=\left(\bar{v}^T\frac{(v-x)}{\|v-x\|}-\bar{w}^T\frac{(w-x)}{\|w-x\|}-\frac{c\phi}{f}\right)^2 .$$

If we set the data, let $\bar{w}=\bar{v}=1, v=2, w=-1, and\ c\phi/f=2.5,$ we can graph the function. The graph on the right in Figure 2.2 shows that the least-squares fit to FDOA is also not convex.

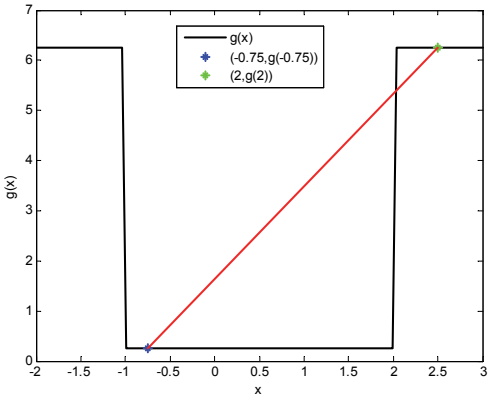
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Figure 2.2
Graph of TDOA and FDOA for Convexity Proof

Graph of TDOA



Graph of FDOA



As a result of the non-convexity, the algorithm may not converge to a global minimum. If it is provided an initial estimate that is close to optimal, the algorithm will converge in most cases. For our application, we know the true position of the emitter and use it as our initial estimate.[9] This does not guarantee convergence for every case; however, it works in most situations. The tool informs the user if the solution did not converge, and these data are removed for the statistical calculations.[10]

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[9] The non-convexity of this problem requires a good initial estimate, in the neighborhood of the optimal solution. Using the true position of the emitter provides an initial estimate that should be close for most cases. This initial estimate will not impact the resulting error ellipse, as the algorithm will still converge at the optimal solution.

[10] The non-convergence is a result of the non-convexity of the problem. Unfortunately, it is unavoidable. When a solution does not converge, it typical means that the initial estimate (the true position) was far from the optimal solution. This situation is the result of poor geometry. As a reviewer noted, removing the failures could impact the accuracy results, since they are the worst cases. I conducted some sensitivity analysis to see the extent of non-convergence. The Monte-Carlo simulation uses 500 iterations, and the percentage of non-convergences is typically very small, less than 5 percent. If the proportion of non-convergences reaches greater than 10 percent, the tool will inform the user that there are not enough samples to estimate the accuracy. I never encountered this situation. In general, if there is non-convergence, the geolocation from that particular application is extremely poor. Removing the failures does

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I reformulate the problem to simplify the notation. Let τ_i denote the i^{th} TDOA measurement for $i = 1, \cdots, m_1$. Similarly, let ϕ_i denote the i^{th} FDOA measurement for $i = 1, \cdots, m_2$. Assume that m_3 unique pairs of receivers collect the measurements. Let $v_i \in \mathbf{R}^n$ and $w_i \in \mathbf{R}^n$ denote the positions of the i^{th} unique pair of receivers for $i = 1, \cdots, m_3$. Similarly, let $\overline{v}_i \in \mathbf{R}^n$ and $\overline{w}_i \in \mathbf{R}^n$ denote the corresponding velocities of the i^{th} unique pair of receivers. Let $T(i) \in [1,2,\cdots,m_3]$ denote the index of the receiver pair that collects τ_i for $i = 1, \cdots, m_1$ and let $F(i) \in [1,2,\cdots,m_3]$ denote the index of the receiver pair that collects ϕ_i for $i = 1, \cdots, m_2$.

$$\text{Let } r_i(x) = \begin{cases} \left\| v_{T(i)} - x \right\| - \left\| w_{T(i)} - x \right\| - \tau_i c & i = 1, \cdots, m_1 \\ \overline{v}_{F(i-m_1)}{}^T \dfrac{\left(v_{F(i-m_1)} - x\right)}{\left\| v_{F(i-m_1)} - x \right\|} - \overline{w}_{F(i-m_1)}{}^T \dfrac{\left(w_{F(i-m_1)} - x\right)}{\left\| w_{F(i-m_1)} - x \right\|} - \phi_i c / f & i = m_1 + 1, m_1 + 2 \cdots, m_1 + m_2 \end{cases}$$

The optimization problem is now:

$$\text{minimize } g(x) = \sum_{i=1}^{m_1+m_2} r_i(x)^2 \quad .$$

This is a non-linear least squares optimization problem, and I use the Gauss-Newton method with a backtracking line search to solve it. The Gauss-Newton method is an algorithm for solving convex non-linear least-squares problems. The method defines a descent direction using the gradient and an approximation of the Hessian denoted H.[11] I use a backtracking line search to determine the step size. The algorithm as applied to our problem is as follows:

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not impact the results throughout this dissertation. In the remainder of this research, I categorize the error ellipse accuracy into high (<100m^2), medium (<1km^2), low (<5km^2), and unusable. Non-convergence would only appear in applications that result in unusable accuracies.

[11] This estimate of the Hessian converges to the Hessian as the gradient vanishes.

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Given an initial point $x \in \mathbf{R}^n$, tolerance $\varepsilon > 0$, parameter $\alpha \in (0,1/2)$
while $\|\nabla g(x)\| > \varepsilon$
  $H = 2\sum_{i=1}^{m_1+m_2} \nabla r_i(x) \nabla r_i(x)^T$
  $u = -H^{-1}\nabla g(x)$ (i.e., solve $Hu = -\nabla g(x)$ for u)
  $t = 1$
  while $g(x+tu) > g(x) + \alpha t \nabla g(x)^T u$
    $t = t/2$
  end
  $x = x + tu$
end

With each run, the estimated position of the emitter is saved. These estimated positions are used to calculate the mean estimated position and a covariance matrix. Using the eigenvalues of the covariance matrix, we can determine the uncertainty in each direction and plot this uncertainty to create an error ellipse.

HOW THE TOOL WORKS

The tool uses a Monte-Carlo simulation to estimate the accuracy of geolocation. For each run of the tool, the true TDOA and FDOA are calculated using the true positions. Then, the errors are incorporated. The errors are modeled as separate random samples each drawn from Gaussian distributions with the variance of the error parameter. During each iteration, the randomly sampled error is added to the true value. All of the errors are included in each model run. The errors for TDOA and FDOA measurement (σ_τ and σ_ϕ, respectively) are introduced using the errors from the Cramér-Rao lower bounds. Random synchronization clock error (σ_T) is also added to the TDOA measurement. Then random noise is added to the positions (σ_p) and velocities (σ_v) of the receivers to simulate the aircraft state vector measurement error. For example, if the true aircraft position was [100m, 150m, 90m] and the random error sample for position was 7.8m, the aircraft position used for that iteration would be [107.8m, 157.8m, 97.8m]. The T/FDOA measurement and positions that incorporate the errors are then used in the non-linear least-squares optimization to determine the most consistent emitter

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position. Statistics between this estimated position and the true emitter position are used as estimates of the geolocation accuracy.

EXAMPLES OF TOOL

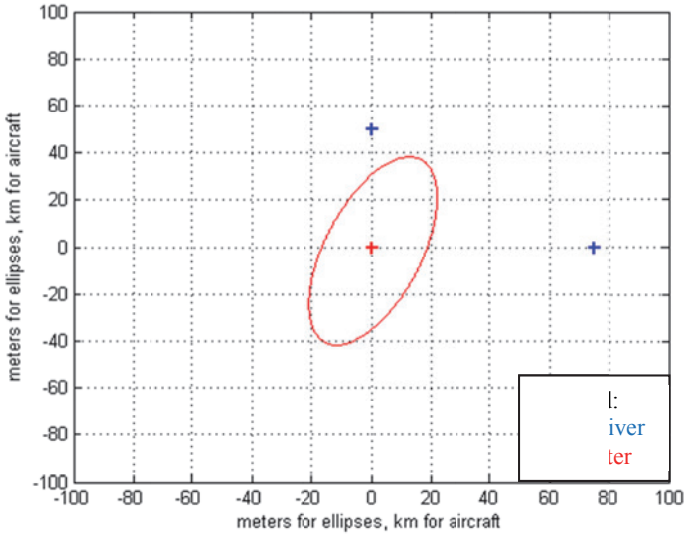
The T/FDOA Accuracy Estimation Model shows how the different inputs to cooperative T/FDOA impact the accuracy with which an emitter can be geolocated. The following examples are meant to illustrate the sensitivity of the tool to several of the model inputs. The accuracy is extremely sensitive to geometry and the number of receivers available. By *geometry*, I am referring to the positioning and speed of the receivers relative to the target. The receivers must be located such that there are time differences between the arrivals of the signal. The receivers must also be traveling with different velocities with respect to the targeted emitter so that there are calculable frequency differences of arrivals. The measurement errors can also significantly impact the accuracy of geolocation.

Example: Impact of Geometry

In this scenario, there are two receivers positioned around the emitter. The emitter has a 164 MHz signal that lasts for 30 seconds with a 25 MHz bandwidth, and 5W EIRP, a typical power for a VHF push-to-talk radio. There is a 190°K noise temperature at the receivers with a 4dB noise figure. The receivers are both headed east at 100 m/sec. Figure 2.3 shows the scenario and the resultant error ellipse. The receivers are the blue crosses, and the emitter is the red cross. Positions are in units of kilometers. The error ellipse is in units of meters.

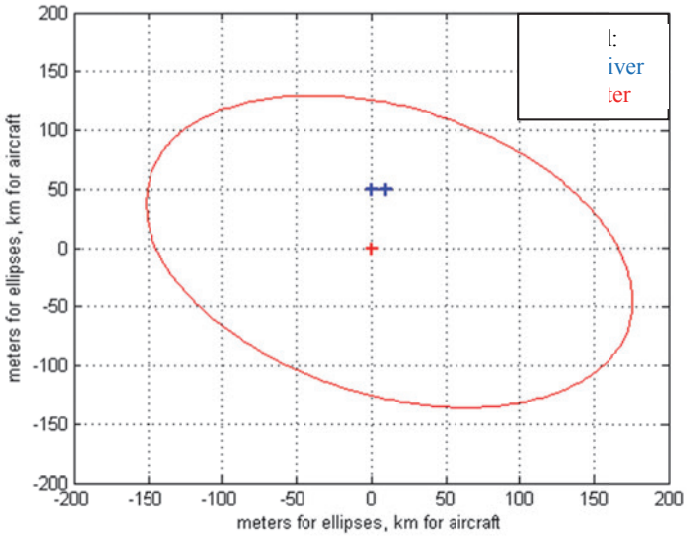
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Figure 2.3
Two Receiver Example with 1-Sigma Error Ellipse



The error ellipse is about 2210m^2 centered on the emitter. If the position of one of the receiver is changed, keeping all else constant, the size of the error ellipse can increase drastically. Figure 2.4 shows the resultant error ellipse after moving one receiver to be much closer to the other.

Figure 2.4
Moving One Receiver for Poor Geometry



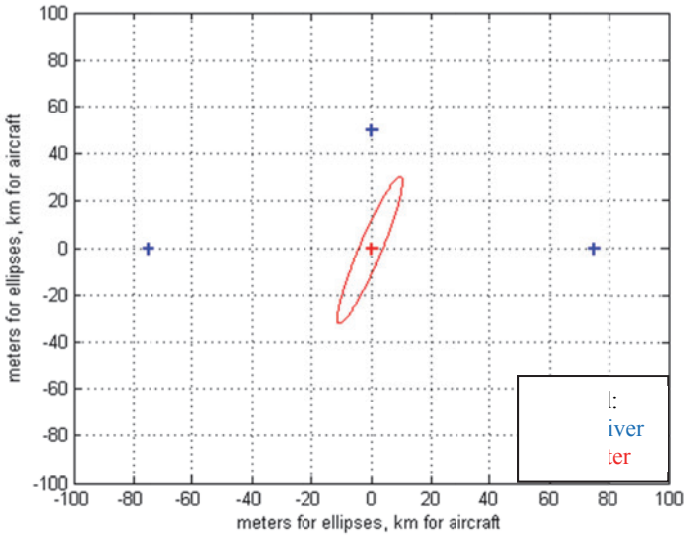
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This new ellipse is about 65,000m^2. As the two receivers move closer together, the difference in arrival for both TDOA and FDOA becomes so small that measurement errors and noise dominant the measurement.

Example: Impact of Number of Receivers

The number of receivers is a major determinant of the size of the error ellipse. Returning to the same scenario as the first example with two receivers positioned advantageously, we can add another receiver.

Figure 2.5
Adding a Receiver



The error ellipse is now much smaller, at 392m^2. The number and positioning of the receivers are significant contributors to the estimated error ellipse.

Example: Impact of Measurement Errors

The measurement errors incorporated in the tool are also important contributors to the size of the error ellipse. Again, returning to the same scenario as the first example with two receivers positioned advantageously, we see the impact of the error inherent in a receiver's

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ability to measure its own position and velocity, σ_p^2 and σ_v^2 respectively. These impacts are shown in Figure 2.6 and Figure 2.7.

Figure 2.6
Ellipse with Reduced Position Error

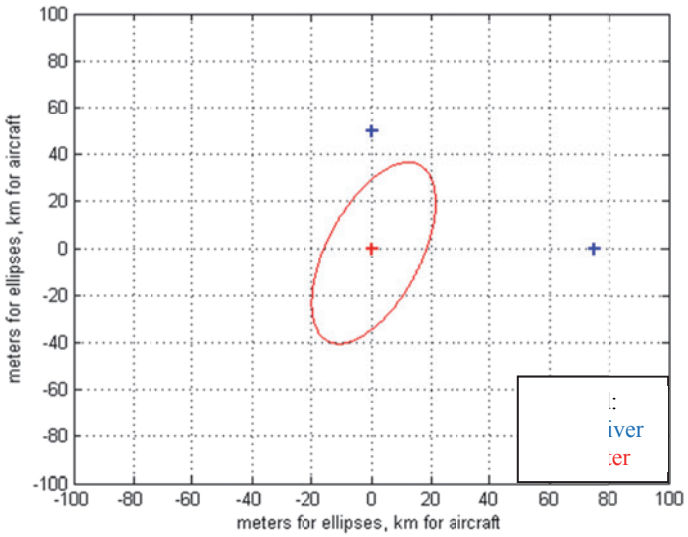
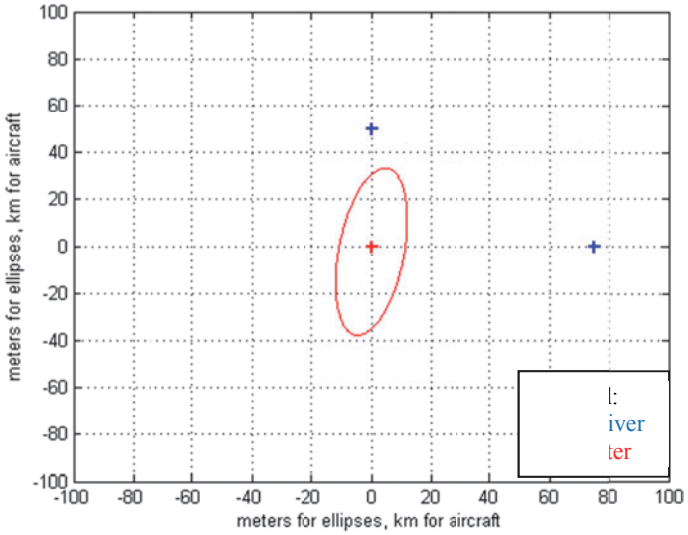


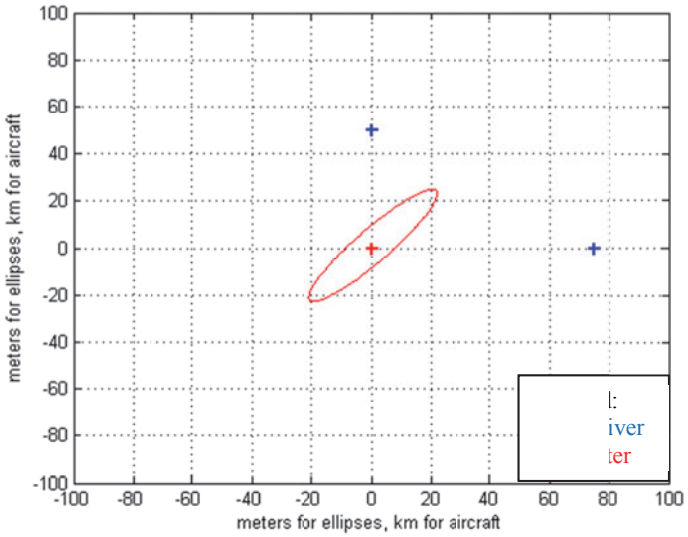
Figure 2.7
Ellipse with Reduced Velocity Error



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Reducing the error in the position measurement by half results in a slight reduction of the error ellipse to 2070m^2. Reducing only the error in velocity measurement by half reduces the error ellipse to 1230m^2.

Figure 2.8
Ellipse with Reduced Time Synchronization Error



Alternatively, decreasing the time synchronization error between the receivers by a factor of 10 reduces the error ellipse to 615m^2. The tool is also capable of handling scenarios in three dimensions. The result is an accuracy ellipsoid that incorporates uncertainty in the estimation of the altitude of the emitter.

The T/FDOA Accuracy Estimation Tool can provide useful information across a variety of applications. The tool can be used to predict the T/FDOA geolocation accuracy given a specific application. It can also be leveraged for research, such as the quantitative analysis in this dissertation. For this research, the tool was needed to evaluate the accuracy of T/FDOA as a means of quantifying the benefits of T/FDOA geolocation.

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3. When Is T/FDOA Geolocation Useful?

This chapter focuses on whether T/FDOA geolocation would be useful as a capability added to UAS operating today. Specifically, I am interested in whether T/FDOA would fill a gap and be a practical capability on UAS. The accuracy of the geolocation of a signal is dependent on the method of geolocation used, the characteristics of the scenario, and the signal of interest. Direction finding is a common geolocation technique; however, T/FDOA geolocation offers distinct advantages over direction finding. I explore these advantages using a simple model of direction finding to contrast the two techniques. The model is described in Appendix A.

Two major shortcomings of T/FDOA geolocation are the sensitivity of geolocation accuracy to the geometry of the receivers and the target and the requirement for multiple equipped platforms. I explore these two drawbacks in the context of today's operating environment. Today, multi-intelligence capable platforms are tasked with one intelligence priority (e.g., full-motion video-prime), and the orbit flown is optimized for that mission. If T/FDOA were to be added to UAS, I assume that UAS would continue performing their primary mission as tasked today, with geolocation done as a secondary mission. I examine the impact of the orbit geometries dictated by the primary intelligence mission on the expected geolocation accuracy using the T/FDOA Accuracy Estimation Tool. For T/FDOA geolocation, the multiple equipped platforms must be operating within line of sight of the same target. Using a combination of geospatial analysis and the T/FDOA Accuracy Estimation Tool, I analyze the line of sight coverage overlap and the resulting accuracy for specific targets in the current operating environment.

A Contrast of Direction Finding and T/FDOA Geolocation

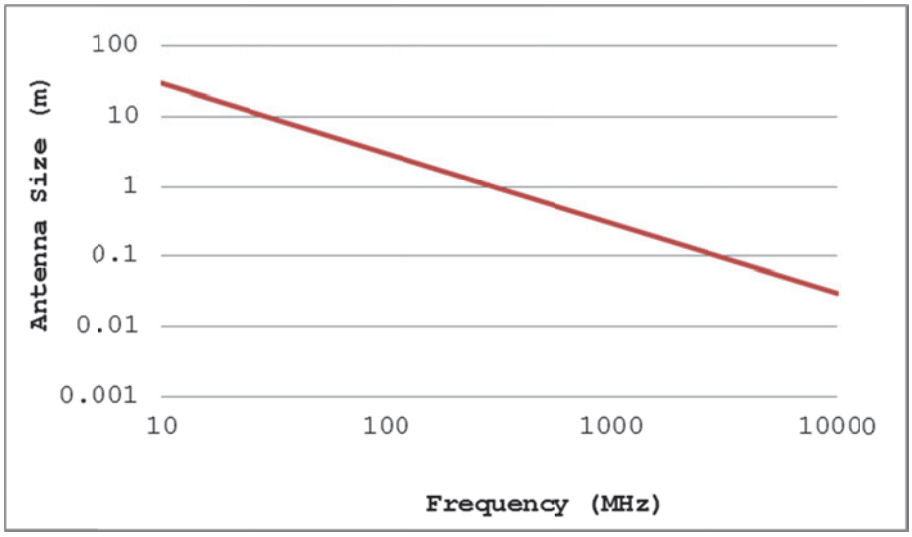
In the Introduction, some advantages and drawbacks to the traditional geolocation technique of direction finding and T/FDOA geolocation were briefly discussed. T/FDOA and direction finding are

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difficult to directly compare, because the accuracy of each technique is sensitive to variables that are specific to each application. It is more useful to contrast the techniques. This section goes into more depth on the advantages of T/FDOA geolocation by contrasting the two techniques. I describe the difference in antenna requirements for each technique and the implication for hosting the antenna on an airborne platform. The accuracy of direction finding is in part dependent on the time that the baseline is flown. I then contrast this time element of each technique. The geometry of the specific application impacts the accuracy of either technique; however, the range between the target and the receiver also influences the accuracy for direction finding.

For a system to use direction finding, it must be equipped with a directional antenna. The capability of a directional antenna to capture signals of different frequencies is directly related to its size. A rule of thumb is that the diameter of a circular antenna must be at least the length of the signal wavelength (Elbert 2008). The minimum circular antenna size required as the signal frequency increases is shown in Figure 3.1.

Figure 3.1
Antenna Size vs Frequency



Tactical communications, such as military push-to-talk radios, often operate in the HF and VHF bands, around 10-300MHz. Attempting to

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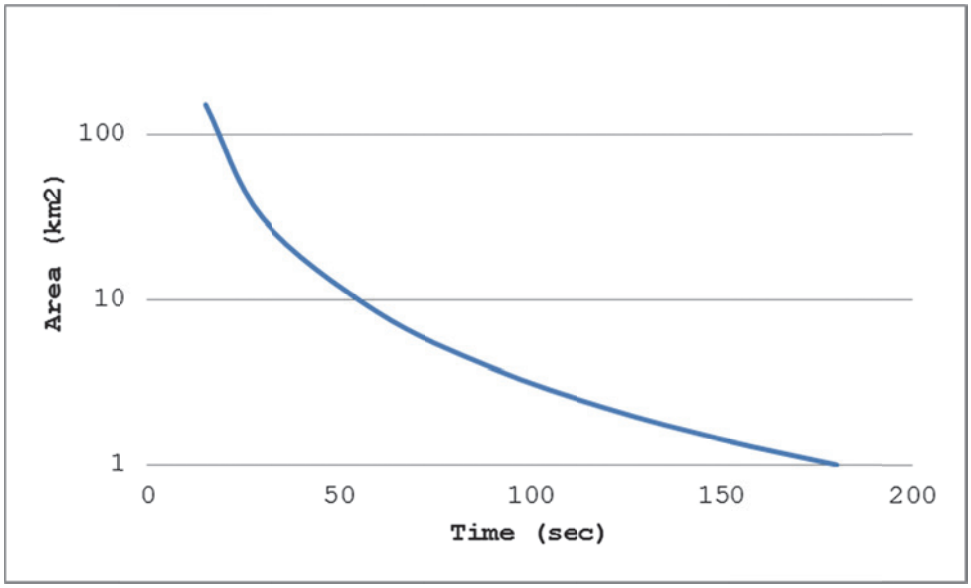
geolocate these types of signals using airborne direction finders can result in unwieldy antennas. For example, locating a 35MHz signal would require an antenna with an approximately 8.6m (~28ft) diameter. To target a 300MHz signal, the edge of the VHF band, requires a directional antenna to have a 1m (3ft) diameter. To put this in perspective, the MQ-1 Predator is only 27ft long, with a 55ft wingspan (ACC Public Affairs 2012). Its much larger counterpart, the MQ-9 Reaper, is 33ft long and has a 66ft wingspan (ACC Public Affairs 2012). Placing a directional antenna capable of receiving VHF band frequencies on a UAS is difficult because of the size, weight, and power (SWAP) limitations inherent with an airborne vehicle. In contrast, T/FDOA geolocation does not require a directional antenna. Instead, a smaller non-directional antenna can be used.[12]

To perform direction finding, an aircraft flies a baseline, measures multiple lines of bearing (LOBs), and then correlates those LOBs to determine the position of the target. The accuracy of direction finding is partly dependent on the length of the baseline, which can be thought of as a length of time. As the length of time a baseline is flown increases, the accuracy of direction finding increases. This relationship is shown in Figure 3.2.

[12] There are additional benefits to a directional antenna. For example, it provides gain, which improves the signal-to-noise ratio. A non-directional antenna does not have that benefit.

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Figure 3.2
Time of Baseline impacts Direction Finding Accuracy



NOTE: Calculations used the DF Model, explained in Appendix A. Assumptions included a range of approximately 125km, an AOA accuracy of 0.08deg, airspeed of 340kts, and a 3sec measurement interval.

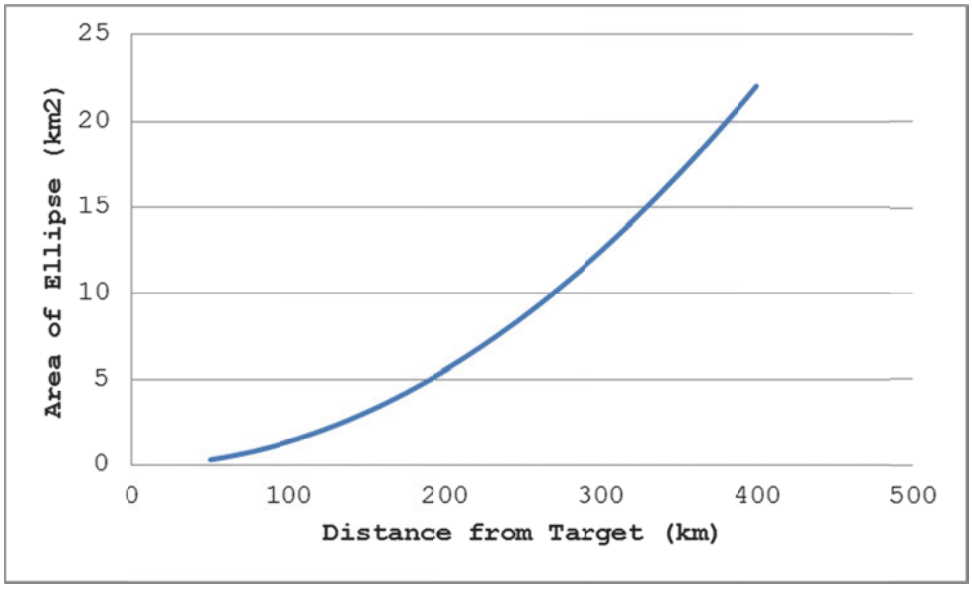
In general, accurate direction finding needs a baseline of a few minutes. For a medium accuracy geolocation of 1km^2, a baseline of approximately three minutes would be needed. The accuracy is therefore dependent on a cooperative target that continues to emit throughout the entire baseline. T/FDOA geolocation is not dependent on the length of time of collection. The collection can be extremely short, because the accuracy of T/FDOA geolocation is impacted by the timing synchronization of the correlated signals and not the length of the emission.

The accuracy of direction finding is more dependent than T/FDOA on the range between the receiver and the target emitter. In general, the closer the receiver is to a target, the better the accuracy of geolocation. Since T/FDOA takes advantage of the differences in time and frequency of arrival, T/FDOA does not suffer the same geometric issue related to range as direction finding. For direction finding, the accuracy degrades in a linear fashion with range. This relationship is shown in Figure 3.3. The ratio of the signal strength to noise level,

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the signal-to-noise ratio (SNR), impacts the accuracy for both direction finding and T/FDOA. The greater the range to the target, the lower the SNR and the more degraded the accuracy. In T/FDOA, the SNR is part of the error contribution from the Cramér-Rao lower bounds. Bardelli, Haworth, and Smith (1995) found that the Cramér-Rao lower bounds on T/FDOA measurement are typically very small and not the dominate source of error. Provided there is an adequate SNR such that T/FDOA can be calculated, there is little dependence on range, compared with direction finding.

Figure 3.3
Range to Target Impacts Direction Finding Accuracy



Calculations used the DF Model, explained in Appendix A. Assumptions included a baseline of approximately 120sec, an AOA accuracy of 0.08deg, airspeed of 340kts, and a 3sec measurement interval.

These three advantages—lack of requirement for directional antenna, lack of dependency on emission duration, and lack of dependency on range to target—of T/FDOA geolocation over direction finding make T/FDOA more robust in the types of emitters that can be targeted and less dependent on a cooperative target. A major drawback to T/FDOA is the requirement that multiple platforms receive the same signal and are able to cooperate to geolocate the target. If it were

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possible to use T/FDOA geolocation in a non-intrusive manner on UAS platforms equipped with other intelligence sensors and continue to achieve highly accurate geolocation, T/FDOA geolocation could greatly expand the geolocation capabilities of the military. The next section investigates the feasibility of using T/FDOA geolocation in a non-intrusive manner on UAS and quantifies the accuracy of geolocation that would be achieved.

Types of Intelligence and Resulting Orbits

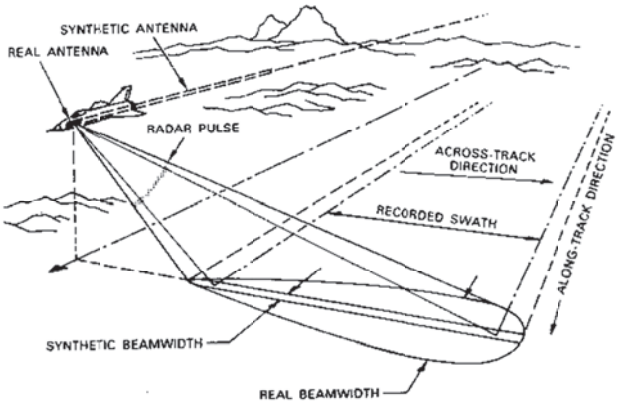
The Air Force categorizes ISR into five intelligence disciplines. These are geospatial intelligence (GEOINT), signals intelligence (SIGINT), measurement and signature intelligence (MASINT), human intelligence (HUMINT), and open-source intelligence (OSINT). Geospatial intelligence is the "exploitation and analysis of imagery and geospatial information to describe, assess, and visually depict physical features and geographically referenced activities on the Earth" (U.S. Air Force 2012). Imagery intelligence (IMINT) is a subcomponent of GEOINT that is defined as images that are recorded and stored (U.S. Air Force 2012). IMINT includes radar, infrared, or multispectral imagery, traditional visual photos, and full-motion video. This analysis focused on the various types of IMINT because those are the types of sensors most often hosted on UAS. The next several paragraphs explain intelligence missions that can be accomplished using UAS and the orbit requirements for each particular intelligence type.

Synthetic Aperture Radar. Synthetic aperture radar (SAR) was developed in the 1950s. It is used to image large areas at very high spatial resolution. In radar, an antenna transmits and receives radio waves to illuminate a scene. The range resolution is determined by the bandwidth of the signal transmitted, and the cross-range resolution is determined by the length of the antenna. An airborne antenna provides a good vantage point but physically limits the length of the antenna. For SAR, a small antenna is put in motion, transmitting and receiving signals to synthesize a much larger antenna, for example, an antenna several kilometers long, to achieve good cross-range resolution. SAR

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depends on specific algorithms to reconstruct the scenes into images. Most of these algorithms assume a straight flight path; any deviations are treated as motion error (Berens 2006).[13] A platform using SAR would fly in straight paths at a constant altitude with the swath width of the sensor as the width between passes.

Figure 3.4
SAR Requires a Straight Flight Path



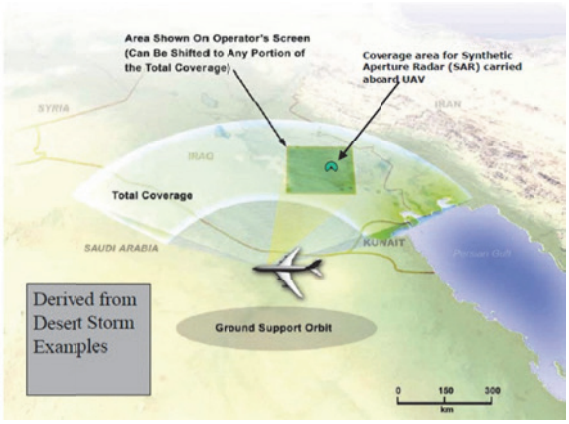
SOURCE: Image from FAO Fisheries and Aquaculture Department (1988).

Ground Moving Target Indicator. Ground moving target indicator (GMTI) is another intelligence collection technique that leverages radar. GMTI detects, locates, and tracks targets that are moving on the surface. For GMTI, the Doppler shift in the frequency of radar returns from a moving target is used to discriminate it from the static surface background (Dunn, Bingham, et al. 2004). GMTI was originally designed to distinguish movements of large objects, such as tanks and trucks, for battle space awareness. When employing GMTI, the platform is typically flown parallel to the area of interest in order to have the most coverage of the area. This results in an elliptical orbit with a small minor axis. A GMTI orbit derived from examples during Desert Storm is shown in Figure 3.5.

[13] Algorithms for SAR image formation using alternative flight paths have been developed, but are not commonly used (see Soumekh, 1999).

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Figure 3.5
GMTI Is Often an Elliptical Orbit



SOURCE: Dunn, Bingham, et al. (2004).

Imagery. By *imagery*, I mean still images generated from an optical sensor. Among other things, imagery is useful in identifying and providing visual information on targets of interest. In airborne applications, aircraft altitude and slant range affect the resolution and image quality. The path or orbit is not prescribed by the intelligence type, but is more dependent on the target deck[14] and efficiently prosecuting all targets. The target deck is likely different each day. A unique scheme of maneuver is developed for each mission; it outlines a track to capture all the requested imagery at the necessary resolution, in the most efficient manner possible. Figure 3.6 shows an example of a scheme of maneuver for imagery.

[14] The target deck or collection deck is a list of all the targets that need to be collected against.

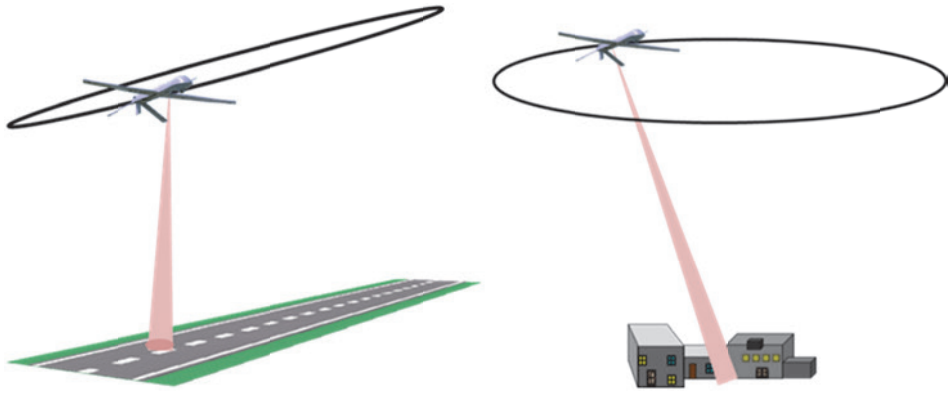
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Figure 3.6
IMINT Does Not Dictate an Orbit



Full-Motion Video. The demand for full-motion video (FMV) grew immensely during operations in Iraq and Afghanistan. FMV sensors are typically a turreted pod with dual electro-optical (EO) and infrared (IR) camera systems that permit operation across day and night. FMV is used in many tasks, with the task often determining the orbit flown. This analysis focuses on two common FMV orbits, a racetrack orbit and a circular orbit. A racetrack orbit would be used for a task such as monitoring a road for IED activity. A circular orbit would be used for a task such as providing 360-degree coverage of a compound prior to or during a raid. Figure 3.7 illustrates both of these orbits.

Figure 3.7
Racetrack Orbit for Road Surveillance and Circular Orbit for 360-degree Coverage of Compound



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MISSIONS HAVE A PRIMARY INTELLIGENCE FOCUS

Today, most UAS are tasked as ISR assets through the Combined Air Operations Center (CAOC). The CAOC takes in all the requests for ISR support, prioritizes the requests, and assigns the available air assets to fulfill the requests (U.S. Air Force 2011). Although many UAS are equipped with multiple sensors, when they are tasked by the CAOC, they are usually tasked with one intelligence type as their primary mission, for example, IMINT-prime or SIGINT-prime (AFISRAI-14-153 2009). The mission is planned to maximize the quality of the intelligence gathered. This results in a plan to collect the intelligence targets from an optimum altitude, velocity, distance, or angle to the target. In this way, the intelligence needed drives the orbit the platform will fly when collecting the intelligence.

SIGINT is typically provided by manned assets (Thompson 2004). UAS are predominately tasked for their imagery sensors, such as FMV. If a T/FDOA capability was added to UAS, multiple platforms would need to receive the signal in order to determine the probable location using T/FDOA geolocation. Given the high demand for FMV collection and the requirement for multiple platforms, T/FDOA geolocation would likely be accomplished as a secondary mission. The accuracy of T/FDOA geolocation is sensitive to the geometry between the collectors and the target. As discussed above, the different intelligence types dictate specific tracks or orbits that must be followed with different levels of rigorousness. The goal of this section is to show what level of accuracy might be expected if T/FDOA geolocation was included as a secondary mission.

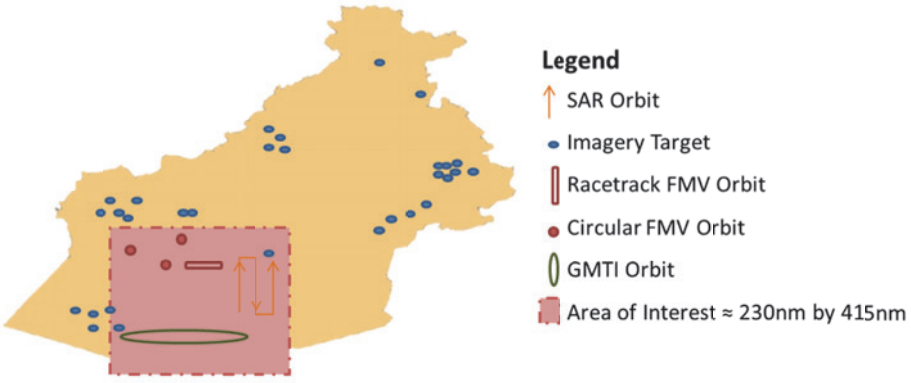
Scenario for Modeling Accuracies

During a day of operations, there will likely be several different intelligence collection missions operating within the same geographic area. Figure 3.8 shows an example of all the different intelligence missions that might be within line of sight of the same targets. There might be a standing target deck for IMINT collections, represented by the blue dots, from a manned or unmanned platform. JSTARS (the joint surveillance and target attack radar system) might be tasked to use its

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GMTI radar for border surveillance, shown as the green ellipse. Several MQ-1/MQ-9s might be using FMV to provide over-watch of a house raid, follow a high-value target, or cover a stretch of road to monitor for IED activity, as represented by the red circles and red ellipse. An MQ-9 equipped with SAR might be collecting high-quality terrain data or doing coherent change detection, shown by the orange track. All of these platforms might be operating within line of sight of a target emitter and capable of opportunistic collection on this target emitter, represented by the red box.

Figure 3.8
Operations Might Be in the same Area



For this analysis, I assumed that the T/FDOA system is capable of operating out to the radar horizon.[15] The radar horizon is dependent on the altitude of the platform. The altitudes that were used in these scenarios and the resulting geometric and radar horizon are listed in Table 3.1.

[15] If externals are collected, a system is theoretically capable of detecting signals out to the radar horizon.

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Table 3.1
Line of Sight Limitations

Altitude16 (kft/km)	Geometric Horizon (nm/km)	Radar Horizon (nm/km)
15 (4.572)	130 (241)	151 (280)
20 (6.096)	151 (280)	174 (322)
25 (7.620)	168 (311)	194 (359)
30 (9.144)	184 (341)	213 (394)

This analysis used five scenarios, with four different orbit geometries modeled: Circular FMV, Racetrack FMV, SAR, and GMTI. The focus was on intelligence types where the orbit is repetitive and must be followed with some level of rigorousness. For this reason, still imagery was not included in this analysis. As discussed above, the track an imagery mission uses is dependent on the collection target deck for that specific mission. It therefore does not require a repetitive orbit, and could be altered to participate in a T/FDOA collection. The scenarios featured two platforms flying to conduct their primary mission. The five scenarios that were modeled are summarized in Table 3.2.

Table 3.2
Scenarios for Orbit Geometries

Scenario	Orbit of #1	Orbit of #2
1	Circular FMV	Circular FMV
2	SAR	Circular FMV
3	SAR	Racetrack FMV
4	GMTI	Circular FMV
5	GMTI	Racetrack FMV

I varied the type of orbit flown, according to the above scenarios, and the parameters of the orbit. These parameters were meant to exemplify a few typical orbits.[17] The inputs for the orbits are summarized in Table 3.3.

[16] Calculated as slant range based on spherical earth, with 0 deg elevation angle.

[17] These parameters were developed in conjunction with members of the dissertation committee. The purpose was not to outline specific tasks and targets for each orbit, but to provide a few notional but practical examples of orbit geometries.

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Table 3.3
Orbit Inputs

	GMTI	SAR	Racetrack FMV	Circular FMV
Altitude	30k, 25k, 20k	30k, 25k, 20k, 15k	30k, 25k, 20k, 15k	30k, 25k, 20k, 15k
Speed*	200kts	200kts	200kts	200kts
Orbit Type	Ellipse	Up and Back Track	Racetrack (ellipse)	Circle
Parameters	100-150km, 20-50km	150km path, 2km turn	40-50km, 5-10km	20km or 10km radius

*Speed is constant; however, velocity is calculated based up the orbit.

The other parameters for the T/FDOA Accuracy Estimation Model were held constant throughout this analysis. In preliminary analysis, these parameter values were chosen as a representative case.[18] These parameters, values, and an explanation are listed in Table 3.4.

Table 3.4
Other Model Parameters held Constant

Parameter	Value	Explanation
Target Location	[0,0,0]	Orbits were rotated around target to account for geometric differences in target location
Number of T/FDOAs	1 TDOA, 1 FDOA	This represents a lower bound on the expected accuracy. At least 1 TDOA and 1 FDOA is required for T/FDOA geolocation.
Frequency of Signal	164 MHz	A representative VHF signal
Bandwidth of signal	25 kHz	A representative noise bandwidth
Integration Time	30 sec	Time for integration of signals
Power	7 dBW	5W EIRP, a typical power for a VHF push-to-talk radio
Sigma P	10.2m	Based on GPS P(Y) code error
Sigma V	5cm/sec	Based on typical error for GPS or low grade IMU
Sigma T	100×10^{-9} sec	10 times the worst case GPS clock synchronization error
Two D	1	Indicator for if third dimension (altitude) is known

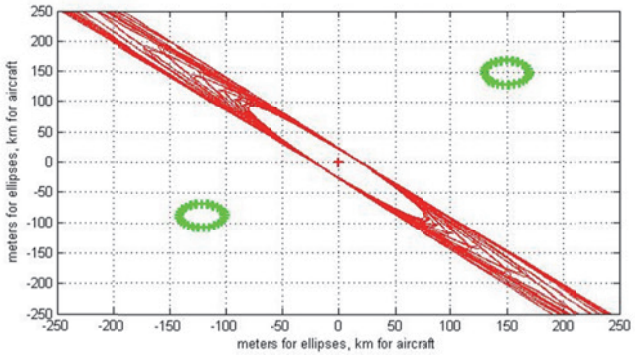
For each scenario, I modeled 10 cases in which the orbit parameters and orbit distances to the target were varied. Each case was run 50 times with a randomized starting point on the orbit for both

[18] There is a discussion of the impacts of parameters/errors in Chapter Two.

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platforms. Within each run, one orbit was rotated around the target to account for differences in geometric orientation and velocity relative to the target. At each rotation point, the orbits were run for 25 position steps, resulting in 200,000 model runs for each scenario. The full results for each scenario are included in Appendix B. An example from Scenario 1: Two Circular FMV Orbits is shown in Figure 3.9.

Figure 3.9
Example of Geolocation Accuracies from Scenario 1



In this example, the target is represented by the red cross. The two UAS orbits, represented in green, are circular orbits centered at (150km, 150km) and (-75km, -125km), respectively. Each red ellipse represents a T/FDOA geolocation in square meters resulting from those orbits. The geolocation is very sensitive to geometry.

Results from Orbit Geometries

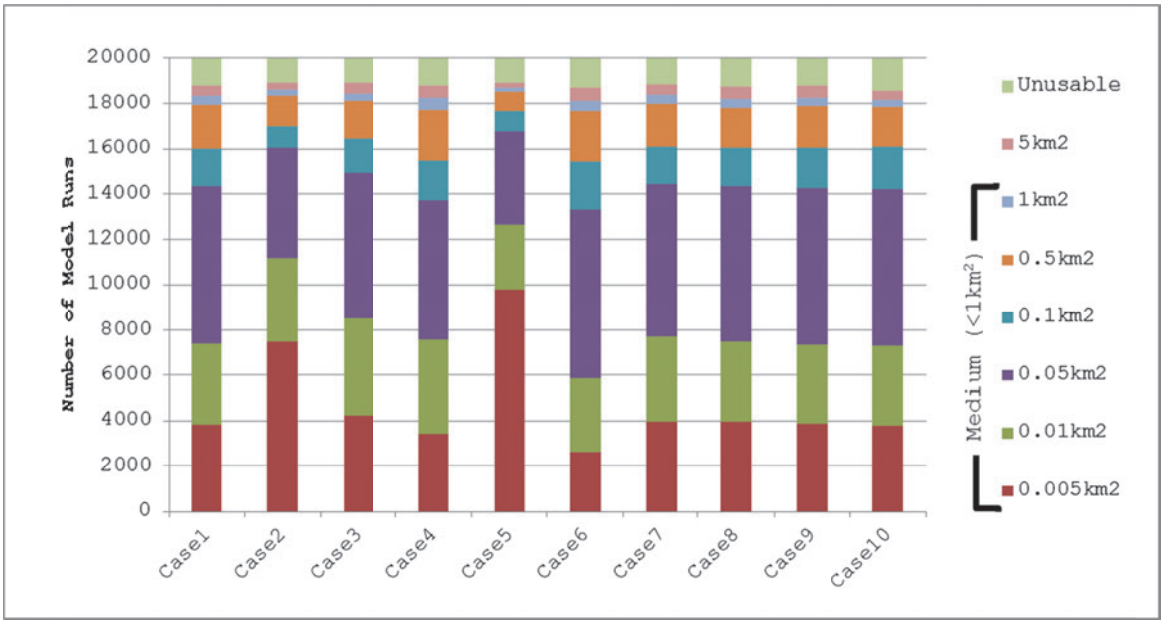
The results from Scenario 1: 2 Circular FMV Orbits indicate that, in most instances, very good accuracies can be achieved with this orbit configuration. A histogram of the area of the ellipses for each case is shown below in Figure 3.10. However, even when the primary mission orbits are placed closely together, there is still enough diversity in the geometry to result in a majority of medium accuracy geolocations.

Some configurations achieved overall better accuracies than others, for example, Case 5. The number of low and extremely low accuracies, those with an area greater than 1km^2, was fairly consistent and low across all the cases. However, examining only those

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geolocations within at least medium accuracy (<1km^2), there is not much stability between the cases. The placement of the orbits in relation to each other drives some areas to be significantly better than others. However, even when the primary mission orbits are placed closely together, there is still enough diversity in the geometry to result in a majority of medium accuracy geolocations.

Figure 3.10
Histogram of Areas from Scenario 1



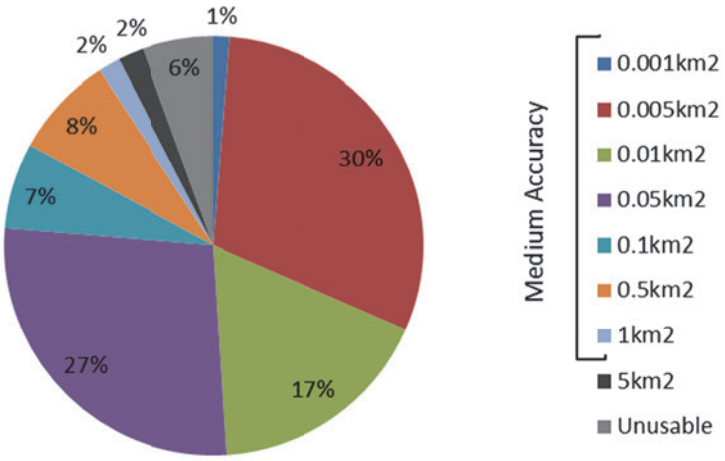
Examining these results categorized only by the area of the ellipse shows that over 90 percent of the geolocations resulted in medium (<1km^2) accuracy. Almost 75 percent of the geolocations had an area less than 0.05km^2, and a little under a quarter were actually within 0.005km^2. Of the approximately 8 percent of geolocations greater than medium accuracy, about 2 percent were of low accuracy (<5km^2), and 6 percent were unusable, resulting in no solution. The situations that did not result in a geolocation were the result of poor geometry.

The results from Scenario 1 indicate that, in most cases, the geometry created by the orbits optimized for FMV intelligence collection will still yield acceptable accuracies. Individually, the other scenarios had similar results. Results for all the scenarios are

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included in Appendix B. Tabulating the data across all the scenarios, the outcomes remain consistent.

Figure 3.11
Results for 5 Scenarios: Percent Distribution of Error Ellipse Areas



The analysis shows that T/FDOA geolocation is robust to the various orbit combinations. In these partly random, non-optimized scenarios, medium-level accuracy geolocations were achieved consistently. Approximately 90 percent of the geolocations were medium accuracy. Occasionally, the geometry will be poor enough to cause geolocation to fail. The geolocation failures were spread fairly evenly across each scenario, and amounted to approximately 6 percent of the total geolocations. In the instances of poor geometry, the two orbits were usually very close to each other, causing small differences in both the timing and the frequency. Infrequently, the geolocation resulted in high accuracy ellipses of less than $100m^2$. Ideally, high-accuracy geolocation would be preferred each time; however, these results can be thought of as an upper bound. For this analysis, I used only two aircraft, the minimum required for T/FDOA geolocation. More sensors would, in general, improve the accuracies. This analysis shows that as a secondary mission, on a completely non-interference basis, T/FDOA geolocation could be expected to provide at least medium-level accuracy in most instances. This level of accuracy could likely be

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improved with the addition of more sensors or including minimal planning for T/FDOA geolocation to coordinate orbit start times, orbit locations, etc.

WOULD UAS OPERATE CLOSE ENOUGH TO LEVERAGE T/FDOA?

To use T/FDOA geolocation, we need at least two platforms with line of sight to the target emitter. I used a model to characterize whether UAS fly close enough to use T/FDOA geolocation in Afghanistan. By FY13, the Air Force plans to have 65 available combat air patrols (CAPs) of MQ-1/9s (Schanz 2011). I used the ArcGIS software to model the CAPs and their line of sight ranges. The model randomly distributes the CAPs throughout the area of interest. It first determines the areas that are within line of sight of each CAP. These areas represent the potential coverage area for SIGINT. Then, it finds the areas that can be seen by multiple CAPs. These areas represent the potential regions for T/FDOA geolocation. The model does not taken into consideration limitations on line of sight caused by terrain. The model is explained in Appendix C. Air assets are typically apportioned according to a weight of effort (Joint Chiefs of Staff 1994). A weight of effort during the height of Operation Enduring Freedom and Operation New Dawn might have been 60 percent Afghanistan, 30 percent Iraq, and 10 percent for the rest of the world. I focused on Afghanistan as the bounding geometry.[19] I modeled the presence of 5, 10, 15, and 20 CAPs in the air simultaneously at four different altitude levels.[20]

As mentioned above, T/FDOA geolocation requires at least two aircraft. I first examined the potential T/FDOA geolocation areas or those areas covered by at least two CAPs. An example of the coverage available with 10 CAPs is shown in Figure 3.12, with green representing areas that are covered by at least two CAPs, red representing areas

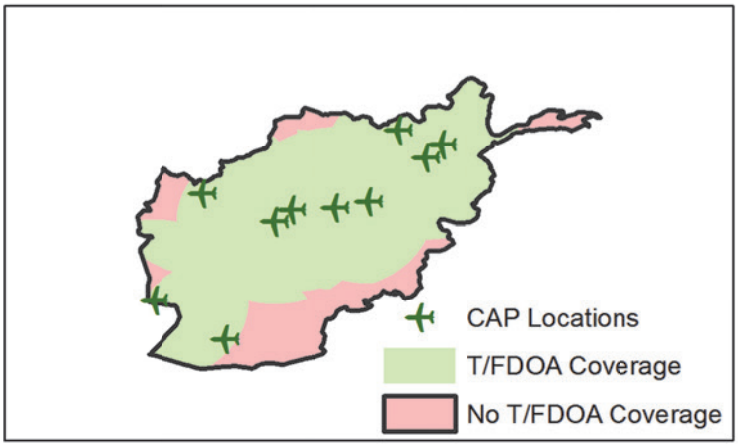
[19] I use Afghanistan for the bounding geometry, however I ignore the line of sight limitation of terrain. The results would be similar for any country or area of interest of similar size to Afghanistan.

[20] By FY13, the Air Force plans to have 65 available combat air patrols (CAPs) of MQ-1/9s (Schanz, 2011). These would be simultaneously available.

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that are covered by only one CAP, and white representing areas with no coverage.

Figure 3.12
Example Coverage with 10 CAPS



Coverage improves as either altitude or the number of CAPs is increased. For example, the line of sight from five CAPs at 30,000ft would be able to cover almost the same area of Afghanistan as 10 CAPs at 15,000ft. These relationships are shown in Figure 3.13 and Figure 3.14.

Figure 3.13
Area Covered by Line of Sight as Altitude Increases

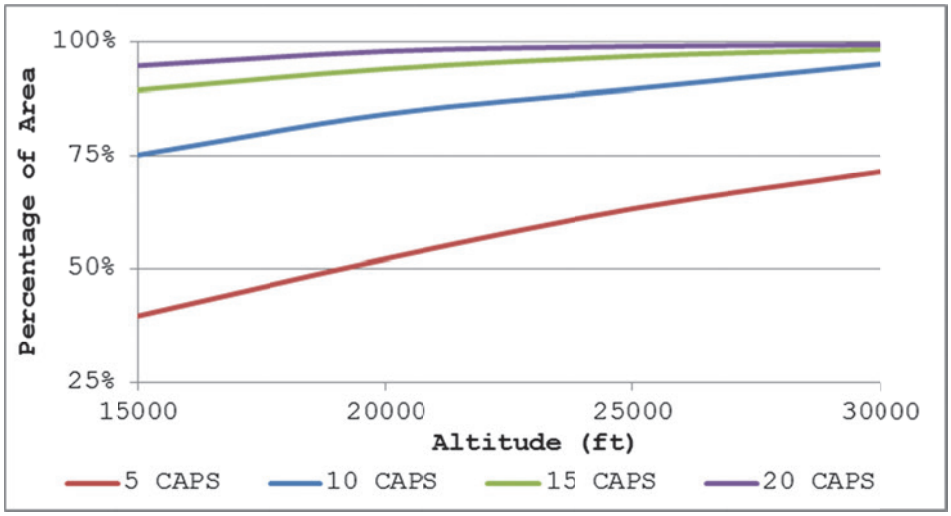
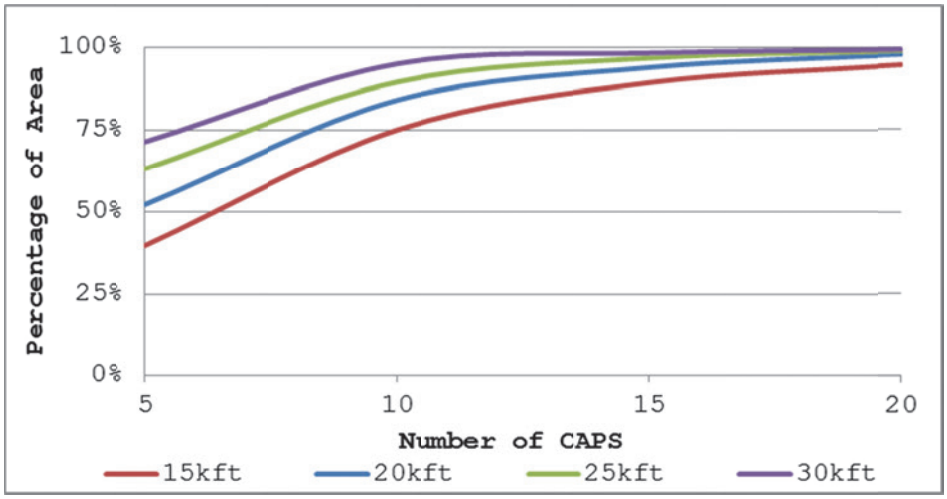


Figure 3.14
Area Covered as CAPs Increase



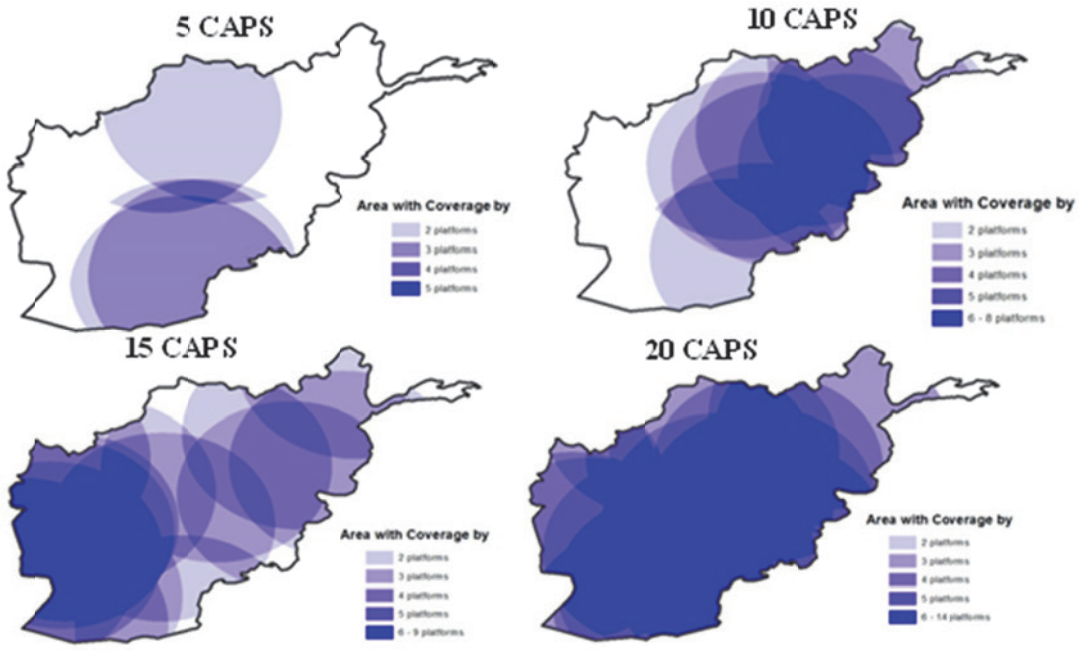
This analysis shows that a small number of UAS CAPs can provide T/FDOA coverage throughout most of an area the size of Afghanistan. Small increases in the number of CAPs and increasing the altitude significantly improves the amount of area covered.

In general, the accuracy of T/FDOA increases as the number of platforms participating in the geolocation increases. Though the accuracy is good when there are collections from two to three platforms, it can be remarkably better if more platforms are involved.[21] We can use the ArcGIS model to further determine exactly how many CAPs cover the area. Figure 3.15 below shows an example of the overlapping areas geographically for one example of 5, 10, 15, and 20 CAPs at an altitude of 20,000ft.

[21] Each new platform increases the number of TDOAs and FDOAs that are available for geolocation.

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Figure 3.15
Coverage for 5, 10, 15, and 20 CAPs at 20,000ft

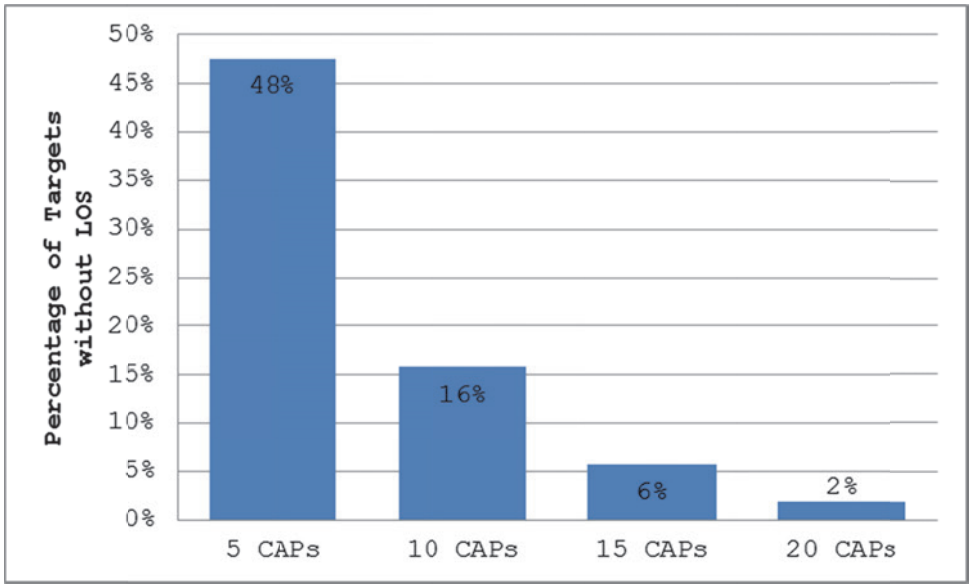


Increasing the number of CAPs available greatly increases the amount of area seen by more than two aircraft. As the area seen by four and five or more aircraft increases, the geolocation accuracy will also significantly increase. T/FDOA geolocation could be performed throughout most of an area the size of Afghanistan using only 20 CAPs; however would the accuracy of geolocations from these small numbers of CAPs be useable?

To test this, I used a combination of geospatial analysis with the T/FDOA Accuracy Estimation Model. I randomly distributed 20 targets throughout Afghanistan. The random location of CAPs from the previous analysis and the layer of random targets were used as inputs in the T/FDOA Accuracy Estimation Model. First, I examined the number of targets that were not within line of sight of at least two CAPs. These targets could not be found using T/FDOA geolocation. The number of targets without line of sight decreases as the number of CAPs increases, as shown in Figure 3.16. At 20 CAPs, the average number of targets that were unavailable was less than one.

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Figure 3.16
Average Percentage of Targets Without Line of Sight at 20,000ft



Next, I examined the accuracies for the targets that were within line of sight using the T/FDOA Accuracy estimation tool.[22] With only five CAPs, only a handful of targets are found with medium or high accuracy. With 10 CAPs at 15,000ft, approximately 25 percent of the targets were located with medium or high accuracy. As the number of CAPs increases or as the altitude increases the number of targets found with medium or high accuracy also increases. With 20 CAPs at 30,000ft, just under 95 percent of the targets can be found with medium or high accuracy. The number of targets found with high accuracies increases more than the number found with medium accuracy. Figure 3.17 and Figure 3.18 below show these relationships for geolocations at both 15,000ft and 30,000ft.

[22] I used the same parameters for the other model inputs as listed in Table 3.4.

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Figure 3.17
Results of Geolocations from 15kft

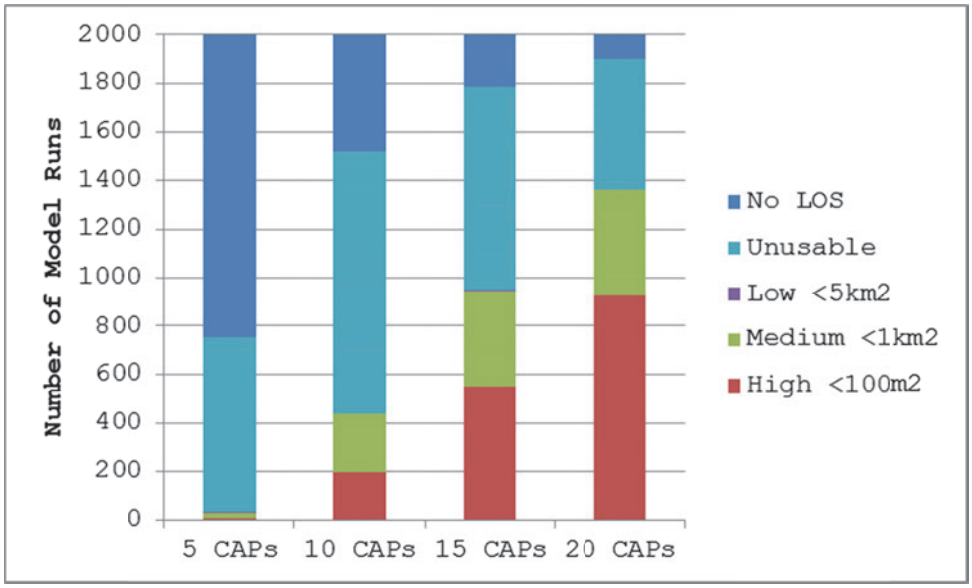
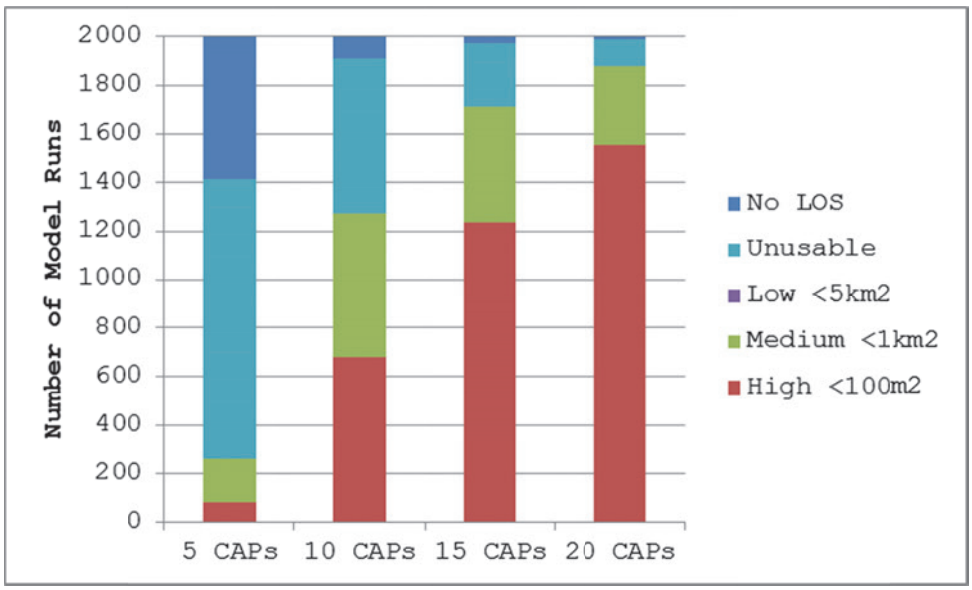


Figure 3.18
Results of Geolocations from 30kft



The results from the analysis indicate that UAS operating in Afghanistan or another similar sized area would be close enough to use T/FDOA throughout most of the area. The geolocations from these UAS have the potential to be very accurate. A few additional UAS CAPs

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greatly increases the likelihood of successful, accurate geolocation. Increasing the altitude at which the UAS are flown also has a significant impact on the amount of medium and high accuracy geolocations. In practice, there would be a trade-off between increasing the altitude for geolocation and impacting the spatial resolution of the primary intelligence.

CONCLUSION

The analysis shows that T/FDOA geolocation would be a very useful capability on UAS. When contrasted with direction finding, T/FDOA is more robust in several key ways that make geolocation of signals like push-to-talk radios less challenging. T/FDOA needs only a non-directional antenna, which is less SWAP restricting. T/FDOA is nearly instantaneous, and the accuracy degrades less with range. I explored the two major limitations of T/FDOA geolocation, sensitivity to the geometry of the receivers and the requirement for multiple equipped platforms, using geospatial analysis and the T/FDOA Accuracy Estimation Tool. The results indicate that T/FDOA would provide high-quality geolocation accuracy even as a secondary mission. The different orbit geometries have only minor impacts on the geolocation accuracy. In all of the orbit combinations, medium-accuracy geolocations accounted for nearly 90 percent of all the geolocations. Many of these medium-accuracy geolocations were closer to the high accuracy threshold.

I can conclude that the geometries created by the different orbit combinations are sufficient for quality T/FDOA geolocations. For T/FDOA geolocation to be possible, the participating platforms must be within line of sight of the same target. I explored this question and determined that with a fraction of today's available UAS CAPs, there would be enough T/FDOA coverage to cover most of an area the size of Afghanistan. The accuracies available from these UAS CAPs were of extremely high quality. With only 20 UAS CAPs at 30,000ft, almost 95 percent of the targets were found with high or medium accuracy.

This research used Afghanistan as the bounding geometry. The results would hold for countries of similar size. Modeling the impact of line of sight limitations caused by terrain features was not the

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point of this research. In general, terrain can impact the line of sight for emissions. Some areas that would be seen with a flat earth would be blocked from view. These blockages would reduce the area for T/FDOA coverage and could impact the number of targets found.

T/FDOA geolocation would be useful addition that would provide supplementary geolocation capability and capacity, while still enabling the UAS assets to continue to conduct their current missions.

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4. What Is Needed to Use T/FDOA Geolocation?

This chapter focuses on what would be needed for T/FDOA geolocation to be implemented on UAS. To be T/FDOA-geolocation-capable, the UAS will need to be equipped with a SIGINT system. I first outline specific requirements for a SIGINT system capable of T/FDOA. Then, I investigate the first T/FDOA capable system, AT3, to uncover technological and design challenges. Using AT3 as a guide, I detail integration on UAS and explain some challenges. An analysis of the costs of the SIGINT system is outside the scope of this work. A SIGINT sensor system on UAS will bring additional data that needs to be processed, exploited, and disseminated (PED) as intelligence. PED is often very manpower-intensive. I estimate the manpower needed for T/FDOA PED and the cost implications of the new manpower.

Equipment for Platforms to Be Capable of T/FDOA Geolocation

Two key choices to be made in designing a SIGINT system are the antenna and the receiver(s) to be used. These two choices drive the capabilities of the system. The system is usually described by several parameters, which are listed in the Table 4.1.

Table 4.1
System Parameters

Term	Definition
Gain	The increase in signal strength (dB) as the signal is processed.
Frequency coverage	The frequency range over which the system can transmit or receive signals.
Polarization	The orientation of the electric field of the radio wave.
Beamwidth	The angular coverage of the antenna (degrees).
Efficiency	Ratio of power radiated by the signal to power absorbed by the system.
Bandwidth	The instantaneous bandwidth of a signal that can be collected.

SOURCE: Adapted from Adamy (2001), p. 32.

For SIGINT tasks, the antenna choices are dominated by the ability to provide the required angular coverage (directional vs. non-

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directional), polarization, and frequency coverage. The receiver choice can be influenced by the information required for the task.

Channelized and digital receivers are the state of the art and the most capable. In previous years, they were considered too expensive and too SWAP-restrictive (Adamy 2001). Digital receivers offer several benefits over analog receivers that are important for a T/FDOA system. Additional channels are low-cost due to economies of scale (Hosking 2006). Digital receivers are low-powered with improved stability and accuracy and high reliability compared with analog receivers. In addition, the programmable nature of digital receivers means that often a software update is all that is needed to upgrade the receiver.

Requirements for T/FDOA

For a system to be capable of T/FDOA, it must first receive the signals. The antenna choice will be primarily driven by the signals of interest. For example, if the targets of interest are push-to-talk radios, then the antenna should provide the requisite frequency coverage of the UHF/VHF bands. A T/FDOA system must also be able to measure both the time of arrival and the RF frequency, so a simple receiver is not enough. Besides geometry, the largest drivers of T/FDOA accuracy are usually the timing synchronization error and the position errors. A T/FDOA system therefore needs the highest-quality timing and position inputs. T/FDOA requires coherent sensors. In this context, *coherent* has a broader definition than the traditional use of the term. A coherent sensor must "provide precise control of amplitude, frequency, and carrier-phase offsets, and must also take into account propagation delays" (Kosinski 2003). It must also provide precise location, timing, and axial orientation to every other sensor that will participate in the T/FDOA calculation. Since T/FDOA is a cooperative technique with geographically separated receivers, a data link is required to pass the data needed to calculate each T/FDOA.

AT3 System

The AT3 system is the first T/FDOA capable system designed from scratch. It was designed to be functional on any tactical platform. It

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leveraged and created new technology to create an affordable package with minimal SWAP burden. The goal for AT3 was an accuracy of at least 50m circular error probable (CEP) at distances greater than 50nm in less than 10secs (Highnam 2001). The T/FDOA techniques require precise measurement of time and frequency as well as transferring that information between participating collectors and conductors of the requisite PED. The precision requirements drive the system components used in AT3. Table 4.2 shows the key components of AT3 needed to accomplish T/FDOA and their functions within the system.

Table 4.2
AT3 Sensor System

Component	Function	Key Features
Radome	Protect antennas from weather, reduce drag on aircraft	Broad band
Antennas	Transduce RF energy into system	Broad band, wide field of view
RF Down Converter	Translate RF signals to an intermediate frequency	Broad band, low noise, wide IF bandwidth
Digital Receiver	Extract signal information from IF	Wide band, high-speed ADC, high sensitivity
Local Oscillator	Provide reference signals for system and RF down-conversion	Low phase noise, narrow phase lock bandwidth
GPS	Provide time, frequency and position information	All-in-view receiver
Frequency and Time Board	Synchronize AT3 with GPS	System clock, GPS time and frequency transfer
Signal Processing	High sensitivity	High-resolution channelizer, many narrow band detectors
	Precision Time	Leading edge measurement

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	Measurement Precision Frequency Measurement Geolocation	Phase measurement TDOA, FDOA, hybrid, derivative of GPS equation, erroneous measurement filtering
Data Link	Exchange data between aircraft	JTIDS, efficient slot utilization
AT3 INSTRUMENTATION SYSTEM		
Cesium Clock	Time and frequency reference	Primary standard
Time Interval Analyzer	Time benchmark between system clock and Cs Clock	
Frequency Measurement System	Short time frequency measurement	Hybrid phase noise/TIA, short time frequency benchmark between reference LO and Cs
Secondary GPS	Time Space Position Information (TSPI)	Commercial survey quality, support kinematic survey of aircraft

SOURCE: adapted from Raytheon (2004), p. 18.

In designing the AT3 system, DARPA encountered several technical challenges that needed to be overcome. The long-range goal of at least 50nm meant that an extremely sensitive receiver was needed. To provide this sensitivity, a digital receiver with a low noise multi-octave RF down converter was used (Raytheon 2004). As mentioned above, T/FDOA requires extremely precise knowledge of position and velocity. DARPA integrated an inertial navigation system (INS) with GPS to determine the precise aircraft state vector (Highnam 2001).

There were also issues with meeting the time and frequency transfer requirements. A Kalman filter was used to help align the data from the analog-to-digital converter into GPS time reference (Raytheon 2004). To verify the accuracy of time and frequency transfer, AT3 employed cesium clocks on each platform that were calibrated before and after each flight (Raytheon 2004). There were no algorithms for tagging

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time of arrival and frequency of arrival at the low SNR levels that would be encountered. The engineers designed a hybrid algorithm that accurately tagged the leading edge as well as identified potential issues within the pulse (Raytheon 2004). Finally, AT3 was required to use the existing Joint Tactical Information Distribution System (JTIDS) as the data link to pass information. JTIDS is a widely used system with limited available bandwidth. The solution was to reduce the data transferred by limiting the number of platforms involved (Raytheon 2004). Only two collectors passed data to a third master platform for each geolocation, reducing the bandwidth needed for T/FDOA. The AT3 system resolved many key challenges for a T/FDOA system.

UAS Integration

T/FDOA can be accomplished with a non-directional antenna. UAS are already equipped with several non-directional antennas for communications purposes that could be leverage by a T/FDOA system. For example, the MQ-1B Predator is equipped with an AN/ARC-210 digital communication system that has a frequency range of 30-941MHz, which includes a UHF/VHF antenna on the top side and under side of the platform (ACC Public Affairs 2012; Rockwell Collins 2012). The presence of a UHF/VHF antenna would allow the UAS to host a T/FDOA system without any external modification to the platform. Following the path set by AT3, a digital receiver would be the best choice because of its performance capabilities. The system would need to be integrated with GPS/INS to provide the needed precision for the aircraft state vector.

The reliance of T/FDOA on precise measurements means the design of the system can have significant influence on the accuracy of geolocation. The location of the system in relation to the GPS receiver can potentially impact the accuracy, especially if the platform will be turning or banking frequently. For example, if a system was located on the wing of the aircraft while the GPS receiver was located centrally on the body of the aircraft, the input of the receiver positions will be inaccurate. If the aircraft flew straight, this difference could be easily factored into the T/FDOA calculation. However, if the aircraft is turning or banking, there could be a difference in all three

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coordinates (x,y,z) that could not be easily corrected. The inaccuracy with which the receiver position is known can create geolocation ellipses that misstate the accuracy. The severity of these misstatements increases as the geometry degrades.

Figure 4.1
Geolocation Error Ellipse Can Be Influenced by Location of GPS in Relation to Receiver

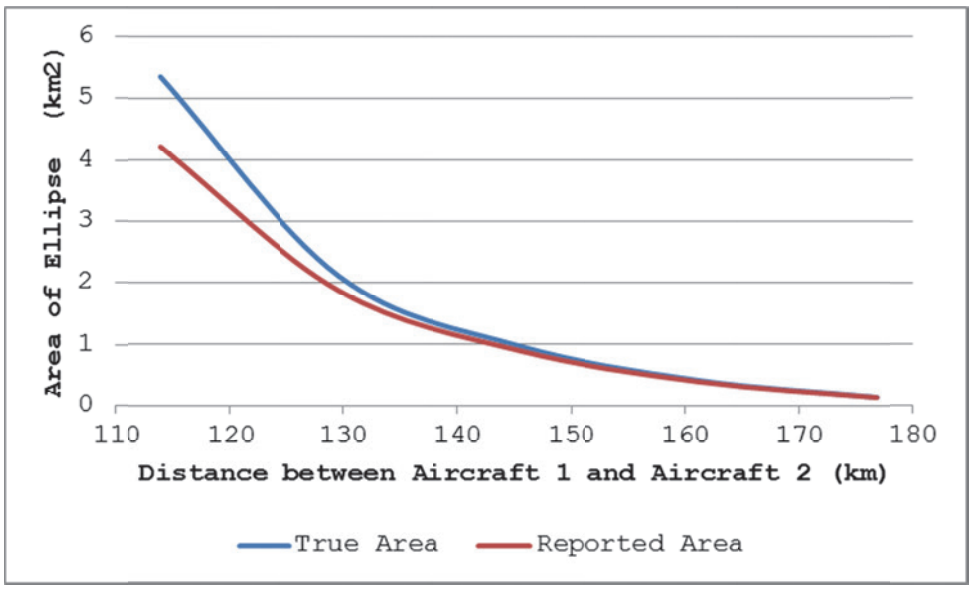


Figure 4.1 shows an example how the area of the ellipse can be misstated due to the position of the receiver in relation to the GPS receiver. In this example, two aircraft are used for the geolocation. One aircraft is in a simulated 30 deg bank. The banking aircraft is moved closer to the second receiver along a diagonal from the target location. Initially, the reported area overstates the true accuracy. However, as the geometry degrades, the reported area begins to understate the true accuracy.

The time interval for the reporting of the aircraft state vector can also influence the geolocation accuracy. These aircraft are moving at a typical speed of 200 knots, or about 100m/s in any given direction. The reporting frequency of the aircraft state vector can influence the accuracy of the state vector data, which in turn impacts the accuracy of geolocation. We can represent the impact of the

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reporting frequency as a change in the error terms for position and velocity. Figure 4.2 and Figure 4.3 show the impact of each error as it is increased and all other inputs are held constant.

Figure 4.2
Size of Error Ellipse Increases as Position Error Increases

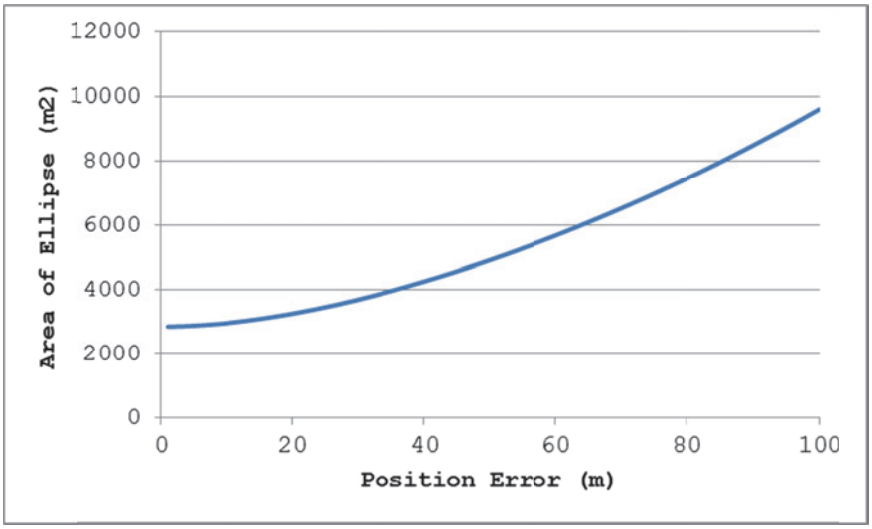
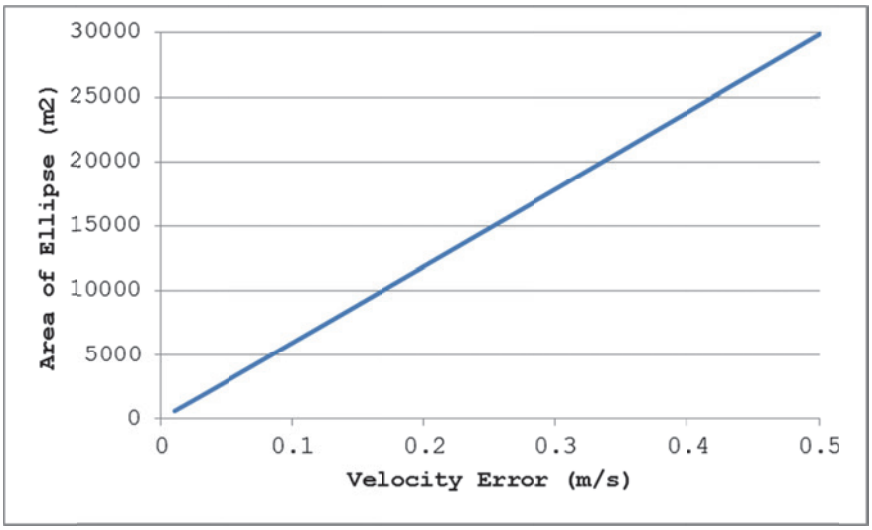


Figure 4.3
Size of Error Ellipse Increases as Velocity Error Increases

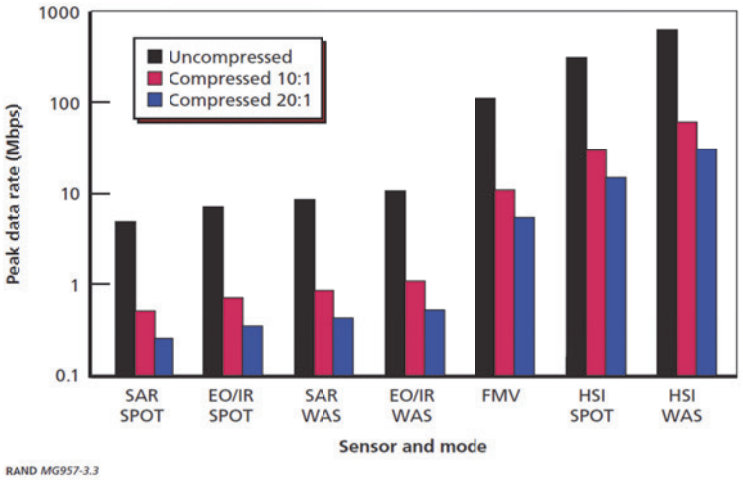


Small inaccuracies in the velocity and position measurement can lead to significant increases in the ellipse size. It is important to minimize the error contribution with quality system design.

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The constraint for using JTIDS data link forced AT3 to severely limit the number of collectors involved in the geolocation to reduce the bandwidth needed. A T/FDOA system on UAS would not be restricted to a similar solution because off-board geolocation calculation could take place at a PED center. For data dissemination and C2, UAS are currently operated with a constant data link. Two types of links are primarily used, a line-of-sight link or a beyond-line-of-sight link using satellite communication (SATCOM). The Army uses a line of sight data link with its RQ-7 Shadow that uses a C-band link to send data to the ground control station and then forward to users. A line of sight data link is a tether, restricting operations to within line of sight of the ground control station. The Air Force uses satellite communication (SATCOM) to send data back from its MQ-1s and MQ-9s (FY09-40 UAS Roadmap Undersecretary of Defense for AT&L 2009). The Reaper and Predator transfer data back to the PED centers using Ku-band SATCOM. The data from T/FDOA would piggyback on the intelligence data collected from the primary mission. Typical data rates for IMINT sensors are shown in Figure 4.4.

Figure 4.4
Typical Peak Data Rates for IMINT Sensors



SOURCE: Alkire, Kallimani, et al. (2010).

I evaluated the data rate that might be created from a T/FDOA system on UAS. A number of factors influence the data rate, including

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the bandwidth monitored, the duration of the emissions, and the periodicity of emissions on each channel. For this analysis, I assumed an emission lasts for 20 seconds, with one emission every ten minutes.[23] A typical VHF push-to-talk radio would have a 25kHz bandwidth per channel.[24] A storage buffer would be required to record the signals until an analyst determined that a geolocation was needed. I assume that the buffer would need to be at least large enough to hold one period's worth of emissions and that thresholding is used.[25] For each 25kHz increase in the bandwidth monitored, the buffer size increases 16Mb. The peak data rate is influenced by the speed with which the data is needed; I call this the urgency. Examining the peak data rate as the urgency changes shows that a quick time requirement can drive the date rate. Figure 4.5 shows the relationship between urgency and the peak data rate. I use an urgency of 90 seconds for the remainder of the analysis.

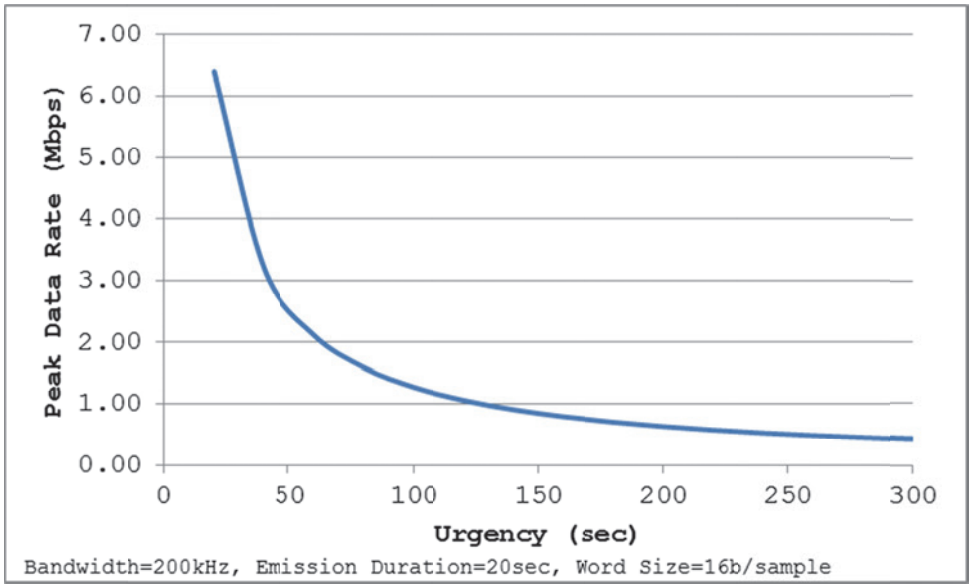
[23] The emission may last longer than 20 seconds. The entire emission is not needed to calculate a T/FDOA. Twenty seconds is more than adequate for the calculation in typical applications.

[24] VHF/UHF radios can be narrowband-capable with 12.5kHz channels. Narrower channels decreases the sampling rate, which in turn decreases the storage needed for one period of emissions and the peak data rate.

[25] Recording only occurs when a signal has been detected. Therefore, silence is not recorded.

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Figure 4.5
Peak Data Rate as Urgency Requirement Changes

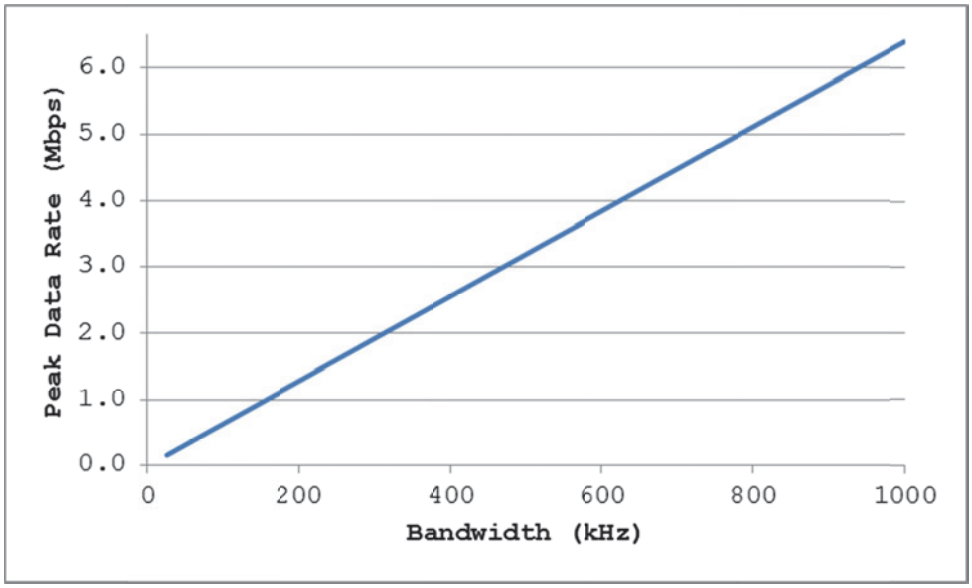


The peak data rate requirement as the bandwidth monitored increases is shown in Figure 4.6. Compared with the typical data rates for IMINT sensors, a T/FDOA system would add a small data rate burden. For forensic analysis, storage on-board the aircraft of all the emissions over the entire mission would be necessary.[26] Using a mission length of 16 hours, each additional 25kHz of bandwidth monitored increases the on-board mission storage requirement by 1.5 gigabits.

[26] This data would be transferred at the end of each mission to a more permanent storage. I expect that data would not be kept more than 30 days in the permanent storage. I do not estimate the capacity needed for more permanent storage.

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Figure 4.6
Peak Data Rate as Bandwidth Monitored Increases



Today, the United States purchases nearly all the SATCOM used for UAS from commercial sources. Since it is contracted, there is some flexibility in the availability of SATCOM. However, there would likely be some additional cost for providing the additional SATCOM for T/FDOA, even if the data rate burden is small. I did not estimate the additional cost of the SATCOM.

An analysis of the cost and SWAP implications of integrating a T/FDOA capable SIGINT system on UAS are outside the scope of this research; however, we can use the Harm Targeting System Revision 7(HTS R7) as an upper bound. The HTS R7 is a T/FDOA capable system that grew out of DARPA's AT3 program. Hosted on F-16 Block 50/52s, the HTS R7 enables these aircraft to cooperate to quickly locate and target surface-to-air missiles (SAMs). Each HTS R7 pod is approximately 1.2m long, with a diameter of 0.2m, and weighs 100lbs (ACC Public Affairs 2012). I estimate that the equipment for T/FDOA capability weighs approximately 20lbs.[27] I estimate that the power of a T/FDOA capable

[27] HTS R7 is an upgrade to the HTS R6. Primarily, the upgrade added the T/FDOA capability, including a digital receiver, GPS hardware, and Link 16 connectivity. The change in weight between HTS R7 and HTS R6

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system would range from 1 to 1.5kW.[28] The HTS R7 was procured for several years starting in 2006 at an approximate cost of $750,000 each (U.S. Air Force SAF/FM 2007).[29] The HTS R7 is much more complex and capable system than would be need to use T/FDOA geolocation on UAS. As such, I can consider it an upper bound on both the cost and SWAP implications of a T/FDOA-capable SIGINT system.

The technology for incorporating T/FDOA geolocation on UAS exists. Improvements have been made in digital receiver technology that reduce the cost and SWAP prohibitions. Many UAS are already equipped with antennas that could be used—for example, the UHF/VHF antenna on the MQ-1B. DARPA's AT3 program laid out many of the technical challenges. There are considerations for UAS that need to be explored, such as the placement of the receiver. The data rate, a limiting factor for AT3, is less of an issue for UAS because of the necessity of a large data link for transferring back other intelligence types, such as FMV. The peak data rate for T/FDOA geolocation would often be less than the data rates of typical IMINT sensors. The peak data rate could also be manipulated as shown in the analysis above to fit the mission demands.

MANPOWER FOR PED

Incorporating new sensors on UAS creates a new source of data that need to be turned into intelligence through processing, exploitation, and dissemination (PED). One of the largest drivers of manpower for UAS is PED. The Air Force's RPA Task Force estimated that for FY2011, approximately 4,750 personnel were dedicated to UAS PED alone (Menthe, Cordova et al. 2012). Each FMV CAP requires about 63 personnel for PED (Gear 2011). In this section, I estimate the manpower and cost implications of the PED for T/FDOA geolocation. I begin by outlining a potential CONOPs and organizational construct using the Air Force PED

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was about 20lbs. Information from ACC Public Affairs (2012). Fact Sheet: High-Speed Anti-Radiation Missile Targeting System.

[28] Estimate based of ASIP-2C power requirements. For more information see Penn, B. (2008).

[29] FY 2006 funds procured 22 HTS R7 pods for $16.917 million. Additionally, an FY08 GWOT submission for $25 million was requested to procure an additional 35 HTS R7 pods. For more information see U.S. Air Force SAF/FM (2007, 2008).

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enterprise, the Distributed Common Ground System. I examine the manpower needs for two organizational constructs, one where a single operator is capable of controlling a single sensor and one where a single operator could control multiple sensors. I then estimate the cost implications of these manpower requirements.

CONOPs, Organization, and Tasks

I assume all Class IV/V UAS would be equipped for T/FDOA. Since the Air Force has majority of these assets, I use the Air Force's PED structure to investigate what the manpower requirements for T/FDOA PED might be. The Air Force operates its large UAS under the remote-split operations concept. In this concept, the aircraft are forward deployed to the operating area with a small crew. The forward crew controls the takeoff of the aircraft with a line of sight data link, then switches to a SATCOM data link and passes control to a stateside crew. The bandwidth and coverage of SATCOM also allows the PED components of the mission to remain stateside.

For the Air Force, intelligence data such as FMV collected by UAS travels through SATCOM to different PED sites in the Distributed Common Ground System (DCGS). The DCGS provides the "capability to conduct multiple, simultaneous multi-intelligence (Imagery, Signals, and Measurements and Signatures) ISR missions worldwide through distributive and collaborative operations" (AFISRAI-14-153 2009). In some cases, DCGS has the capability to control the sensors (AFISRAI-14-153 2009). I would expect that the set up for T/FDOA would be similar. The DCGS would control the SIGINT sensors for T/FDOA. All of the data gathered from these sensors would be processed within the DCGS enterprise. The geolocation from T/FDOA would be calculated at the DCGS, and the DCGS would be responsible for disseminating the intelligence. T/FDOA is a multi-platform technique. Consequently, the systems would need to be setup as "master/slaves." The operator would initiate a T/FDOA on one system, the master, and all other systems in the area would automatically tune to the frequency, the slaves.

I considered two different organizations, one where a single T/FDOA operator controls one sensor (one-to-one) and one where a single

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T/FDOA operator controls multiple sensors (one-to-many). I placed the T/FDOA PED in different settings within the DCGS. For the one-to-one construct, it makes the most sense to place T/FDOA PED with the platform PED crew. Today, the PED crew is tied to the platform it is supporting. Placing the PED for T/FDOA within the crew would keep with the focus on the crew. T/FDOA would be employed in a supporting manner to other intelligence types, and so having close contact with other crew members might facilitate employment. In the one-to-many construct, the T/FDOA PED would be done within the DCGS Analysis and Reporting Team (DART). The DART is a regionally focused fusion cell designed to correlate and synthesize the intelligence data collected from the platforms/sensors that the DCGS manages or exploits and fuse this data with external sources of intelligence. The multi-platform nature of T/FDOA and the multi-intelligence correlation for PED fits nicely with the mission of the DART. Placing the PED for T/FDOA within the DART would leverage the area focus of the DART.

Regardless of how many sensors the operator can control and where the operator is located, there are certain tasks that he or she would do. First, the operator would need to work with the contact from the ground forces to determine the frequencies of interest. In most missions, T/FDOA geolocation should be employed using prior information, as opposed to a means to discover new adversary frequencies. The operator would be in control of the receiver(s) and initiate the geolocations.[30] For example, if a known frequency became active, the operator might choose to create a new T/FDOA geolocation every time the frequency is active for more than 10secs. The operator would actively work to cross-cue with other intelligence types, including intelligence gathered from the same platform and intelligence gathered from nearby platforms. The operator would report the geolocation intelligence. For example, he or she might create a short document that shows the error ellipse, the frequency, and any other information known about the target. Finally, the operator would be

[30] It is likely possible to automate the initiation of geolocation; however, an operator would likely still verify the results before reporting the intelligence.

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responsible for sending the document to the supported unit and informing the DART for correlation with other area intelligence. Given these tasks, the operator would most likely be at least a SrA with an all-source (1N0XX), electronic signals exploitation (1N5XX), or cryptologic linguist (1N3XX) background.

PED Within Platform Crew

Today, a typical FMV crew for UAS is composed primarily of imagery specialists. The crew positions, specialties, and minimum ranks are shown in Table 4.3.

Table 4.3
UAS FMV Mission Crew Positions

Crew Position	AFSC	Rank	Previous Qualification
Mission Operations Commander (MOC)	14N	2Lt	
Imagery Mission Supervisor (IMS)	1N1 (imagery)	SSgt	IRE
Mission Planner (MP)	1N1 (imagery)	SrA	IA
Imagery Report Editor (IRE)	1N1 (imagery)	A1C	IA
Imagery Analyst (IA)	1N1 (imagery)	AMN	
Multi-Source Analyst (MSA)	1N0 (all-source)	A1C	
Screener	1N1 (imagery)	A1C	IA
TACOM	1N4 (networks)	AMN	

SOURCE: Adapted from AFISRAI-14-153V3 (2009).

The MOC and MSA are the only crew positions with defined multi-intelligence responsibilities.[31] The MOC is the overall supervisor, responsible for the direction of the ISR mission. As such, the MOC manages all SIGINT, IMINT, and/or MASINT collection. The MOC is also responsible for facilitating cross-cues in conjunction with the MSA.

[31] Both positions have additional responsibilities. For full description of roles and responsibilities see the Air Force Distributed Common Ground System Operations (AFISRA 14-153V3 2009) Attachment 2.

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The MSA is responsible for collecting and maintaining the target research necessary to complete the IMINT, SIGNINT, and MASINT tasking. The MSA also coordinates with the MOC on cross-cues. In contrast, the PED crew positions for other assets with both SIGINT and IMINT missions include a position dedicated to correlating the various intelligence data collected by the platform, the correlation analyst (CAN), and several other positions with some multi-intelligence responsibilities in addition to a MOC and MSA.

The CAN is considered the focal point for multi-intelligence correlation. One of his or her responsibilities is to monitor all of the SIGINT, MASINT, and IMINT reporting and identify potential for cross-cueing and dynamic sensor re-taskings. The CAN is also responsible for coordinating with the different intelligence mission supervisors during cross-cue opportunities. The CAN has an all-source or networks intelligence background, is at least a SrA, and previously performed duties as the TACOM or MSA.

Given the tasks required for T/FDOA geolocation and the imagery expertise of current crew positions, a new position for T/FDOA PED would likely be needed. This position would be similar to the CAN position for the SIGINT crews. He or she would be responsible for the tasks outlined above for T/FDOA geolocation as well as the focal point for multi-intelligence synthesis for the crew.

PED Within DART

The DART is a relatively new concept created to add flexibility and responsiveness into the DCGS for the COIN/counterterrorism missions encountered in Operations Enduring Freedom and Iraqi Freedom. The DART construct includes five DARTs at each of the five core distributed ground station sites and additional specialized DARTs. The core distributed ground station cells are regionally focused, supporting specific theater(s). The DARTs are responsible for maintaining an overall picture of all DCGS platforms/sensors and a status of mission execution to enable ad-hoc taskings. The DARTs are also tasked to continuously monitor the overall adversary situational awareness picture for their specific area. Beyond providing situational

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awareness, the DARTs rapidly correlate data from the various intelligence sources and create integrated products for the supported units. As part of this analysis, the DART is expected to identify developing targets from the association of the disparate intelligence sources.

There is no specific guidance on positions within the DART. It is difficult to say whether the DART already has the expertise and available personnel to incorporate the T/FDOA PED tasks into the workload of an existing position; therefore, I will assume that a new position is necessary. This assumption will provide an upper bound for the manpower estimation. It is also difficult to say how many sensors a T/FDOA CAN could manage. I will analyze the manpower where control of 2-4 sensors is possible.

Manpower and Costs Implications for Approaches

The DCGS operates 24 hours, seven days a week to conduct PED for missions flown around the world. There are therefore limitations on the length of a crew duty period. A PED crew member may work a maximum crew duty of 12 hours. Crew duties are those that directly support the mission. For example, time spent preparing, planning, executing, and post-mission recordkeeping are all included. General military training and general squadron duties and tasks are not considered crew-related duties. For each CAP supported with T/FDOA PED embedded with the platform crew, we need five people to fill the one position.[32] The number of CAPs that we wish to support heavily influences the total minimum manpower requirement.

Table 4.4
Manpower for T/FDOA PED

	With Crew	With DART		
		2 Sensors	3 Sensors	4 Sensors
35 CAPs	157	79	53	40
50 CAPs	224	112	75	55
65 CAPs	291	146	97	73

[32] See Appendix D for the minimum manpower factor calculation.

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Table 4.4 shows the minimum manpower requirement at several different CAP levels. These manpower requirements are relatively small when compared with the requirements for other aspects of the PED. There are significant manpower savings if an operator is capable of controlling multiple sensors.

I can estimate the cost implications for the minimum manpower requirements. I calculated the cost implications using the FY2011 Total Annual Composite Rates from the Military Annual Standard Composite Pay based on the President's Budget. The rate includes costs for basic pay, health care, retired pay, allowances and incentive pays, etc. Since I expect the operator to be at least a SrA (E-4), I averaged the rate for E-4 to E-6. The resulting rate was $76,680.

The cost implication per CAP is $383,400 annually for T/FDOA PED with the crew. Table 4.5 shows the estimated cost implications for T/FDOA PED at several different numbers of CAPs. Again, there are significant savings if an operator is capable of controlling multiple sensors. I estimate the maximum cost implication of T/FDOA PED to be $20.6 million for the Air Force annually. This cost would be for using T/FDOA on all planned Air Force UAS with T/FDOA PED done by a new position with one-to-one positions per CAP.

Table 4.5
Costs for Manpower for T/FDOA PED in $100,000

	With Crew	With DART		
		2 Sensors	3 Sensors	4 Sensors
35 CAPs	$12,038	$6,058	$4,064	$3,067
50 CAPs	$17,176	$8,588	$5,751	$4,294
65 CAPs	$20,626	$10,352	$6,901	$5,214

The manpower and cost implications for T/FDOA PED are minimal compared with the rest of the manpower dedicated for UAS PED. The minimum manpower requirements can be reduced by enabling one operator to control multiple sensors.

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CONCLUSION

The analysis shows that small changes are needed for T/FDOA geolocation to be implemented on UAS. Each UAS would need to be equipped with a SIGINT system; however, the technology for T/FDOA already exists, and many of the pieces are already in place. For example, most UAS are already equipped with several different antennas that could provide frequency coverage of communication bands like UHF/VHF. AT3 broke through many of the technical barriers to T/FDOA. There will be unique design considerations for implementation on UAS, but these can be positive. For example, the data transfer issues would be easier on UAS because of the use of large data pipes for other intelligence distribution and C2. I caveat this research by acknowledging the difficulties that can be faced when integrating new technologies on aircraft.

Additional collection of intelligence data requires additional manpower to process, exploit, and disseminate that data as usable information. For the Air Force, T/FDOA PED would likely be done within the DCGS, similar to PED of other intelligence data. The CONOPs and tasks needed for T/FDOA PED influence the estimate of the manpower required. I let the number of sensors the operator can control vary and determine the minimum manpower required to sustain 24/7 operations. This manpower ranges from 40 to 291 people, depending on the number of sensors an operator can control and the number of CAPs of T/FDOA PED used. The cost implications of these manpower requirements range from $3 million to $20.6 million annually. The manpower and cost implications for T/FDOA PED are minimal compared with the rest of the manpower dedicated for UAS PED.

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5. How Can T/FDOA Be Leveraged in Multi-Intelligence Operations?

This chapter focuses on how T/FDOA can be leveraged in multi-intelligence operations. I first provide some background on why multi-intelligence operations are useful. I then present an example to show how T/FDOA geolocation can improve multi-intelligence operations. Finally, I investigate the command, control, and communication (C3) that would be needed for these complex operations to be successful.

Background for Multi-Intelligence Operations

There are tradeoffs between the intelligence type used and the information that can be provided. For example, IMINT can provide some identification and location, but not necessarily intent. FMV can provide identification, location, tracking, and intent, but has a very limited field of view. As targets improve their concealment, mobility, and dispersion it becomes more difficult to generate the intelligence necessary to prosecute the targets (Isherwood 2011). Fusing intelligence gathered from multiple sources provides a much more complete picture.

Table 5.1
Intelligence Types Provide Different Information About the Target

	Who	What	Where	When	Why	Field of View
SIGINT	Yes	Yes	Yes	Yes	Yes	Wide
GMTI	No	Yes	Yes	Yes	No	Wide
IMINT	No	Yes	Yes	Yes	No	Medium
FMV	No	Yes	Yes	Yes	No	Narrow

SOURCE: Adapted from Isherwood (2011), p. 20.

Layering ISR by positioning ISR assets over the same geographic areas at the same time is one way to generate intelligence that can be fused. Layering complementing ISR can provide more information about each target. For example, by fusing IMINT and SIGINT, we might be able to identify a decoy SAM from an actual SAM. Layering ISR can also

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improve the accuracy of information. For example, suspicious movement characterized by GMTI and paired with FMV could show that the movement is an illegal checkpoint set up by the enemy. These improvements in quantity and quality enhance operational decisionmaking and the ability to respond. Using SIGINT with T/FDOA geolocation on UAS would help layer at least two intelligence types for nearly every UAS mission.

Cross-cueing is defined as an exchange of intelligence data between units intended to generate additional collection on the same target/activity to create higher confidence, more accurate, or more complete reporting (480th ISR Wing 2010). It is also known as a tip-off, intended to increase situational awareness (480th ISR Wing 2010). Cross-cueing is typically thought of as cueing between the different intelligence types or assets to provide additional information. It is an important force-multiplier, allowing the complementing capabilities of each intelligence type to be focused on one target. In today's war, multiple sources of intelligence are often needed to find and locate the enemy (Isherwood 2011). One example of cross-cueing would be using the GMTI to track a target that has been geolocated from SIGINT.

Impact of T/FDOA Geolocation

Two of the advantages of T/FDOA, speed and accuracy, could significantly improve our ability to conduct multi-intelligence operations and use cross-cueing. In a cross-cue, the second intelligence type often must search a particular location to find the target of interest. For example, if trying to cue FMV from a SIGINT hit, an analyst might have to search throughout the ellipse to find the target. Therefore, the accuracy of the geolocation is a large driver of the time it can take to find the target.

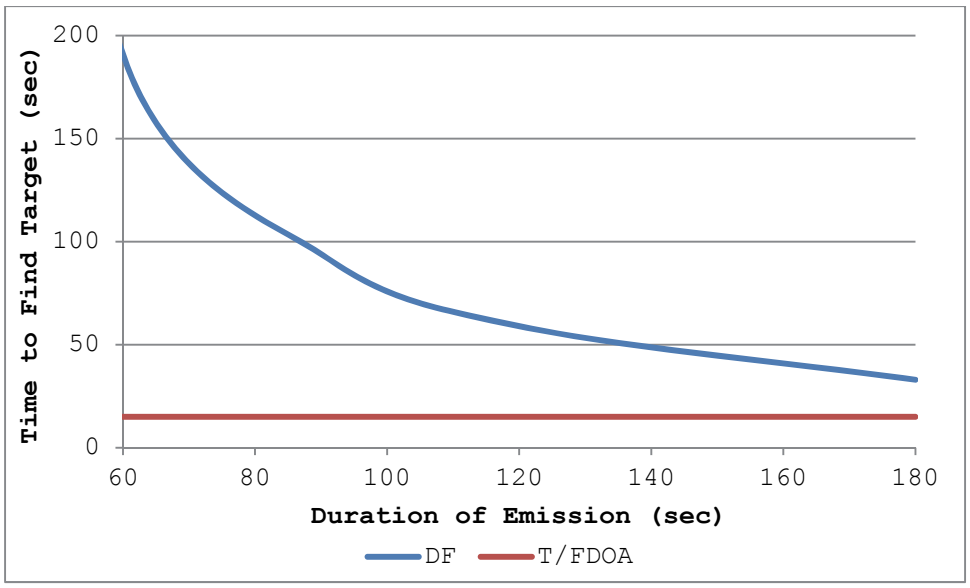
Operation with Direction Finding versus T/FDOA Geolocation

I compared the time it would take to find a target using FMV if the geolocation of the SIGINT cue was accomplished using direction finding or T/FDOA. I use two UAS each equipped with FMV to search the error ellipses resulting from the geolocations. For direction finding, the length of the baseline severely impacts the accuracy of

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geolocation. I assume the baseline is as long as the duration of the emission. As the emission duration increases, the error ellipse shrinks, and so the time to find the target using direction finding decreases. However, as Figure 5.1 shows, using T/FDOA geolocation is better than even a baseline of more than three minutes.

Figure 5.1
Size of SIGINT Ellipse Impacts Time Needed to Find Target



NOTES: The analysis assumes a static target with the SIGINT platform in close proximity (50km) to the target. I use a report time of 10sec for the SIGINT to FMV cue. For FMV, a resolution of 0.3 meters is required. An FMV platform at 25 km range, 12.4kft altitude, equipped with a 0.16 meter diameter optic with 8 meter focal length at 0.8 micrometer (near IR) wavelength with 0.02 by 0.02 meter detector array will have a resolution of 0.3 meters (diffraction limited). The spot size would be 62.5 by 413 meters (0.02582 km2). I use a dwell time of 5sec for each FMV spot and slew time of 2sec to move the spot to a new location.

The longer FMV must search for a target, the higher the chance that the target will be lost. The accuracy of T/FDOA geolocation can greatly reduce the search time for an emitter.

In this example, the FMV platform did not need to travel a great distance to arrive at the geolocation error ellipse. Although T/FDOA geolocation can be nearly instantaneous, and therefore reduce the time to search the area, the same limitations on aircraft movement exist.

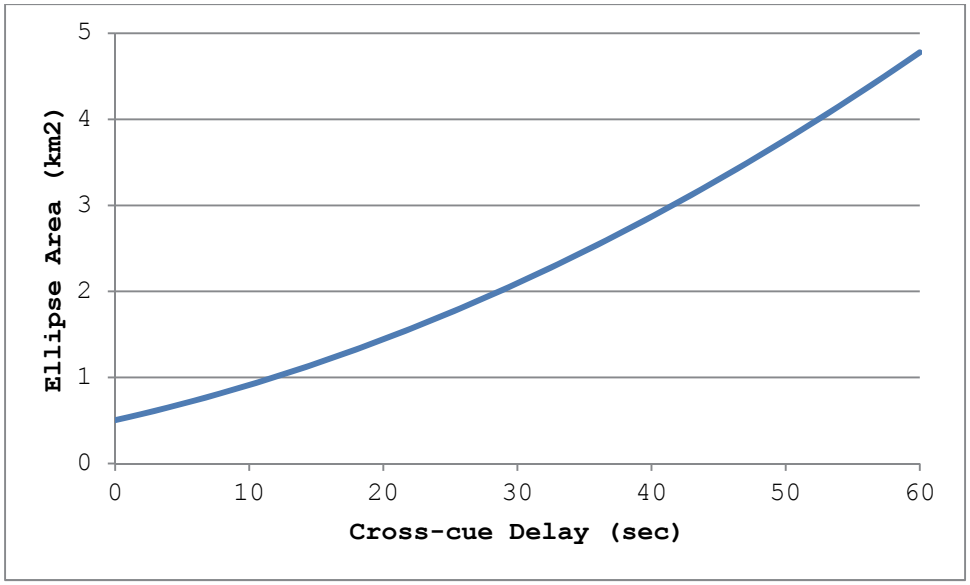
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For example, a UAS traveling at 100m/s would take over 16 minutes to travel 100km. The limitations on aircraft movement mean that the second intelligence collector must be relatively close to the target to cross-cue.

Importance of Timing

The timing of target handoffs is crucial to the success of cross-cueing. The passing of the target from one sensor/platform to another must happen very quickly, or the area that needs to be searched can grow very large. In some cases, the area grows so much that the target will be lost. Figure 5.2 shows an example of how the cross-cue delay impacts the error ellipse for SIGINT to FMV cross-cue with a moving target.

Figure 5.2
Delay in Cross-cue Increases the Area Needed to Search



NOTES: Analysis uses an initial ellipse of .50km2. Target is travelling 50 km/hr in an open area unconstrained by travelling on roads or terrain limitations.

The cross-cue delay can cause a medium accuracy error ellipse to become unusable. Cross-cueing of a challenging target, like a moving target, must happen within a minute for the cross-cue to be successful. T/FDOA geolocation meets this quickness standard. The speed of T/FDOA

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reduces the time from initial SIGINT hit to geolocation ellipse without degrading the accuracy. The near-real-time geolocation from T/FDOA can reduce the cross-cue delay in a multi-intelligence operation.

COMMAND, CONTROL, AND COMMUNICATION

Cross-cueing between intelligence types becomes more difficult and less fruitful the longer the delay between target handoff. This section examines what C3 would be required for successful multi-intelligence operations with T/FDOA and how that C3 can be provided using the emerging ISR Mission Type Orders (MTOs) concept.

What C3 Is Needed for Multi-Intelligence Operations with T/FDOA?

Cross-cueing can be very complicated. Someone needs access to the multiple streams of intelligence (HUMINT, SIGINT, IMINT, etc.) in order to determine the potential for a cross-cue. If SIGINT geolocated a target signal, but was unaware of the presence of the FMV, the cross-cue will not happen. To effectively cross-cue, the supporting unit, for example the UAS and relevant PED, should have an understanding of the situation on the ground. Knowing the commander's intent, the purpose of the operation, and other pertinent background information allows the UAS operators and PED analysts to leverage their expertise.

When responsibility is passed, the units try to avoid a "blink" where the target is lost. Latency and incompatible or incomplete data can cause a cross-cue to fail. As discussed above, the timing of target handoffs is crucial to the success of cross-cueing. The passing of the target from one sensor/platform to another must happen very quickly, or the target is easily lost.

The dynamic tasking and targeting needs to be flexible in order to deviate from the planned collection and enable collection on a cross-cue. The receiving sensor (the second or third, etc., participating in the cue) likely has some intelligence request that it is currently fulfilling. Once there is potential for a cross-cue, the authority to change the tasking for the receiving sensor needs to be immediate. This authorization needs to have prioritized the time sensitivity of this cross-cue with other requests, decided which other requests can be

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delayed or dropped, and done this within seconds. For a multi-intelligence equipped asset cueing to a second sensor on the same asset, this authorization process would likely be simpler, since they still continue supporting their primary task.[33]

Quick and clear coordination with other assets is essential to cross-cueing. Often, these assets are owned by different components and supporting different units. For these multi-intelligence operations, those involved must communicate closely with ground forces and other supporting assets. Cross-cues depend on quickly and accurately conveying information. Standardized communication practices, similar to a 9-line, would enable clear communication.

Using ISR MTOs

ISR MTOs grew out of a desire to deviate from the preplanned, rigid taskings and target decks. Joint Publication 3-50 defines MTOs as "an order to a unit to perform a mission without specifying how it is to be accomplished." An ISR MTO is typically a more narrative tasking that provides background information on the supported unit's commander's intent (Green 2011). ISR MTOs can also introduce more flexibility in the planning and integration process (Green 2011). A major difference between ISR MTOs and the traditional tasking is the establishment of direct liaison authority (DIRLAUTH), which allows the collectors and the units they are supporting to communicate and work together directly to accomplish the mission (Green 2011). DIRLAUTH encourages the collectors, the supporting unit, and the PED unit to coordinate in initial planning and C2 methods (Green 2011). Through this pre-coordination, the DIRLAUTH established by ISR MTOs fosters dynamic changes within a complex operational environment.

Using ISR MTOs meets most of the C3 demands for leveraging T/FDOA geolocation through cross-cueing. Establishing DIRLAUTH promotes pre-coordination with the ground unit, enabling communication and understanding during the mission. MTOs can also be written so that

[33] Today though, these assets are tasked with only one of their sensors as prime. Oftentimes, the other sensors are unsupported and so not available (Green 2011).

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there is flexibility with the target deck. In an MTO, the authorization to cue would be from the ground unit. Since constant communication is established, that authorization would likely be very quick.

CONCLUSION

The analysis shows that using T/FDOA on UAS would strengthen our multi-intelligence capabilities. Adding SIGINT with T/FDOA geolocation on UAS immediately creates the potential to layer complementing sensors. Since these sensors provide different information, fusing the data from layer sensors offers much more intelligence on the target. T/FDOA would improve our abilities to cross-cue. The accuracy advantages of T/FDOA with short duration emissions reduce the time needed to search for a target with a SIGINT to FMV cross-cue. Time is extremely important for a cross-cue. A cross-cue delay of more than seconds can cause the cross-cue to fail, especially with a moving target.

Multi-intelligence operations are complex and place unique demands on the command, control, and communication of airborne ISR. The new ISR MTO construct provides a unique way to support cross-cueing with T/FDOA geolocation. The establishment of DIRLAUTH enables quick communication between all the units in the operation, which is key to these operations.

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6. Conclusions and Recommendations

This research shows that DoD can better leverage UAS and improve multi-intelligence capabilities by expanding its geolocation capacity through the use of T/FDOA geolocation on UAS. I demonstrated that a T/FDOA geolocation would be useful in the context of today's operations. I outlined some requirements needed to implement T/FDOA geolocation, both on the platform and for the PED. Finally, I showed how the speed and accuracy of T/FDOA could improve multi-intelligence collection.

T/FDOA geolocation is useful against many targets, particularly those in an IW/COIN environment that are difficult to geolocate using direction finding. These difficult targets include those in lower frequencies (HF/VHF), those that limit the emission duration, and those that are farther from the receiver aircraft. Two of the major drawbacks to T/FDOA are the need for multiple platforms and the sensitivity to geometry. The drawbacks do not hinder employment of T/FDOA as a secondary capability on UAS. The orbits demanded by the primary intelligence collection do not negatively impact the accuracy of geolocation using T/FDOA. Without impacting the primary mission, UAS with T/FDOA capability would likely be within line of sight of the same targets.

Small changes are necessary to implement T/FDOA on UAS. The technology for T/FDOA capable sensors already exists. Many UAS are nearly equipped to be capable. Each UAS would need a SIGINT sensor with certain characteristics. The receiver(s) likely needs to be a digital receiver to meet the demands for precision and sensitivity. The system needs to be integrated with the GPS/INS systems of the UAS to provide the aircraft state vector with high enough precision. The new sensor would need to be integrated on the UAS. Integration issues are beyond the scope of this research. Today, one of the largest drivers of manpower for UAS is the PED needed to turn the data collected into actionable intelligence. The PED for T/FDOA would likely mirror PED for the other intelligence types. Focusing on the Air Force, this means

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that PED would be conducted within the DCGS. I present two options for organizing the PED based on how many sensors a single operator is capable of controlling. The manpower and cost implications appear to be small compared with the requirements to PED other sensors.

T/FDOA can be leveraged to improve multi-intelligence operations. Adding a SIGINT with T/FDOA capability to UAS instantly increases our ability to provide more information about targets by layering complementing ISR sensors. The accuracy and speed of T/FDOA geolocation can make a large impact in our ability to cross-cue. Cross-cueing must happen within seconds to be successful. T/FDOA geolocation provides high-accuracy geolocation very quickly, reducing the time delay between intelligence types and the area that a second intelligence, such as FMV, would need to search. For C3, the emerging ISR MTO concept meets the C3 needs for T/FDOA geolocation in complex operating environments.

This research was intended as a theoretical "proof of concept" for the use of T/FDOA geolocation on UAS. It shows what we would gain from using T/FDOA geolocation in an opportunistic fashion and as a secondary mission on UAS. There are many questions and analysis beyond the scope of this research that would need to be investigated before realizing a T/FDOA geolocation capability on UAS. This work outlined what would be necessary for a SIGINT system capable of T/FDOA geolocation. There is much more work that would need to be accomplished to create this SIGINT system. Additional sensors on a platform can cause issues with the current sensors, including SWAP trade-offs and issues from emissions on overlapping frequencies. For each platform that would host T/FDOA, the compatibility of a T/FDOA sensor with the other sensors would need to be investigated. In this work, only the cost implications of the manpower for PED were examined. The complete costs of implementation are much broader and range from costs associated with maintenance in the field to potential costs of additional bandwidth. These costs would need to be thoroughly researched. This research points out the importance of quickly transitioning between intelligence types, but does not delve into the tasking and re-tasking of sensors. The best method of tasking of multi-intelligence capable assets to leverage

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sensors for primary and secondary missions would need to be further investigated.

There are many potential stakeholders for T/FDOA geolocation. At the DoD level, the major stakeholder is the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD AT&L). Within USD AT&L, Unmanned Warfare (UW) is the lead for providing oversight of UAS acquisitions, including all subsystems such as sensors. For each individual service, stakeholders fall into similar groups. There are those that operate the UAS, those that conduct the PED for the intelligence data collected by the UAS, those that use the intelligence, and those that purchase the sensors. Each of these stakeholders will need to work together to create the most useful T/FDOA-capable sensor. Cooperation across services and organizations is important to create the most capable sensor. The accuracy of T/FDOA can be improved by increasing the number of sensors participating in the geolocation. Sensors that are interoperable are essential for T/FDOA geolocation to be the most useful.

There are several next steps that DoD should take to continue pursuing T/FDOA geolocation on UAS. This research shows how T/FDOA geolocation on UAS would complement direction finding and provide an ability to go after difficult targets in a COIN/IW environment. A full gap analysis should be done to illustrate how T/FDOA would fit in DoD's geolocation portfolio. As stated above, this research touches only on one cost implication for T/FDOA. A complete cost-benefit analysis would be needed to justify the capability. Finally, a technology demonstration would be needed before moving forward.

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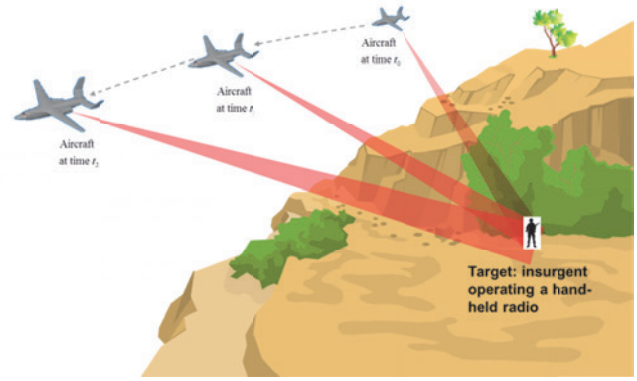
APPENDIX

A. DIRECTION FINDING MODEL

DIRECTION FINDING

The military commonly uses direction finding, also known as triangulation, to fix the position of an emitter. For example, in direction finding, an aircraft would measure the angle of arrival (AOA) at multiple locations along a baseline to create lines of bearing (LOBs) between the receiver and the emitter. Two or more LOBs enable the emitter to be fixed at the intersection of these different LOBs. An example of direction finding is depicted in Figure A.1. Direction finding requires one receiver to measure the signal at one position and then move and re-measure the same signal. There are many algorithms available to calculate the emitter location. These range from plotting lines of bearing on a common map to calculations based on the various statistical techniques such as least-squares error estimation and the discrete probability density method. One of the first and classical techniques is a variant of maximum-likelihood estimation advanced by Stansfield in his "Statistical Theory of D.F. Fixing."

Figure A.1
Aircraft Calculates LOBs Along a Baseline



THEORETICAL BASIS, THE STANSFIELD ESTIMATOR

The Stansfield Estimator assumes lines of bearings are measured from multiple locations. In practice, measured bearings include both

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systematic error and random error. Typically, systematic errors are known and therefore can be accounted for in the implementation. As with successor models, Stansfield assumes that bearings are corrupted only by random errors, which are assumed to be from a Gaussian distribution with a mean of zero.[34] Stansfield uses the following geometry:

$J, K, L, M, N =$ positions of d. f. stations

$n =$ number of d. f. stations

$d =$ semi $-$ distance between two d. f. stations

$D =$ distance of point to be located from d. f. station

$D_j =$ distance from station J, etc.

$\theta =$ station bearing

$\theta_J =$ bearing from station J, etc.

$\psi =$ error in bearing

$\psi_J =$ error in bearing from station J, etc.

$p_J =$ distance from point to be located to line of bearing from station J, etc.

$q_J =$ distance from an arbitrary point to line of bearing from station J, etc.

If the true position of the emitter is unknown, but guessed to be at point S, with coordinates x,y and perpendicular distance q_J from the line of bearing of station J, then:

$$q_J = p_J + x\sin(\theta_J) - y\cos(\theta_J)$$

The equation for the likelihood of the set of position lines is then:

$$P(q_1 \dots q_n)dq_1 \dots dq_n = \frac{1}{(2\pi)^{\frac{n}{2}}\sigma_{p1} \dots \sigma_{p1}} \exp\left[-\frac{1}{2}\sum \frac{\left(p_J + x\sin(\theta_J) - y\cos(\theta_J)\right)^2}{\sigma_{pJ}^2}\right] dp_1 \dots dp_n$$

Using the following substitutions to make the equations easier to write:

[34] Stansfield validated the assumption of Gaussian with mean of zero using actual data gathered during World War 2. He removed approximately 1 percent of the bearings that were determined to have egregious errors.

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$$\lambda = \sum \left(\frac{\sin \theta_J}{\sigma_{pJ}} \right)^2 = \sum \left(\frac{\sin \theta_J}{\sigma_{\psi J} D_J} \right)^2$$

$$\mu = \sum \left(\frac{\cos \theta_J}{\sigma_{pJ}} \right)^2 = \sum \left(\frac{\cos \theta_J}{\sigma_{\psi J} D_J} \right)^2$$

$$\nu = \sum \left(\frac{\sin \theta_J \cos \theta_J}{\sigma_{pJ}^2} \right) = \sum \left(\frac{\sin \theta_J \cos \theta_J}{\sigma_{\psi J}^2 D_J^2} \right)$$

The $(\hat{x}, \hat{y})$, which maximizes the expression in the exponent above, is the best guess for the fix:

$$\hat{x} = \frac{1}{(\lambda\mu - \nu^2)} \left[\sum p_J \frac{(\nu \cos(\theta_J) - \mu \sin(\theta_J))}{\sigma_{pJ}^2} \right]$$

$$\hat{y} = \frac{1}{(\lambda\mu - \nu^2)} \left[\sum p_J \frac{(\lambda \cos(\theta_J) - \nu \sin(\theta_J))}{\sigma_{pJ}^2} \right]$$

If this is repeated, the distribution of the "optimal fixes" is:

$$P(x,y)dxdy = \frac{\sqrt{(\lambda\mu - \nu^2)}}{2\pi} \exp\left[-\frac{1}{2}(\lambda x^2 - 2\nu xy + \mu y^2) \right] dxdy$$

This can be transformed into

$$P(X,Y)dXdY = \frac{1}{2\pi ab} \exp\left[-\frac{1}{2}\left(\frac{X^2}{a^2} + \frac{Y^2}{b^2} \right) \right] dXdY$$

where,

$$\frac{2}{a^2}, \frac{2}{b^2} = \lambda + \mu \pm \sqrt{(\lambda - \mu)^2 + 4\nu^2}\,.$$

ERRORS

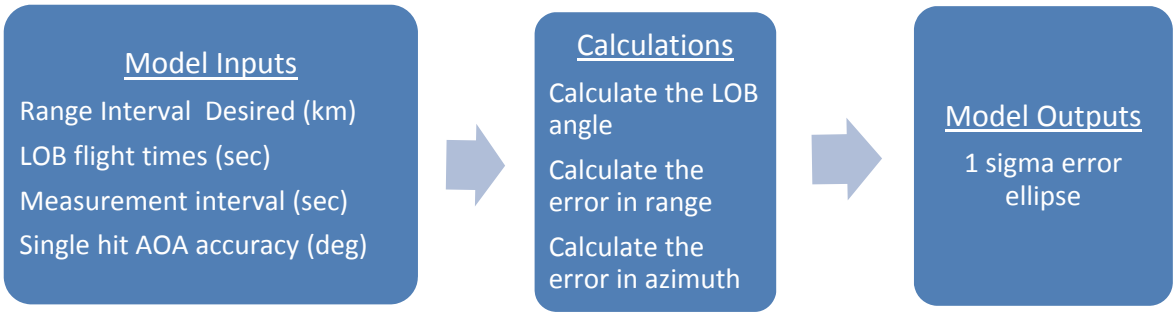
The errors that impact direction finding include measurement errors, position errors, and random errors. This model focuses on measurement error, particularly the measurement of the angle of arrival. For simplicity, the errors for AOA measurement are determined using a constant LOB angular error. This could be changed to a random draw from a normal distribution, with mean of zero and standard deviation defined by the parameter sigma.

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Model Implementation

I adapted a model that had been previously used in work done for RAND's Project AIR FORCE. This model is based on the Stansfield approach described above. A graphical depiction of the model is shown in Figure A.2. The inputs are the range interval between the target and receiver (ex. 50km – 400km), the flight times of the LOBs (ex. 60sec, 120sec, 180sec), the measurement interval for each AOA (ex. 3 sec), and the single-hit AOA accuracy (ex. 0.07 deg). Using those inputs, the true LOB angle is calculated. The error in range and azimuth are then determined for each point along the range interval. These estimates are then used to create a 1-sigma error ellipse for each range increment.

Figure A.2
Graphical Depiction of Direction Finding Model



Stansfield's method is a simple method that will provide a good first cut of the accuracy. There are other, more complex and more accurate methods to estimate the error of direction finding. For the comparisons in this dissertation, Stansfield's method is a good approximation.

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B. ORBIT GEOMETRY RESULTS

SCENARIO 1: TWO CIRCULAR FMV ORBITS

In this scenario, there are two UAS each flying circular FMV orbits. The orbit parameters for each case are listed in Table B.1.

Table B.1
Orbit Parameters for Scenario 1

	Aircraft 1: Circular FMV Orbit				Aircraft 2: Circular FMV Orbit			
	X Offset	Y Offset	Altitude	Radius	X Offset	Y Offset	Altitude	Radius
Case 1	150km	150km	20kft	20km	150km	150km	20kft	20km
Case 2	200km	200km	20kft	20km	75km	75km	20kft	20km
Case 3	200km	200km	20kft	20km	125km	125km	20kft	20km
Case 4	300km	100km	25kft	20km	150km	150km	25kft	20km
Case 5	250km	250km	30kft	20km	50km	50km	20kft	20km
Case 6	150km	150km	15kft	20km	250km	250km	30kft	20km
Case 7	150km	150km	15kft	20km	150km	150km	15kft	20km
Case 8	150km	150km	15kft	10km	150km	150km	15kft	20km
Case 9	150km	150km	30kft	10km	150km	150km	30kft	20km
Case 10	150km	150km	20kft	10km	150km	150km	20kft	10km

An example of the output of the model for this scenario is shown in Figures B.1 and B.2.

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Figure B.1
Example of Scenario 1: Two Circular FMV Orbits

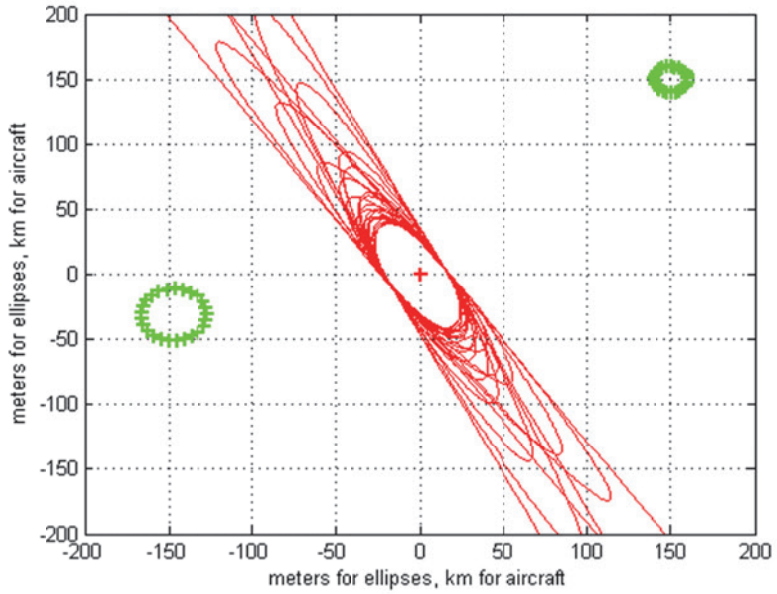
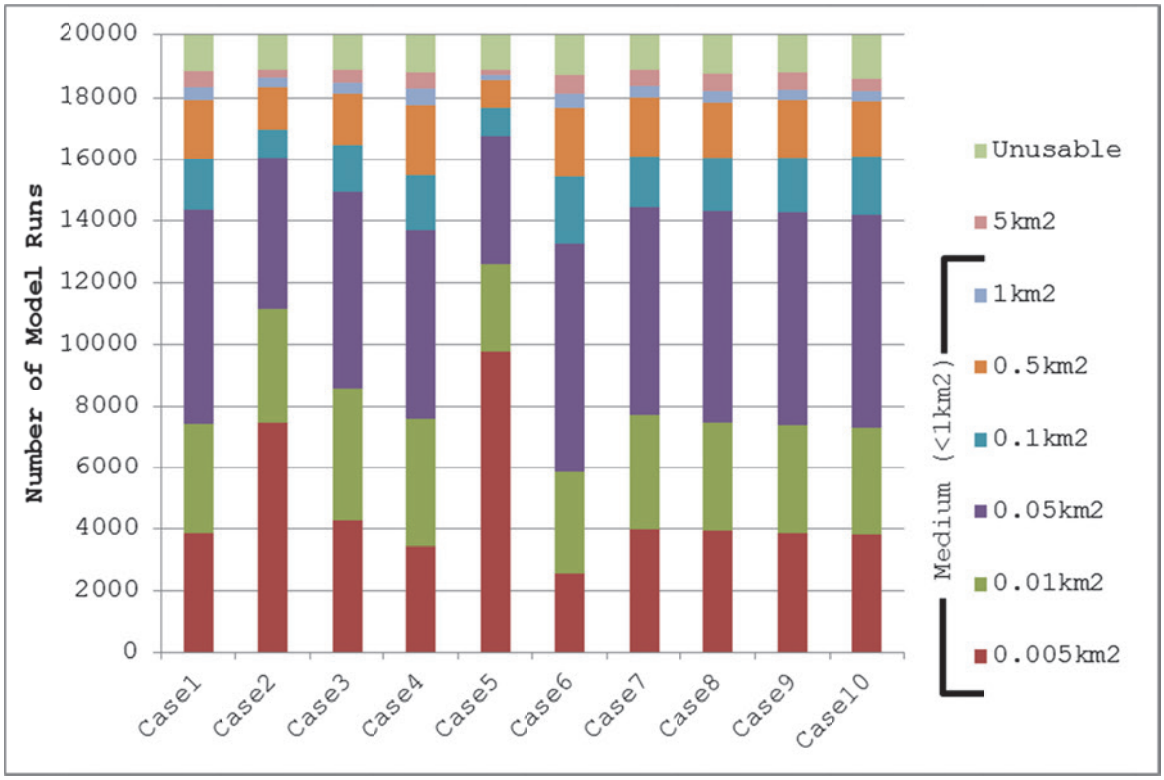


Figure B.2
Histogram of Scenario 1 Error Ellipse Areas



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SCENARIO 2: ONE SAR, ONE RACETRACK FMV

In this scenario, one of the UAS is collecting SAR imagery and the other is flying a racetrack FMV orbit. The orbit parameters for each case are listed in Table B.2.

Table B.2
Orbit Parameters for Scenario 2

	Aircraft 1: SAR Orbit				Aircraft 2: Racetrack FMV Orbit				
	X Offset	Y Offset	Alt	Axis of Path	X Center	Y Center	Alt	RA	RB
Case 1	50km	150km	20kft	X	150km	150km	20kft	40km	5km
Case 2	75km	100km	20kft	X	150km	150km	20kft	5km	40km
Case 3	150km	200km	30kft	X	250km	250km	30kft	5km	40km
Case 4	150km	75km	25kft	X	250km	250km	30kft	40km	5km
Case 5	200km	50km	30kft	X	75km	125km	15kft	40km	5km
Case 6	100km	75km	25kft	Y	125km	125km	15kft	10km	50km
Case 7	200km	50km	30kft	Y	125km	125km	25kft	50km	10km
Case 8	75km	150km	20kft	Y	50km	250km	25kft	50km	10km
Case 9	100km	100km	15kft	Y	200km	200km	30kft	10km	50km
Case 10	75km	200km	30kft	Y	100km	100km	20kft	10km	50km

An example of the output of the model for this scenario is shown in Figures B.3 and B.4.

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Figure B.3
Example of Scenario 2: One SAR, One Racetrack FMV

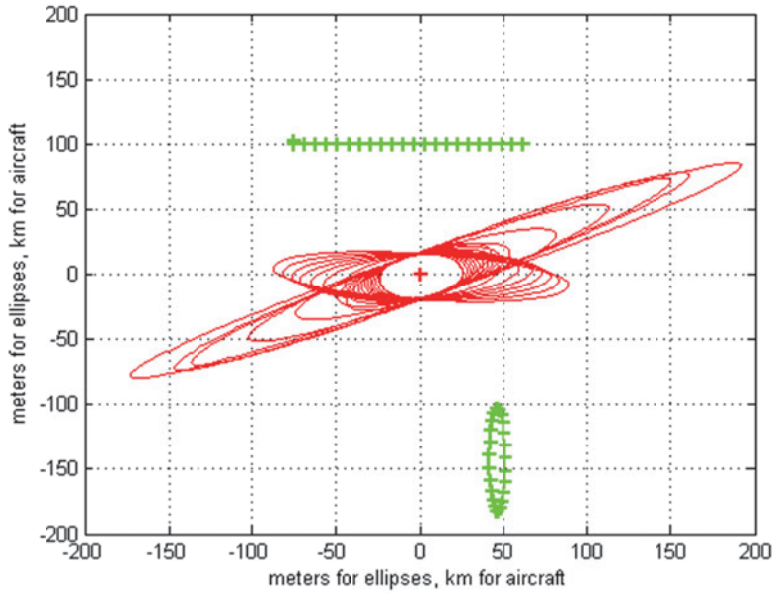
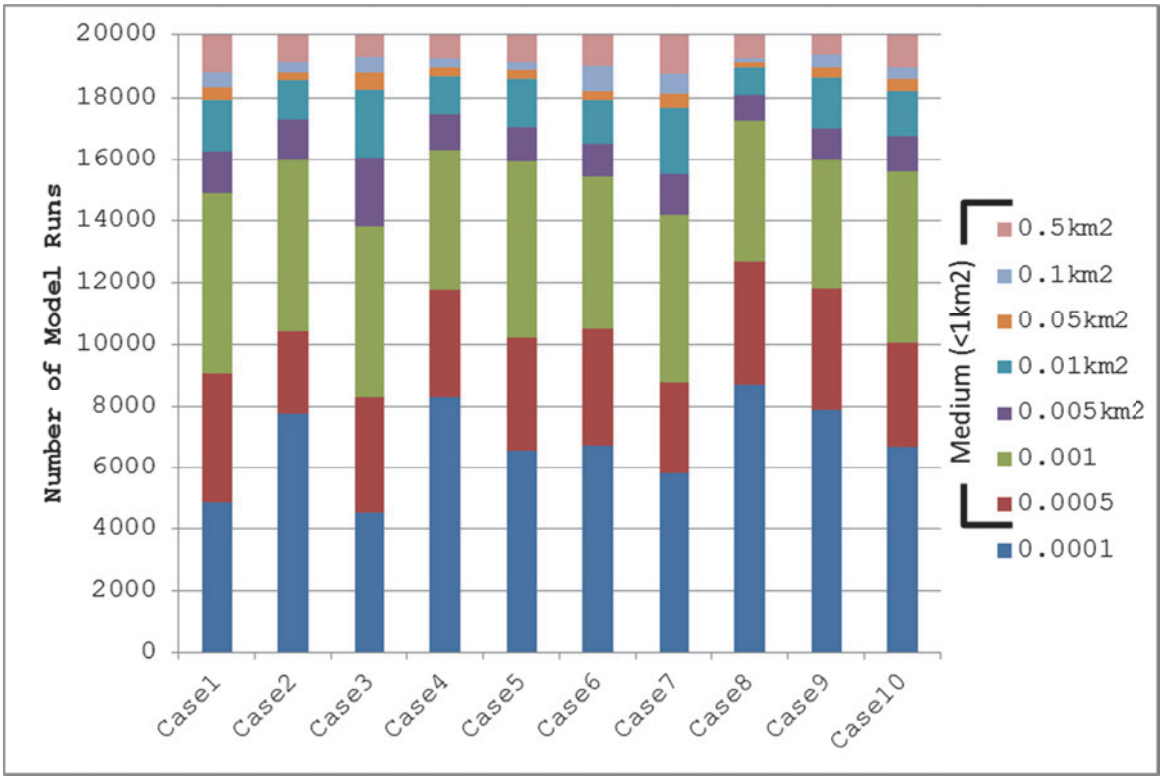


Figure B.4
Histogram of Scenario 2 Error Ellipse Areas



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SCENARIO 3: SAR FMV 2 CASES SUMMARY

In this scenario, one of the UAS is collecting SAR imagery and the other is flying a circular FMV orbit. The orbit parameters for each case are listed in the Table B.3.

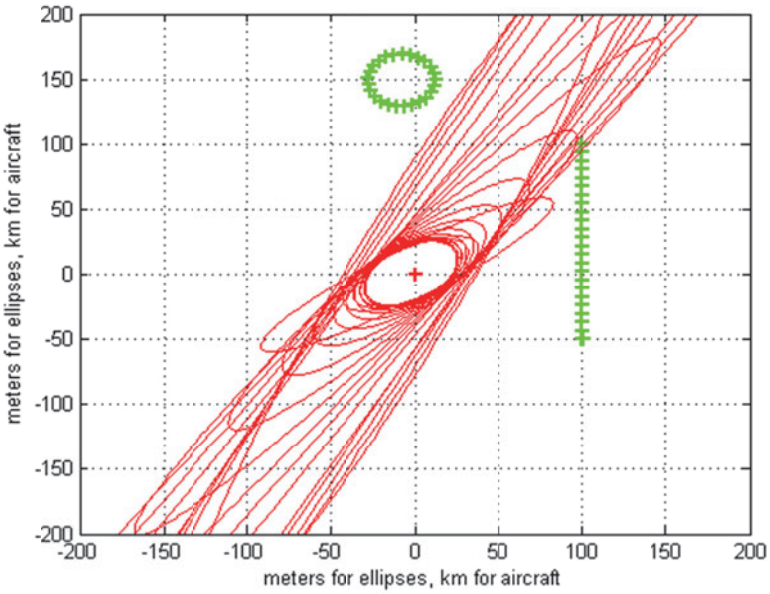
Table B.3
Orbit Parameters for Scenario 3

	Aircraft 1: SAR FMV				Aircraft 2: Circular FMV Orbit			
	X Offset	Y Offset	Alt	Axis of Path	X Offset	Y Offset	Alt	Radius
Case 1	50km	150km	20kft	X	150km	150km	30kft	20km
Case 2	75km	100km	20kft	X	150km	150km	20kft	20km
Case 3	150km	200km	30kft	X	100km	100km	20kft	20km
Case 4	150km	75km	25kft	X	100km	100km	20kft	10km
Case 5	200km	50km	30kft	X	75km	125km	20kft	10km
Case 6	100km	75km	25kft	Y	100km	100km	20kft	10km
Case 7	200km	50km	30kft	Y	150km	150km	15kft	20km
Case 8	75km	150km	20kft	Y	200km	200km	20kft	20km
Case 9	100km	100km	15kft	Y	75km	150km	20kft	20km
Case 10	75km	200km	30kft	Y	150km	150km	20kft	10km

An example of the output of the model for this scenario is shown Figure B.5 and B.6.

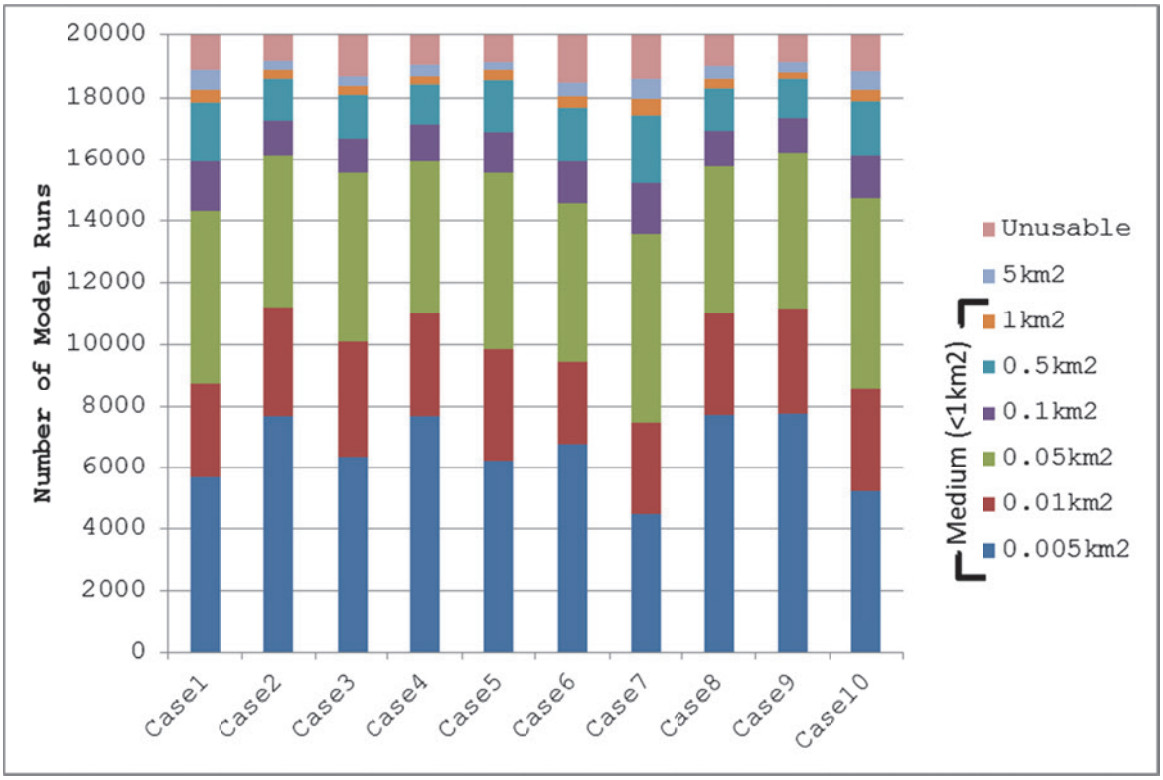
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Figure B.5
Example of Scenario 3: One SAR, One Circular FMV



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Figure B.6
Histogram of Scenario 3 Error Ellipse Areas



SCENARIO 4: GMTI-FMV 1 CASES

In this scenario, one of the UAS is flying a GMTI orbit and the other is flying a racetrack FMV orbit. The orbit parameters for each case are listed in Table B.4.

Table B.4
Orbit Parameters for Scenario 4

	Aircraft 1: GMTI Orbit					Aircraft 2: Racetrack FMV Orbit				
	X Center	Y Center	Alt	RA	RB	X Center	Y Center	Alt	RA	RB
Case 1	100km	100km	20kft	100km	20km	150km	150km	20kft	40km	5km
Case 2	100km	100km	20kft	150km	50km	150km	150km	20kft	5km	40km
Case 3	0km	100km	25kft	100km	20km	250km	250km	30kft	5km	40km
Case 4	0km	100km	25kft	150km	0km	250km	250km	30kft	40km	5km

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Case 5	100km	0km	30kft	100km	20km	75km	125km	15kft	40km	5km
Case 6	100km	0km	30kft	150km	50km	125km	125km	15kft	10km	50km
Case 7	100km	0km	20kft	100km	20km	125km	125km	25kft	50km	10km
Case 8	0km	100km	20kft	150km	50km	50km	250km	25kft	50km	10km
Case 9	150km	150km	30kft	100km	20km	200km	200km	30kft	10km	50km
Case 10	150km	150km	30kft	150km	50km	100km	100km	20kft	10km	50km

An example of the output of the model for this scenario is shown in Figures B.7 and B.8.

Figure B.7
Example of Scenario 4: One GMTI, One Racetrack FMV

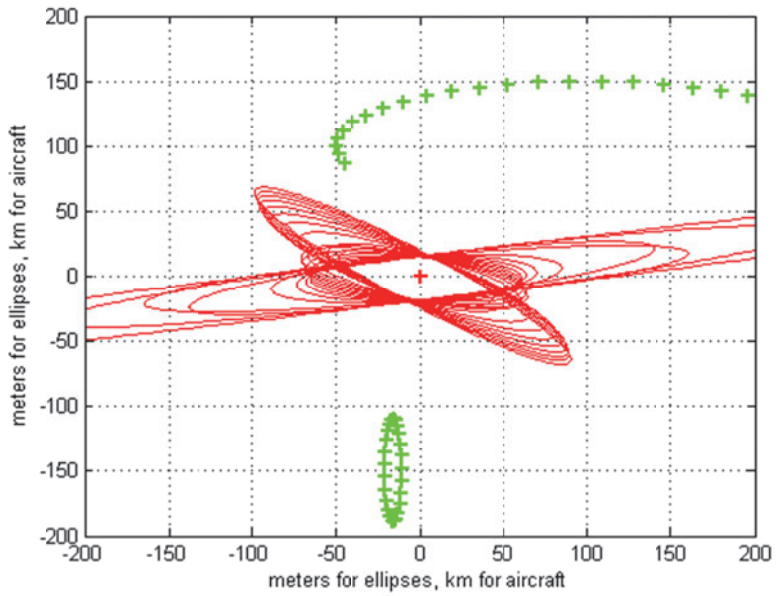
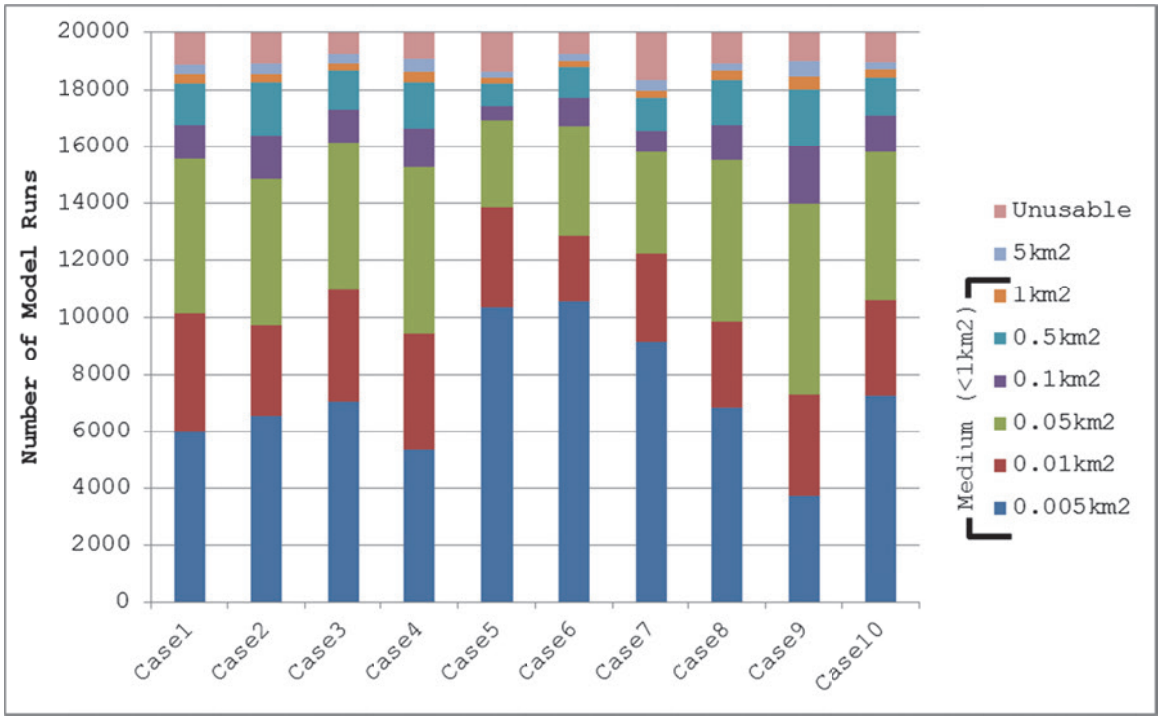


Figure B.8
Histogram of Scenario 4 Error Ellipse Areas



SCENARIO 5: GMTI-FMV2 CASES SUMMARY

In this scenario, one of the UAS is flying a GMTI orbit and the other is flying a circular FMV orbit. The orbit parameters for each case are listed in Table B.5.

Table B.5
Orbit Parameters for Scenario 5

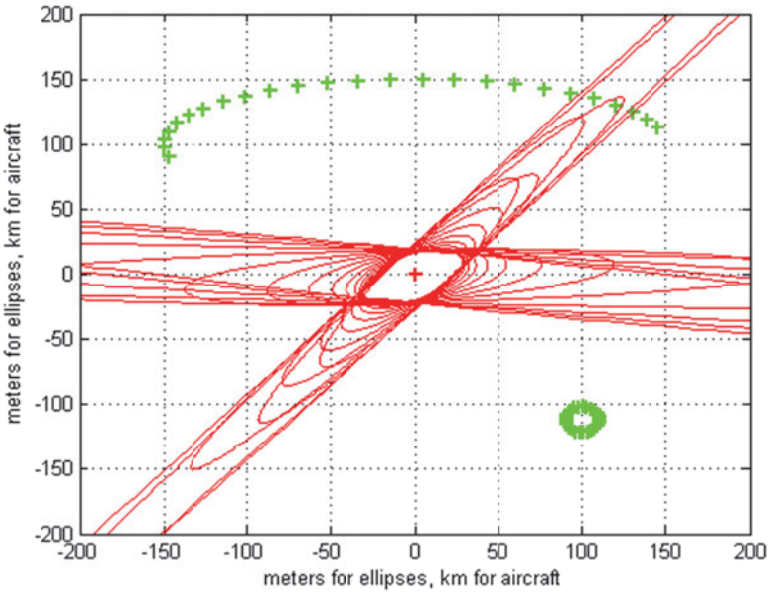
	Aircraft 1: GMTI Orbit					Aircraft 2: Circular FMV Orbit			
	X Center	Y Center	Alt	RA	RB	X Offset	Y Offset	Alt	Radius
Case 1	100km	100km	20kft	100km	20km	150km	150km	15kft	20km
Case 2	100km	100km	20kft	150km	50km	200km	200km	20kft	20km
Case 3	0km	100km	25kft	100km	20km	200km	200km	20kft	20km
Case 4	0m	100km	25kft	150km	50km	300km	100km	25kft	50km
Case 5	100km	0km	30kft	100km	20km	250km	250km	30kft	20km

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Case 6	100km	0km	30kft	150km	50km	150km	150km	15kft	50km
Case 7	100km	0km	20kft	100km	20km	150km	150km	15kft	20km
Case 8	0km	100km	20kft	150km	50km	150km	150km	15kft	10km
Case 9	150km	150km	30kft	100km	20km	150km	150km	30kft	10km
Case 10	150km	150km	30lft	150km	50km	150km	150km	20kft	10km

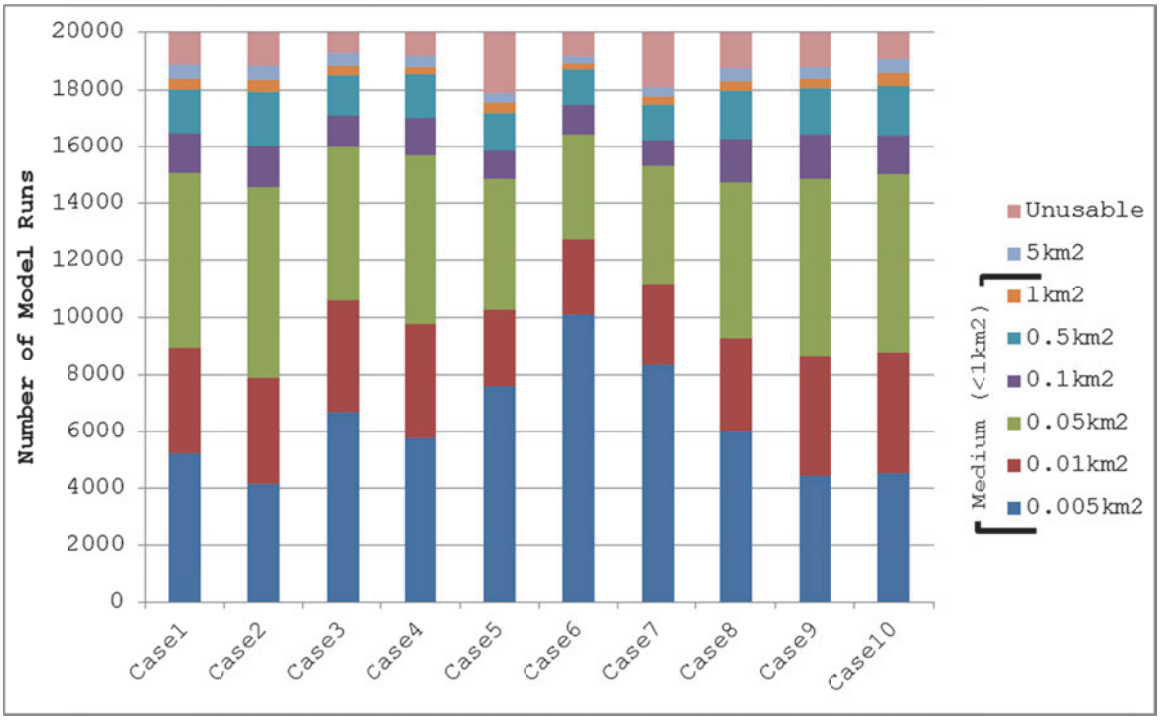
An example of the output of the model for this scenario is shown in Figures B.9 and B.10.

Figure B.9
Example of Scenario 5: One GMTI, One Circular FMV



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Figure B.10
Graph of Scenario 5 Error Ellipse Areas



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C. CAP ALLOCATION MODEL

I used the Model Builder within ArcGIS to create the CAP model. The layout of the model is shown in Figure C.1. The model inputs are the altitude of the platforms, the number of CAPs to be modeled, and the line of sight distance to be used.

Figure C.1
CAP Model



1. Model CAP Locations

Create Random Points: Using the input for number of CAPS, random points are created within the boundaries of Afghanistan to represent the locations of the CAPs.

Add XY Coordinates: The latitude and longitude of each of these points is added to the attribute table and the point shapefile is saved.

2. Model Line of Sight Overlap

Buffer: Using the point shapefile, a ring is created around each point at the inputted line of sight distance.

Intersect: These rings are intersected with each other to determine sections that can be seen by multiple CAPs. Each intersection is a separate polygon within a polygon shapefile.

Clip: The intersected rings are cut to fit within the boundaries of Afghanistan.

Dissolve: The intersected rings are dissolved and a count field is added to keep track of the number of CAPs that have line of sight to each resulting intersection.

3. Add Areas

Project: The analysis until now has been performed using a Geographic Coordinate System. To enable ArcGIS to calculate the areas of each intersection in meters squared, the polygon shapefile needs to be projected into a Project Coordinate System. The standard WGS 84 to Plate Carree transformation is used.

Dissolve (2): The intersected polygons are dissolved based on the number of CAPs that have line of sight to each area. The result is a polygon shapefile with a polygon for example the areas that can be seen by 2 CAPs, and a separate polygon for the areas that can be seen by 3 CAPS, etc.

Add Field/Calculate Field: A field for the percentage area is added and calculated. A polygon shapefile with the polygons and areas by the number of CAPS is saved.

This is repeated with a third dissolve to determine the area that can be seen by at least 2 CAPs. A polygon shapefile with the polygon and area for what can be seen by at least 2 CAPs is saved.

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D. MANPOWER CALCULATIONS

I used Air Force Manual 38-208 Volume 2 to calculate the Minimum Manpower Factor (MMF) as follows:

$$MMF\ per\ CAP = \frac{(Days/Wk)(Hrs/Day)(4.348\ Wks/Mo)(DRF)(Crew\ Size)}{Manhour\ Available\ Factor\ \times Overload\ Factor}$$

I used the man-hour available factor and overload factor for a military work force on a 40-hour workweek.

$$MMF\ per\ CAP = \frac{(7)(24)(4.348\ Wks/Mo)(1)(1)}{151.5\ \times 1.077}$$

$$MMF\ per\ CAP = 4.476$$

The total MMF depends on the number of CAPs used for T/FDOA geolocation.

$$Total\ MMF\ = MMF\ per\ CAP\ \times Number\ of\ CAPs$$

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U.S.ARMY

ARMY EQUIPMENT MODERNIZATION PLAN







2013

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DEPARTMENT OF THE ARMY
DEPUTY CHIEF OF STAFF, G-8
700 ARMY PENTAGON
WASHINGTON, DC 20310-0700

MAY 16 2012

Today we are faced with uncertain strategic and operational environments coupled with fiscally constrained resources. The Army's equipment modernization strategy reflects the need to support the current fight, respond to uncertainties and implement the Army strategy for the force in 2020 all nested with DOD's strategic guidance. This strategy is focused on equipment needed to deter and defeat hybrid threats. We will network the force; replace, improve or transform our combat platforms; and empower, protect, and unburden our Soldiers.

The Army Equipment Modernization Plan 2013 describes the Research, Development and Acquisition (RDA) portion of our Fiscal Year 2013 President's Budget request which reflects the Army's priority materiel programs and identifies the critical capabilities to succeed in the full range of missions while maintaining a decisive advantage over any adversary.

The Army must continue to develop and field a versatile and affordable mix of equipment. The balanced approach to achieving this goal contains three main principles: integrated capability portfolios that align our equipment modernization communities to identify capability gaps and eliminate unnecessary redundancies, incremental modernization to deliver new and improved capabilities, and Army force generation processes to ensure unit equipment readiness.

Although we are a force in transition, we must continue to provide the Nation with the best equipped, most modernized, and highly capable Army to prevail in any operational environment. We will do this with affordability as our watchword and remain committed stewards of our Nation's resources. With a balanced equipment modernization strategy, the Army will remain on track to equip the Army of 2020.

DONALD C. TISON
Acting Deputy Chief of Staff, G-8

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EXECUTIVE SUMMARY

The Army Equipment Modernization Plan 2013 (ModPlan13) describes the Research, Development and Acquisition (RDA) portion of our Fiscal Year 2013 (FY13) President's Budget request. It is a unique document that breaks down the RDA investments into ten capability portfolio areas, highlights the portfolio accomplishments over the last two years and provides the intent for FY13 investments as well as the way ahead.

In addition to capability portfolio investment strategies, ModPlan13 links RDA investments to Army strategy and discusses specific modernization priorities and objectives, priority materiel programs, the Army's science and technology program and equipment fielding and distribution.

Today we are faced with uncertain strategic and operational environments coupled with declining resources. The Army will continue to develop and field a versatile and affordable mix of equipment to allow Soldiers and units to succeed in the full range of missions today and tomorrow and to maintain our decisive advantage over any adversary we face. The balanced and affordable approach to achieving this goal uses integrated capability portfolios and portfolio reviews to align our equipment modernization communities to identify capability gaps and eliminate unnecessary redundancies, incremental modernization to deliver new and improved capabilities and Army force generation processes to ensure unit equipment readiness. The Army's equipment modernization plan reflects the need to deter and defeat hybrid threats. We will network the force; replace, improve or transform our combat platforms; and empower, protect and unburden our Soldiers.

Although we are a force in transition, we must continue to provide the Army with the best equipped, most modernized and most highly capable units that will prevail on any battlefield. We will do this with affordability as our watchword and remain committed stewards of our Nation's resources. With a balanced equipment modernization strategy, the Army will remain on track to equip a smaller force without sacrificing its decisive edge.

Details on major Army acquisition programs can be found in the **2012 Army Weapon Systems handbook** at: http://armyalt.va.newsmemory.com/wsh2012.php

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LINKING RESOURCE DECISIONS TO ARMY STRATEGY

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LINKING RESOURCE DECISIONS TO ARMY STRATEGY

> *"All of these changes are enabling us to craft a military that's better suited for the 21st-century challenges that we confront — one that can defeat any adversary on any battlefield, be it on land, be it in the air, be it in sea, be it in space or be it in cyberspace."*
>
> ***— Secretary of Defense Leon E. Panetta***

The Army has global responsibilities requiring large technological advantages to prevail decisively in combat. Just as Airmen and Sailors seek supremacy in the air and on the seas, Soldiers must dominate their enemies on land. Modernizing, especially as end-strength is reduced, is the key to ensuring that our dominance continues.

The Army is setting priorities and making prudent choices to provide the best possible force for the Nation within the resources available. We are developing and fielding a versatile and affordable mix of equipment to enable us to succeed in the full range of missions and maintain a decisive advantage over our enemies. To meet the challenges of an evolving strategic and fiscal environment, our strategy is based on three tenets: integrated capability portfolios, incremental modernization and leveraging the Army Force Generation cycle.

> *"To meet current and future threats our military must remain the finest in the world. It must be an agile and deployable full spectrum force that can deter conflict, project power and win wars."*
>
> ***— Army Secretary John M. McHugh***

- Integrated capability portfolios align stakeholders to identify capability gaps and eliminate unnecessary redundancies.
- Incremental modernization enables us to deliver new and improved capabilities by leveraging mature technologies, shortening development times, planning growth potential and acquiring in quantities that give us the greatest advantage while hedging against uncertainty.
- Army Force Generation processes synchronize the distribution of equipment to units providing increased readiness over time and delivering a steady and predictable supply of trained and ready modular forces. The Army has consolidated its materiel management process under a single command and designated U.S. Army Materiel Command as the Army's Lead Materiel Integrator. Additionally, we consolidated all of our materiel data into a single authoritative repository called the Logistics Information Warehouse.

> *"To prevent conflict, we must maintain credibility, which is partly based on modernization…"*
>
> ***—GEN Raymond T. Odierno***

These emerging systems and processes represent a powerful new approach for implementing the Army's equipping priorities, policies and programs to meet new security demands of the 21st century. Equipment requested in the FY13 President's Budget

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strikes a balance between current and future needs, provides the basis for an affordable equipping strategy over time and takes into account Army requirements and priorities. In developing this request, the Army made difficult decisions to shift funds previously programmed for future capabilities to current needs. The decisions came at the expense of promising and needed technologies with capabilities that did not fit within resource limitations. The Army's FY13 budget priorities are to network the force, replace, improve and/or transform selected platforms and to empower, protect and unburden the Soldier.

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ARMY FISCAL YEAR 2013 BUDGET PRIORITIES AND OBJECTIVES

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ARMY FISCAL YEAR 2013 BUDGET PRIORITIES AND OBJECTIVES

The Army's FY13 budget request is strategy based and reflects the need for equipment to deter and defeat adaptive threats that use hybrid approaches. Below are the priorities and specific objectives that guide FY13 equipment modernization investments.

PRIORITIES	OBJECTIVES
NETWORK the FORCE	• Provide secure and common joint architecture that is synchronized with real time information. • Provide broadband capabilities to commanders on-the-move and voice / data / imagery to company and platoon level.
REPLACE, IMPROVE and/or TRANSFORM:	**• COMBAT VEHICLES** • Replace the Infantry Fighting Vehicle (IFV) accommodating an entire Infantry Squad, balancing mobility and survivability and providing unmatched lethality. • Replace aging M113 family of vehicles with improved protection and mobility. • Improve Abrams, non-IFV Bradleys, Paladin and Stryker Vehicles. **• LIGHT TACTICAL VEHICLE** • Modernize the wheeled vehicle fleet with a Joint Light Tactical Vehicle (JLTV), the first Network-ready vehicle providing protection while allowing more maneuverability. **• AVIATION** • Upgrade highest demand capability platform with increased sensors.
EMPOWER, PROTECT and UNBURDEN the SOLDIER	• Enhance the lethality, protection, situational awareness and mobility of the individual Soldier. • Ensure overmatch capabilities for the Squad, the cornerstone of all units and the foundation of the decisive force.

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PRIORITY PROGRAMS

The priority Army materiel programs for FY 13 are:

THE NETWORK

- **Warfighter Information Network-Tactical (WIN-T)** [$1.2 billion (B) ($278 million (M) Research, Development, Test and Evaluation (RDTE) / $947M Other Procurement, Army (OPA))] provides the broadband backbone communications necessary for the tactical Army. It extends an Internet Protocol based satellite and line-of-sight communications network through the tactical force supporting telephone, data and video. In FY12, we begin fielding the second increment of WIN-T, providing an initial on-the-move capability as well as a robust line-of-sight transmission network and greater satellite throughput down to company level for 54 maneuver brigades and ten division headquarters. In FY15, we begin fielding the third increment of WIN-T, providing full on-the-move capabilities as well as exponential improvements in throughput on the line-of-sight transmission network and enabling an aerial layer to thicken the network.

- **Joint Tactical Radio System (JTRS)** [$556M (OPA)] is the Army's future deployable mobile communications family of radio systems, providing advanced joint tactical end-to-end networking data and voice communications to dismounted troops and aircraft platforms. JTRS utilizes Internet Protocol based technologies and provides network routing, embedded information assurance and simultaneous exchange of voice, data and video with multiple channels.

- **Joint Battle Command-Platforms (JBC-P)** [$141M (OPA)] is the next generation of Force XXI Battle Command Brigade and Below (FBCB2) / Blue Force Tracking (BFT) and is the foundation for achieving information interoperability on current and future battlefields and is the principal command and control / situation awareness (C2/SA) system for the Army and Marine Corps at the brigade level and below.

- **Distributed Common Ground System-Army (DCGS-A)** [$315M ($41M RDTE / $274M OPA)] provides integrated intelligence, surveillance, reconnaissance processing, exploitation and dissemination of airborne and ground sensor platforms providing commanders, at all levels, access to the Defense Intelligence Information Enterprise and leverages the entire national, joint, tactical and coalition intelligence, surveillance and reconnaissance (ISR) community.

- **Nett Warrior** [$150M ($47M RDTE / $103M OPA)]. Squads are the foundation of the decisive force and Soldiers are the centerpiece of the Army's formation. Nett Warrior is a mission command system worn by the dismounted Soldier providing unprecedented C2 / SA capabilities and support to the combat leader. The design incorporates operational unit mission needs and leverages operational lessons learned.

COMBAT VEHICLES

- **Ground Combat Vehicle (GCV)** [$640M (RDTE)] is the Army's replacement program for the IFV in Heavy Brigade Combat Teams (HBCTs) and is the centerpiece of the Army's overall combat vehicle modernization strategy. The GCV accommodates a nine-man infantry squad, balances mobility and survivability and provides unmatched lethality on the battlefield. Key GCV attributes include modular armor allowing commander adjustments based on operational threats as well as a design which allows

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incorporation of future size, weight, power and cooling technologies (SWAP-C). The Army expects to award engineering and manufacturing development contracts in FY14.

- **Armored Multi-Purpose Vehicle (AMPV)** [$74M (RDTE)] replaces the M113 family of vehicles and provides required protection, mobility and networking for the Army's critical enablers including mortars, medical evacuation and treatment as well as command and control vehicles. An analysis of alternatives (AoA) is underway following the February 2012 approval of the AMPV requirement for materiel development.

- **Paladin Integrated Management (PIM)** [$374M ($168M RDTE / $206M Weapons and Tracked Combat Vehicles (WTCV))] is an important part of the Army's Ground Combat Vehicle modernization strategy and provides readily available, low risk upgrades enhancing the responsiveness, force protection, survivability and mobility of the self-propelled Howitzer fleet. The PIM replaces the current M109A6 Paladin and M992A2 Field Artillery Ammunition Supply Vehicle chassis with a more robust platform incorporating Bradley common drive train and suspension components in a newly designed hull. The program completed the initial developmental testing phase and was designated as an Acquisition Category I Major Defense Acquisition Program in FY11.

LIGHT TACTICAL VEHICLES

- **Joint Light Tactical Vehicle (JLTV)** [$72M (RDTE)] is the centerpiece of the Army's tactical wheeled vehicle modernization strategy replacing approximately one third of the light wheeled vehicle fleet by 2035. The multi-mission vehicle design provides protected, sustained, networked mobility for personnel and payloads across the full range of missions (traditional to irregular). The Army released the request for proposals (RFP) for potential JLTV vendors in January 2012 and expects a Milestone B decision in 3rd Quarter FY12. The Army anticipates a Milestone C decision in Second Quarter FY15.

AVIATION

- **Kiowa Warrior (KW)** [$280M ($85M RDTE / $192M Aircraft Procurement, Army (ACFT) / $3M Operations and Maintenance Army (OMA))]. The Army recognizes a continuing requirement for a light, armed helicopter for manned armed aerial reconnaissance, surveillance and light attack operations missions. The Kiowa Warrior OH-58 model upgrade provides enhanced cockpit and sensor capabilities which includes the Cockpit Display Subsystem 5, a nose mounted sensor, a Dual-Channel Full Authority Digital Electronic Control engine and integrated Manned / Unmanned Teaming capability.

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EQUIPMENT PORTFOLIO OVERVIEWS

MOVEMENT & MANEUVER (SOLDIER) PORTFOLIO

Section I-Overview:

The squad is the foundation of the decisive force and the cornerstone of all units. Ensuring our squads are never in a fair fight and have overmatch in the future, the Soldier portfolio focuses on equipment for squad success. It consists primarily of small arms, crew-served weapons, shoulder-fired and vehicle-mounted missiles, mortars, Soldier sensors and lasers, night vision devices, body armor, Soldier clothing, individual equipment, parachutes, unmanned ground vehicles and limited tactical communications equipment (see table 1). Collectively, these systems enable lethality, protection, situational awareness and mobility for the individual Soldier and squad. To meet the readiness and the modernization objectives of the Army Campaign Plan the Soldier portfolio focus for FY13 is:

- Supporting a battalion-level, in-theater Limited User Evaluation of the Individual Semi-automatic Airburst System (ISAAS) as the next step in employing this revolutionary Soldier-level, precision weapon system.

SOLDIER SYSTEM PORTFOLIO MATERIEL STRATEGY

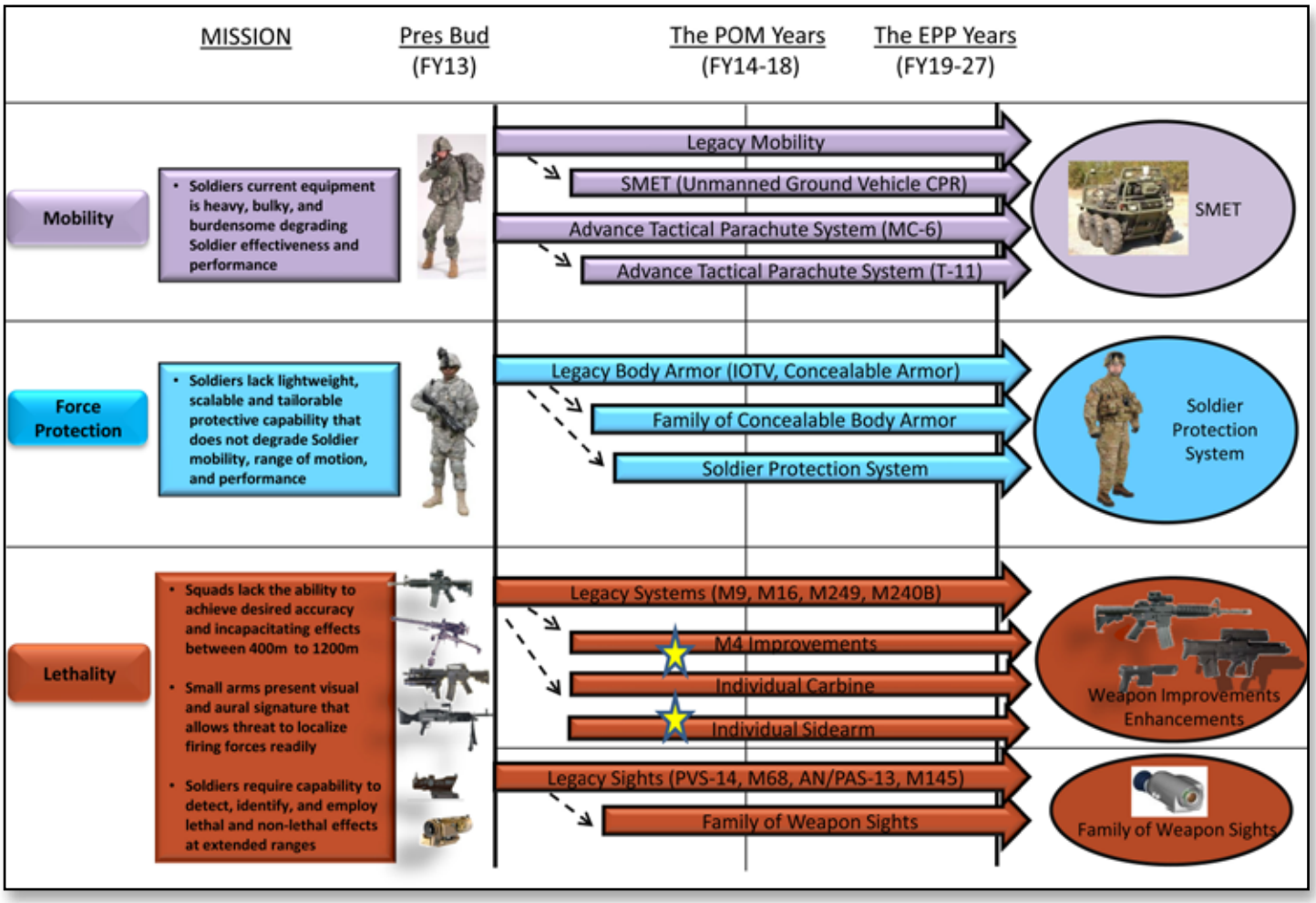


Table 1. Soldier Portfolio (see Acronym Glossary)

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- Continuing the fielding of Enhanced Night Vision Devices to deploying Special Operation Forces and Brigade Combat Teams.

- Executing small arms procurement, as informed by the results of a full and open carbine competition, while simultaneously improving the current carbine capability for deployed forces.

- Continuing replacement of the conventional force parachute inventory with the Advanced Tactical Parachute System.

- Continuing Soldier load reduction efforts through research and development in body armor and weapons including the Lightweight .50 Cal Heavy Machinegun, the M240L Medium Machinegun and Mortars (60mm and 81mm).

- Providing the Fire Resistant Environmental Ensemble to aircrews improving their protection and comfort.

- Continuing fielding of Operation Enduring Freedom Camouflage Pattern Fire Resistant Army Combat Uniforms and organizational and individual equipment to forces deploying to Afghanistan.

Section II – Key Soldier Portfolio Accomplishments (FY11/12):

- Reduced Soldier load in Afghanistan by replacing 501 M240B Medium Machine Guns with Lightweight Medium Machineguns (10 pounds) and 44,000 Outer Tactical Vests with plate carriers (3.2 pounds). In addition, reduced the weight of the 81mm Mortar by 20 pounds and the 60mm Mortar by 8.8 pounds.

- Provided the American Soldier with the best possible carbine by procuring improved M4A1s (rather than M4 Carbines) and converting existing M4 Carbines into improved M4A1s. Capability improvements include a heavier barrel, fully automatic trigger and selector switch, ambidextrous controls, greater barrel life, improved sustained rate of fire, a consistent trigger pull and improved ergonomics and handling characteristics.

- Continued procuring the following small arms weapon initiatives with:

  » 1,655 Lightweight M240L Machineguns lightening the Soldier load.

  » 5,000 additional .50 cal Machine guns supporting increased requirements for Theater and Sustainment, Protection and Logistics deploying units.

- Limited procurement and increased research and development of Soldier night vision equipment for current and future contingencies enhancing Soldier lethality and situational awareness across the full range of missions:

  » 3,425 Sniper Night Sights for Special Operations Forces (SOF), Brigade Combat Teams (BCT) and Battlefield Surveillance Brigades.

  » 7,181 Sense-Thru-the-Wall sensors for deploying BCTs and SOF.

  » 36,229 Thermal Weapon Sights (TWS) for deploying Combat Support (CS) and Combat Service Support (CSS) units.

  » 1,348 Laser Target Locators for BCTs.

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» 1,437 Small Tactical Optical Rifle-Mounted (STORM) (micro laser range finders) for dismounted infantry and scouts in BCTs.

» 24,846 Green Laser Interdiction Systems for BCTs.

Section III - Key FY13 Soldier Portfolio Investments:

The FY13 Soldier investments total $1.1B ($166M RDTE / $230M WTCV / $482M OPA / $166M Missile Procurement, Army (MSLS) / $81M OMA) and include small arms (individual and crew-served weapons), night vision, Soldier sensors, body armor, individual networked C2, Soldier clothing and individual equipment and parachutes. Specific investments in this portfolio include:

- $126M (OPA) procures Enhanced Night Vision Goggles for deploying SOF and 250 systems per deploying BCT.
- $82M (OPA) procures 4,244 TWS III enhancing lethality for deploying BCT units.
- $21M (WTCV) continues small arms investment. Quantities dependent on cost per item as determined through the carbine competition.
- Full spectrum dominance Soldier sensors and lasers for deploying BCTs and SOF :
  - » $27.2M (OPA) procures 587 Laser Target Locators.
  - » $20.7M (OPA) procures 1,381 STORM (micro laser range finders).
- $36M (OPA) fields new parachutes and accessories for three BCTs.
- $29.8M (WTCV) procures the new XM806 Lightweight .50 cal Machinegun with an initial 750 weapons. This weapon is approximately 60 percent lighter than the current weapon – the M2 Heavy Machine Gun.
- $21.3M (WTCV) procures 12,000 improved M4A1s.
- $27.2M (WTCV) procures carbine accessories (Close Combat Optics, Rifle Combat Optics, M4 Rails, Close Quarters Battle Kits, Cleaning Kits and Magazines).
- $14.3M (WTCV) procures M4 product improvement Kits to convert 20,140 M4s to improved M4A1s.
- $83.9M (OPA) fields 76 Small Unmanned Ground Vehicles (SUGV) to two Infantry Brigade Combat Teams (IBCT).

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MISSION COMMAND PORTFOLIO

Section I - Overview:

The Army's One Network Strategy is a deployable, integrated and interoperable network which spans all echelons of command and supports Army, Joint and coalition operations, forming a true enterprise network (see table 2). The Mission Command (MC) portfolio consists of three distinct capability areas: **Transport, Applications** and **Network Services.** Warfighter Information Network – Tactical (WIN-T) and Joint Tactical Radio Systems (JTRS) are the primary Transport programs; Tactical Battle Command (TBC), Joint Battle Command – Platform (JBC-P) and Global Command Support System – Army (GCSS-A) are the key Application programs; and Communication Security (COMSEC) with Key Management Infrastructure (KMI) and network management are the key Network Service programs. The Army integrates these elements into a coherent network of sensors, Soldiers, platforms and command posts linked by a robust transport network with an enabling suite of command and control (C2) applications providing our Warfighters greater access to greater and more varied network capabilities and

MISSION COMMAND PORTFOLIO

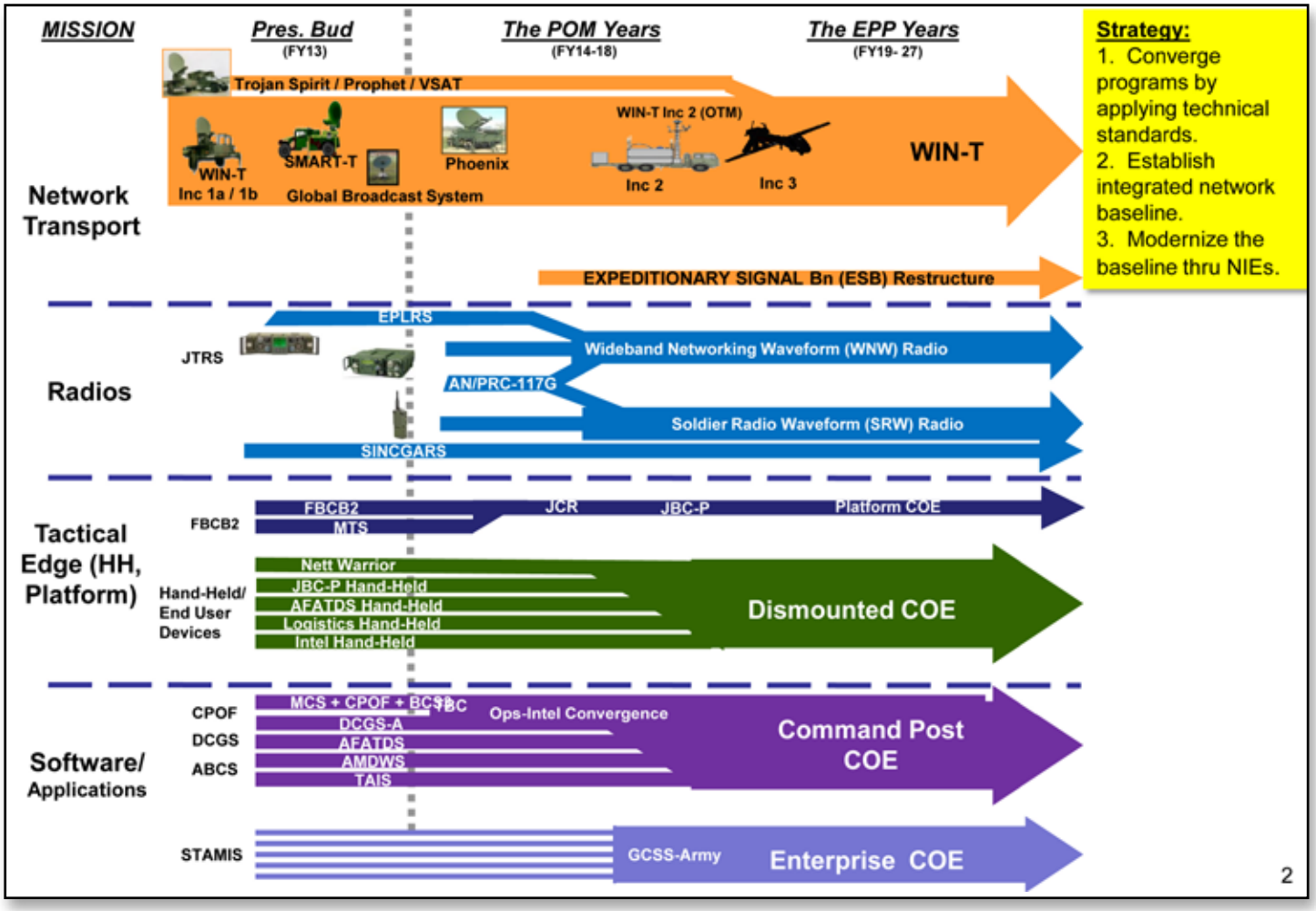


Table 2. Mission Command Portfolio (see Acronym Glossary)

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services. The network supports both the operating and generating force, shares information across levels of classification and enables rapid application development and deployment. The network is the combat multiplier for a versatile Army and every Soldier has access.

Section II – Key Mission Command Portfolio Accomplishments (FY11/12):

- Completed the fielding of WIN-T Increment (Inc) 1 and Inc 1a initial capabilities to 216 units. Beginning in FY12, all Inc 1 and 1a units will be upgraded to Inc 1b providing Enhanced Networking at the Halt capabilities by introducing the Net Centric Waveform (NCW) modem and the "colorless core" for interoperability.
- Conducted the Initial Operational Test and Evaluation (IOTE) for WIN-T Inc 2 providing an initial on-the-move capability to BCTs and divisions and extending the network to the company level.
- Awarded a production contract upgrading Secure Mobile Anti-Jam Reliable Tactical Terminals (SMART-T) supporting the Advanced Extremely High Frequency waveform and providing a significant increase in provided data rates. The Army fields SMART-T to maneuver brigades, Expeditionary Signal Battalions, divisions and corps.
- Fielded a Global Command Support System-Army (GCSS-A) web-based Army automation information system as the primary tactical logistics enabler in support of Army and Joint Transformation for Sustainment using an Enterprise Resource Planning system.
- Fielded a Windows based platform of Advanced Field Artillery Tactical Data System (AFATDS).
- Started the fielding of an Advanced Medium Mobile Power Source (AMMPS) replacing second generation Tactical Quiet Generators (TQG) employing advanced technologies improving engine / fuel efficiency, system reliability and increased survivability for military applications.

Section III: Key FY13 Mission Command Portfolio Investments:

FY13 Mission Command investments total $3.8B ($957M RDTE / $2.8B OPA) and include communications transport, applications and network services capabilities. Specific investments in this portfolio include:

- $98M (OPA) procures WIN-T Increment 1b upgrading 32 Brigades.
- $731M (OPA) procures WIN-T Increment 2 equipping seven BCTs.
- $566M (OPA) procures Wideband Data Radio systems, JTRS Manpack radios and Rifleman Radios for eight BCTs.
- $112M (OPA) replaces the Standard Army Management Information Systems (STAMIS) family of programs with integrated logistician tools and services starting in FY12.
- $68M (RDTE) collapses development and integration efforts of the Army Battle Command Systems (ABCS) producing a collaborative battle command (BC) environment for the maneuver, fires and air warfighting functions.
- $141M (OPA) procures JBC-P for ten BCTs.
- $150M ($47M RDTE / $103M OPA) funds Nett Warrior Initial Operational Test and Evaluation, on-going software development and procures the dismounted leader improved situational awareness (SA) capability for eight BCTs.

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INTELLIGENCE PORTFOLIO

Section I-Overview:

The Intelligence Portfolio incorporates key components of intelligence collection, exploitation and analysis organized into four primary layers: Foundational, Terrestrial, Aerial and Space. The goal of the portfolio is full integration of core intelligence capabilities including Full Motion Video, Signals Intelligence (SIGINT) collection and geolocation and Human Intelligence (HUMINT) interrogation and source operations. The portfolio also includes a secure intelligence communications architecture which is well-synchronized and integrated with the Army's network initiatives and supports all aspects of exploitation, analysis and dissemination meeting the readiness and modernization objectives of the Army Campaign Plan.

As depicted in table 3, the Intelligence portfolio provides essential modernization keeping pace with the evolving threat and rapid technology advancements. It equips Soldiers with advanced intelligence

ARMY INTELLIGENCE PORTFOLIO -- SYSTEMS MODERNIZATION STRATEGY

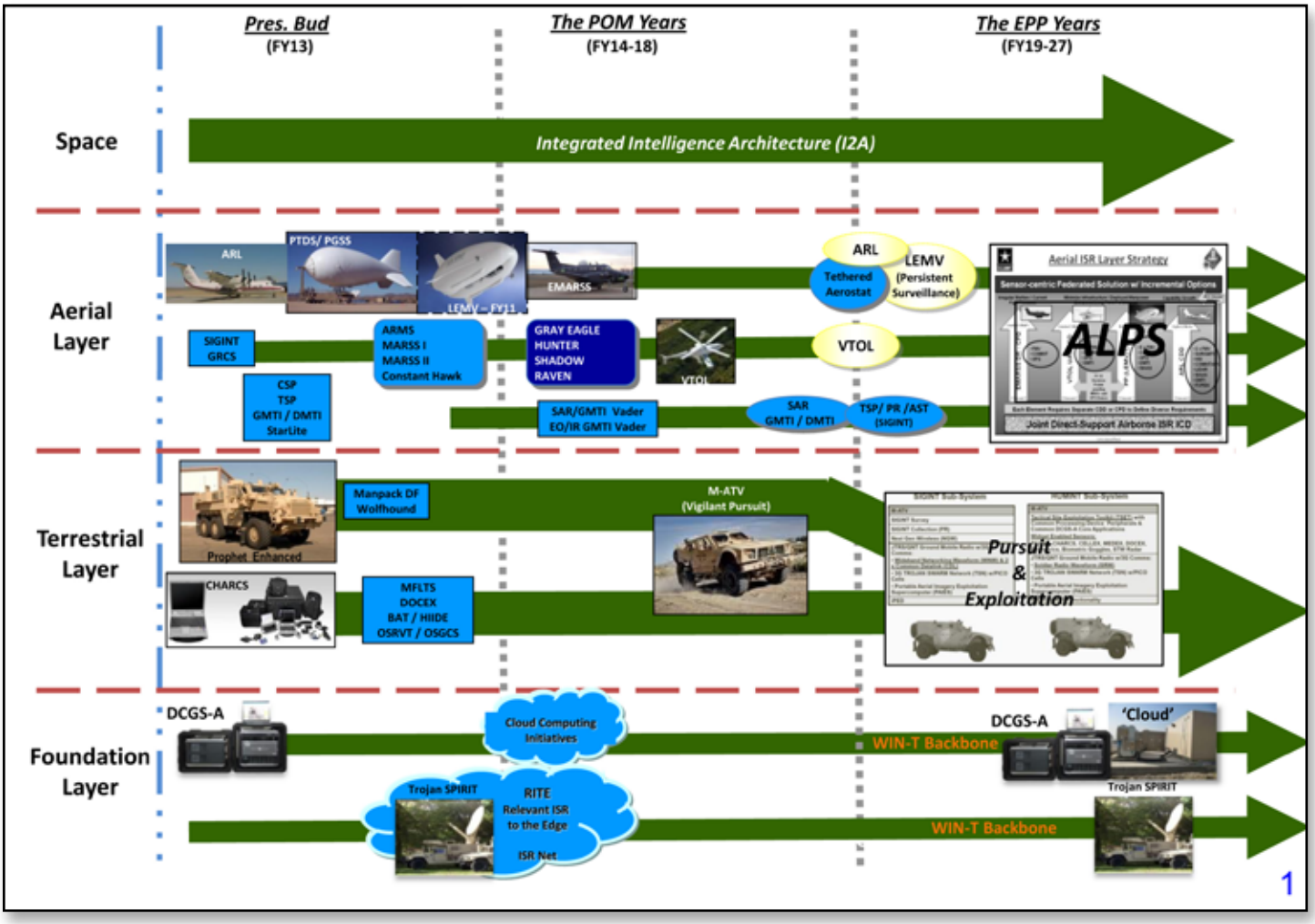


Table 3. Intelligence Portfolio (see Acronym Glossary)

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processing, analytical and dissemination tools. This modernization strategy delivers manned and unmanned aerial ISR platforms and sensors to the Soldier. It also funds essential team-oriented signals, human intelligence and counterintelligence capabilities and Top Secret / Sensitive Compartmented Information communications for tactical intelligence systems. This strategy continues investment in tools which enable collection, exploitation and dissemination with precision and speed, such as biometrics, identity resolution and counter-deception detection.

Section II – Key Intelligence Portfolio Accomplishments (FY11/12):

- Trained 1,958 students on the Distributed Common Ground System - Army (DCGS-A) in 160 events and fielded the following:
  - » Five DCGS-A Enabled (DE) Analysis and Control Elements
  - » 43 DE Analysis and Control Team - Enclaves
  - » 21 DE Common Ground Stations
  - » 33 DE Digital Topographic Support Systems
  - » 281 DCGS-A ISR Fusion Servers
  - » 1,544 DCGS-A Portable Multi-Function Workstations
- Transitioned DCGS-A Operation Enduring Freedom (OEF) capabilities to "cloud computing" architecture with user gateways from Company Intelligence Support Team (CoIST) to the International Security Assistance Force Headquarters.
  - » Began unit training on the software baseline in 1st Qtr, FY11 and the operational cloud computing capability reached Initial Operating Capability in April 2011.
  - » Fielded tactical edge nodes at OEF field operating bases providing advanced analytics and increasing storage capabilities in FY12.
  - » Completed a formal Initial Operational Test and Evaluation of DCGS-A in FY12 in preparation for a 1st Qtr, FY13 Information Technology Board Full Deployment Decision.
- Achieved Enhanced Medium Altitude Reconnaissance Surveillance System (EMARSS) Milestone (MS) B and entered the Engineering, Manufacturing and Development (EMD) phase with contract award for four EMD EMARSS aircraft to the Boeing Corporation. Began development and initial testing of these EMD aircraft in preparation for MS C (FY13).
- Delivered the first seven of 14 fully modernized RC-12X Guardrail Common Sensor (GRCS) aircraft in FY11 and immediately deployed them in support of ground combat operations. In FY12, the Army procures and integrates Enhanced Situational Awareness (ESA) and High Band COMINT (HBC) on the remaining seven RC-12X GRCS systems for fielding this year.
- Completed the Airborne Reconnaissance – Low (ARL) multifunctional conversion program in FY11 standardizing the current aircraft fleet of eight ARL with SIGINT / Imagery Intelligence (IMINT) and Moving Target Indicator (MTI) radar payloads. In FY12, continue upgrading system payloads with improved interface software and radar improvements in order to remain a relevant ISR collection asset against a dynamic range of targets.

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- Equipped and fielded the first Gray Eagle UAS with the Common Sensor Payload (CSP), Full Motion Video and Small Tactical Radar Lightweight (STARLite) Synthetic Aperture Radar (SAR) system in FY11. RDTE efforts initiated engineering development of High Definition video and Target Location Accuracy improvements for CSP, enhancements to STARLite range and resolution and initiation of EMD of the Tactical SIGINT Payload (TSP).

- Fielded Prophet Enhanced Ground Signals Intelligence, a more modular and vehicle-agnostic version of Prophet Signals Intelligence capability, to BCTs and Battlefield Surveillance Brigades (BfSBs) operating in combat theaters.

  » Fielded 22 of the Prophet Enhanced sensors to next deployers as Theater Provided Equipment in FY12.

  » Provided RDTE for both software and hardware upgrades to the Prophet Enhanced sensors maintaining operational relevance.

- Fielded 596 Machine Foreign Language Translation System quick reaction capability through FY11.

  » Deployed 102 smart phones capable of two-way speech-to-speech translation which represents a significant step forward from previous phrase-based one-way translation devices.

  » Developed, refined and tested the technology providing speech-to-speech translation in three languages and text-to-text translation capability in two languages in FY12.

Section III – Key FY13 Intelligence Portfolio Investments:

Fiscal Year 13 Intelligence investments total $703M ($197M RDTE / $254M OPA / $252M ACFT) and includes the key components of intelligence, surveillance and reconnaissance collection, exploitation and analysis. Specific investments in this portfolio include:

- $225M ($184M OPA / $41M RDTE) funds DCGS-A.

  » Integrates DCGS-A software and cloud computing capabilities into one baseline capability package (DCGS-A Software Baseline 1.1) and develops the Army Common Operating Environment Command Post Computing Environment.

  » Procures 2,214 DCGS-A Portable Multi-Function Workstations, 202 DCGS-A Intelligence Fusion Servers and 23 DE Analysis and Control Team - Enclave in support of one corps, three divisions, 12 BCTs, three special operations units, three maneuver enhancement brigades, three combat aviation brigades, three fires brigades and other combat support (CS), combat service support (CSS) units entering the ARFORGEN available pool.

- $47M (RDTE) procures four developmental EMARSS aircraft which will deploy and operate as part of Task Force ODIN – Afghanistan in FY13.

  » Completes Engineering, Manufacturing and Development (EMD) of four developmental aircraft and completes the requirements of the current contract.

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» Continues assessments of future aerial intelligence requirements to determine additional capabilities beyond current Army, QRC and joint systems.

- $16M (ACFT) modernizes GUARDRAIL Common Sensor (GRCS) and completes (retrofits) the final software and hardware upgrades (ESA and HBC) on the first set of seven RC-12X systems (due to the unavailability of these systems during fielding of aircraft 1-7). The modernized GRCS system provides improved irregular warfare SIGINT support to BCT commanders through better look-down intercept angles and enhanced frequency collection while maintaining superior full spectrum, deep-look capability to echelons above brigade commanders.

- $259M ($232M ACFT / $27M RDTE) for UAS ISR Payloads providing the optimal mix for the Gray Eagle platform with day / night capability to collect and display continuous imagery, wide-area all-weather search capability, persistent stare, Ground Moving Target Indicator (GMTI) and SAR. Provides development and procurement of 27 CSP Electro-Optical/Infra-Red/Laser Designator sensors and 39 STARLite SAR/GMTI sensors for integration and fielding support to the ARFORGEN schedule. RDTE funding facilitates continued improvements to CSP and STARLite and baseline development of TSP.

- $59M ($49M OPA / $10M RDTE) for Prophet Ground Signals Intelligence.

  » Procures nine Prophet Enhanced sensors mounted on Panther Medium Mine Protected Vehicles and four Prophet Control systems for fielding to BCTs and BfSBs operating in combat theaters. Funding will also procure six next-generation receivers and hardware/software improvements to keep pace with rapidly changing threat technology and tactics, techniques and procedures.

  » Funds RDTE product upgrades for next-generation Signals, develops a geolocation capability per pre-planned product improvement requirements and initiates integration and testing of a software-defined radio / receiver solution to the Prophet Enhanced sensor.

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MOVEMENT AND MANEUVER (GROUND) PORTFOLIO

Section I - Overview

The Movement and Maneuver (Ground) Portfolio goal is to develop and field an integrated combined team, linked by the network, capable of dominating across the range of missions today and into the future. Key to this effort is our Combat Vehicle Modernization Strategy which transforms the capability of the Brigade Combat Team by acquiring the Ground Combat Vehicle (GCV), replaces the M113 Family of Vehicles with an Armored-Multi Purpose Vehicle (AMPV) and improves the Abrams tank, the Bradley Cavalry, Fire Support and Engineer Vehicles and the Stryker by increasing protection, ensuring required mobility and allowing integration of the network.

Section II – Key Movement and Maneuver (Ground) Portfolio Accomplishments (FY11/12):

- Began an aggressive testing program of the Stryker Double V Hull and began fielding this

MANEUVER PORTFOLIO

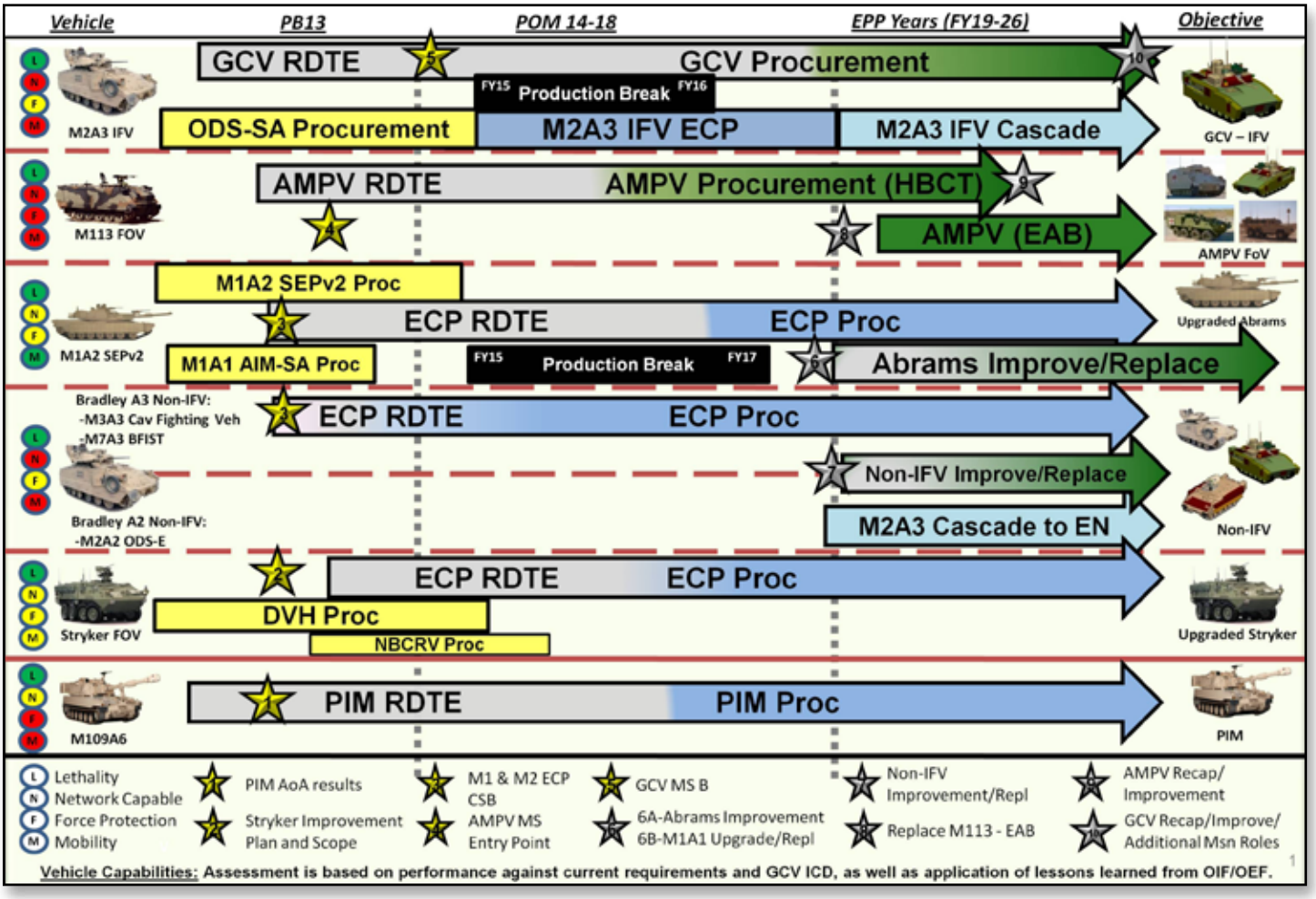


Table 4. Maneuver Portfolio (see Acronym Glossary)

3201 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



more survivable vehicle to Afghanistan meeting the changing operational needs of our deployed Warfighters.

- Fielded nine IBCTs with the Mortar Fire Control System-Dismounted providing dismounted infantry the mortar fire control capability previously found only in our heavy forces.

- Converted the 3rd Armored Cavalry Regiment HBCT to a Stryker Brigade Combat Team better balancing the Army force structure.

- Modernized 1st Infantry Division (Fort Riley) and the 116th HBCT (Idaho Army National Guard) with the most modern versions of the Abrams tank (M1A2 System Enhancement Program (SEP) v2) and the Bradley Fighting Vehicle (M2A3).

- Focused on achieving standardization of two variants of our dominant combat maneuver platforms (M1 Abrams Tank and M2 Bradley Fighting Vehicle (BFV)) combined with expansion of the versatile and lethal Stryker Combat Vehicle.

  » Modernized the older M1 variant with M1A1 Situational Awareness (SA) upgrade kits while upgrading the M1A2 Abrams with the M1A2 SEP kit. Procured 87 M1A1 SA kits and 21 M1A2 SEP kits providing enhanced situational awareness for operators and command elements, increased force protection and integration optimization between systems.

  » Upgraded kits made the M2A3 Operation Desert Storm (ODS) and M3A2 ODS Bradleys compatible with the M1A1 SA Abrams providing greater lethality, survivability and sustainability.

Section III – Key FY13 Movement and Maneuver (Ground) Portfolio Investments

The FY13 Movement and Maneuver (Ground) investments total $1.8B ($868M WTCV / $919M RDTE) and include the Army's combat vehicles such as Abrams, Bradley, Stryker and the development of the GCV. Specific investments in this portfolio include:

- $640M (RDTE) develops GCV technologies which continues through 4th quarter FY13.

- $374M ($168M RDTE / $206M OPA) begins M109A6 PIM procurement by purchasing the Paladin Digital Fire Control System-Replacement. RDTE funds development and integration of common components into prototype vehicles.

- $74M (RDTE) funds AMPV Analysis of Alternatives and Pre-Milestone A development activities. Initial focus is on replacing M113s within the HBCTs. The remaining efforts focus on a future decision point to address the M113's located in echelons above brigade.

- $393M ($379M WTCV / $14M RDTE) procures 58 Nuclear Biological Chemical Reconnaissance Vehicles (NBCRV) and supports protection and Overseas Contingency Operation requirements. The NBCRV provides an unprecedented capability to the Joint Force and Homeland Defense by detecting and identifying biological, chemical and nuclear hazards.

- $301M ($204M WTCV / $97M RDTE) completes the fielding of M1A2SEPv2 Abrams achieves Modular Two Variant Fleet Configuration: 1,547 M1A2SEPv2s and 791 M1A1AIM SA. RDTE funds the Technology Development phase for Abrams Engineering Change Proposal (ECP) improvements.

- $230M ($148M WTCV / $82M RDTE) completes Army National Guard (ARNG) Bradley non-IFV procurement modernization with M2A2 ODS Situational Awareness kits. RDTE focuses on ECP improvements for the Bradley Cavalry, Fire Support and Engineer Vehicles.

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MOVEMENT AND MANEUVER (AIR) PORTFOLIO

Section I - Overview:

The Movement and Maneuver (Air) portfolio consists of core aviation programs, including utility and cargo, fixed wing mission profiles, reconnaissance / attack, Intelligence, Surveillance and Reconnaissance (ISR) and Unmanned Aircraft Systems (UAS) which meet readiness and modernization objectives of the Army Campaign Plan.

As depicted within tables five through seven, key objectives and decision points in the Movement and Maneuver (Air) portfolio are:

- Fully fund the Kiowa Warrior OH-58F program.
- Fully fund the Apache Milestone C decision.
- Fully fund Gray Eagle UAS production.

AVIATION PORTFOLIO (CORE PROGRAMS)

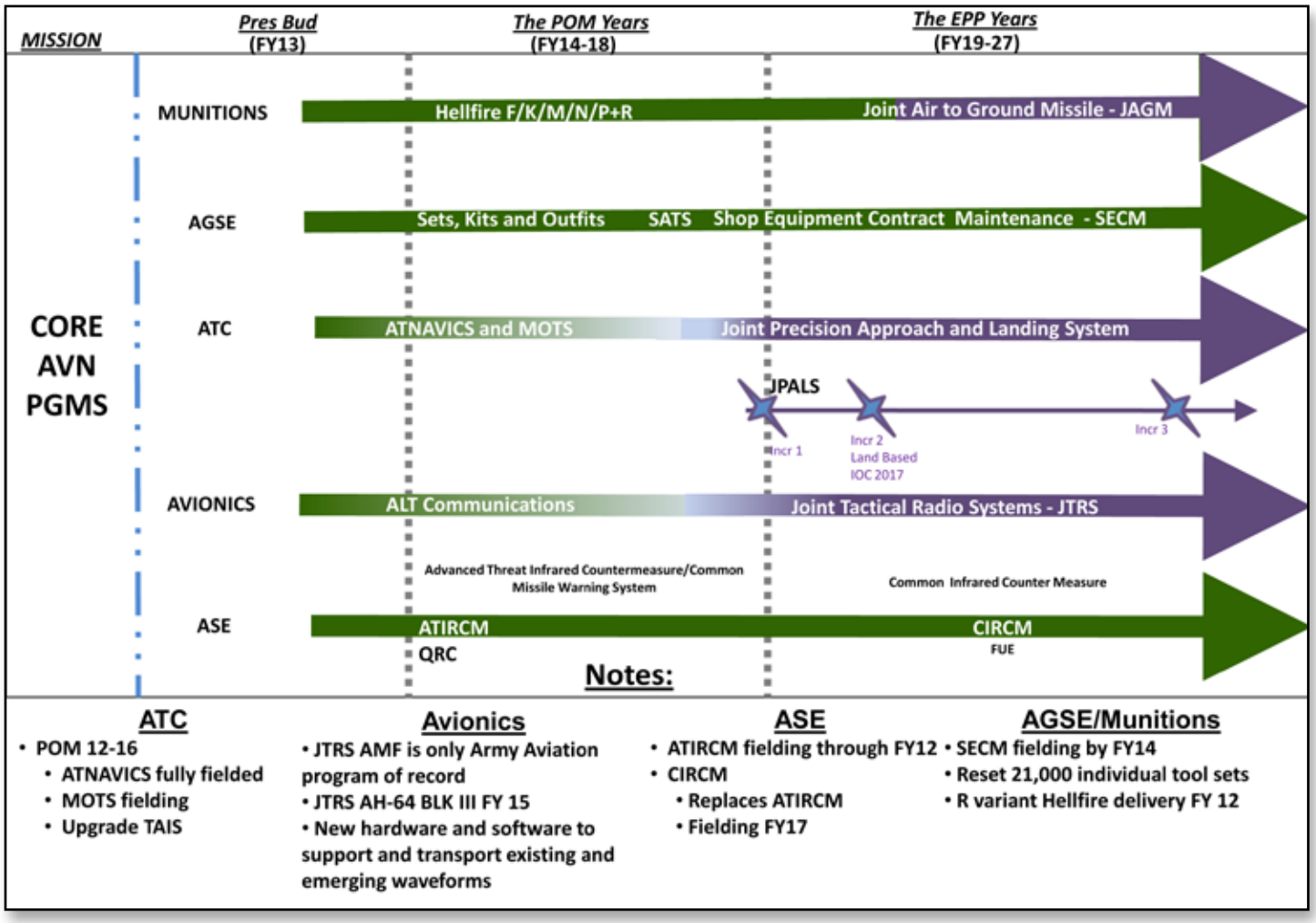


Table 5. Aviation Portfolio (see Acronym Glossary)

3203 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

- Fully fund UH-60 production meeting 13th Combat Aviation Brigade (CAB) growth and Special Operations increased aircraft requirement.

- Continue procurement of the Lakota, Light Utility Helicopter program in support of cascading OH-58 aircraft to the training base.

- Fully fund 13th CAB and Special Operations CH-47 aircraft requirements.

Section II – Key Movement and Maneuver (Air) Portfolio Accomplishments (FY11/12):

- Continued induction of the first battalion of Apache helicopters for remanufacture to AH-64D Apache Block III.

- Continued First Unit Equipped for the Advanced Threat Infrared Countermeasures (ATIRCM) on the CH-47D helicopter (FY10).

- Continued fielding the Digital Data Link (DDL) with 217 DDL systems in FY11, procured 291

AVIATION PORTFOLIO (UTILITY/CARGO/FIXED WING)

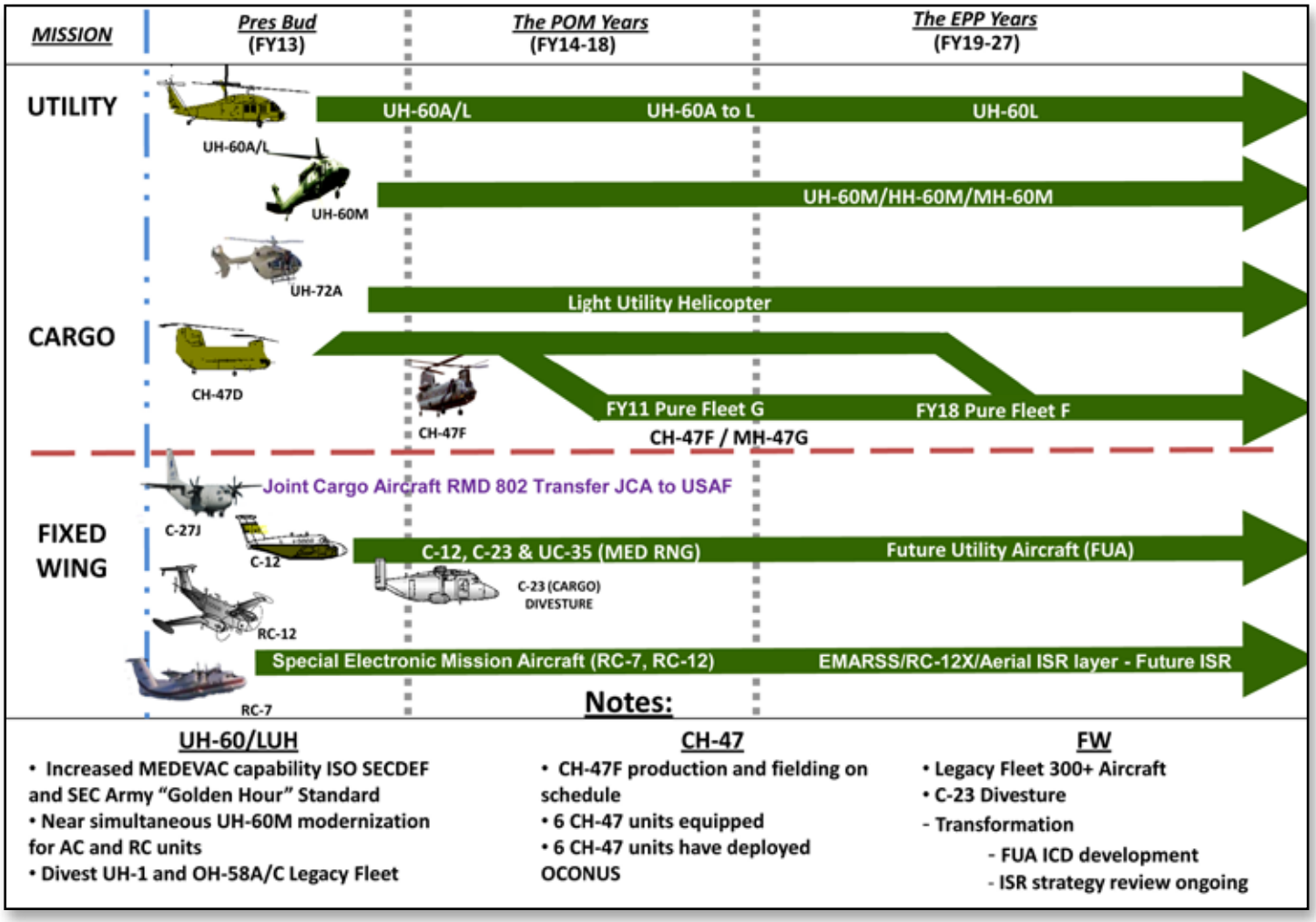


Table 6. Aviation Portfolio (see Acronym Glossary)

3204 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

new DDL systems and converted 456 analog systems to DDL. DDL increases the amount of channels Raven aircraft use within a single geographic area providing the supported unit more full motion video coverage across the entire area of operations.

- Fielded the 1-104th Attack Reconnaissance Battalion (ARB) (Pennsylvania ARNG) with AH-64D Apache Block II helicopters and inducted the AH-64A aircraft of the 1-135th ARB (Missouri ARNG) as part of modernizing the ARNG attack helicopter fleet.

- Provided four Tactical Airfield Lighting Systems to Theater Provided Equipment in FY11 enhancing the safety and efficiency of theater airfields in Iraq and Afghanistan.

- Fielded Medical Evacuation (MEDEVAC) helicopters (HH-60M) to six General Support Aviation Battalions supporting Army and Department of Defense leadership emphasis on increased MEDEVAC Capability.

- Procured 29 MQ-1C Gray Eagle Unmanned Aircraft and the associated ground support equipment ($456M). Gray Eagle missions include Reconnaissance, Surveillance, Target Acquisition, Armed Reconnaissance, Signals Intelligence, Communications Relay and Battle Damage Assessment.

  » Fielded two Gray Eagle Quick Reaction Capability platoons equipped with four aircraft each (one was in Operation New Dawn (OND) and the other is deployed in Operation Enduring Freedom (OEF)).

  » Completed fielding the first MQ-1C Gray Eagle Company to the 1st Cavalry Division CAB and the unit subsequently deploys in FY12.

  » Fielded the second MQ-1C Gray Eagle Company to the 1st Infantry Division CAB in the 3rd quarter of FY12 and this unit conducts Initial Operational Test and Evaluation and subsequently deploys.

  » At end state, the Army fields 17 Gray Eagle Companies; two fully equipped companies within the Special Operations Command; five fully equipped Companies in the General Purpose Force available / deployed pool; and ten partially equipped companies in the training / reset pool.

- Procured Shadow modifications including 52 Laser Designators, 20 Universal Ground Control Stations and 46 Tactical Common Data Link retrofit kits.

- Focused rotary wing aircraft modernization on the UH-60 (Black Hawk), CH-47 (Chinook) and AH-64 (Apache) helicopters:

  » Procured 48 UH-60M (utility mission) and 24 HH-60M (MEDEVAC mission) helicopters. The M model provides a digitized cockpit, new engine for improved lift and range and wide-chord rotor blades. By the end of FY11, the Army equipped five Assault Helicopter Battalions (AHBs) with the UH-60M.

  » Procured 40 F model Chinook aircraft while providing modifications including a loading system enabling more rapid reconfiguration from cargo to passenger support missions.

  » Procured 16 new Apache Block III aircraft and upgraded existing aircraft to Block II models. Block II modifications integrate Target Acquisition Designation Sight / Pilot Night Vision Sensor upgrades and other safety and reliability modifications. The

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3205 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Block III model is the Army's attack helicopter bridge to the future force and provides unmanned aerial system control capability, a visual near-infrared sensor to aid target acquisition and other force protection and reliability enhancements.

- Funded $48M for RDTE and $35M APA for Hostile Fire Quick Reaction Capability development, testing and fielding of capability in May 2012.

- Funded $26M for the KW helicopter addressing obsolescence and weight reduction efforts for our aging KW fleet; specifically the continued research and development of the Cockpit and Sensor Upgrade Program and procurement of long lead items for the first lot of Limited Rate Initial Production (LRIP) of OH-58F helicopters.

- Funded $15M in FY12 the Armed Aerial Scout (AAS) supporting program RDTE.

- Funded $1.7B in FY12 for the Blackhawk helicopter Multi Year Procurement procuring 47 UH-60M and 24 HH-60M aircraft. The first year of Multi-Year/Multi-Service VIII Contract is FY12.

- Funded $250M for Lakota in FY12 of which $244M remains allocated for the Army National Guard. Procures 39 aircraft in FY12.

- Funded $1.4B in FY12 procuring 47 modernized CH-47F and one MH-47G aircraft.

- Planned FY12 fixed wing aircraft modifications include the Global Air Traffic Management (GATM) upgrade, Aircraft Survivability Equipment (ASE) and Blue Force Tracker (BFT) installation.

- Funded $666M in FY12 for Apache Block III. The Army remains on schedule for Apache Block III First Unit Equipped in FY13.

- Funded $165M in FY12 for RQ-7B Shadow supporting the acquisition of 8 Tactical Communication data Link retrofit kits and 400 One System Remote Video Terminals (OSRVT) modification kits.

- Funded $86M in FY12 for RQ-11B Raven procuring 300 gimbaled systems (900 Air Vehicles) and assuming other hardware costs including ground control stations, remote video terminal and an initial deployment spares package. The gimbaled payload combines the Electro-optical/Infrared cameras one-to-one payload ball and is a major improvement over the current payloads. In addition, funding answers unit requests for a virtual training device for system operators.

- Funded $551M in FY12 maximizing the production rate of the MQ-1C Gray Eagle program by procuring 36 MQ-1C aircraft, 18 ground control stations, 18 ground data terminals, nine satellite communication ground data terminals and other ground support equipment. Under this acceleration, the Army increases procurement of aircraft and associated ground support equipment in FY12 and FY13 from 27 aircraft per year to the new procurement profile of 29 aircraft in FY11 and 36 aircraft in FY12.

- Funded $8M in FY12 for Vertical Take Off and Landing (VTOL) UAS providing the BCT a multi-intelligence platform capable of conducting beyond-line-of-sight full motion video, wide area surveillance and signals intelligence. VTOL UAS reduces the need for burdensome runway and infrastructure requirements and provides sensor capability expansion given the aircrafts ability to hover as well as in flight slow airspeed.

3206 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

- Funded $127M in FY12 for the Joint Air to Ground Missile (JAGM) which supports the transition of Army Hellfire missile to a joint missile system and replaces the Marine Corps air launched version of the Tube-launched Optically-tracked Wire-guided missile and Navy Maverick missiles. In addition, funds were applied to the JAGM program re-structure which extended the technology development phase.

- Funded $43M in FY12 for the Long Endurance Multi-Intelligence Vehicle (LEMV). Provides sustainment to LEMV Airship 1 operations achieving Initial Operating Capability and fully mission capable status in OEF and builds additional airships and configurable ISR / communications payloads.

- Funded $163M in FY12 for 350 of the Gen3 Electronic Control Units for Common Missile Warning System (CMWS).

Section III – Key FY13 Movement and Maneuver (Air) Portfolio Investments:

FY13 Movement and Maneuver (Air) investments total $6.6B ($776M RDTE / $123M Procurement

AVIATION PORTFOLIO (RECON/ATTACK/UAS)

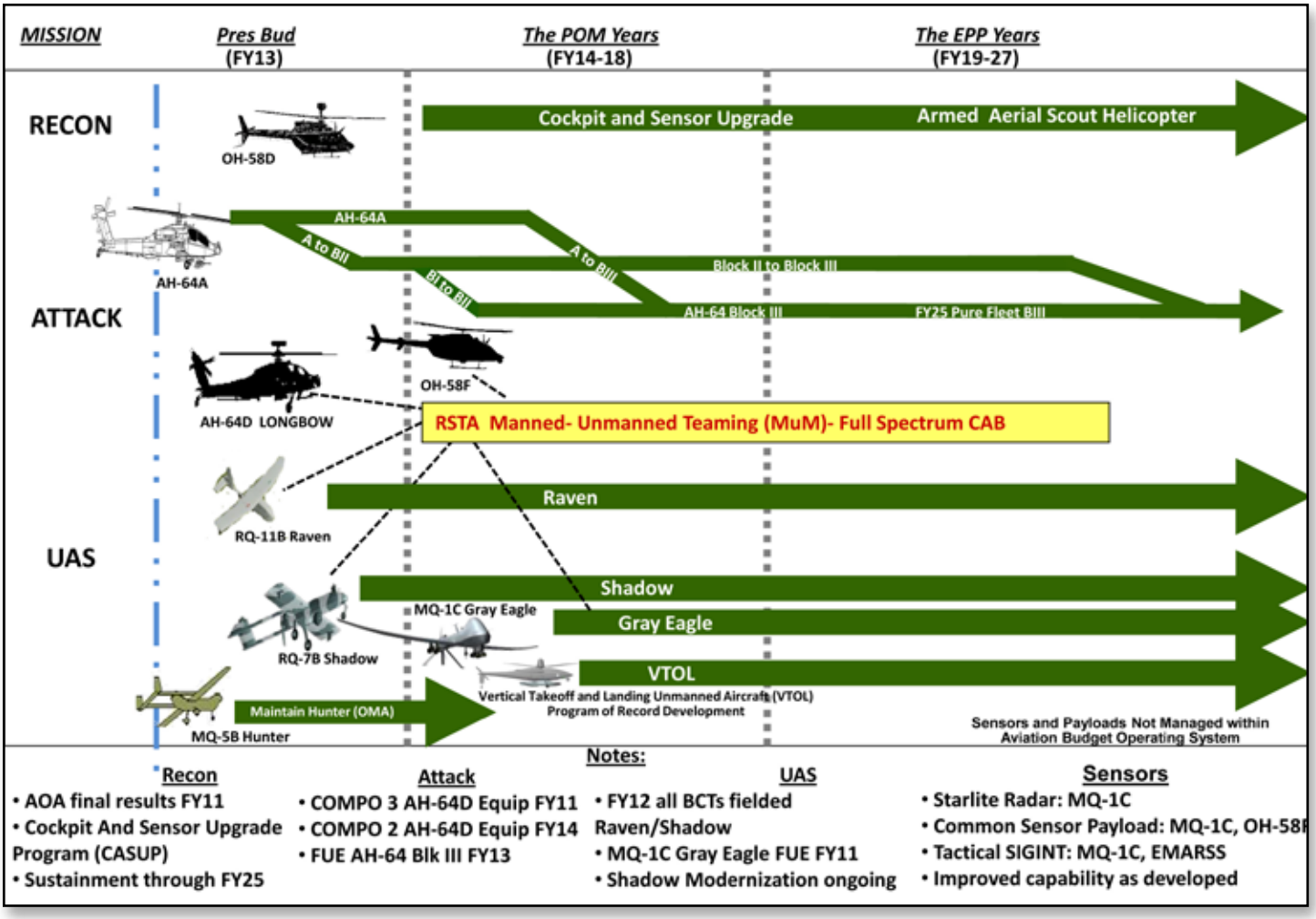


Table 7. Aviation Portfolio (see Acronym Glossary)

3207 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



of Ammunition, Army (AMMO) / $1M MSLS / $5.6B ACFT) and include required capabilities in the reconnaissance, attack, unmanned aerial systems, utility and cargo and fixed wing mission profiles. Specific investments in this portfolio include:

- $97M (RDTE) for the Technology Development phase of the Common Infrared Countermeasure (CIRCM) system for Army aviation platforms. CIRCM is a light-weight, low cost, highly reliable laser-based countermeasure system which works in conjunction with Service missile warning systems (i.e. CMWS). Proposed Full Rate Production is approximately FY18.

- $30M ($4M RDTE / $25.8M ACFT) for RQ-11B Raven procuring 78 systems (234 Air Vehicles) and other hardware including ground control stations, remote video terminal and an initial deployment spares package. In addition, funding answers unit requests for a virtual training device for system operators during the ARFORGEN training cycle.

- $135M ($31.2M RDTE / $104M ACFT) for RQ-7B Shadow supporting acquisition of seven Shadow Tactical Communication Data Link (TCDL) retrofit kits (and associated spare parts), seven launchers, 44 enhanced mission computers, eight universal mission simulators and 400 One System Remote Video Terminal (OSRVT) modification kits. Shadow support the ARFORGEN training cycles.

- $2M (RDTE) funding for VTOL UAS.

- $593M ($74.6M RDTE / $518M ACFT) procures 19 MQ-1C aircraft and associated ground support equipment.

3208 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

FIRES (INDIRECT) PORTFOLIO

Section I – Overview:

To prevail in future operational environments and succeed in a wide range of contingencies, the Army must have a campaign-quality, expeditionary Field Artillery (FA) force that delivers and integrates lethal and non-lethal fires enabling joint and maneuver commanders the ability to dominate their operational environment across the full range of missions. The Fires portfolio consists of required fire support capabilities in the following four areas: Precision Sensors, Delivery Platforms (Shooters), Munitions and FA (C2) Systems. (See table 8).

To meet the threats of an ever adaptive adversary who uses unconventional tactics, the Army must carefully balance the quantity, quality and management of its equipment. The Fires (Indirect) portfolio includes several types and variants of equipment which focuses on a vast number of precision and near-precision

FIRES - FIELD ARTILLERY PORTFOLIO

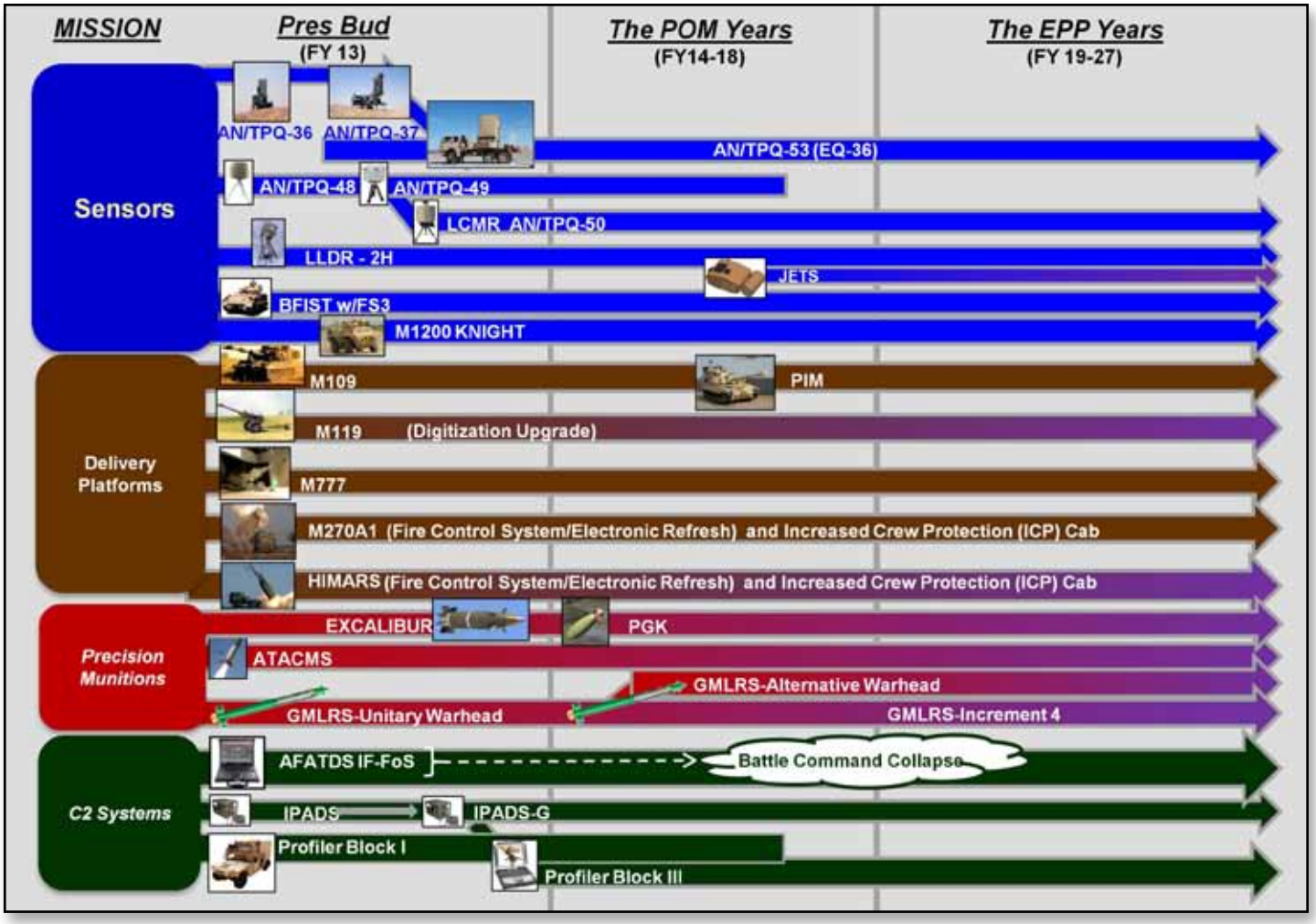


Table 8. Fires Portfolio (see Acronym Glossary)

3209 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



Field Artillery missions. To that end, the key strategic objectives for the Fires portfolio are:

- Improve Precision Targeting capability, especially lightweight, handheld targeting systems.
- Incorporate Joint Fires into procurement planning.
- Develop and procure Precision Munitions supporting Total Army Munitions Requirements.
- Enhance organic Precision Fires capabilities of IBCTs.
- Sustain and modernize firing platforms in synchronization with Army modernization plans.
- Support command and control program merge into the Battle Command Network architecture.
- Seek Common User Interface across all Fires launch and radar systems.
- Seek fielding opportunities in providing technologies rapidly to the Warfighter.

Section II – Key Fires (Indirect) Portfolio Accomplishments (FY11/12):

- Completed fielding and deployed the 12 initial production model Q-53 radar systems in support of OND and OEF. Fielded 20 additional Q-53 radar systems for units deploying in support of OEF (FY12).
- Upgraded Firefinder radars (AN/TPQ-36 and AN/TPQ -37) with a new more reliable radar processor (Q-36 and Q-37) and improved power amplifier modules and antenna array (Q-37).
- Upgraded Lightweight Laser Designator Rangefinders (LLDR) supporting the Army-Directed Requirement for increasing precision in employment of currently fielded Precision Munitions.
- Began initial development of the Joint Effects Targeting System (JETS) Target Location Designation System with the Technology Demonstration phase planned for FY13.
- Continued improvement of the Q-50 Lightweight Counter Mortar Radar (LCMR) system capabilities increasing the range and accuracy over the previous LCMR version radar system (FY12).
- Procured 78 M1200 Targeting Under Armor (TUA) retrofits of the M1200 Armored Knight. The TUA modification increases Soldier survivability by placing the Soldier inside the vehicle during mission operation.
- Continued improving crew survivability with the retrofit of previously fielded High Mobility Artillery Rocket System (HIMARS) Multiple Launch Rocket System (MLRS) launchers incorporating an increased crew protection cab in both active and reserve component units.
- Completed competitive prototyping for the Guided Multiple Launch Rocket System alternative warhead and began engineering, manufacturing and development in FY12.
- Began development of PIM addressing long-term sustainability and fires capabilities for the HBCT.
- Began procuring additional M777A2 Howitzers enhancing organic precision fires capability to IBCTs.

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3210 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

- Continued the development of the digitized modifications for the M119A2, 105mm Towed Howitzer addressing responsiveness of fires to support IBCTs.

- Recertified the Excalibur 155mm Precision Munitions program with the Office of the Secretary of Defense and Congress through the Nunn-McCurdy process.

- Tested and began procurement of an Urgent Materiel Release quantity of the Precision Guidance Kit fuse for the 155mm non-precision munitions.

- Completed fielding of Profiler Laptop systems displacing the two vehicle helium balloon meteorological measuring system.

Section III – Key FY13 Fires (Indirect) Portfolio Investments:

FY13 Fires (Indirect) investments total $1.6B ($404M RDTE / $335M WTCV / $426M OPA / $148M AMMO / $259M MSLS) and include lethal and non-lethal fires and effects such as radars, cannons, launchers, munitions and automated enablers. Specific investments in this portfolio include:

- $22M (OPA) develops and procures Lightweight Laser Designator Rangefinder (LLDR) 2H modifications enhancing target location accuracy.

- $22M (RDTE) provides RDTE for JETS.

- $57M (WTCV) sustains and improves Bradley Fire Support Team (BFIST) Hardware / Software modifications with the Fire Support Sensor System (FS3).

- $73M (OPA) procures and fields Q-50 Lightweight Counter Mortar Radar (LCMR) Systems.

- $3M (RDTE) develops Q-50 LCMR Common Front End (CFE) and Extended Range software.

- $12M (MSLS) completes fielding of the (HIMARS) Launcher.

- $21M (WTCV) develops and procures Digitization modifications to M119A2 Howitzer for more responsive fires for IBCT.

- $13M (OPA) procures 136 Block III Meteorological Measuring Set Profilers (laptop).

- $115M (AMMO) develops and procures Excalibur 155mm munitions in accordance with recent Nunn-McCurdy recertification.

- $67M (RDTE) continues development and testing of the Guided Multiple Launch Rocket System alternative warhead.

- $168M (RDTE) provides PIM RDTE and $206.1M begins funding PIM Low Rate Initial Production (LRIP).

- $262M ($9M RDTE / $253M OPA) continues procurement of the Q-53 radar system.

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3211 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

PROTECTION (AIR AND MISSILE DEFENSE) PORTFOLIO

Section I – Overview:

The Air and Missile Defense (AMD) modernization strategy is driven by a complex and changing operational environment which requires capabilities from the tactical through strategic levels and provides defenses against advancements in ballistic missiles; manned and unmanned aircraft; as well as rockets, artillery and mortars which threaten friendly forces as well as defended assets at home and abroad. The AMD portfolio consists of required capabilities in the following areas: Ballistic Missile Defense; Counter UAS / Cruise Missile Defense; Indirect Fire Protection; and C2 Defense.

As depicted in table 9, key imperatives in the AMD portfolio include the common battle manager development and fielding, improvements and recapitalization of current systems as well as fielding new capabilities.

AIR AND MISSILE DEFENSE PORTFOLIO

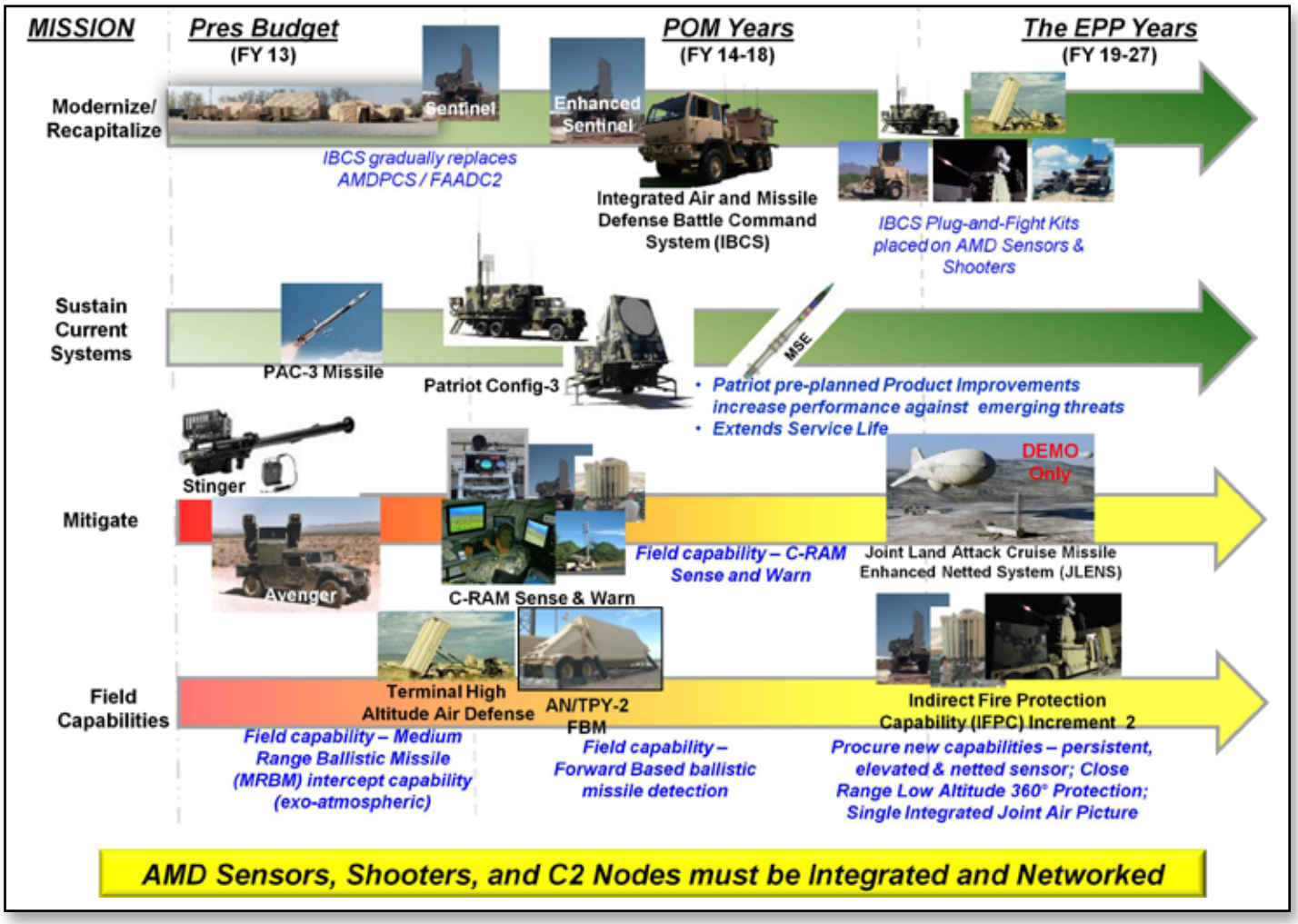


Table 9. Air and Missile Defense Portfolio (see Acronym Glossary)

3212 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Given the trends and essential capabilities for future U.S. Army AMD systems articulated above, the strategic modernization imperatives for AMD are:

Modernize: Develop and acquire new equipment and improve or recapitalize current systems remaining relevant and capable of closing capability gaps and achieving dominance in core capabilities.

- Increase capabilities to the Counter-Rockets, Artillery and Mortar (C-RAM) systems deployed in Theater.
- Improve Patriot missiles by replacing the Patriot Advanced Capability-3 (PAC-3) missile with the improved Missile Segment Enhancement (MSE).
- Conduct a comprehensive pre-planned product improvement effort incrementally modernizing and upgrading performance of the Patriot system.
- Conduct Service Life Extension Program (SLEP) and capability improvements on Stinger missiles increasing their counter-UAS capabilities.

Sustain: Close capability gaps, extend useful life of existing equipment.

- Develop, acquire and field a common battle manager / C2 node for all U.S. Army AMD forces which is a modular, open, net-centric system that is operationally scalable.
- Fuse / integrate the air picture with fire control quality data.
- Integrate sensors and weapons on the network through "plug and fight."
- Enable Joint Integrated Fire Control across U.S. Army, U.S. Navy and U.S. Air Force platforms.

Mitigate: Procure systems capable of meeting the threats of today and tomorrow.

- Develop and procure a next generation Indirect Fire Protection Capability (IFPC) to providing effective, full spectrum protection for the joint and maneuver forces.

Field: Provide the Soldier with the quantity and type of equipment required, at the proper time enabling training, preparation and employment for mission successes.

- Field Terminal High-Altitude Area Defense (THAAD), a new capability providing a robust and capable medium-range ballistic missile intercept capability.

Section II – Key Air and Missile Defense Portfolio Accomplishments (FY11/12):

- Upgraded the last of three older Patriot units to PAC-3 capability (launcher upgrades continue).
- Continued fielding of Grow The Army battalion #15 with expected completion by the end of FY12.
- Continued reset of Patriot equipment operating in the U.S. Central Command area of responsibility, completing two battalion sets by July 12.
- Provided C-RAM sense and warn capabilities to 27 different sites in Iraq during Operation Iraqi Freedom (OIF) and Operation New Dawn (OND). Additionally, deploying C-RAM sense and warn capabilities in support of Operation Enduring Freedom at 22 sites in Afghanistan.
- Provided C-RAM Intercept capabilities for six different sites in Iraq initially in support of OIF and later in support of OND.

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3213 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING



- Planned transition of C-RAM sense and warn capabilities to nine Office of Security Cooperation - Iraq and Department of State sites in Iraq as part of support for United States Mission - Iraq. The 22 C-RAM intercept systems withdrawn from Iraq are projected for fielding to newly established IFPC/Avenger Composite Battalions.

- Conducted reset of 20 Air Defense and Airspace Management (ADAM) Cells and 18 Forward Area Air Defense Command and Control (FAAD C2) shelters.

- Fielded three Air and Missile Defense Planning and Control Systems to Patriot Battalions (Composite).

- Conducted reset of 39 ADAM Cells and 33 FAAD C2 shelters.

- Transitioned the Air and Missile Defense Work Station to the Windows operating system.

- Completed Sensor C2 and Sentinel Radar fielding to all division headquarters.

- Completed modernization of six Basic Sentinel radars to Improved Sentinel radars in the National Capital Region (NCR). These radars have enhanced target range and classification as well as radar reliability / supportability via improved electronics.

- Completed developmental testing of the Sentinel Radar IFPC, enhancing fratricide prevention and improving integration into the C-RAM Command and Control architecture. Completed software release to the AOR and NCR in July 2011 and to the remainder of the fleet in September 2011.

- Validated the acquisition strategy to procure 431 Army Integrated Air and Missile Defense (AIAMD) Battle Command System Engagement Operation Centers in line with the strategy to transition all current and future AMD capabilities to one mission command architecture for AMD battle management.

Section III – Key FY13 Air and Missile Defense Portfolio Investments:

The Fiscal Year 2013 Air and Missile Defense investments total $2.3B ($1.3B RDTE / $153M OPA / $4M AMMO / $866M MSLS) and include developing and acquiring new equipment and improving or recapitalizing current systems that offer increased capabilities to the C-RAM systems; improving Patriot missiles; conducting pre-planned product improvement efforts of the Patriot system; conducting Service Life Extension Program and capability improvements on Stinger missiles; closing capability gaps, extend useful life of existing equipment; and fielding Terminal High-Altitude Area Defense, a robust and capable Medium Range Ballistic Missile intercept capability. Specific investments in this portfolio include:

- $401M (RDTE) meets U.S. financial obligations for Medium Enhanced Air Defense System (MEADS) in accordance with the current Memorandum of Understanding.

- $191M (RDTE) continues Joint Land Attack Cruise Missile Elevated Netted System (JLENS) Engineering and Manufacturing Development with completion in FY14. Includes testing and a CONUS-based exercise.

- $82M (RDTE) completes the MSE live fire test / evaluation, ground system integration, corrective

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3214 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

actions and completes initial production facilitation by FY14.

- $316M ($110M RDTE / $206M MSLS) continues upgrading Patriot (including modern man stations, radar digital processor and modern adjunct processor) and completes fielding to the force by FY18.

- $262M (RDTE) continues AIAMD development and enables initial deliveries by FY16.

- $88M ($54.3M RDTE / $34M OPA) initiates improvements to the C-RAM systems deployed to theater and acceleration of IFPC Increment II Milestone B to FY15.

- $21M (RDTE) begins SLEP and integrates capability improvements to field 850 Stinger missiles by FY15.

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3215 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

FORCE PROTECTION PORTFOLIO

Section I – Overview:

The Force Protection modernization plan procures selected Chemical, Biological, Radiological and Nuclear (CBRN), mobility and other protection equipment that is effective and affordable. This equipment provides American Soldiers with the highest levels of force protection, civil affairs / military information operations capabilities and enhanced engineering abilities consistent with the functional application of these materiel solutions in support of assigned missions. Current modernization efforts include procuring new and improved materiel solutions enhancing our capabilities in current and future years. Figures 10-12 display a selected array of mature capabilities as projected from current, near and extended term perspectives.

CBRN PROGRAMS

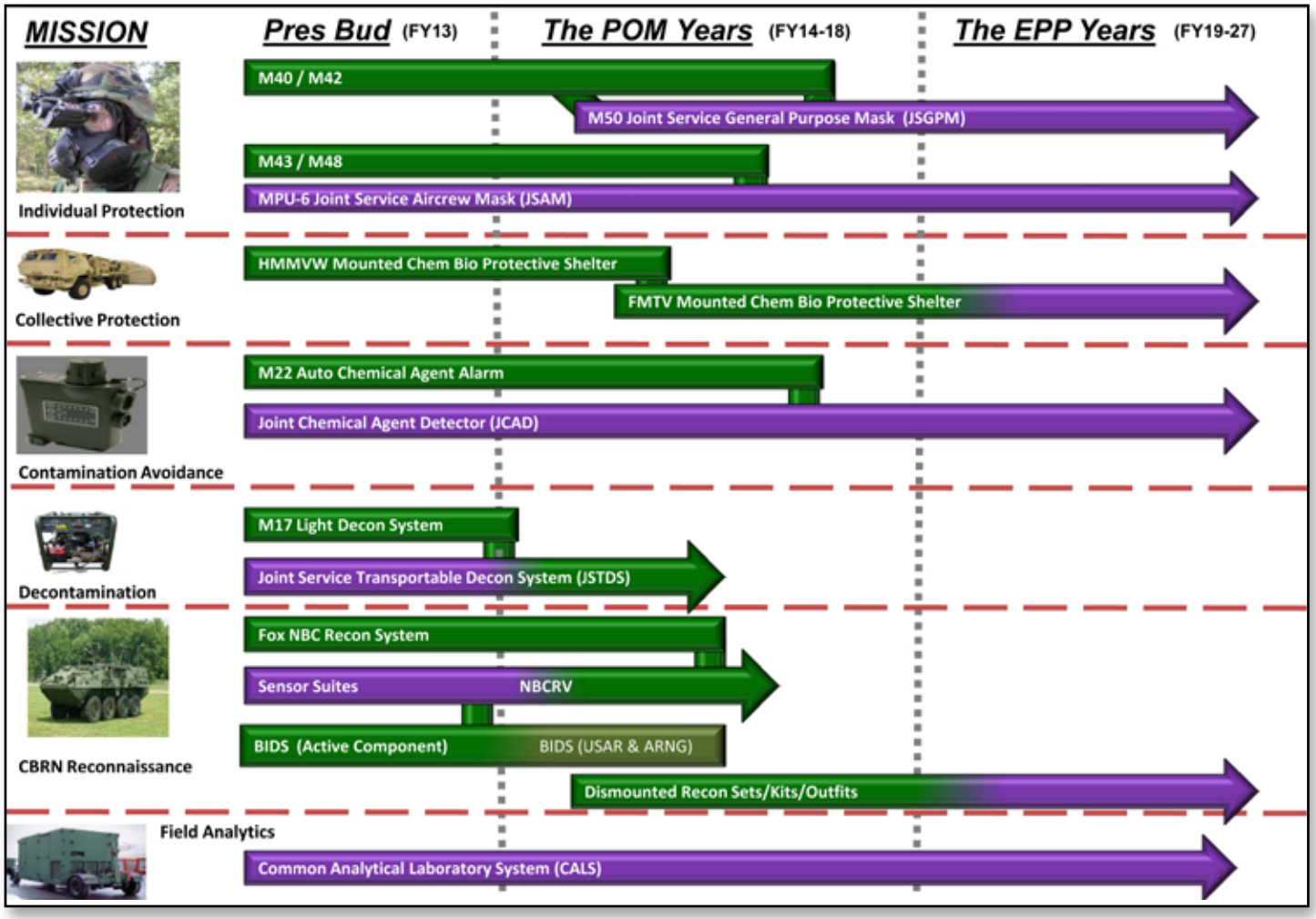


Table 10. Force Protection Portfolio: CBRN Programs (see Acronym Glossary)

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3216 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Section II – Key FY11-12 Force Protection Portfolio Accomplishments:

- Fielded 42 additional Biological Integrated Detection Systems (BIDS). These systems complete the final three platoons of the 307th Chemical Company (21 systems) and one platoon for the 308th Chemical Company (7 systems) in FEMA region IX. They also added two platoons of capability to the 365th Chemical Company (14 systems) in Salt Lake City, Utah. BIDS is a fully deployable, Critical Dual Use (CDU) system that can be used for contingency operations as well as homeland defense.

- Fielded 200 Vehicle Optic Sensor Systems, 122 Husky Mounted Detection Systems, 1,934 Self Protective Adaptive Roller Kit (SPARK) II Rollers and 46 Counter Improvised Explosive Device (IED) Interrogation Arms in support of Route Clearance units.

- Fielded Hydraulic Excavator (HYEX) Type I excavators providing 26 Multi-Role Bridge

MOBILITY PROGRAMS

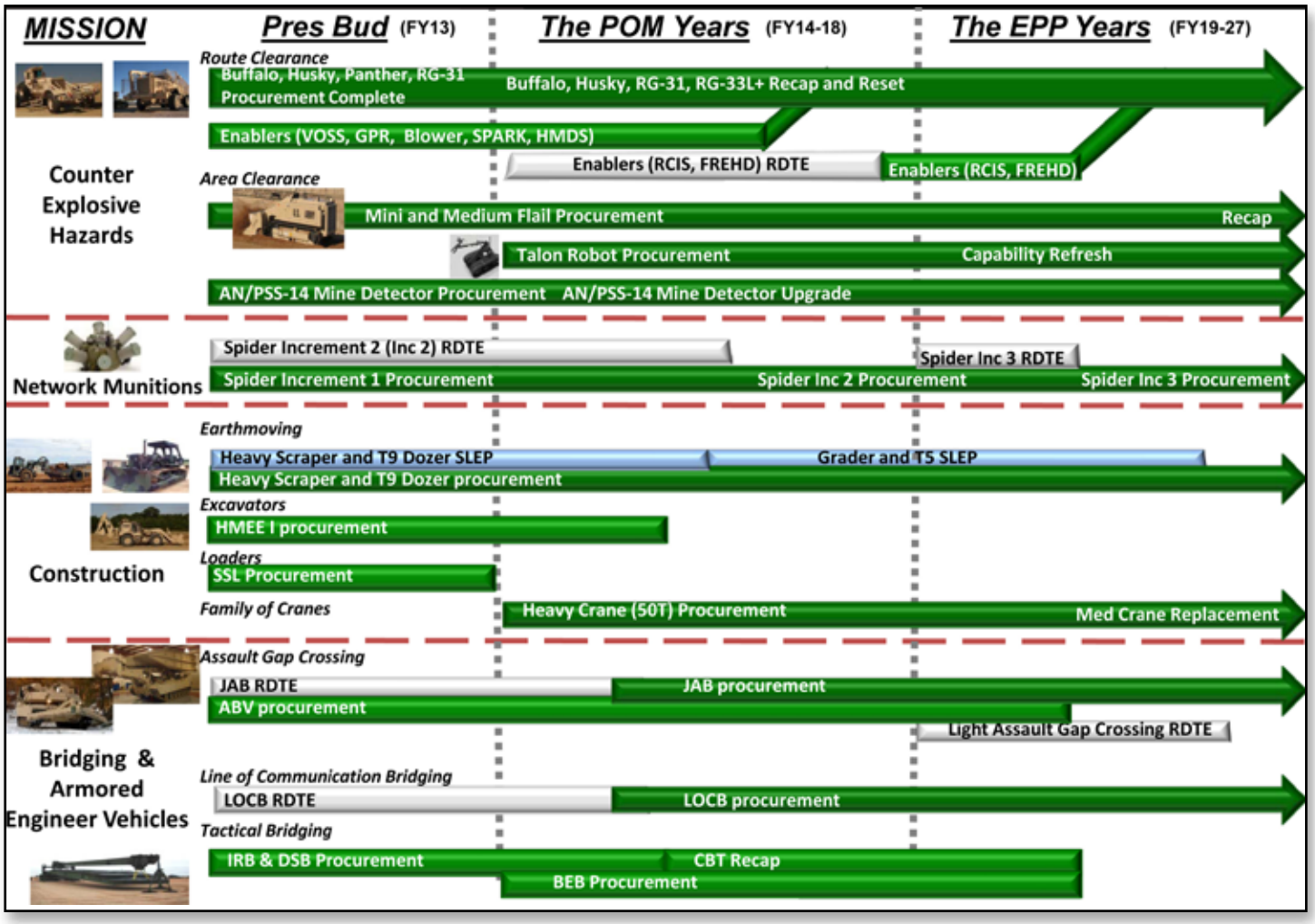


Table 11. Force Protection Portfolio: Mobility Programs (see Acronym Glossary)

3217 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Companies an improved deep excavation capability and procured 19 Assault Breacher Vehicles (ABV) fielding 3 HBCTs.

- Provided 476 Urban Operations Sets to platoons and squads enabling assured mobility in the urban environment.

- Procured 20 ABVs, 30 Heavy Scrapers, 171 T9 Dozers, 60 Water Distributors and 280 Instrument Set, Reconnaissance and Surveying (ENFIRE) surveying sets for three HBCTs in FY12.

- Recapitalized over 200 Route Clearance and Explosive Ordnance Disposal (EOD) vehicles into their program of record configuration in FY12.

Section III – Key FY13 Force Protection Portfolio Investments:

The FY13 Force Protection investments totaling $96M ($12M RDTE / $84M OPA) ensure Soldiers are protected from the effects of chemical, biological, radiological and nuclear hazards. Specific investments in this portfolio include:

PROTECTION PROGRAMS

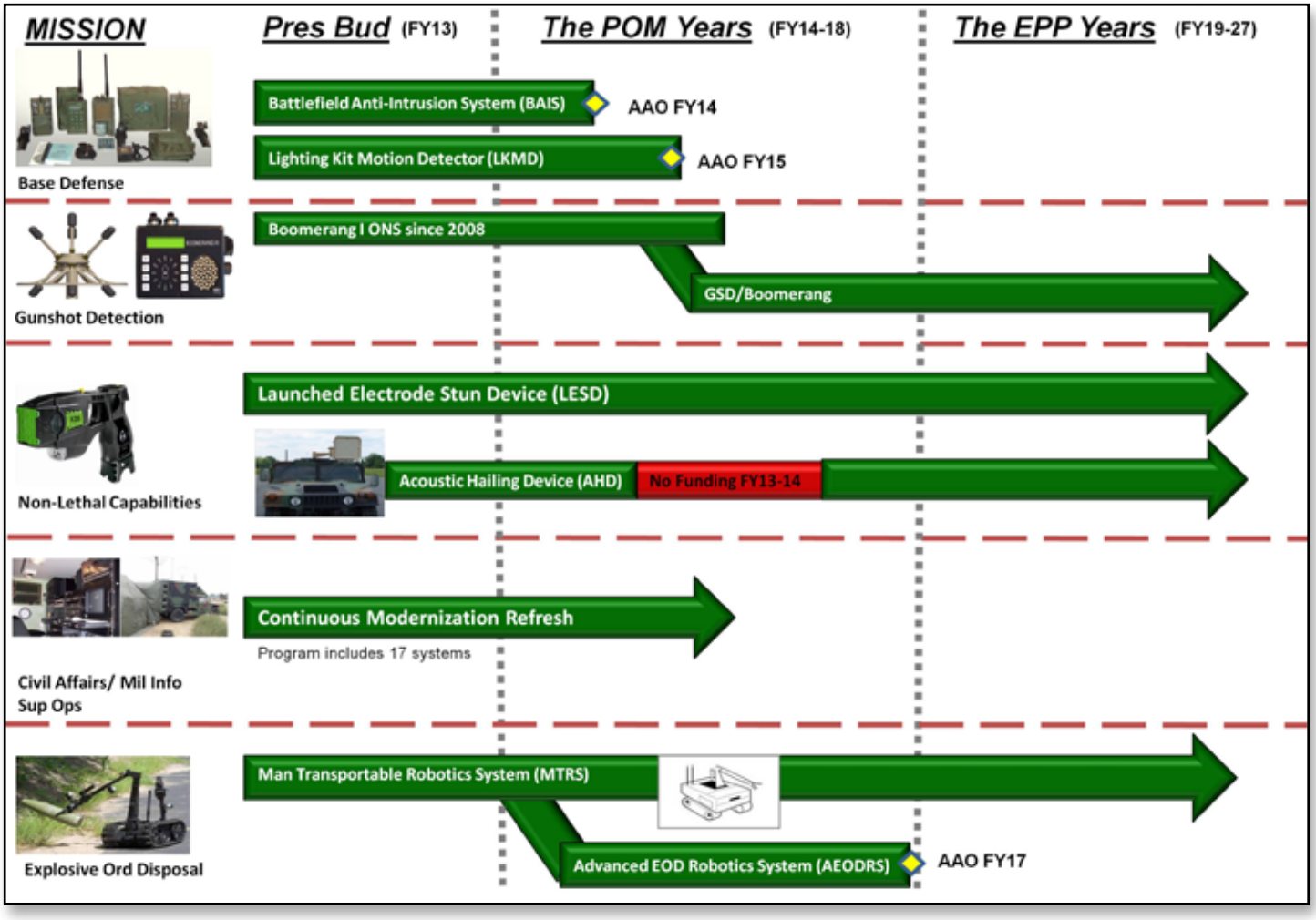


Table 12. Force Protection Portfolio: Other Protection Programs (see Acronym Glossary)

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3218 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

- $18M (OPA) procures 1,306 Battlefield Anti-Intrusion System (BAIS) (14.6 percent of the Army Acquisition Objective (AAO) of 8,933). Provides early seismic/acoustic warning, intrusion detection and characterization of approaching ground intrusion threats.

- $5M (RDTE) for Gunshot Detection System (GDS) providing the capability to detect / identify point-of-origin location of incoming small arms gunfire.

- $27M (OPA) procures 6,525 Lighting Kit, Motion Detector (LKMD) systems (18.8 percent of the AAO of 34,711). Provides close-in motion detection and visible light / infra-red illumination of approaching ground intrusion threats.

- $29M (OPA) procures 1,508 EOD Equipment systems. This program includes 12 systems comprised of Man-Transportable Robotic Systems (MTRS) and associated equipment providing EOD technicians with a rapid, reliable and secure means for identifying and disarming EOD munitions.

- $466K (RDTE) funds EOD Equipment RDTE extending the current Non-Line-of-Sight capability of the Man-Transportable Robotic System providing increased standoff distances for EOD Technicians while conducting dismounted operations.

- $37M (OPA) procures 890 Civil Affairs/Military Information Support Operations (CA/MISO) systems. This program includes 17 systems providing essential command and control, communications, computers and intelligence (C4I) capabilities for CA / MISO General Purpose Forces.

- $212M (OPA) funds recapitalization of over 177 Route Clearance and EOD vehicles and 24 M160 Mini Flails into program of record configuration for fielding. Procures four new M160 Mini Flails to complete a Theater ONS. Provides $98M in RDTE for the next generation of standoff detection, neutralization and clearance systems.

- $50M (OPA) procures 10 Assault Breacher Vehicle (ABV) systems for two HBCTs enabling rapid breaching, proofing and marking of full width lanes through complex obstacles and minefields.

- $14M (RDTE) utilizes RDTE in developing Joint Assault Bridge (JAB) technology modernizing the obsolete Armored Vehicle Launched Bridge fleet.

- $80M (OPA) for Tactical Bridging. Modernizes dry and wet gap bridging with the Improved Ribbon Bridge (IRB), a float bridge; $34.6M for 14 systems) and Dry Support Bridge (DSB, $34M for 8 systems).

- $134M (OPA) for Construction Equipment. Modernizes by replacing 61 dozers, nine heavy scrapers, 76 High Mobility Engineer Excavators (HMEE) and 40 water distributors.

- $15M (OPA) procures 153 Instrument Set, Reconnaissance and Surveying systems to Engineer formations across the Army.

- $68M ($14M RTDE / $36M OPA / $17M AMMO) procures 222 Spider Increment 1 systems (anti-personnel), 120 systems worth of ammunition and develops Increment II system with improved controller and anti-vehicular capability.

3219 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

SUSTAINMENT (TRANSPORT) PORTFOLIO

Section I – Overview:

The Sustainment (Transport) Portfolio consists of Tactical Wheeled Vehicles (TWV) and Watercraft (See table 13).

The TWV portfolio includes the Light, Medium and Heavy Tactical Vehicle fleets and the Mine Resistant Ambush Protected (MRAP) family of vehicles. The Army employs TWVs in a wide variety of roles including armament carriers, logistics vehicles, ambulances and C2 vehicles. The evolution of the "Army truck" has progressed tremendously in a short period of time. While simple, unprotected motorized transportation is practical in the training base, it does not address current threats in deployed environments. Remaining relevant on today's multi-spectrum battlefields requires armored or armor capable trucks with additional capacity and power for additional weight and power required to protect personnel and support a wide variety of missions.

The Watercraft portfolio includes the Harbormaster Command and Control Center (HCCC), Logistic

SUSTAINMENT TRANSPORT MODERNIZATION

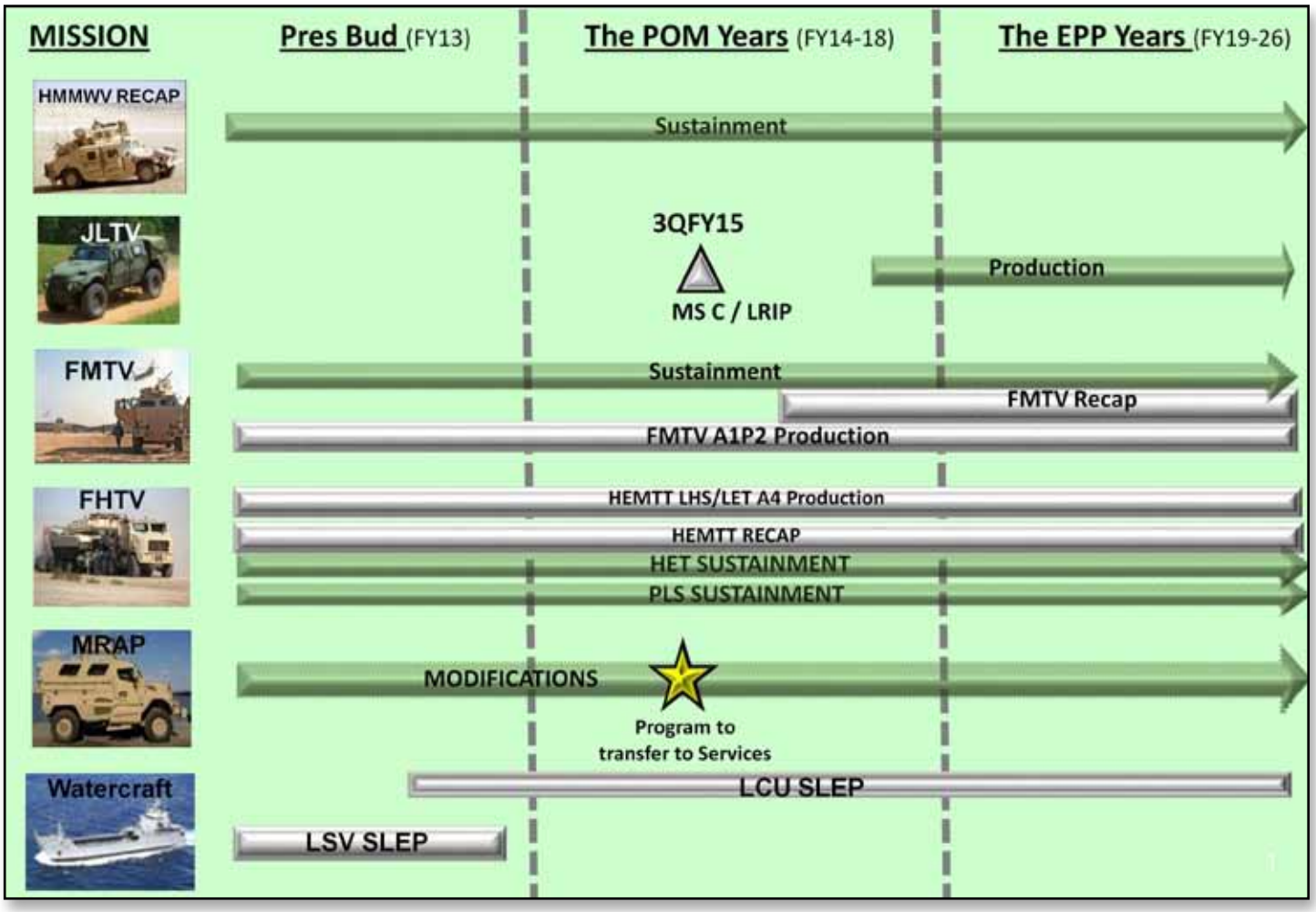


Table 13. Sustainment Transport Portfolio (see Acronym Glossary)

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3220 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Support Vessel (LSV) and Landing Craft Utility (LCU). The HCCC provides command and control tools and sensors for watercraft asset management. The watercraft fleet consists of the LSV and LCU which both provide transport of combat vehicles and sustainment cargo in various waterways in support of combat, contingency and humanitarian relief efforts. The LSV SLEP revitalizes aging vessels with new and modernized parts.

As depicted in table 13, key objectives and decision points in the Tactical Wheeled portfolio include:

- Fully funding Joint Light Tactical Vehicle (JLTV) development and fielding.
- Producing sufficient Heavy Expanded Mobility Tactical Truck (HEMTT) Load Handling System (LHS)/Light Equipment Transporter (LET) filling fleet shortages.
- Modernizing the legacy Medium Tactical Vehicle fleet, replacing M900 series 5-ton trucks with armored and armor capable Family of Medium Tactical Vehicles (FMTV).
- Integrating the MRAP fleet as an Army program of record.
- Sustaining one LSV vessel through a SLEP extending its useful life with new / upgraded C4ISR, force protection and engineering equipment.

Section II – Key Sustainment (Transport) Portfolio Accomplishments (FY11/12):

- Fielded 1,912 MRAP All Terrain Vehicle (M-ATV), 186 MRAP Wreckers in support of OEF.
- Completed the depot-level repair (RESET) of 989 and recapitalization (RECAP) of over 2,414 Tactical Wheeled Vehicles (TWVs).
- Completed the SLEP of 3 of 17 (LSV and LCU); which will complete 6 of 17 watercraft in the 34 vessel fleet.
- Fielded in excess of 17,891 TWVs (MTV and HTV fleets).
- Procured over 1,463 trucks and 702 trailers within the FMTV. Within the Family of Heavy Tactical Vehicles, the Army procures over 3,217 trucks, trailers and other associated systems.

Section III – Key FY13 Sustainment (Transport) Portfolio Investments:

The FY 13 Sustainment (Transport) investments total $661M ($81M RDTE / $580M OPA) and includes light, medium, heavy tactical wheeled vehicle fleets and the MRAP family of vehicles. Specific investments in this portfolio include:

- $72M (RDTE) for JLTV Engineering and Manufacturing Development.
- $3M (OPA) procures HEMTT LHSs filling unit shortages.
- $36M (OPA) procures HEMTT LETs replacing the M916 Tractor in Engineer units.
- $374M (OPA) procures FMTV A1P2s and replacing aging M900-series 5T vehicles.
- $27M (OPA) recapitalizes HEMTTs into armor capable configuration.
- $18M (OPA) recapitalizes PLSs into armor capable configuration.
- $6M (OPA) completes LSV SLEP on hull numbers LSV 1 and LSV 2 and thus completing the six vessel SLEP program.

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SUSTAINMENT PORTFOLIO

Section I – Overview:

The Sustainment portfolio consists of multiple systems providing essential enabling equipment (See table 14). These systems include: Joint Precision Airdrop Systems (JPADS), Modular Fuel System (MFS), Load Handling System Compatible Water Tank Rack System (Hippo), Assault Kitchen, Multi-Temperature Refrigerated Container System (MTRCS), 5K Light Capacity Rough Terrain Forklift (LCRTF), Hydraulic System Test and Repair Unit (HSTRU), Metal Working and Machine Shop Set (MWMSS), Next Generation Automatic Test System (NGATS), Maintenance Support Device (MSD) Version 3 and Calibration Sets.

SUSTAINMENT PORTFOLIO MODERNIZATION



Table 14. Sustainment Portfolio (see Acronym Glossary)

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Section II – Key Sustainment Portfolio Accomplishments (FY11/12):

- Fielded 100 percent of the 2,000 pound JPADS requirements (1548) and beginning initial fielding of the 10,000 pound JPADS. The 2K and 10K JPADS provide rapid, precise, high-altitude delivery capabilities to forces without the use of ground transportation.
- Fielded the MFS to nine SBCTs providing a fuel distribution and storage capability at any location without construction equipment or material handling equipment.
- Delivered 100 MTRCS to Afghanistan in 2011 increasing storage capabilities and enhancing quality of life for units / detachments operating in remote locations.
- Fielded 509 Hippo systems providing a capability which receives, stores and issues large quantities of potable water anywhere in the theater of operations. The Hippo replaces the Forward Area Water Point Supply System.
- Fielded 229 5K LCRTF providing a C-130 deployable, CH-47 sling-load capable, low velocity airdrop and PLS Flatrack compatible system in support of the Army family of ISO containers of commercial sized pallets and replaces the 4K forklift.

Section III – Key FY13 Sustainment Portfolio Investments:

The FY13 Sustainment investments total $355M ($110M RDTE / $245M OPA) for support programs and includes fuel and water systems, load handling systems, airdrop systems, tool sets, medical systems and other combat enablers. Specific investments in this portfolio include:

- $23M (OPA) procures 179 Tank Rack Modules and 27 Pump Rack Modules providing a mobile fuel storage capability for 12 BCTs.
- $27M (OPA) procures 1,644 MSDs V3 replacing obsolete test sets in 16 BCTs.
- $19M (OPA) procures five NGATS replacing legacy Direct Support Electrical System Test Sets (DSESTS) and legacy Base Shop Test Facility (BSTF) in five BCTs.
- $22M (OPA) procures 159 Multi-Temperature Refrigeration Container System (MTRCS) providing rapid refrigerated transport and storage of Class I items for 11 BCTs.
- $13M (OPA) procures 124 Load Handling System Compatible Water Tank Rack System (Hippos) replacing obsolete Semi-Trailer Mounted Fabric Tanks (SMFT) and Forward Area Water Point Supply Systems (FAWPSS) in seven BCTs.
- $11M (OPA) procures three calibration sets replacing obsolete calibration sets in three BCTs.
- $7M (OPA) procures 55 10K JPADS in support of joint precision aerial delivery operations conducted in numerous theaters of operations/ training missions.
- $6M (OPA) procures 64 5,000 pound forklifts replacing legacy 4,000 pound forklifts throughout the Army.
- $5M (OPA) procures 86 Assault Kitchens (AK) replacing legacy field fielding systems in Special Forces detachments and IBCTs.

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SCIENCE AND TECHNOLOGY PROGRAM

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SCIENCE AND TECHNOLOGY PROGRAM

The Army Science and Technology (S&T) investments support Army modernization goals to develop and field affordable equipment in a rapidly changing technological environment by fostering invention, innovation, maturation and demonstration of technologies for the current and future fight. The S&T efforts are focused on the Army's equipment modernization priorities: network the force, replace, improve and/or transform selected platforms and empower, protect and unburden the Soldier.

The Army S&T program is organized into investment portfolios that address challenges in six capability areas: four Army-wide areas (Air; Soldier; Ground and Command, Control, Communications and Intelligence (C3I)) and two areas unique to S&T (Basic Research and Enduring Technologies):

- The Air Portfolio includes technologies for manned and unmanned systems; air-delivered lethality; and air-platform safety, survivability and protection.

- The Soldier Portfolio includes technologies for Soldier and Squad Lethality, Survivability, Mobility; Leader Development; Training; Combat Casualty Care and Clinical and Rehabilitation Medicine capabilities.

- The Ground Portfolio includes technologies for weapons systems, active and passive protection systems for ground vehicles, manned and unmanned ground platforms and mobility systems, countermine/counter-IED efforts and deployable small base protection.

- The C3I Portfolio includes technologies for ground, air and Soldier communications devices and networks, air and space sensor and network payloads and Mission Command.

- The Basic Research Portfolio provides a fundamental S&T foundation to enable Army-relevant technology capabilities.

- The Enduring Technologies Portfolio includes technology development associated with environmental quality and installations, such as sustainable ranges and lands, pollution prevention, military materials in the environment and adaptive and efficient installations. It also includes the Department of Defense (DoD) High Performance Computing Modernization Program, which was devolved from the Office of the Secretary of Defense to the Army in FY12. This program supports all Services and DoD Agencies, enables incorporating advanced computational capabilities as a solution of first resort to explore and evaluate new theories; reduces time and cost of acquiring weapons systems; and provides real-time calculations in support of military operations.

- The S&T projects are planned and executed collaboratively through partnerships among industry, academia and the 21 Army Research, Development and Engineering Centers (ARDECs) and laboratories. The Army's S&T investments reflect a balanced approach to far-term, basic research for discovery and understanding of phenomena (RDT&E Budget Activity (BA) 6.1); mid-term, applied research for laboratory concept demonstrations (RDT&E BA 6.2); and near-term, advanced technology demonstrations in relevant environments outside the laboratory (RDT&E BA 6.3). In FY12, the Army began the Technology Maturation Initiative, a new program supported with RDT&E BA 6.4 funds. This program establishes a stronger partnership between Army S&T and acquisition by maturing and demonstrating technologies and providing competitive prototypes to help

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expedite technology transition from the laboratory to operational use.

Results of Army S&T investments can be seen in many capabilities currently in the field. Examples include the following:

- **Deployable Force Protection (DFP)** S&T Program developed designs and methods to expediently establish mortar pits and provide overhead cover using modular systems that incorporate blast and ballistic protection. Members of the DFP team worked with troops on design and employment options. The 82nd Airborne Division will deploy in 2012 with a number of modular protective mortar pit and overhead cover systems that will be used in an operational assessment in theater. Use of these systems will save time associated with establishing mortar pits and will improve force protection for Soldiers.

- **Husky Mounted Detection System (HMDS)** S&T Program used an advanced, high-performance ground penetrating radar to detect both non-metallic and metal-cased buried threats, including IEDs constructed of bulk explosives and low-metal pressure plates, buried in primary and secondary roads. Under a Joint Urgent Operational Needs Statement (JUONS), 220 systems were fielded to Operation Enduring Freedom (OEF) in support of the Army and Marine Corps. HMDS transitioned to the Product Manager for Countermine and Explosive Ordinance Disposal (PM CM&EOD) in April 2009 and the PM initiated a competitive Program of Record for the HMDS capability in FY12.

- **The Universal Collaboration Bridge (UCB)** S&T Program is a software architecture that provides interoperability between different chat systems. The UCB will interface Variable Message Format (VMF) and Extensible Messaging and Presence Protocol (XMPP) for text chat to provide important text chat interoperability between Joint Battle Command – Platform (JBC-P) equipped vehicles and Tactical Operations Center-based XMPP users. The software has been transitioned to the Product Manager for Tactical Battle Command in FY10 and is being integrated into JBC-P.

- **The Advanced Affordable Turbine Engine (AATE)**, S&T Program developed and demonstrated two new helicopter turbine engines that provide significant improvements in engine power and operating efficiencies. In FY12, the program transitioned to the Army's Improved Turbine Engine Program (ITEP) to retrofit the Blackhawk and Apache fleet.

- **The Target Location/Designation System (TLDS)**, S&T Program demonstrated an improved, man-portable, target acquisition, targeting and laser designation system with reduced size, weight and power. In FY10 PEO Soldier transitioned the TLDS common designator module into the Lightweight Laser Designator Rangefinder Block II and Joint Effective Targeting System programs. In FY11, PEO Soldier integrated Far Target Location technology into the JETS program.

DoD's shift towards more capabilities-focused processes has led the Army to re-assess how technology matures and transitions from the laboratory to Program Executive Offices, Program Managers and Industry. The Army revised its S&T process with increased focus on the delivery of capabilities within a predetermined timeframe. The new Technology-Enabled Capability Demonstration (TECD) process realigns strategic planning with strategic processes,

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aligns investment priorities with Army senior leadership goals and shifts emphasis from demonstrating technology to demonstrating fully integrated technology-enabled capabilities. The purpose of the TECD process is to develop and demonstrate technologies or sets of technologies to solve near-term Army needs within three years of project initiation.

The Army Science and Technology Advisory Group (ASTAG) validated this approach and prioritized Army challenges for TECD funding. Priority TECD programs validated by the ASTAG include the following:

- Force Protection – Basing: demonstrate ability to construct and protect a 300- person combat outpost or patrol base in 30 days with integrated sensing and defense capabilities.

- Force Protection – Soldier and Small Units: define a new paradigm where Mobility, Lethality/SA and Survivability are all factors in Personal Protection Equipment design and employment.

- Force Protection – Occupant Centric Platform: develop, design, demonstrate and document an occupant centered Army ground vehicle design philosophy that improves vehicle survivability and force protection by mitigating Soldier injury due to underbody IED and mine blast, vehicle rollover and vehicle crash events.

- Overburdened Physical Burden: develop and demonstrate capabilities that reduce physical burden on the Soldier and small unit without reducing operational effectiveness.

- Surprise/Tactical Intelligence – Mission Command (MC): reduce tactical surprise and achieve overmatch at the squad level by providing tools that enable MC on the move and allow tactical leaders to synchronize action, seize the initiative and maintain situational awareness.

- Surprise/Tactical Intelligence – Actionable Intelligence: provide critical time-sensitive information to the small unit from higher echelon down through company in time to prevent surprise/ambush.

- Sustainment/Logistics – Basing: reduce the need for fuel and water resupply and decrease waste while increasing quality of life for Soldiers in combat outposts/patrol bases.

- Human Performance – Individual Training to Tactical Tasks: develop innovative, effective training methods that expedite training and adapt to Soldiers' learning needs in three domains: cognitive – infantry squad leader, procedural-fires and new/evolving systems-unmanned systems.

- Human Performance – Medical Assessment and Treatment: develop technologies that can be used by small units that will facilitate more accurate decisions about treatment, return-to-duty (RTD) and evacuation for mild to moderate traumatic brain injury (TBI) and post traumatic stress (PTS). Develop therapies to improve recovery from TBI and PTS.

In FY13, the Army has dedicated more than $2B to its S&T programs: $444M in RDT&E BA 6.1 (basic research), $875M in RDT&E BA 6.2 (applied research) and $891M in RDT&E BA 6.3 (advanced technology demonstrations).

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CAPABILITY FIELDING AND DISTRIBUTION

DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

CAPABILITY FIELDING AND DISTRIBUTION

Two key aspects of ensuring Soldiers have the equipment they need when they need it are the Army equipment distribution plans and the Army Equipping and ReUse Conference (AERC).

The plans, published at: https://www.g8.army.mil/pdf/AES2012_lq.pdf, provide equipping guidance and describe the ends, ways and means the Army will use to ensure Soldiers have the right equipment in the quantities needed to accomplish assigned missions in support of Combatant Commander requirements. The AERC, attended by the Army's equipment stakeholders, enables a holistic review of the Army's equipping posture, policies and issues. It is used to synchronize equipment distribution based on Army priorities.

The first aspect of ensuring Soldiers have the equipment they need is the **Army Equipment Plan**, which establishes goals and metrics for achieving a balance between requirements and resources. It describes how equipment and capabilities provided by the Army Equipment Modernization Plan are distributed and placed into a unit to synchronize it with its assigned mission. It addresses the rotational and non-rotational Operational Force and the Generating Force. The plan is dynamic and flexible, addressing divergent needs and requirements of the Total Army. The plan's goals and objectives are achieved using three lines of operation: unit-based equipping, managing friction and building long-term readiness.

- **Unit-Based Equipping**. The Army's equipping goal is to ensure that Soldiers always have the equipment they require to execute assigned missions. It measures success in doing so using a series of equipping goals or Aim Points (AP). During FY11 and FY12, the Army's short-term equipping goals for Active Component units with a 1:2 Boots on the Ground (BOG):Dwell ratio, is to equip them to S-3 (65-79 percent of their authorized equipment) at Aim Point (AP) 1 (Return (R)+6 months) and S-2 (80-89 percent) at AP2 (R+1 year). Units will be equipped to S-1/Assigned Mission Equipping (AME)-1 (90 percent or greater) by the time a unit enters the available phase. The short-term equipping targets for Reserve Component (RC) units are to equip them to S-3 at AP2 (R+2 years), S-2 at AP3 (R+3 years) and S-1 at AP4 (R+4 years). This line of operation also includes maintaining the Generating Force and RC Critical Dual Use equipping levels to no less than 80 percent and tailoring equipment distributions to better manage shortages and maximize capabilities.

- **Managing Friction**. Friction is the term used to describe critical Army requirements such as filling training sets, equipment in transit over strategic distances, equipment in Reset, etc., that prevent materiel from being used to fill unit requirements. Success in managing friction is measured by how well the Army can see its own equipment inventories and make informed management decisions about how to allocate that inventory to build Army readiness. Friction consumes valuable resources and it increases the complexity of equipping units.

- **Building Long-term Readiness**. The Army will continue to focus on Army management policies and structure to bring resources, resourcing processes, requirements validation and priorities into better synchronization with cyclic equipping readiness requirements. Some of the methods the Army uses to build long-term readiness include ensuring documents accurately reflect equipping status, updating the readiness reporting system and examining the relevance of long-standing equipping programs and policies.

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The second aspect of ensuring Soldiers have the equipment they need is the **Army Equipping and Reuse Conference**. The goal of the AERC is to ensure Soldiers are equipped for the current fight and for future contingencies. The AERC combines knowledgeable, experienced equippers with representatives from all stakeholders across the Army in a focused venue that ensures Combatant Commanders have the most capably equipped units the Army can provide, while allowing participants an opportunity to address a wide range of key Army equipping concerns.

The AERC enables a holistic view of the Army's equipping posture, policies and issues. It is a venue in which stakeholders (equipment providers and using units) can refine equipping plans. The results of each AERC are briefed to the senior Army leadership. During this brief the HQDA DCS, G-8, provides an analysis of the Army equipping situation and identifies issues that affect readiness.

The conference provides two key outputs. The first is the information sharing that comes from special topic working sessions. These sessions sustain communications across the community of stakeholders on strategic issues affecting Army equipping policy and posture. They provide the commands with a forum to receive updates and address questions or concerns on current and evolving issues that impact our collective equipping effort. The second is a refined distribution plan for the next 21 months. The plan ensures Soldiers get the right equipment at the right place at the right time.

Lead Materiel Integrator

The Army Materiel Command is the Army's Lead Materiel Integrator (LMI) to increase efficiencies, eliminate redundancies, increase cost savings and improve materiel readiness. The LMI approach to Army materiel management combines transparency of decisions, collaboration among all materiel stakeholders, a strategic view of all materiel requirements and sources of supply over time and the consolidation of multiple authoritative inputs in one place, yielding a truly synchronized materiel distribution and redistribution process that optimizes supply against demand.

The Army Materiel Command is developing an automated decision support tool (DST) to help it formulate equipping recommendations to the field. The DST will provide increased asset visibility using data from the Army's authoritative materiel data repository, the Logistics Information Warehouse (LIW). The LIW, along with the LMI's DST, will optimize supply against demand allowing the Army to distribute and redistribute materiel with unprecedented speed and precision.

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CONCLUSION

CONCLUSION

Equipment requested in the FY13 President's Budget strikes a balance between current and future needs, provides the basis for an affordable equipping strategy over time and takes into account Army requirements and priorities. In developing this request, the Army made difficult decisions to shift funds previously programmed for future capabilities to current needs. The decisions came at the expense of promising and needed technologies with capabilities that did not fit within resource limitations and represented significant changes in almost 100 programs. Nevertheless, the Army is committed to maintaining the most capable Army in the world with the resources available. We continuously assess programs to find overlapping or joint capabilities that meet the need, or programs that are simply unaffordable or result in acceptable capability risk.

The Army will continue to develop and field a versatile and affordable mix of equipment to allow Soldiers and units to succeed in the full range of missions today and tomorrow and to maintain our decisive advantage over any adversary we face. The balanced and affordable approach to achieving this goal uses integrated capability portfolios that align our equipment modernization communities to identify capability gaps and eliminate unnecessary redundancies, incremental modernization to deliver new and improved capabilities and Army force generation processes to ensure unit equipment readiness.

Although we are a force in transition during a period of declining resources, we must continue to provide the Army with the best equipped most modernized and most highly capable units that will prevail on any battlefield. We will do this with affordability as our watchword and remain committed stewards of our Nation's resources. With a balanced equipment modernization strategy, the Army will remain on track to equip the Army of 2020.

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ACRONYM GLOSSARY

DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

ACRONYM GLOSSARY

AAE	Army Acquisition Executive
AAO	Army Acquisition Objective
AAS	Armed Aerial Scout
ABCS	Army Battle Command Systems
ABV	Assault Breach Vehicle
ACAT	Acquisition Category
ACFT	Aviation Procurement, Army
ACOM	Army Command
ACR	Armored Cavalry Regiment
ACTD	Advanced Concept Technology Demonstration
ADAM	Air Defense Airspace Management (Cell)
AEHF	Advanced Extremely High Frequency
AEODRS	Advance EOD Robotics System
AERC	Army Equipping and Reuse Conference
AFATDS	Advanced Field Artillery Tactical Data System
AGSE	Aviation Ground Support Equipment
AHB	Assault Helicopter Battalions
AIAMD	Army Integrated Air and Missile Defense
AIM SA	Abrams integrated management situational awareness
AIT	Automatic Identification Technology
AK	Assault Kitchen
AKMS	Army Key Management System
AKP	Adjustable Keyboard Podium
ALPS	Aerial Layer Platforms and Sensors
AMD	Air and Missile Defense
AMDPCS	Air and Missile Defense Planning and Control System
AMDWS	Air and Missile Defense Work Station
AMF	Airborne Maritime Fixed (AMF) variant of Joint Tactical Radio System (JTRS)
AMMPS	Advanced Medium Mobile Power Source
AMPV	Armored Multi-purpose Vehicle
AN/PLT-5	EOD Transmitter, Countermeasure
AOA	Analysis of Alternatives
APO	Army Procurement Objective
ARB	Attack Reconnaissance Battalion
ARFORGEN	Army Force Generation
ARGCS	Agile Rapid Global Combat Support
ARL	Airborne Reconnaissance Low
ARMS	Aerial Reconnaissance Multi-Sensor
ARNG	Army National Guard
AROC	Army Requirements Oversight Council
ASAS	All Source Analysis System

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ASCC	Army Service Component Command
ASE	Aircraft Survivability Equipment
ASTAG	Army Science and Technology Advisory Group
ATACMS	Army Tactical Missile System
ATC	Air Traffic Control
ATIRCM	Advanced Threat Infrared Countermeasures
ATLAS	All-Terrain Lifter Army System
ATLS	Automated Tactical Landing System
ATNAVICS	Air Traffic Navigation, Integration and Coordination System
AW	Alternative Warhead
B	Billions
BAIS	Battlefield Anti-Intrusion System
BAT	Biometrics Automated Toolset
BCBL	Battle Command Battle Lab
BCPL	Battle Command Product Line
BCS3	Battle Command Sustainment Support System
BCT	Brigade Combat Team
BEB	Bridge Erection Boat
B-FIST	Bradley Fire Support Team (Vehicle)
BFSB	Battlefield Surveillance Brigade
BFT	Blue Force Tracker
BI, BII, BII	Block I, II, III
BIDS	Biological Integrated Detection System
BLOS	Beyond Line of Sight
BSTF	Base Shop Test Facility
C2	Command and Control
C4I	Command, Control, Communications, Computers and Intelligence
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CA/MISO	Civil Affairs and Military Information Support Operations
CAB	Combat Aviation Brigade
CAL	Caliber
CALS	Common Analytical Laboratory System
CARA	CBRNE Analytical and Remediation Activity
CASUP	Cockpit And Sensor Upgrade Program
CBDP	Chemical Biological Defense Program
CBRN	Chemical, Biological, Radiological and Nuclear
CBRNE	Chemical, Biological, Radiological, Nuclear and Enhanced Conventional Weapons
CBT	Common Bridge Transporter
CDS-5	Cockpit Display System 5
CHARCS	Counterintelligence and Human Intelligence Automated Reporting and Collection System

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CHIMS	CI/HUMINT Management System
CI	Counterintelligence
CIRCM	Common Infrared Countermeasures
CMWS	Common Missile Warning System
COE	Common Operating Environments
COIST	Company Intelligence Support Team
COMSEC	Communications Security
COTS	Commercial Off the Shelf
CPOF	Command Post of the Future
CPR	Capability Portfolio Review
C-RAM	Counter-Rockets, Artillery and Mortars
CROWS	Common Remotely Operated Weapon System
CS	Combat Support
CSB	Configuration Steering Board
CSM	Capability Set Management
CSP	Common Sensor Payload
CSS	Combat Service Support
CTSF	Central Technical Support Facility
DAB	Defense Acquisition Board
DAE	Defense Acquisition Executive
DARPA	Defense Advanced Research Projects Agency
DE	DCGS-A Enabled
DF	Direction Finding
DCGS-A	Distributed Common Ground System - Army
DDL	Digital Data Link
DHCP	Digital Host Communication Protocol
DMTI	Digital Moving Target Indicator
DOCEX	Document Exploitation
DPICM	Dual Purpose Improved Conventional Munitions
DSB	Dry Support Bridge
DSESTS	Direct Support Electrical System Test Set
DST	Decision Support Tool
DTSS	Digital Topographic Support System
DVH	Double V Hull
EAB	Echelons Above Brigade
EAC	Echelons Above Corps
ECP	Engineering Change Proposal
ECS	Engagement Control Station
EMARSS	Enhanced Medium Altitude Reconnaissance Surveillance System
EMD	Engineering and Manufacturing Development
EN	Engineers

3236 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

ENFIRE	Instrument Set, Reconnaissance and Surveying
EOIP	Everything Over Internet Protocol
EO/IR	Electro-optical/Infrared
EOC	Engagement Operations Center
EOD	Explosive Ordnance Disposal
EPLRS	Enhanced Position Location and Reporting System (Radio)
ERMP	Extended Range Multi-Purpose (Unmanned Aerial System) (Gray Eagle)
ESA	Enhanced Situational Awareness
ESB	Expeditionary Signal Battalion
FA	Field Artillery
FAA	Functional Area Assessment
FAAD C2	Forward Area Air Defense Command and Control
FAASV	Field Artillery Ammunition Supply Vehicle
FADEC	Full Authority Digital Electronic Control
FAWPSS	Forward Area Water Point Supply System
FBCB2	Force XXI Battle Command Brigade-and-Below
FDP	Full Dimension Protection
FHTV	Family of Heavy Tactical Vehicles
FIB	Fires Brigade
FMC	Fully Mission Capable
FMTV	Family of Medium Tactical Vehicles
FOT&E	Follow-on Operational Test and Evaluation
FOV	Family of Vehicles
FRHN	Fixed Regional Hub Nodes
FRP	Full Rate Production
FSSP	Fuel System Supply Point
FUA	Future Utility Aircraft
FUE	First Unit Equipped
FY	Fiscal Year
GATM	Global Air Traffic Management
GCSS-A	Global Command Support System – Army
GCV	Ground Combat Vehicle
GGB	Guardrail Ground Baseline
GMLRS	Guided Multiple Launch Rocket System
GMR	Ground Mobile Radio
GMTI	Ground Moving Target Indicator
GNEC	Global Network Enterprise Construct
GRCS	Guardrail Common Sensor
GRRIP	Global Rapid Response Intelligence Package
HALE	High Altitude Long Endurance (airship)
HBC	High Band COMINT

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3237 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

HBCT	Heavy Brigade Combat Team
HCCC	Harbormaster Command and Control Center
HEMTT	Heavy Expanded Mobility Tactical Truck
HEMTT-LHS	Heavy Expanded Mobility Tactical Truck-Load Handling System
HET	Heavy Equipment Transporter
HF	High Frequency
HIIDE	Handheld Interagency Identity Detection Equipment
HIMARS	High Mobility Artillery Rocket System
HME CIED	Home Made Explosives Counter Improvised Explosive Device
HMEE	High Mobility Engineer Excavator
HMMWV	High Mobility Multipurpose Wheeled Vehicle
HMS	Handheld, Manpack and Small Form Fit (radios)
HQ	Headquarters
HQDA	Headquarters Department of the Army
HSTRU	Hydraulic System Test and Repair Unit
HTV	Heavy Tactical Vehicle
HUMINT	Human Intelligence
I2A	Image Interpolation Algorithm
IBCS	Integrated Air and Missile Defense – Battle Command System
IBCT	Infantry Brigade Combat Team
ICD	Initial Capabilities Document
IED	Improvised Explosive Device
IETM	Interactive Electronic Technical Manuals
IFPC	Indirect Fire Protection Capability
IFTE	Integrated Family of Test Equipment
IFV	Infantry Fight Vehicle
IMETS	Integrated Meteorological System
IMINT	Imagery Intelligence
IOC	Initial Operating Capability
IOTE	Initial Operational Test and Evaluation
IOTV	Improved Outer Tactical Vest
IP	Internet Protocol
IPADS	Improved Position and Azimuth Determining System
IPN	Installation Processing Node
IRB	Improved Ribbon Bridge
ISAAS	Individual Semi-Automatic Airburst System
ISR	Intelligence Surveillance and Reconnaissance
ISRIS	Intelligence, Surveillance, Reconnaissance Information Service
JAB	Joint Assault Bridge
JAGM	Joint Air to Ground Missile
JBC-P	Joint Battle Command-Platform

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JBPDS	Joint Biological Point Detection System
JC4ISR	Joint Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
JCAD	Joint Chemical Agent Detector
JCR	Joint Capabilities Release
JCTD	Joint Capability Technology Demonstration
JETS	Joint Effects Targeting System
JIOC	Joint Information Operations Center
JLENS	Joint Land Attack Cruise Missile Defense Elevated Netted Sensor
JLTV	Joint Light Tactical Vehicle
JMPS	Joint Mission Planning System
JNN	Joint Network Node
JPADS	Joint Precision Airdrop System
JPALS	Joint Precision Approach and Landing System
JSAM	Joint Service Aircrew Mask
JSGM	Joint Service General Purpose Mask
JSTDS	Joint Service Transportable Decontamination System
JTRS	Joint Tactical Radio Systems
KMI	Key Management Infrastructure
KW	Kiowa Warrior
LCMR	Lightweight Counter-Mortar Radar
LCRTF	Light Capability Rough Terrain Forklift
LCU	Landing Craft Utility
LEMV	Long Endurance Multi-Intelligence Vehicle
LESD	Launched Electrode Stun Device
LET	Light Equipment Transport
LHS	Load Handling System
LKMD	Lighting Kit Motion Detector
LLDR	Lightweight Laser Designator Rangefinder
LMI	Lead Materiel Integrator
LOCB	Line of Communication Bridging
LOS	Line of Sight
LRIP	Low Rate Initial Production
LSV	Logistic Support Vessel
LUH	Light Utility Helicopter
LWN	LandWarNet
M	Millions
MAAS	Multi-INT Analysis and Archive System
MAP-HT	Mapping the Human Terrain
MARSS	Medium Altitude Reconnaissance Surveillance System
M-ATV	MRAP All Terrain Vehicle

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MC	Mission Command
MDD	Materiel Development Decision
MDS	Mission-Design Series
MEADS	Medium Extended Air Defense System
MEB	Maneuver Enhancement Brigade
MEDEVAC	Medical Evacuation
MFCS-D	Mortar Fire Control System - Dismounted
MFLTS	Machine Foreign Language Translation System
MFS	Modular Fuel System
MGS	Mobile Gun System
MISO	Military Information Support Operations
MLRS	Multiple Launch Rocket System
MMPV	Medium Mine Protected Vehicle
MNVR	Mid-tier Networking Vehicular Radio
MOTS	Mobile Tower System
MRAP	Mine Resistant Ambush Protected (vehicle)
MRBC	Multirole Bridge Company
MRBM	Medium Range Ballistic Missile
MS A	Milestone A (acquisition milestone)
MS B	Milestone B (acquisition milestone)
MS C	Milestone C (acquisition milestone)
MSD	Maintenance Support Device
MSE	Missile Segment Enhancement
MSLS	Missile Procurement, Army
MTI	Moving Target Indicator
MTOE	Modified Table of Organization and Equipment
MTRCS	Multi-Temperature Refrigerated Container System
MTRS	Man Transportable Robotic System
MTV	Medium Tactical Vehicle
MUM	Manned - Unmanned Teaming
MWMSS	Metal Working and Machine Shop Set
NBCRV	Nuclear Biological, Chemical Reconnaissance Vehicle
NCW	Net Centric Waveform
NCR	National Capital Region
NDT	Nuclear Disablement Teams
Nett	Not an acronym - honors World War II Medal of Honor recipient Col. Robert B. Nett
NGATS	Next Generation Automatic Test System
NGB	National Guard Bureau
NTNF-GSM	National Technical Nuclear Forensics-Ground Sampling Mission
NVG	Night Vision Goggles
ODS-E	Operation Desert Storm - Engineer

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ODS-SA	Operation Desert Storm-Situational Awareness (Abrams Tank variant)
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OMA	Operations & Maintenance, Army
ONS	Operational Need Statement
OPA	Other Procurement, Army
OSGCS	One System Ground Control Station
OSRVT	One System Remote Video Terminal
OTM	On The Move
OWF	Ozone Widget Framework
P3I	Preplanned Product Improvement
PAC	Patriot Advanced Capability
PB	President's Budget
PCASS	Preliminary Credibility Assessment Screening System
PDB	Post Deployment Build
PDFCS-R	Paladin Digital Fire Control System - Replacement
PED	Processing, Exploitation and Dissemination
PGK	Precision Guidance Kit
PGSS	Persistent Ground Surveillance Systems
PIM	Paladin Integrated Management
POM	Program Objective Memorandum
PLS	Palletized Load System
PM	Product or Program Manager
POP	Points of Presence
POR	Program of Record
PSDS2	Persistent Surveillance Dissemination System of Systems
PTDS	Persistent Threat Detection System
QRC	Quick Reaction Capability
RAID	Rapid Aerostat Initial Deployment
RAM	Rockets, Artillery and Mortars; also Reliability, Availability and Maintainability
RC	Reserve Component
RDA	Research, Development and Acquisition
RDTE	Research, Development, Test and Evaluation
RF-ITV	Radio Frequency In-transit Visibility
RFP	Request for Proposals
RSTA	Reconnaissance, Surveillance and Target Acquisition
RTCH	Rough Terrain Container Handler
S&T	Science and Technology
SA	Situational Awareness
SALE	Single Army Logistics Enterprise
SAR	Synthetic-Aperture Radar

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SATCOM	Satellite Communications
SATS	Standard Aircraft Towing System
SATS	Standard Automotive Tool Set
SBCT	Stryker Brigade Combat Team
SECM	Shop Equipment Contact Maintenance
SEP	System Enhancement Package
SIGINT	Signals Intelligence
SINCGARS	Single Channel Ground and Airborne Radio System
SKL	Simple Key Loader
SKO	Sets, Kits and Outfits
SLEP	Service Life Extension Program
SMART-T	Secure Mobile Anti-Jam Reliable Tactical Terminal (satellite system)
SMET	Squad Multi-purpose Equipment Transport
SMFT	Semi-trailer Mounted Fabric Tank
SOF	Special Operations Forces
SOSE	System of System Engineer
SPARK	Self Protective Adaptive Roller Kit
SRW	Soldier Radio Waveform
STAMIS	Standard Army Management Information Systems
STARLITE	Small Tactical Radar Lightweight
STEP	Strategic-Tactical Entry Points
STG	SIGINT (Signals Intelligence) Terminal Guidance
SWAP	Space, Weight and Power
SWAP-C	Size, Weight, Power and Cooling
TAIS	Tactical Airspace Integration System
TAMR	Total Army Munitions Requirement
TBC	Tactical Battle Command
TCDL	Tactical Common Data Link
TECD	Technology Enabled Capability Demonstration
THAAD	Terminal High Altitude Area Defense
THDD	Tactical Handheld Digital Device
TIGR	Tactical Ground Reporting
TLDS	Target Location Designation System
TOW	Tube Launched, Optically Tracked, Wire Guided
TQG	Tactical Quiet Generator
TSET	Tactical Site Exploitation Tool Set
TSP	Tactical SIGINT Payload
TUA	Targeting Under Armor
TWS	Thermal Weapon Sight
TWV	Tactical Wheeled Vehicles
UAS	Unmanned Aerial System

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UAV	Unmanned Aerial Vehicle
UGCS	Universal Ground Control Station
UHF	Ultra High Frequency
USAR	United States Army Reserve
USMC	United States Marine Corps
VSAT	Very Small Aperture Terminal
VTOL	Vertical Take Off and Landing
VUIT	Video Unmanned Intel Teaming
WIN-T	Warfighter Information Network – Tactical
WMD-E	Weapons of Mass Destruction-Elimination
WNW	Wideband Networking Waveform
WTCV	Weapons and Tracked Combat Vehicles

Details on major Army acquisition programs can be found in the 2012 Army Weapon Systems handbook at:

http://armyalt.va.newsmemory.com/wsh2012.php



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FY 2012 Annual Report

Since my confirmation as Director of Operational Test and Evaluation (DOT&E) in 2009, I have implemented initiatives to improve the quality of test and evaluation (T&E) within the Department of Defense. I have emphasized early engagement of testers in the requirements process, improving system suitability by designing reliability into systems from the outset, and integrating developmental, operational, and live fire testing. Implementing these initiatives has revealed the need for an additional area of focus – the requirement to incorporate statistical rigor in planning, executing, and evaluating the results of testing.

There are significant opportunities to improve the efficiency and the outcomes of testing by increasing interactions between the testing and requirements communities. In particular, there should be early focus on the development of operationally relevant, technically feasible, and testable requirements. In this Introduction, I discuss the crucial role the T&E community can and should play as requirements are developed. Additionally, I describe DOT&E efforts to institutionalize the use of statistical rigor as part of determining requirements and in T&E. I also provide an update on the Department's efforts to implement reliability growth planning and improve the reliability and overall suitability of our weapon systems. And lastly, I describe challenges and new developments in the area of software T&E.

Last year, I added a new section to my Annual Report assessing systems under my oversight in 2010 – 2011 with regard to problem discovery during testing. My assessment fell into two categories: systems with significant issues observed in operational testing that should, in my view, have been discovered and resolved prior to the commencement of operational testing, and systems with significant issues observed during early testing that, if not corrected, could adversely affect my evaluation of those systems' effectiveness, suitability, and survivability during Initial Operational Test and Evaluation (IOT&E). This year, I am providing an update to the status of those systems identified last year, as well as my assessment of systems under my oversight in 2012 within those two categories.

THE ROLE OF T&E IN REQUIREMENTS

There is an inherent and necessary link between the requirements and the test communities. The requirements community must state our fighting force's needs in the form of concrete, discrete capabilities or *requirements*. The testing community must then assess a system that is developed and produced to meet those requirements to determine whether it provides the military capability being sought; that is, we evaluate the system's operational effectiveness and suitability when used by our forces in combat. In my opinion, the collaboration needed between the requirements and the test communities to discharge these responsibilities needs to be strengthened.

In my report last year, I discussed the Defense Acquisition Executive (DAE) independent assessment of concerns that the Department's developmental and operational test communities' approach to testing drives undue requirements, excessive cost, and added schedule into programs. The DAE assessment team "found no significant evidence that the testing community typically drives unplanned requirements, cost, or schedule into programs." However, they did note that there were four specific areas that needed attention:

> *"The need for closer coordination and cooperation among the requirements, acquisition, and testing communities; the need for well-defined testable requirements; the alignment of acquisition strategies and test plans; and the need to manage the tension between the communities."*

The lack of critically needed collaboration among the technical, test, and requirements communities is not new. The 1986 Packard Commission found that success in new programs depends on "an informed trade-off between user requirements, on one hand, and schedule and cost, on the other." It therefore recommended creation of a new body representing both military users and acquisition/technology experts. This ultimately led to the creation of the Joint Requirements Oversight Council (JROC), which includes the military operators as formal members but includes, as advisors only, the acquisition and test communities. In 1998, the National Research Council (NRC) identified the need for greater interaction between the test and the requirements communities; the NRC pointed out that operational test personnel should be included in the requirements

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process in order to assist in establishing "verifiable, quantifiable, and meaningful operational requirements." And the National Defense Authorization Act for FY11 specifically named DOT&E as an advisor to the JROC. However, obstacles for close collaboration remain. I discuss below three specific areas where increased interactions could result in improved test outcomes, which should then result in systems with needed and useful combat capability being delivered to our forces more quickly.

Mission-Oriented Metrics

OT&E is defined in Title 10 United States Code as:

> *"The field test, under realistic combat conditions, of any item of (or key component of) weapons, equipment, or munitions for use in combat by typical military users; and the evaluation of the results of such tests."*

Weapon systems sit in the motor pool, at the pier, or on the runway. Individual systems do not have missions; it takes Soldiers, Sailors, Airmen, and Marines to make them work. Operational testing is about assessing mission accomplishment of the unit equipped with a system. To evaluate operational effectiveness we seek to answer the question, "can a unit equipped with the system accomplish the mission?" Operational effectiveness is defined in the Joint Capabilities Integration and Development System (JCIDS) manual as:

> *"Measure of the overall ability of a system to accomplish a mission when used by representative personnel in the environment planned or expected for operational employment of the system considering organization, doctrine, tactics, supportability, survivability, vulnerability, and threat."*

And the Defense Acquisition Guide emphasizes "the evaluation of operational effectiveness is linked to mission accomplishment." End-to-end testing with operational users across the intended operational envelope is essential to assessing the system's impact on mission accomplishment. Additionally, each system must be evaluated within the context of the system-of-systems within which it will operate.

In January 2010, I provided guidance to the Operational Test Agencies on the reporting of OT&E results reiterating that the appropriate environment for any operational evaluation includes the system being tested and all interrelated systems needed to accomplish an end-to-end mission in combat. I emphasized that the primary purpose of OT&E is to describe the operational effectiveness and suitability of the system being tested within that environment. A subsidiary purpose of OT&E, stated in DoDI 5000.02, is to determine if thresholds in the approved Capability Production Document (CPD) have been satisfied. The measures used for this purpose are appropriately referred to in the context of "performance" as in "key performance parameters (KPPs)," or "measures of performance." But these measures associated strictly with evaluating KPPs are not the full set necessary to evaluate operational effectiveness in combat.

Requirements are often stated in terms of technical parameters whose satisfaction is necessary, but not sufficient to determine a system's effectiveness, suitability, and survivability when used in combat. Ideally, KPPs should provide a measure of mission accomplishment, lend themselves to good test design, and encapsulate the reasons for procuring the system. However, DOT&E has seen many examples of KPPs that are not informative to an evaluation of mission accomplishment. For example, a previous ground combat vehicle had KPPs that only required it seat nine passengers, be transportable by a C-130, and have a specific radio system; these requirements could have been met by a passenger van. Another example was an amphibious ship with KPPs for the number of helicopter spots, the number of storage spaces, and the maximum speed of the ship; these requirements could have been measured with a stopwatch and a tape measure and could have been satisfied by a commercial ship with no capability to survive amphibious combat. While these technical performance requirements are important, they are not sufficient to determine whether the ground vehicle or ship can be used successfully in combat. In these cases, the test community encouraged the use of metrics for evaluation directly tied to mission success such as accomplishing geographic objectives while minimizing blue force losses or meeting an aircraft sortie generation rate and surviving likely attacks. If the test and requirements communities engage early, requirements can be stated in a manner that makes them directly relevant to mission success and therefore, both directly relevant to operational testing and much more capable than technically-oriented parameters of informing whether the sought-for combat capabilities have been achieved in the system to be produced.

Leveraging T&E Knowledge in Setting Requirements

Interactions between the requirements writers and the testers can also help identify alternatives to hard-to-test or impossible-to-test requirements. Requirements that cannot be verified in testing may as well not exist. The T&E community can help identify unrealistic, unaffordable, and un-testable requirements. Additionally, T&E knowledge of the current threat environment and test infrastructure can help the requirements community understand what resources will be needed to test a given requirement. We have seen Service requirements officers state they want demanding if not technically unachievable

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requirements to drive vendors to deliver the best possible system performance; but, history has shown setting very high or unachievable requirements is particularly destructive to program success. For example, the Future Combat System program required high survivability ("tank-like") and tactical transportability (via C-130) that, together, were impossible to achieve. Additionally, reliability requirements for that system were much higher – nearly 10 times – that of our current systems, making achievement of those requirements both unrealistic and unaffordable. Clearly, we should not eliminate requirements simply because they are difficult to test. We must, however, carefully consider whether difficulty (or impossibility) of testing requirements implies the same for their achievement.

Testers have experience with the difficulty and cost associated with the testing needed to demonstrate whether certain metrics have been achieved. For example, consider a requirement for 99 percent reliability for completing a 6-hour mission. This is comparable to 600 hours between failures and would require at a minimum 1,800 hours of testing to verify. However, if the requirement were 95 percent reliability for completing the same 6-hour mission, the associated mean time between failures is only 120 hours and testing to that requirement could be accomplished in a minimum of 360 hours. If the testing revealed 40 hours between failures (instead of 120 or 600) that would indicate an 86 percent probability of completing a 6-hour mission. Would 95 percent or 86 percent be good enough? To answer that question, the rationale, or so-what factor, for the requirement should be fully explained. Accordingly, I intend to require that Test and Evaluation Master Plans (TEMPs) have an annex explaining the user's rationale for the requirements contained in the Capability Development Document. The requirements and their associated rationale should be revisited as often as needed as a program proceeds and knowledge is gained regarding the ability to achieve the program's currently stated requirements.

In addition to the value selected for a requirement, the manner in which a requirement is stated can also make testing expensive or impractical. For example, metrics stated as binomial probabilities (99 percent probability of detecting a target) are expensive to test because they require large sample sizes to gain statistical confidence in the results. Metrics that are physical, continuous, easily measured, and operationally meaningful can be used instead of such probabilities. For example, the "median miss distance" can be measured at high confidence with about a third the number of tests as the "probability of hit," and also provides more information from the resulting distribution of measurements (how close or far away) than a simple hit/miss answer. In many instances, the probabilities now often used to state requirements can be subsequently estimated using test data collected to evaluate continuous response metrics. Thus, wherever possible, I am requiring test plans that measure continuous performance variables as the basis for evaluating thresholds for requirements that have been written in terms of probabilities.

Evaluation Across the Operational Envelope

Another disconnect among the requirements, test, and operational communities is that often requirements are narrowly-focused and do not cover the operational envelope; a notional depiction is shown in Figure 1. To be adequate, the operational evaluation must report performance of the system across the operational envelope, not just at single conditions specified in the capabilities documents. There is a common concern that failing to specify a certain, limited set of conditions within requirements could lead to an unwieldy test. This is a key reason DOT&E is using Design of Experiments (DOE) to plan testing that efficiently spans the operational envelope. Requirements would be much more useful and meaningful if they identify multiple conditions in which the system is likely to be operated.

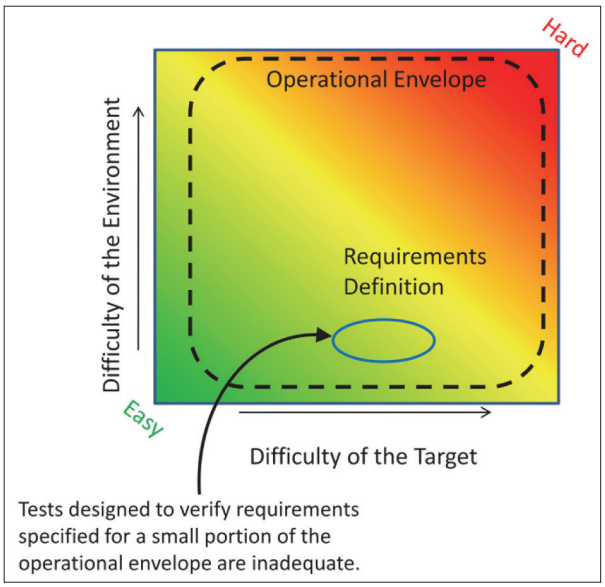


FIGURE 1. NOTIONAL TWO-DIMENSIONAL DIAGRAM OF A WEAPON SYSTEM'S OPERATIONAL ENVELOPE

I will continue to advocate for and require the use of DOE to plan and execute tests that span the operational envelope. One of the key tenets of a well-designed experiment is that all stakeholders must be engaged in the determination of the goals, metrics, operational envelope, and test risks. The requirements community is a key stakeholder that can provide valuable input regarding what the key factors (or conditions) are that will most influence mission performance and thus should be considered in operational test.

In summary, through early and continuous engagement between the testing and requirements communities, we can craft requirements that are technically feasible, mission-oriented, realistic, testable, and responsive to the limitations and opportunities revealed during system development.

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INCREASING STATISTICAL RIGOR OF T&E

In support of all of my initiatives, I have advocated for increasing the statistical rigor employed in planning and executing T&E. To that end, my office has recently completed a roadmap to institutionalize Test Science and statistical rigor in T&E. The roadmap was a collaborative activity among DOT&E, Deputy Assistant Secretary of Defense for Developmental Test and Evaluation (DASD(DT&E)), the Service Operational Test Agencies (OTAs), and the Service T&E Organizations.

By increasing statistical rigor and using state-of-the-art test and analysis methodologies, we will ensure defensible and efficient T&E. The Test Science Roadmap accomplishes the following:

- Assesses the current state of analytic capabilities within each of the Services and Office of the Secretary of Defense (OSD)
- Develops qualification guidelines for personnel performing test design and analytic services for different kinds of T&E organizations
- Identifies the training, education, and other support that Services and agencies will need to attain the required test design and analytic capabilities
- Develops case studies of the implementation of scientific test design across test programs
- Provides guidance for the documentation of test design and statistical rigor in TEMPs, test plans, and reports
- Forms a permanent Advisory Board to continually identify and advocate for the use of methods to incorporate statistical rigor in all test planning and execution

We have made significant progress in the past two years across all areas of the roadmap, as discussed below.

Education & Training

DASD(DT&E) is leading the way in improving the educational materials needed by our T&E community, and I strongly support them in this initiative. In the past year, we have added courses and content on statistical methods for T&E to courses offered by the Defense Acquisition University. We have also made training widely available across DOT&E, DASD(DT&E), and all of the Services.

Case Studies & Best Practices

Case studies are an essential educational tool illustrating the application of statistical methods, including DOE to T&E. Over the past couple of years, my office has developed and published many case studies demonstrating the usefulness of applying DOE and statistical methods to T&E. Additionally, in the roadmap meetings, each of the Services shared case studies highlighting the application of DOE to solve their Service-specific problems. DOT&E has compiled these case studies as a resource for the T&E community (https://extranet.dote.osd.mil). They highlight challenges, areas for further research, and best practices.

Guidance & Policy

Policy that supports the use of scientific test techniques is essential to ensuring a continued commitment to Test Science in years to come. Both DASD(DT&E) and DOT&E have supported including more detailed language in DoDI 5000.02 on increasing statistical rigor of T&E. DOT&E also published a TEMP guidebook highlighting the important content for TEMPs and test plans. This guidance is available on the DOT&E public website (www.dote.osd.mil). DASD(DT&E) has also taken the lead on incorporating Test Science topics into other guidance documents including the T&E Management Guide and the Guide on Incorporating T&E into DoD Acquisition Contracts. All of these resources provide clear and consistent guidance to the T&E community on the importance of statistics in T&E. DOT&E insists that TEMPs and test plans submitted for approval include substantive documentation of the application of DOE to test planning, execution, and evaluation.

Advisory Board

Two different advisory groups have been formed in the past two years. The first is the Science of Test Research Consortium, funded by DOT&E and the Director of Test Resource Management Center; this academic consortium provides technical advice to the DoD on Test Science issues. The second is the Scientific Test and Analysis Techniques (STAT) Center of Excellence (COE). The STAT COE funded by DASD(DT&E) is charged with assisting program managers of major acquisition programs. Together, these two groups are working to operationalize Test Science in active programs.

Future Efforts to Institutionalize Statistical Rigor

Notwithstanding the significant progress that has been made in the past two years, there is still work to be done to utilize the full toolset the scientific community has available to support T&E. I have seen the Service OTAs modify their test design and planning techniques to incorporate DOE and take advantage of the efficiencies afforded by the use of its

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methods. Further, I have observed an improvement to the quality of the TEMPs and test plans that are based on these methods. However, there are two areas requiring improvement as the Department's institutionalizes statistical rigor in testing:

- Execution of testing in accordance with the planned test design
- Analysis of test data using the advanced statistical methods commensurate with test designs developed using DOE

For the former, I have seen some cases where a test is well-designed, but the desired conditions of the test in the field are not the same as required by the original plan. This has the effect of limiting the conclusions that can be made from the subsequent data or, at worst, wasting time and resources. Since most of our tests are focused on characterizing the performance of the system across the actual conditions in which the operators will employ the system, it is crucial that the planned conditions are achieved during the test.

For the second area, I have not yet observed all of the OTAs employing the data analysis methods that would reap the benefits of the efficiencies afforded by DOE. In other words, although the OTAs use statistical rigor in their test planning, they are not always following up with the same rigor in their analysis of test data. The simplest case of this is where a test is designed to cover all or many of the important operational conditions, and is optimized to be extremely efficient in the number of test iterations in each condition, but the data analysis is limited to reporting a single average (mean) of the performance across all the test conditions. This result throws away all of the careful test design efficiencies afforded by the use of DOE. A more statistically rigorous analysis would enable all the available information to be extracted from the data, which is critical to evaluating the performance of systems across their full range of operational use. The more advanced statistical analysis also enables statements of system performance to be made with higher confidence in many cases, so that acquisition decisions can be based on certain knowledge rather than supposition.

I will work with the Service OTAs during the next year to rectify these remaining shortfalls in the application of DOE to test execution and analysis.

RELIABILITY ANALYSIS, PLANNING, TRACKING, AND REPORTING

Improving system reliability has been a DOT&E initiative since 2006; the Department has also recognized the significant adverse long-term life cycle cost impacts and reduced operational capability resulting from systems being unreliable. DOT&E initiatives have emphasized the need for reliability growth planning and assessment, establishment of reliability maturity goals and entrance criteria for each phase of testing and documenting the reliability test and evaluation strategy (TES) in the TEMP. Accordingly, the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L)) in 2011 released a Directive Type Memorandum (DTM 11-03) on Reliability, Analysis, Planning, Tracking, and Reporting; this DTM was continued into 2012 and will be incorporated into the updated DoDI 5000.02 "Operation of the Defense Acquisition System."

I am tracking the impact of the new directive on system reliability. The Office of the Deputy Assistant Secretary of Defense for Systems Engineering (DASD(SE)) is developing an implementation guide, which is in final staffing and should be available in early 2013. DOT&E has been an ardent advocate for the reliability concepts contained in the directive, and has institutionalized them in our priorities and policies. Figure 2 plots the outcomes of initial operational tests reported to Congress for systems tested between fiscal years 1997 to 2012. A total of 118 reports were included; each report includes an evaluation of operational effectiveness, operational suitability, and reliability.

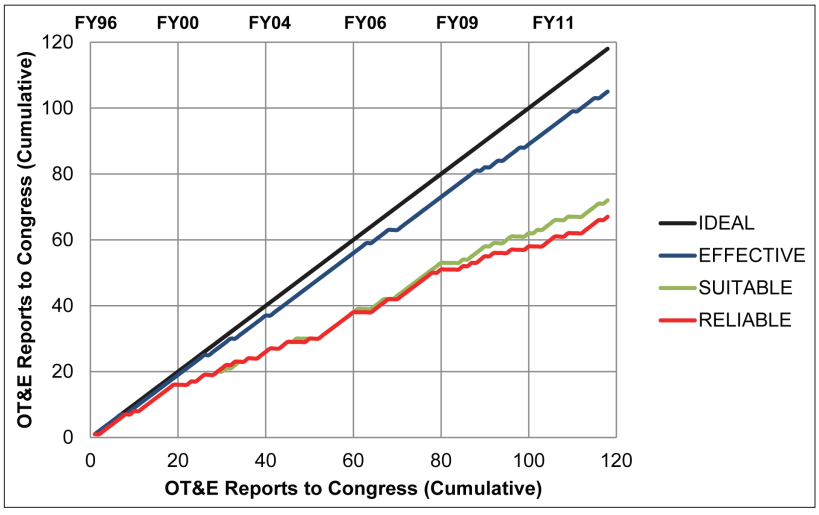


FIGURE 2. CURRENT TRENDS IN RELIABILITY

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While evaluations of operational effectiveness and suitability are based on many factors, the evaluations displayed in this chart are based solely on whether the system met its required reliability threshold. As shown in Figure 2, reliability continues to lag; only 7/13 systems (54 percent) evaluated in 2012 met their reliability thresholds and overall between 1997 and 2012 only 67/118 systems (57 percent) were reliable.

To further understand the reliability trends in Figure 2, I surveyed 52 programs for which I approved TEMPs or TESs in FY11 following up on the survey I did in FY10 for all oversight programs. The TEMPs approved in FY11 continue the positive trends I am seeing for all TEMPs approved after June 2008 (when the Department began initiatives to improve reliability). These trends include programs:

- Having an approved System Engineering Plan
- Incorporating reliability as an element of the test strategy
- Having a reliability growth strategy and documenting it in the TEMP
- Incorporating reliability and availability requirements

Unfortunately, the programs reviewed in FY11 did not show improvement in establishing reliability-based milestone or operational test entrance and exit criteria. However, I believe the recent emphasis on reliability has had some demonstrable positive impacts. Having reliability growth curves alone did not correlate with attainment of reliability requirements, but programs with comprehensive reliability plans were more likely to meet their reliability requirements. A larger fraction of programs that establish growth curves with intermediate goals; anchor milestone or entrance/exit criteria to reliability performance; use metrics to ensure reliability growth is on track; predict changes caused by the implementation of corrective actions; and calculate reliability growth potential met their operational test reliability entrance and exit criteria compared to programs that do not follow these practices.

Examining the TEMP survey trends by Service shows that higher percentages of Army and Air Force programs: have added a reliability growth strategy since June 2008; have reliability growth curves; and are calculating the reliability growth potential. Army and Navy programs show increasing improvement in ensuring there is time in the schedule to implement and verify corrective actions and document the reliability test strategy. Army programs are most likely to: use reliability growth curves and intermediate reliability goals; put systems into the hands of representative users before Milestone C; and document reliability changes caused by implementation of corrective actions. Figure 3 shows the fraction of systems meeting reliability thresholds at IOT&E for programs on DOT&E oversight between 1997 and 2012 (the same programs depicted in Figure 2 now broken out by Service).

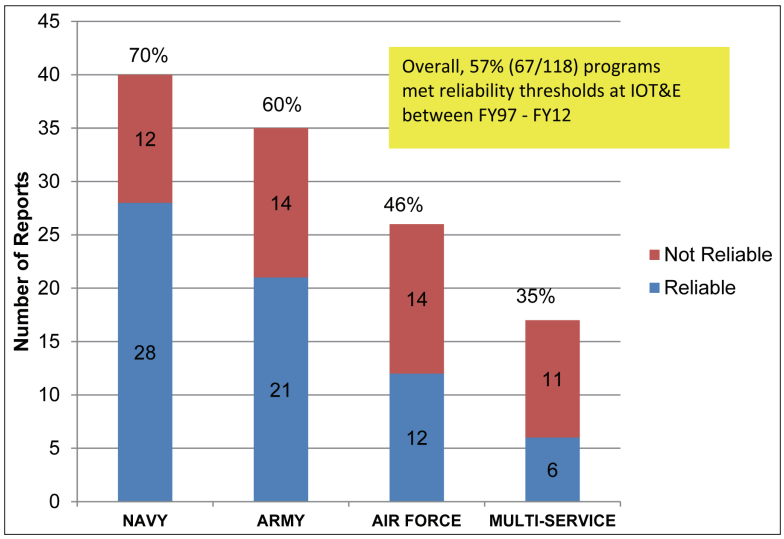


FIGURE 3. FRACTION OF PROGRAMS MEETING RELIABILITY THRESHOLDS AT IOT&E, BY SERVICE (FY97-FY12)

I am not yet seeing more systems actually meet their reliability requirements than in past years, but I believe the recent emphasis on reliability planning has had some demonstrable positive impacts. While the majority of programs now have and are documenting their reliability growth strategy in the TEMP, they are not fully incorporating the design for reliability tenets described in the ANSI/GEIA-STD-0009 Reliability Program Standard for Systems Design, Development, and Manufacturing. In particular, programs are failing to "get on" their planned reliability growth curve at the beginning. I have seen evidence that programs with a procedure for calculating reliability growth potential (a calculation that places emphases on initial reliability, which in turn requires that the system be designed for reliability) have a much greater likelihood of meeting reliability based entry criteria for operational test phases.

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Figure 4 shows the distribution of root failure causes for the 51 programs that did not meet their reliability thresholds between 1997 and 2012. The root causes include: 1) inadequate systems management (failures traceable to incorrect interpretation or implementation of requirements, processes, or procedures); implementation of "bad" requirements (missing, inadequate, ambiguous, or conflicting); or failure to provide the resources required to design and build a robust system; 2) inadequate design margins (failures resulting from lack of design robustness to the stresses and loads in usage environment); 3) inadequate software (failures of a system to perform its intended function due to software issues); 4) induced failures (failures resulting from externally applied stresses such as operator or maintainer interfaces); 5) part quality (random failures); and 6) manufacturing anomalies.

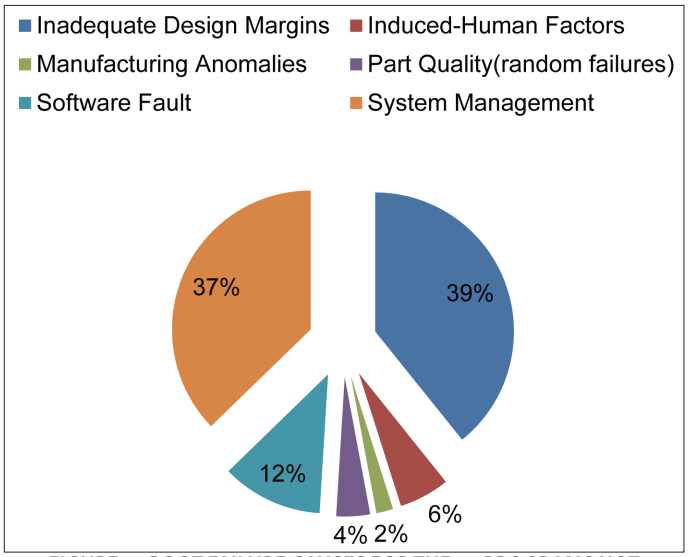


FIGURE 4. ROOT FAILURE CAUSES FOR THE 51 PROGRAMS NOT MEETING RELIABILITY THRESHOLDS BETWEEN FY97 AND FY12

Inadequate design margins and system management combine to account for 76 percent of the root causes for reliability failures in these data. Clearly, inadequate attention to reliability during engineering design, and inadequate management focus on best practices for reliability design and growth testing have been and continue to remain a concern – improvements in these areas, particularly using a Design For Reliability strategy, would help programs get on their planned reliability growth curve and have a greater likelihood of meeting their ultimate reliability goals. Additionally, software reliability design and growth testing are of concern. The 12 percent of systems that failed due to software root causes in Figure 4 are mostly software intensive systems like APG-79 Active Electronically Scanned Array (AESA) Radar (software immaturity causes excessive and inexplicable radar hang-ups; the built-in test function is not automated to isolate software failures); F-15 Mission Planning System (suitability is poor due to software instability, high frequency of system crashes); and Large Aircraft Infrared Countermeasures (LAIRCM) Phase II (software design bugs caused 19 critical failures; bugs were traced to software coding errors).

SOFTWARE TESTING

I continue to see software issues in programs of all types. Most commonly, programs do not create adequate ability to track software reliability and test software patches. Software requirements are poorly stated and in some cases wrongly tested. There are also unique needs for the special class of programs, business systems, which are being developed by the Services to meet the 2014 and 2017 Congressional deadlines for auditability.

Software Reliability

Software reliability is broadly similar to reliability for any weapon system with subtle distinctions in failure definitions, defect tracking, and the speed of the test-fix-test cycle. The overall effect of these distinctions has led me to conclude that new policy is needed that will the mandate the use of some software test automation for most programs that utilize software.

Failure Definition and Defect Tracking: Software is nearly always multi-functional. Software use is not well represented by failure-per-hour metrics. Except in cases where the same operation is performed repeatedly (for example spacecraft during planetary cruise), programs should simply track counts of defects. Defects should always be categorized by severity in accordance with Institute for Electrical and Electronics Engineers standards. Programs should track open and closure rates of the defects in each category. For multi-functional systems, it is helpful to track defects against distinct capabilities as well.

Test-Fix-Test: The test-fix-test cycle for software is faster and less visible than for other systems types. For many software issues, there is no meaningful distinction between maintenance and follow-on development. Given the speed

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of software development, the inability to oversee software in detail, and the fact that one must develop code to fix code, the line between fixing defects and adding features is nearly always blurred. Given the pace at which new security patches and product updates and changes in the computing environment occur, there is also essentially no such thing as a stable software system. For all of these reasons, I have concluded that operational testing of software must include a demonstration of the program's ability to perform robust and repeatable testing in support of software maintenance.

In support of robust and repeatable within-program testing, I have begun enforcing the following test automation policies, which will be contained in the next version of the DoDI 5000.02:

- *At Milestone A, program managers shall identify an approach to software test automation, including when key test automation software components or services will be acquired and how those decisions will be made. The test automation approach shall be updated in the Milestone B and Milestone C TEMPs as appropriate.*
- *Program managers shall demonstrate system sustainment maturity at IOT&E. Sustainment maturity shall include routine T&E to support routine technology upgrades. For Information Systems, Defense Business Systems, and software components of Weapons Systems, program managers shall demonstrate mature test automation to include an end-to-end trace of test information from requirements to test scripts to defect tracing*

This year, I recommended the following programs demonstrate this test-fix-test cycle: Next Generation Enterprise Network (NGEN), Integrated Strategic Planning and Analysis Network (ISPAN), Defense Enterprise Accounting and Management System (DEAMS), EProcurement, and Global Combat Support System – Army (GCSS-Army). Because the development of automation tools can be time consuming given the complexity of many of these programs, I anticipate that most programs will take several years to create an automated test-fix-test approach to satisfy these recommendations. Currently, very few acquisition programs have mature test automation solutions for regression testing that can be demonstrated at IOT&E and even fewer can create the environments and conditions to validate their regression testing processes. Without substantial help from a central resource, it is likely that most programs will have this deficiency assessed during IOT&E.

The need for test automation will create demand for the corresponding expertise in program offices. Program managers need a resource in the form of a center of excellence to help meet that demand, and DOT&E is taking the initial steps to establish such a center. The center of excellence would work with vendors and government providers to promote the use of various test automation solutions under the construct of "Test as a Service (TaaS)." A center of excellence will:

- Centralize knowledge of the various automation approaches
- Assist programs in applying test automation
- Create "in-house" test automation expertise

A center of excellence TaaS capability may lessen the tendency of program offices and vendors to use a "stove-piped" approach to test automation, may reduce duplicative resources (technological and human), should increase programs' use of existing capabilities, and should improve the consistency and adequacy in the types of testing accomplished.

Testers do not have questions about system maturity that are distinct from the questions the systems managers should have. System managers should always know how well the system is functioning. If testers have reasonable questions about system performance that the system managers cannot answer with the data they are already gathering, then the system management probably is not as mature as it should be. Examples of performance parameters that should be routinely and continuously reported to the system management include defect tracking, helpdesk use, system productivity/utilization, schedule of upcoming changes (commercial releases, changes in interfacing system, etc.), staff turnover rate, and training and documentation adequacy.

Software Requirements

Software requirements typically involve KPPs for system response time, data loss and restoration, and data transmission accuracy. DOT&E has seen many examples of metrics that incorrectly capture this information. For example, a KPP might specify 95 percent accuracy for information retrieval; but if a random 5 percent of your data is garbled every time you use the system, the utility of that system is very much in question. Some programs include requirements for data loss in event of an outage or other emergency that requires a system restore from backups, and these are almost always expressed as percentages. The data loss requirements should be expressed in time, not percentages. In every case, the system is expected to lose 100 percent of the data that has been entered following the most recent backup interval before the outage. I have seen that testers are dutifully reporting the amount of data loss, but that is not meaningful. Rather, testers should always perform a demonstration test that verifies the ability of the system to backup and restore data on a schedule consistent with the operational need for the system to be available for use.

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Finally, some programs have percentage KPPs for data accuracy. These KPPs reference a variety of technical circumstances: transmission across interfaces, retrieval from databases, account balances, and so on. These are often treated as global metrics but they should be treated as percentages that apply to some relevant set of channels. For example, in general, once an interface is correct it is always correct. It is much less important to know that 95 percent of the data transmitted across all interfaces is correct than it is to know which 5 percent of the interfaces are transmitting incorrectly. The metric should not simply be the global number of errors per the number of transmissions. The mission need is for the data elements with errors to be limited. Therefore, the metrics should be looking at counts of element types containing errors. Global metrics also contribute less to finding and fixing problems than would differentiated metrics.

Vulnerability of Business Systems

The HOUSE ARMED SERVICES COMMITTEE PANEL ON DEFENSE FINANCIAL MANAGEMENT AND AUDITABILITY REFORM FINDINGS AND RECOMMENDATIONS (January 24, 2012), Recommendation 4.9 directed DOT&E and others to identify and address shortfalls in workforce levels and corresponding skill sets for Enterprise Resource Programs (ERPs). A clear shortfall in the testing of these systems is in identification of financial vulnerabilities. I have accordingly begun directing that the financial vulnerabilities of ERPs be probed in a manner analogous to Information Assurance, and anticipate that such testing will draw, at least initially, on the existing commercial services that provide such testing. The programs to which this applies are:

- Air Force Integrated Personnel and Pay System (AF-IPPS)
- Defense Agency Initiative (DAI)
- Defense Enterprise Accounting and Management System – Increment 1 (DEAMS – Increment 1)
- Defense Enterprise Accounting and Management System – Air Force (DEAMS – AF)
- EProcurement
- Future Pay and Personnel Management Solution (FPPS – Navy) Pre-MAIS
- General Fund Enterprise Business System (GFEBS)
- Global Combat Support System – Army (GCSS – Army)
- Integrated Personnel and Pay System – Army (Army IPPS)
- Navy Enterprise Resource Planning (ERP)

In support of this initiative, the DCMO has initiated a study of commercial providers of financial Red Team test services. In general, commercial vendors of these services focus on protect and detect capabilities (both system and people). They work with their clients to identify likely targets for fraud or theft within the system; they may attempt (within established rules of engagement) to circumvent controls and processes; and they assess the audit processes that are in place to catch fraud or theft. In addition, together with the Deputy Chief Management Officer, DASD(DT&E), and DASD(SE), we will ensure that developmental and operational testing helps fulfill the Federal Information System Controls Audit Manual requirements.

OTHER AREAS OF INTEREST

Electronic Warfare Test Infrastructure

In February 2012, I identified shortfalls in electronic warfare test resources that prevent adequate developmental and operational testing of many systems, including, but not limited to, the Joint Strike Fighter. I am working to address these shortfalls in government anechoic chambers, open-air ranges, and the Joint Strike Fighter electronic warfare programming laboratory. My staff participated in a "tiger team" assigned by the USD(AT&L) to review the issue, which concurred with my conclusions and recommended additional enhancements.

Cyber Testing

Implementation of the February 2011 Chairman of the Joint Chiefs Execute Order (EXORD), which directed increased cyber-adversary realism for training events, has been modest. During FY12, most of the exercise assessments and tests involved operations largely against low- and mid-level cyber threats and on networks that were only moderately stressed in terms of loading or network degradation. In the cases where the adversary team portrayed higher-level threats, exercise training audiences frequently misinterpreted these portrayals as maintenance issues, poor system performance, or anomalies. This indicates that the Department has not yet developed sufficiently advanced cyber defensive tactics to counter advanced adversary tactics and to consistently operate in degraded cyber environments. Following publication

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of the FY11 Annual Report, I provided a separate and classified amplification of findings, which resulted in a series of meetings with the Deputy Secretary of Defense on the topic of how these operational and training shortfalls might be resolved. A number of actions resulting from these discussions are in progress, including the consolidation and enhancement of training support capabilities, additional guidance on meeting the intent and requirements of the EXORD, and improving the way the Department ensures that critical shortfalls are resolved. Additionally, the lessons garnered from operational network assessments are being applied to the acquisition and testing of information systems to ensure that subsequent systems procurement does not contain cyber shortfalls already discovered and documented by the Department. I also remain closely engaged with U.S. Cyber Command and other key stakeholders to ensure priority is given to the necessary investments supporting improved Red Team availability, capability, and accessibility.

Testing Protocols for Personal Protective Equipment

I continue to exercise oversight over the testing of personal protective equipment. The National Academy of Sciences' Committee to Review the Testing of Body Armor published its final report in May of 2012 and I and the Services are pursuing the report's recommendations. Congressional interest in the testing of the Army's Advanced Combat Helmet (ACH) resulted in the Department's Inspector General initiating a technical assessment of the ACH. In response to this Congressional interest in the ACH, we have also asked the NRC to conduct an independent review of the helmet testing protocols. This is a direct follow-up to the NRC's independent review of hard body armor testing, which included a review of test protocols. One of the objectives of the review is to examine the rigor of statistical metrics. My staff will leverage the knowledge of some of the nation's leading statisticians to improve and advance the use of statistical techniques in test. I will also conduct a comprehensive technical assessment of the ACH to characterize its ballistic performance more comprehensively than is possible with existing data. The results of these assessments will provide the basis for any changes to the current helmet test protocols that might be appropriate.

Warrior Injury Assessment Manikin (WIAMan)

I am sponsoring a five-year research and development program to increase the Department's understanding of the cause and nature of injuries incurred in underbody blast combat events and to develop appropriate instrumentation to assess such injuries in testing. This program, known as the Warrior Injury Assessment Manikin, utilizes expertise across multiple commands and disciplines within the Army to generate a medical research plan from which data will, at pre-determined times, be transitioned to the materiel and T&E communities. These data will feed the design of a biofidelic prototype Anthropomorphic Test Device designed to capture occupant loading from the vertical direction, reflecting the primary load axis to which occupants are exposed in an under-vehicle blast event.

Environment and Renewable Energy Effects on Test Ranges

The Department's ranges are experiencing encroachment from infrastructure associated with the electrical energy production and transmission industry. This encroachment can affect test operations as well as systems under test through a variety of means. These include physical obstructions, electromagnetic interference, and thermal effects. The sources of such encroachment include wind turbines, solar power towers, photovoltaic panels, and high voltage bulk power transmission lines. I will continue to cooperate with the Department's Siting Clearing House and the Services to identify potential encroachment of our ranges resulting from renewable energy infrastructure and work to mitigate the impact of such encroachment.

CONCLUSION

Since my first report to you in 2009, we have made significant progress increasing the scientific and statistical rigor of OT&E; we have engaged early with the requirements community to develop realistic, feasible, and testable requirements; we have focused attention on reliability management, design, and growth testing; and we continue to support rapid fielding through flexible and early operational test events. I submit this report, as required by law, summarizing the operational and live fire T&E activities of the Department of Defense during FY12.



J. Michael Gilmore
Director

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DOT&E Activity and Oversight

DOT&E Activity and Oversight

Activity Summary

DOT&E activity for FY12 involved oversight of 327 programs, including 41 Major Automated Information Systems (MAIS). Oversight activity begins with the early acquisition milestones, continues through approval for full-rate production and, in some instances, during full production until deleted from the DOT&E oversight list.

Our review of test planning activities for FY12 included approval of 43 Test and Evaluation Master Plans (TEMPs) and 1 Test and Evaluation Strategy, as well as 73 Operational Test Plans and 1 Live Fire Test and Evaluation (LFT&E) Management Plan. In FY12, DOT&E prepared for the Secretary of Defense and Congress 14 Beyond Low-Rate Initial Production (BLRIP) reports, 2 Early Fielding reports, 6 Follow-on Operational Test and Evaluation (FOT&E) reports, 2 LFT&E reports, 1 MAIS report, and 2 special reports, as well as the Ballistic Missile Defense (BMD) Programs FY11 Annual Report. Additional FY12 DOT&E reports that did not go to Congress included 25 Operational Assessment reports, 1 FOT&E report, 1 LFT&E report, 6 MAIS reports, and 3 special reports.

DOT&E also prepared and submitted numerous reports to the Defense Acquisition Board (DAB) principals for consideration in DAB deliberations.

During FY12, DOT&E met with Service operational test agencies, program officials, private sector organizations, and academia; monitored test activities; and provided information to the DAB committees as well as the DAB principals, the Secretary and Deputy Secretary of Defense, the Under Secretary of Defense (Acquisition, Technology and Logistics), the Service Secretaries, and Congress. Active onsite participation in, and observation of, tests and test-related activities are a primary source of information for DOT&E evaluations. In addition to onsite participation and local travel within the National Capital Region, approximately 925 trips supported the DOT&E mission.

Security considerations preclude identifying classified programs in this report. The objective, however, is to ensure operational effectiveness and suitability do not suffer due to extraordinary security constraints imposed on those programs.

TEST AND EVALUATION MASTER PLANS / STRATEGIES APPROVED

Advanced Extremely High Frequency (AEHF) Satellite Communications System TEMP

Advanced Medium-Range Air-to-Air Missile (AMRAAM) Electronic Protection Improvement Program (EPIP) TEMP

Air and Space Operations Center – Weapon System (AOC-WS), Increment 10.1 TEMP

Air Force Integrated Personnel and Pay System (AF-IPPS) TEMP

Amphibious Assault Ship Replacement (LHA (R)) TEMP

AN/ALR-69A Radar Warning Receiver Program TEMP

Apache Block III (AB3) TEMP

Army Integrated Air and Missile Defense TEMP

Automatic Radar Periscope Detection and Discrimination (ARPDD) Upgrade TEMP

B-61 Life Extension Program Tailkit Assembly Test and Evaluation Strategy

Battle Control System – Fixed (BCS-F), Increment 3, Release 3.2 (R3.2) TEMP

Cooperative Engagement Capability (CEC) TEMP Revision 5

Defense Enterprise Accounting and Management System (DEAMS) TEMP

Distributed Common Ground System – Army (DCGS-A) Increment 1 TEMP

Distributed Common Ground System – Marine Corps (DCGS-MC) Milestone B TEMP

Enhanced AN/TPQ-36 (EQ-36) Milestone C Update TEMP

EProcurement (EProc) TEMP

EProcurement Addendum to Milestone C TEMP

F/A-18E/F and EA-18G Flight Plan TEMP No. 1787

Global Broadcast Service (GBS) TEMP

Global Positioning System (GPS) Enterprise TEMP (ETEMP)

Ground/Air Task Oriented Radar (G/ATOR) TEMP

Guided Multiple Launch Rocket System – Alternate Warhead (GMLRS – W) Milestone B TEMP

Integrated Defensive Electronic Countermeasures (IDECM) Suite Block 4 TEMP

Integrated Defensive Electronic Countermeasures (IDECM) Suite Block 4 TEMP No. 1490 Annex C Change

Integrated Submarine Imaging System (ISIS) Program TEMP

Joint High Speed Vessel (JHSV) TEMP

Joint Lightweight Tactical Vehicle (JLTV) Increment I Milestone B TEMP

Joint Warning and Reporting Network (JWARN) Increment I TEMP

Key Management Infrastructure (KMI) Increment 2 TEMP

M109 Family of Vehicles Paladin Integrated Management (PIM) TEMP

Mark XIIA Mode 5 Identification Friend or Foe (IFF) TEMP

Mk 48 Mod 7 Common Broadband Advanced Sonar System (CBASS) and the Mk 48 Mod 6 Advanced Common Torpedo with Advanced Processor Build (APB) Spiral 4 TEMP No. 0371

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MQ-1C Increment 1 Gray Eagle (GE) Unmanned Aircraft System (UAS) TEMP

MQ-4C Broad Area Maritime Surveillance (BAMS) Unmanned Aircraft System (UAS) TEMP

MQ-9 Reaper Increment 1 Unmanned Aircraft System TEMP

MQ-9 Reaper Increment 1 Unmanned Aircraft System TEMP Update 1

RC-135 Multi-functional Information Distribution System (MIDS) Joint Tactical Radio System (JTRS) Integration TEMP

Remote Minehunting System (RMS) TEMP Revision D

Rolling Airframe Missile (RAM) Block 2 TEMP

Ship-to-Shore Connector (SSC) TEMP

Space-Based Infrared System (SBIRS) Enterprise TEMP (ETEMP)

Submarine Electronic Warfare Support (ES) System (AN/BLQ-10) TEMP

Surface Mine Countermeasures Unmanned Undersea Vehicle (SMCM UUV) TEMP (February 2012)

Surface Mine Countermeasures Unmanned Undersea Vehicle (SMCM UUV) TEMP (August 2012)

Teleport, Generation 3, Phase 2 (G3P2) TEMP Update

Virginia (SSN 774) TEMP with Design of Experiments (DOE) Appendix

Warfighter Information Network – Tactical (WIN-T) Increment 2 TEMP

OPERATIONAL TEST PLANS APPROVED

Advanced Extremely High Frequency (AEHF) Operational Utility Evaluation (OUE) 2 Operational Test Agency (OTA) Test Plan

Aegis Baseline 7.1R and Cooperative Engagement Capability (CEC) FOT&E Test Plans

Air and Space Operations Center (AOC) – Weapon System (WS) Increment 10.1 Recurring Event (RE) 11 Force Development Evaluation (FDE) Plan

Air and Space Operations Center (AOC) – Weapon System (WS) Increment 10.1 Overarching OT&E Plan

Air Intercept Missile-9X Block II IOT&E Plan

Airborne Warning and Control System (AWACS) Block 40/50 Upgrade IOT&E Plan

AN/ALR-69A Radar Warning Receiver (RWR) IOT&E Test Plan

Apache Block III Force Development Test and Experimentation II (FDT&E II) and IOT&E Operational Test Agency (OTA) Test Plan

Automatic Radar Periscope Detection and Discrimination (ARPDD) Upgrade IOT&E Plan

B-2 EHF SATCOM Increment 1 IOT&E Plan

Battle Control System – Fixed Release 3.2 (BCS-F R3.2) IOT&E Plan

C-130 Avionics Modernization Program IOT&E Test Plan

C-130J Data Transfer and Diagnostics System (DTADS) FOT&E Plan

C-130J Station Keeping Equipment (SKE) Software Enhancement (SSE) FOT&E-2 Plan

C-5 Reliability Enhancement and Re-Engining Program Operational Flight Program 3.5 FDE Test Plan

CNO Project No. 1714, Enterprise Test (ET-03) Phase 2 of the Air Warfare/Ship Self-Defense (AW/SSD) Enterprise, CNO Project 1400, FOT&E (OT-IIIF) of the Ship Self-Defense System (SSDS) Mark 2 Mod 1A and CNO Project 1471, FOT&E (OT-D2) of the Evolved SeaSparrow Missile (ESSM) Program

CNO Project No. 1787, FOT&E OT-D1 of the EA-18G Airborne Electronic Attack Aircraft System Configuration Set H8E Test Plan

CNO Project No. 3980 1552-OT-B2/1583-OT-B2, Operational Assessment (OA) (OT-B2) of the MH-60S Block 2 Airborne Mine Countermeasures System (AMCM) and the AN/AES-1 Airborne Laser Mine Detection System (ALMDS) Test Plan

CNO Project No. J1656, MOT&E (OT-D3) of the Mobile User Objective System (MUOS) Test Plan

Common Aviation Command and Control System (CAC2S), Increment 1, Phase 1 Limited User Evaluation Plan

Consolidated Afloat Networks and Enterprise Services (CANES) OA Test Plan

Cooperative Engagement Capability (CEC) FOT&E (OT-IIIF) Test Plan

Distributed Common Ground System – Army (DCGS-A) Increment 1, DCGS-A Software Baseline (DSB) 1.0 IOT&E OTA Test Plan (TP)

Distributed Common Ground System – Navy (DCGS-N) FOT&E Plan

Dry Cargo and Ammunition Ship (T-AKE) Program Change Transmittal II to Test Plan

E-2D Advanced Hawkeye (AHE) IOT&E/CEC FOT&E Test Plan

EProcurement Release 1.2 IOT&E Plan

EProcurement Release 1.2 OA Test Plan

F/A-18/F System Configuration Set (SCS) H8E Software Qualification Test (SQT) And Active Electronically Scanned Array (AESA) Radar Upgrade Phase III OT&E Plan

Gerald R. Ford Class CVN-78 Aircraft Carrier Test Plan for OA OT-B3

Global Command and Control System – Joint (GCCS-J) Global Version 4.2.0.9 Release OT&E Plan

H-1 Upgrades Program FOT&E (OT-IIIB) Test Plan

HC/MC-130J Recapitalization (RECAP) IOT&E Plan

Integrated Defensive Electronic Countermeasures (IDECM) Suite Block 4 OA Test Plan

Integrated Personnel and Pay System – Army (IPPS-A) Test and Evaluation Plan (TEP)

Integrated Strategic Planning and Analysis Network (ISPAN) Increment 2 IOT&E Plan

Joint Chemical Agent Detector (JCAD) Visit, Board, Search, Seizure (VBSS) OTA Test Plan for Developmental Test/Operational Test (DT/OT)

Joint Space Operations Center (JSpOC) Mission System (JMS) Increment 1 OUE OTA Test Plan

Joint Space Operations Center (JSpOC) Mission System (JMS) Increment 2 Early OA (EOA) Plan

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Joint Tactical Radio System (JTRS) Enterprise Network Manager (JENM) for Soldier Radio Waveform (SRW) IOT&E Test Plan

Joint Tactical Radio System (JTRS) Handheld, Manpack, Small Form Fit (HMS) Manpack Radio MOT&E OTA Test Plan

Joint Tactical Radio System (JTRS) Handheld, Manpack, Small Form Fit (HMS) Rifleman Radio IOT&E OTA Test Plan

Joint Warning and Reporting Network (JWARN) Increment 1 FOT&E OTA Test Plan

Key Management Infrastructure (KMI) Increment 2, Spiral 1, IOT&E Plan

Littoral Combat Ship (LCS) Quick Reaction Assessment (QRA) Data Management and Analysis Plan (DMAP)

LPD-17 Data Management and Analysis Plan (DMAP) for Deficiency concerning reliability during the first five hours of Amphibious Assault (R5)

LPD-17 FOT&E Test Plan for Chemical, Biological, Radiological Defense (CBRD) and Magnetic Signature Check Range Run

Mark XIIA Identification Friend or Foe (IFF) Mode 5 Joint Operational Test Approach (JOTA) Test Plan

Mark XIIA Identification Friend or Foe (IFF) Mode 5 Joint Operational Test Approach (JOTA) Version 2.0

Miniature Air-Launched Decoy – Jammer (MALD-J) ADM-160C IOT&E Test Plan

Mk 48 Test Plan

Mk 48 Mod 6 Advanced Common Torpedo (ACOT) and Mk 48 Mod 7 Common Broadband Advanced Sonar System (CBASS) Torpedo FOT&E Test Plan

Mk 54 Test Plan Change 1

MQ-1C Gray Eagle Unmanned Aircraft System IOT&E OTA Test Plan

MQ-9 Operational Flight Program 904.2 FDE Plan

MV-22B Block C FOT&E Test Plan

Ohio Class Replacement Submarine EOA Test Plan (1771-OT-A1)

P-8A Poseidon Multi-mission Maritime Aircraft (MMA) IOT&E Test Plan

Patriot Limited User Test (LUT) OTA Test Plan

RC-135 Multi-functional Information Distribution System (MIDS) Joint Tactical Radio System (JTRS) Integration Test Plan

Small Diameter Bomb Increment II (SDB II) Multi-Service OA Plan

Space Fence EOA OTA Test Plan

Space-Based Infrared System Effectivity 5 OUE OTA Test Plan

Standard Missile-6 (SM-6) OT-IIB IOT&E Test Plan Annex A Model and Simulation Runs for the Record (RFR) (U)

Stryker Double-V Hull (DVH) Mortar Carrier Vehicle (MCVV) OTA Test Plan

Stryker Double-V Hull (DVH) Addendum to the LFT&E Phase 2/3 OTA Test Plan and the Detailed Test Plan (DTP)

Submarine Electronic Warfare Support (ES) System (AN/BLQ-10) Integrated Evaluation Framework (IEF)

Surveillance Towed Array Sensor System (SURTASS) Compact Low Frequency Active (CLFA) Test Plan for IOT&E (OT-IIG)

Teleport Generation 3, Phase 2 (G3P2) OA OTA Plan

U.S. Air Forces Central (AFCENT) Combined Air and Space Operations Center (CAOC) Information Assurance Assessment Plan

Vertical Take-off and Landing Tactical Unmanned Aerial Vehicle (VTUAV) System Quick Reaction Assessment (QRA) Data Management and Analysis Plan (DMAP)

Warfighter Exercise (WFX) 12-4 Information Assurance and Interoperability Assessment Plan

Warfighter Information Network – Tactical Increment 2 IOT&E OTA Test Plan

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LIVE FIRE TEST AND EVALUATION STRATEGIES, TEST PLANS, AND MANAGEMENT PLANS

57 mm Ammunition LFT&E Management Plan

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FY12 DOT&E REPORTS TO CONGRESS		
Program	**Report Type**	**Date**
BLRIP Reports		
Stryker Nuclear, Biological, and Chemical Reconnaissance Vehicle (NBCRV)	Combined OT/LFT	November 2011
Navy Multiband Terminal (NMT) with Classified Annex	OT Report	November 2011
Large Aircraft Infrared Countermeasure (LAIRCM) Phase II System	OT Report	January 2012
Global Positioning System Selective Availability/Anti-Spoof Module (GPS SAASM)	Multi-Service OT Report	February 2012
Terminal High-Altitude Area Defense (THAAD) and AN/TPY-12 Radar	Combined OT/LFT	February 2012
Spider XM7 Network Command Munition with Confidential Annex	Combined OT/LFT	February 2012
Mine Resistant Ambush Protected (MRAP) Family of Vehicles: Dash with Independent Suspension System (ISS), MRAP Recovery Vehicle (MRV), Marine Corps Cougar Ambulance	Combined OT/LFT	March 2012
Global Combat Support System – Army (GCSS-Army)	OT Report	June 2012
Direct Attack Moving Target Capability (DAMTC)	OT Report	June 2012
Mark XIIA Mode 5 Identification Friend or Foe (IFF) System	OT Report	July 2012
AH-64D Apache Block III (AB3) Attack Helicopter with Classified Annex	Combined OT/LFT	August 2012
AGM-88E Advanced Anti-Radiation Guided Missile (AARGM)	OT Report	August 2012
Warfighter Information Network – Tactical (WIN-T) Increment 2 with Classified Annex	OT Report	September 2012
Common Remotely Operated Weapon Station (CROWS)	OT Report	September 2012
Early Fielding Reports		
Mk 54 Lightweight Torpedo with Block Upgrade (BUG) Software	OT Report	January 2012
Massive Ordnance Penetrator (MOP)	OT Report	April 2012
FOT&E Reports		
Virginia Class Submarine Low Frequency Active (LFA) (ACCM)	OT Report	November 2011
Tomahawk Land Attack Missile	OT Report	February 2012
Verification of Correction of Deficiencies Report on the Multi-functional Information Distribution System (MIDS) Joint Tactical Radio System (JTRS)	OT Report	March 2012
EA-18G Airborne Electronic Attack (AEA) Aircraft	OT Report	March 2012
F/A-18E/F Super Hornet	OT Report	April 2012
Combined MH-60R Multi-Mission Helicopter and the MH-60S Multi-Mission Combat Support Helicopter Preplanned Product Improvement (P3I) Program	OT Report	April 2012
LFT&E Reports		
Family of Medium Tactical Vehicles (FMTV) A1P2	LFT Report	October 2011
Enhanced Combat Helmet (ECH)	LFT Report	May 2012
MAIS Reports		
EProcurement System	OT Report	June 2012
Special Reports		
Active Protection Systems (APS) Live Fire Test and Evaluation	LFT Report	February 2012
Assessment of Department of Defense (DoD) Information Assurance during Major Combatant Command (CCMD) Service Exercises	Information Assurance	April 2012
BMD Reports		
FY11 Assessment of the Ballistic Missile Defense System (BMDS) (includes classified appendices A, B, C)	Annual Report	February 2012

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OTHER FY12 DOT&E REPORTS		
Program	**Report Type**	**Date**
Operational Assessment Reports		
MQ-9 Unmanned Aerial System (UAS)	OT Report	October 2011
B-2 Extremely High Frequency (EHF) Satellite Communications (SATCOM) and Computer Upgrade Increment 1	OT Report	October 2011
AN/AAR-47 Missile Warning Set (MWS) Hostile Fire Indication (HFI) Software Upgrade, Operational Flight Program (OFP) 30.41	OT Report	October 2011
Key Management Infrastructure (KMI) Spiral 1	OT Report	October 2011
Surveillance Towed Array Sensor System (SURTASS) with Compact Low Frequency Active (CLFA)	OT Report	October 2011
Stryker Double-V Hull (DVH) Configuration of the Engineer Squad Vehicle (ESVV)	Combined OT/LFT	October 2011
Family of Medium Tactical Vehicles (FMTV) A1P2	Combined OT/LFT	October 2011
Stryker Double-V Hull (DVH) Configuration of the Infantry Carrier Vehicle (ICVV) Scout	Combined OT/LFT	January 2012
Network Integration Evaluation (NIE) 11.2 with Classified Annex	OT Report	January 2012
Distributed Common Ground System – Army (DCGS-A) Software Baseline (DSB) 1.0	OT Report	January 2012
Block Cycle Change 03 (BCC 03) for the C-5 Avionics Modernization Program (AMP)	OT Report	February 2012
C-17 Formation Flight System (FFS)	OT Report	February 2012
C-130J Station Keeping Equipment (SKE) Software Enhancement (SSE)	OT Report	February 2012
Integrated Strategic Planning and Analysis Network (ISPAN) Increment 2, Spiral 1	OT Report	March 2012
MQ-1C Gray Eagle Unmanned Aircraft System (UAS)	OT Report	April 2012
Department of Defense Teleport System, Generation Three Phase Two	OT Report	May 2012
Stryker Double-V Hull (DVH) Configuration of the Mortar Carrier Vehicle (MCVV)	Combined OT/LFT	May 2012
MH-60S Airborne Mine Countermeasures Helicopter and AN/AQS-20A Mine Detecting Sonar	Combined OT/LFT	June 2012
Visit, Board, Search, and Seizure (VBSS) Joint Chemical Agent Detector (JCAD)	OT Report	July 2012
Stryker Double-V Hull (DVH) Configuration of the Medical Evacuation Vehicle (MEVV)	Combined OT/LFT	July 2012
Joint Tactical Radio System (JTRS) Handheld, Manpack, Small Form Fit (HMS) Manpack Radio and Joint Enterprise Network Manager (JENM)	OT Report	July 2012
Joint Tactical Radio System (JTRS) AN/PRC-154 Rifleman Radio and Soldier Radio Waveform Network Manager (SRWNM)	OT Report	August 2012
Mine Resistant Ambush Protected (MRAP) Family of Vehicles: Navistar Dash Ambulance and MRAP All-Terrain Vehicle (M-ATV) Underbody Improvement Kit (UIK)	Combined OT/LFT	August 2012
MQ-9 Reaper Block 5 Remotely Piloted Aircraft	OT Report	September 2012
Defense Enterprise Accounting and Management System (DEAMS) Increment 1 Release 1	OT Report	September 2012
FOT&E Reports		
BAE-Tactical Vehicle System (TVS) Caiman Mine Resistant Ambush Protected (MRAP) Vehicle	LFT&E Report	June 2012
LFT&E Reports		
Stryker Double-V Hull (DVH) Configuration of the Commander's Vehicle (CVV)	LFT&E Report	January 2012
MAIS Reports		
Battle Control System – Fixed (BCS-F) Increment 3.1	OT Report Update 1	October 2011
Joint Mission Planning System – Expeditionary (JMPS-E)	IOT&E Report	October 2011
Public Key Infrastructure (PKI) Increment 2	IOT&E Report	January 2012
Global Command and Control System – Joint (GCCS-J) Version 4.2.0.9	OT Report	January 2012
Joint Mission Planning System (JMPS) E-8 Joint Surveillance Target Attack Radar System (JSTARS) Mission Planning Environment (MPE)	IOT&E Report	February 2012
Battle Control System – Fixed (BCS-F) Increment 3, Release 3.1 (R3.1)	OT Report Update 2	May 2012
Special Reports		
Hellfire Romeo Missile	LFT&E Report	November 2011
Stryker Mobile Gun System (MGS) Engineering Change Order (ECO) Block 3	Combined OT/LFT	January 2012
Surface-Launched Advanced Medium-Range Air-to-Air Missile (SLAMRAAM)	OT Report	May 2012

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Program Oversight

DOT&E is responsible for approving the adequacy of plans for operational test and evaluation and for reporting the operational test results for all major defense acquisition programs to the Secretary of Defense, Under Secretary of Defense (Acquisition, Technology and Logistics), Service Secretaries, and Congress. For DOT&E oversight purposes, major defense acquisition programs were defined in the law to mean those programs meeting the criteria for reporting under Section 2430, Title 10, United States Code (U.S.C.) (Selected Acquisition Reports (SARs)). The law (Section 139(a)(2)(B)) also stipulates that DOT&E may designate any other programs for the purpose of oversight, review, and reporting. With the addition of such "non-major" programs, DOT&E was responsible for oversight of a total of 327 acquisition programs during FY12.

Non-major programs are selected for DOT&E oversight after careful consideration of the relative importance of the individual program. In determining non-SAR systems for oversight, consideration is given to one or more of the following essential elements:

- Congress or OSD agencies have expressed a high level of interest in the program.
- Congress has directed that DOT&E assess or report on the program as a condition for progress or production.
- The program requires joint or multi-Service testing (the law (Section 139(b)(4)) requires DOT&E to coordinate "testing conducted jointly by more than one military department or defense agency").
- The program exceeds or has the potential to exceed the dollar threshold definition of a major program according to DoD 5000.1, but does not appear on the current SAR list (e.g., highly classified systems).
- The program has a close relationship to or is a key component of a major program.
- The program is an existing system undergoing major modification.
- The program was previously a SAR program and operational testing is not yet complete.

This office is also responsible for the oversight of LFT&E programs, in accordance with 10 U.S.C 139. DoD regulation uses the term "covered system" to include all categories of systems or programs identified in 10 U.S.C. 2366 as requiring LFT&E. In addition, systems or programs that do not have acquisition points referenced in 10 U.S.C. 2366, but otherwise meet the statutory criteria, are considered "covered systems" for the purpose of DOT&E oversight.

A covered system, for the purpose of oversight for LFT&E, has been determined by DOT&E to meet one or more of the following criteria:

- A major system, within the meaning of that term in 10 U.S.C. 2302(5), that is:
  - User-occupied and designed to provide some degree of protection to the system or its occupants in combat
  - A conventional munitions program or missile program
- A conventional munitions program for which more than 1,000,000 rounds are planned to be acquired.
- A modification to a covered system that is likely to affect significantly the survivability or lethality of such a system.

DOT&E was responsible for the oversight of 127 LFT&E acquisition programs during FY12.

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Programs Under DOT&E Oversight
Fiscal Year 2012
(As taken from the September 2012 DOT&E Oversight List)

DoD PROGRAMS

AC-130J

Ballistic Missile Defense System (BMDS) Program

Ballistic Missile Technical Collection (BMTC)

Chemical Demilitarization – Chemical Materials Agency (Army Executing Agent) (CHEM DEMIL-CMA)

Chemical Demilitarization Program – Assembled Chemical Weapons Alternatives (CHEM DEMIL-ACWA)

Conventional Prompt Global Strike

Defense Agency Initiative (DAI)

Defense Enterprise Accounting and Management System (DEAMS) Increment 1

Defense Readiness Reporting System – Strategic

Defense Security Assistance Management System (DSAMS) – Block 3

EProcurement

Global Combat Support System – Joint (GCSS-J)

Global Command and Control System – Joint (GCCS-J)

Integrated Electronic Health Record (iEHR)

Joint Aerial Layer Network

Joint Biological Standoff Detection System (JBSDS)

Joint Biological Tactical Detection System (JBTDS)

Joint Chemical Agent Detector (JCAD)

Joint Command and Control Capabilities (JC2C) [Encompasses GCCS-FoS (GCCS-J, GCCS-A, GCCS-M), TBMCS-FL, DCAPES, GCCS-AF, USMC JTCW, USMC TCO]

Joint Tactical Radio System (JTRS) Airborne and Maritime/Fixed Station (AMF)

Joint Tactical Radio System (JTRS) Enterprise Network Manager (JENM)

Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) Radios

Joint Tactical Radio System (JTRS) Network Enterprise Domain (NED)

Joint Warning and Reporting Network (JWARN)

Key Management Infrastructure (KMI) Increment 2

Mid-Tier Networking Vehicle Radio

Multi-Functional Information Distribution System (MIDS) (includes all current and planned integrations of MIDS JTRS into USAF and USN aircraft: F/A-18 E/F, E-2D, E-8, RC-135, EC-130 (all applicable series designations))

Next Generation Diagnostic System

Public Key Infrastructure (PKI) Increment 2

Soldier Radio Waveform (SRW) Network Manager

Special Operations Command Dry Combat Submersible Medium (DCSM)

Special Operations Command Next Generation Dry Deck Shelter

Teleport, Generation III

Theater Medical Information Program – Joint (TMIP-J) Block 2

Virtual Interactive Processing System (VIPS)

ARMY PROGRAMS

.300 Winchester Magnum Mk248 Mod 1 ammunition

25 mm Individual Semi-Automatic Airburst System (ISAAS)

Abrams Tank Modernization (M1E3)

Abrams Tank Upgrade (M1A1 SA / M1A2 SEP)

Apache Block III (AB3)

Armed Aerial Scout (previously named ARH Armed Recon Helicopter)

Armored Multi-Purpose Vehicle (AMPV)

Armored Truck – Heavy Dump Truck (HDT)

Armored Truck – Heavy Equipment Transporter (HET)

Armored Truck – Heavy Expanded Mobility Tactical Truck (HEMTT)

Armored Truck – M915A5 Line Hauler

Armored Truck – M939 General Purpose Truck

Armored Truck – Palletized Loading System (PLS)

Army Integrated Air and Missile Defense (AIAMD)

Army Vertical Unmanned Aircraft System

Biometrics Enabling Capability (BEC) Increment 1

Black Hawk Utility Helicopter (UH-60M) Upgrade Program

Bradley Fighting Vehicle System Upgrade

Bradley Modernization (M2A3 V2)

Cartridge, 7.62 mm, M80A1

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ARMY PROGRAMS (continued)

CH-47F – Cargo Helicopter

Common Infrared Countermeasures (CIRCM)

Common Remotely Operated Weapon Station (CROWS) III

Distributed Common Ground System – Army (DCGS-A)

Enhanced AN/TPQ-36 Radar System (EQ-36)

Excalibur – Family of Precision, 155 mm Projectiles

FMTV – Family of Medium Tactical Vehicles

Force XXI Battle Command Brigade and Below – Joint Capability Release (FBCB2 – JCR)

Force XXI Battle Command Brigade and Below (FBCB2) Program

General Fund Enterprise Business System (GFEBS)

Global Combat Support System – Army (GCSS-Army)

Ground Combat Vehicle (GCV)

Guided Multiple Launch Rocket System (GMLRS) – Alternate Warhead (AW)

Guided Multiple Launch Rocket System (GMLRS) – Dual Purpose Improved Conventional Munitions (DPICM)

Guided Multiple Launch Rocket System (GMLRS) – Unitary

Hellfire Romeo

High Mobility Artillery Rocket System (HIMARS)

High Mobility Multi-purpose Wheeled Vehicle (HMMWV)

Hostile Fire Detection System

Individual Carbine

Integrated Personnel and Pay System – Army (Army IPPS)

Interceptor Body Armor

Javelin Anti-Tank Missile System – Medium

Joint Air-to-Ground Missile (JAGM)

Joint Assault Bridge

Joint Battle Command Platform (JBC-P)

Joint Cooperative Target Identification – Ground (JCTI-G)

Joint Future Theater Lift Concept (JFTLC)

Joint Land Attack Cruise Missile Defense Elevated Netted Sensor (JLENS) System

Joint Lightweight Tactical Vehicle (JLTV)

Joint Personnel Identification (JPIv2)

Kiowa Warrior Upgrade

Land Warrior – Integrated Soldier Fighting System for Infantrymen

Light Utility Helicopter (LUH)

Logistics Modernization Program (LMP)

Long Endurance Multi-Intelligence Vehicle (LEMV)

M1200 Knight Targeting Under Armor (TUA)

M270A1 Multiple Launch Rocket System (MLRS)

M829E4

Mark XIIA Identification Friend or Foe (IFF) Mode 5 (all development and integration programs)

Modernized Expanded Capacity Vehicle (MECV) – Survivability Demonstration

MQ-1C Unmanned Aircraft System Gray Eagle

Nett Warrior

One System Remote Video Terminal (OSRVT)

Paladin/Field Artillery Ammunition Supply Vehicle (FAASV) Integrated Management (PIM)

Patriot Advanced Capability 3 (PAC-3) (Missile only)

Patriot/Medium Extended Air Defense System (MEADS)

RQ-11B Raven – Small Unmanned Aircraft System

RQ-7B SHADOW – Tactical Unmanned Aircraft System

Spider XM7 Network Command Munition

Stryker M1126 Infantry Carrier Vehicle including Double-V Hull Variant

Stryker M1127 Reconnaissance Vehicle

Stryker M1128 Mobile Gun System

Stryker M1129 Mortar Carrier including the Double-V Hull Variant

Stryker M1130 Commander's Vehicle including the Double-V Hull Variant

Stryker M1131 Fire Support Vehicle Including the Double-V Hull Variant

Stryker M1132 Engineer Squad Vehicle Including the Double-V Hull Variant

Stryker M1133 Medical Evacuation Vehicle Including the Double-V Hull Variant

Stryker M1134 Anti-Tank Guided Missile (ATGM) Vehicle Including the Double-V Hull Variant

Stryker M1135 Nuclear, Biological, and Chemical Reconnaissance Vehicle (NBCRV) Including the Double-V Hull Variant

Stryker Modernization Program

Surface-Launched Advanced Medium-Range Air-to-Air Missile (SLAMRAAM)

Tactical Edge Network – Extension

Warfighter Information Network – Tactical (WIN-T) Increment 1

Warfighter Information Network – Tactical (WIN-T) Increment 2

Warfighter Information Network – Tactical (WIN-T) Increment 3

Warfighter Information Network – Tactical (WIN-T) Increment 4

XM1156 Precision Guidance Kit (PGK)

XM395 Accelerated Precision Mortar Initiative (APMI)

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NAVY PROGRAMS

Acoustic Rapid Commercial Off-the-Shelf (COTS) Insertion (A-RCI) for SONAR

Advanced Airborne Sensor

Advanced Extremely High Frequency (AEHF) Navy Multiband Terminal (NMT) Satellite Program

Aegis Modernization

AGM-88E Advanced Anti-Radiation Guided Missile (AARGM)

AH-1Z

AIM-9X Air-to-Air Missile Upgrade Block II

Air and Missile Defense Radar (AMDR)

Air Warfare Ship Self-Defense Enterprise

Airborne Laser Mine Detection System (AN/AES-1) (ALMDS)

Airborne Mine Neutralization System (AN/ASW-235) (AMNS)

Amphibious Assault Vehicle Upgrade

Amphibious Combat Vehicle (ACV)

AN/APR-39 Radar Warning Receiver

AN/AQS-20A Minehunting Sonar

AN/BLQ-10 Submarine Electronics Support Measures

AN/BVY-1 Integrated Submarine Imaging System

AN/SQQ-89A(V) Integrated USW Combat Systems Suite

Anti-Torpedo Torpedo Defense System including all associated programs (Countermeasure Anti-Torpedo (CAT), Torpedo Warning System (TWS), and SLQ-25X (NIXIE))

AR/LSB – Airborne Resupply/Logistics for Seabasing

Assault Breaching System Coastal Battlefield Reconnaissance and Analysis System Block II

Broad Area Maritime Surveillance (BAMS) Unmanned Aircraft System

BYG-1 Fire Control (Weapon Control and TMA)

CH-53K – Heavy Lift Replacement Program

Close-In Weapon System (CIWS) including SEARAM

Cobra Judy Replacement – Ship-based Radar System

Common Aviation Command and Control System (CAC2S)

Consolidated Afloat Networks and Enterprise Services (CANES)

Cooperative Engagement Capability (CEC)

Countermeasure Anti-Torpedo

CVN-78 – *Gerald R. Ford* Class Nuclear Aircraft Carrier

CVN-78 – Electro-Magnetic Aircraft Launching System

DDG-1000 – *Zumwalt* Class Destroyer – includes all supporting PARMs and the lethality of the LRLAP, 57 mm and 30 mm ammunition

DDG-51 – *Arleigh Burke* Class Guided Missile Destroyer – includes all supporting PARMs

DDG-51 Flight III – *Arleigh Burke* Class Guided Missile Destroyer – includes all supporting PARMs

Department of Navy Large Aircraft Infrared Countermeasures (DoN LAIRCM) Program

Distributed Common Ground System – Marine Corps (DCGS-MC)

Distributed Common Ground System – Navy (DCGS-N)

E-2D Advanced Hawkeye

EA-18G – Airborne Electronic Attack Variant of the F/A-18 Aircraft

Enhanced Combat Helmet (ECH)

Evolved SeaSparrow Missile (ESSM)

Evolved SeaSparrow Missile Block 2

F/A-18E/F – Super Hornet Naval Strike Fighter

Future Pay and Personnel Management Solution (FPPS)

Global Combat Support System – Marine Corps (GCSS-MC)

Global Command and Control System – Maritime (GCCS-M)

Ground/Air Task Oriented Radar (G/ATOR)

Infrared Search and Track System

Integrated Defensive Electronic Countermeasures (IDECM) (All Blocks)

Joint and Allied Threat Awareness System (JATAS)

Joint Expeditionary Fires

Joint High Speed Vessel (JHSV)

Joint Precision Approach and Landing System (JPALS) Increment 1 (Ship system)

Joint Precision Approach and Landing System (JPALS) Increment 2 (Land system)

Joint Standoff Weapon C-1 Variant (JSOW C-1)

KC-130J with Harvest Hawk

Landing Ship Dock Replacement (LSD(X))

LHA 6 – *America* Class Amphibious Assault Ship – includes all supporting PARMs

LHD 8 Amphibious Assault Ship

Light Armored Vehicle (LAV)

Light Weight Tow Torpedo Countermeasure (part of LCS ASW Mission Module)

Littoral Combat Ship (LCS) – includes all supporting PARMs, and 57 mm lethality

Littoral Combat Ship (LCS) Mission Modules including 30 mm and missile lethality

Littoral Combat Ship (LCS) Surface-to-Surface Missile Module (follow-on to the interim Griffin Missile)

Littoral Combat Ship (LCS) Variable Depth Sonar (VDS)

Logistics Vehicle System Replacement

LPD-17 – *San Antonio* Class Amphibious Transport Dock Ship – includes all supporting PARMs and 30 mm lethality

Marine Personnel Carrier

Maritime Prepositioning Force (Future) Mobile Landing Platform

Mark XIIA Identification Friend or Foe (IFF) Mode 5 (all development and integration programs)

Medium Tactical Vehicle Replacement (MTV) Program (USMC)

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NAVY PROGRAMS (continued)

Medium-Range Maritime Unmanned Aircraft System

MH-60R Multi-Mission Helicopter Upgrade

MH-60S Multi-Mission Combat Support Helicopter

Mine Resistant Ambush Protected (MRAP) Family of Vehicles (FoV) – including Special Operations Command vehicles

Mk 54 Torpedo/Mk 54 Vertical-Launch Anti-Submarine (VLA)/MK 54 Upgrades Including High-Altitude Anti-Submarine Warfare (ASW) Weapon Capability (HAAWC)

Mk 48 CBASS Torpedo

Mk 48 Torpedo Mods

Mobile User Objective System (MUOS)

Multi-static Active Coherent (MAC) System CNO project 1758

MV-22 Osprey – Joint Advanced Vertical Lift Aircraft

Naval Integrated Fire Control – Counter Air (NIFC-CA)

Navy Enterprise Resource Planning (ERP)

Navy Unmanned Carrier Launched Airborne Surveillance and Strike (UCLASS) System

Next Generation Enterprise Network (NGEN)

Next Generation Jammer (NGJ)

Offensive Anti-Surface Warfare

Offensive Anti-Surface Warfare Interim Capability (also called Tomahawk Offensive Anti-Surface Warfare Interim Capability)

Ohio Replacement Program (Sea-based Strategic Deterrence) – including all supporting PARMs

Organic Airborne and Surface Influence Sweep (OASIS)

P-8A Poseidon Program

Rapid Airborne Mine Clearance System (RAMICS)

Remote Minehunting System (RMS)

Replacement Oiler

Rolling Airframe Missile (RAM) including RAM Block 1A Helicopter Aircraft Surface (HAS) and RAM Block 2 Programs

Sea-Based Support to Special Forces

Ship Self-Defense System (SSDS)

Ship-to-Shore Connector (SSC)

Small Tactical Unmanned Aerial System (STUAS) – UAS Tier II

SSN 774 *Virginia* Class Submarine

SSN 784 *Virginia* Class Block III Submarine

Standard Missile-2 (SM-2) including all mods

Standard Missile-6 (SM-6)

Submarine Torpedo Defense System (Sub TDS) including countermeasures and Next Generation Countermeasure (NGCM) System

Surface Electronic Warfare Improvement Program (SEWIP) Block 2

Surface Electronic Warfare Improvement Program (SEWIP) Block 3

Surface Electronic Warfare Improvement Program (SEWIP) Block 4

Surface Mine Countermeasures Unmanned Undersea Vehicle (also called Knifefish UUV) (SMCM UUV)

Surveillance Towed Array Sonar System/Low Frequency Active (SURTASS/LFA) including Compact LFA (CLFA)

Tactical Tomahawk – Follow-on to Tomahawk Baseline Missile

T-AKE – *Lewis & Clark* Class of Auxiliary Dry Cargo Ships (T-AKE) – includes all supporting PARMs

Torpedo Warning System (Previously included with Surface Ship Torpedo Defense System) including all sensors and decision tools

Trident II Missile – Sea Launched Ballistic Missile

UH-1Y

Unmanned Influence Sweep System (UISS) include Unmanned Surface Vessel (USV) and Unmanned Surface Sweep System (US3)

Unmanned Undersea Vehicle Program

Vertical Take-off and Landing Tactical Unmanned Air Vehicle (VTUAV) (Fire Scout)

VXX – Presidential Helicopter Fleet Replacement Program

AIR FORCE PROGRAMS

20 mm PGU-28/B Replacement Combat Round

Advanced Extremely High Frequency (AEHF) Satellite Program

Advanced Medium Range Air-to-Air Missile (AMRAAM)

Advanced Pilot Trainer

Air Force Distributed Common Ground System (AF-DCGS)

Air Force Integrated Personnel and Pay System (AF-IPPS)

Air Force Intranet (AFNet) Combat Information Transport System (CITS) Migration Urgent Operational Need

Air Force Intranet (AFNet) Increment 1

Air Force Intranet (AFNet) Increment 2

Air Force Intranet (AFNet) Modernization capabilities (Bitlocker, Data at Rest , Situational Awareness Modernization)

Air Operations Center – Weapon System (AOC-WS) Initiatives 10.0 and 10.1

Air Operations Center – Weapon System (AOC-WS) Initiative 10.2

Airborne Signals Intelligence Payload (ASIP) Family of Sensors

Airborne Warning and Control System (AWACS) Block 40/45 Upgrade

ALR-69A Radar Warning Receiver

B-2 Advanced Extremely High Frequency (EHF) Satellite Communications (SATCOM) and Computer Capability Increment I

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AIR FORCE PROGRAMS (continued)

B-2 Advanced Extremely High Frequency (EHF) Satellite Communications (SATCOM) and Computer Capability Increment II

B-2 Defensive Management System Modernization (DMS)

B-61 Mod 12 Life Extension Program

Battle Control System – Fixed (BCS-F) 3.1

Battle Control System – Fixed (BCS-F) 3.2

C-130 Aircraft Avionics Modernization Program (AMP)

C-130J – Hercules Cargo Aircraft Program

C-17A – Globemaster III Advanced Cargo Aircraft Program

C-27J Joint Cargo Aircraft (JCA)

C-5 Aircraft Avionics Modernization Program (AMP)

C-5 Aircraft Reliability Enhancement and Re-Engining Program (RERP)

C-5 Core Mission Computer and Weather Radar Replacement

Cobra Judy Replacement Mission Planning Tool

Command and Control Air Operations Suite (C2AOS)/Command and Control Information Services (C2IS) (Follow-on to Theater Battle Management Core Systems)

CV-22 Osprey – Joint Advanced Vertical Lift Aircraft

Defense Enterprise Accounting and Management System – Air Force (DEAMS – AF)

Enhanced Polar System (EPS)

Evolved Expendable Launch Vehicle

Expeditionary Combat Support System (ECSS)

F-15E Radar Modernization Program

F-22 – Raptor Advanced Tactical Fighter

F-35 – Lightning II Joint Strike Fighter (JSF) Program

Family of Beyond Line-of-Sight Terminals (FAB-T)

Family of Beyond Line-of-Sight Terminals (FAB-T), Increment 2 (High Data Rate Airborne Terminal)

Full Scale Aerial Target

Global Broadcast Service (GBS)

Global Broadcast Service (GBS) Defense Enterprise Computing Center (DECC)

Global Hawk (RQ-4B) Block 30 – High Altitude Endurance Unmanned Aircraft System

Global Hawk (RQ-4B) Block 40 – High Altitude Endurance Unmanned Aircraft System

Global Positioning Satellite (GPS) Next Generation Control Segment (OCX)

Global Positioning Satellite III (GPS-IIIA)

HC/MC-130 Recapitalization

HH-60G/CRH (Combat Rescue Helicopter)

Information Transport System (ITS) Increment 2

Integrated Strategic Planning and Analysis Network (ISPAN) Increment 2

Integrated Strategic Planning and Analysis Network (ISPAN) Increment 4

Joint Air-to-Surface Standoff Missile (JASSM) and JASSM – Extended Range (JASSM-ER))

Joint Direct Attack Munition (JDAM)

Joint Mission Planning Systems (JMPS) – Air Force (including RC-135, E-8/E-3, F-22, A-10)

Joint Space Communication Layer

Joint Space Operations Center (JSpOC) Mission System (JMS)

KC-46 – Tanker Replacement Program

Large Aircraft Infrared Countermeasures (LAIRCM) Program

Long Range Stand Off (LRSO) Weapon

Long Range Strike Bomber

Mark XIIA Identification Friend or Foe (IFF) Mode 5 (all development and integration programs)

Massive Ordnance Penetrator (MOP)

Military GPS User Equipment (MGUE)

Miniature Air-Launched Decoy (MALD)

Miniature Air-Launched Decoy – Jammer (MALD-J)

MQ-9 Reaper – Unmanned Aircraft System

MQ-X

Multi-Platform Radar Technology Insertion Program (MP RTIP)

Navstar Global Positioning System (GPS) (includes Satellites, Control, and User Equipment)

Nuclear Detection (NUDET) System (NDS)

Presidential Aircraft Recapitalization (PAR) Program – Air Force One Recapitalization Program

Small Diameter Bomb, Increment I

Small Diameter Bomb, Increment II

Space Fence (SF)

Space-Based Infrared System (SBIRS) Program, High Component

Space-Based Space Surveillance (SBSS) Block 10 Follow-on

Three-dimensional Expeditionary Long-Range Radar (3DELRR)

Vulnerability Lifecycle Management System (VLMS) 1.5

Weather Satellite Follow-on (WSF)

Wideband Global Satellite Communications (SATCOM) (WGS) Program

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Problem Discovery Affecting Operational Test and Evaluation

One purpose of test and evaluation is to determine if thresholds in the approved Capability Production Document (CPD) have been satisfied. The Acquisition Executive needs this information in making production decisions, but satisfying these measures is often not equivalent to achieving the required combat capability needed for mission accomplishment. A comprehensive evaluation of operational effectiveness, operational suitability, and survivability provides the Acquisition Executive and operational users with information regarding a system's combat capability. This evaluation can only be done after operational testing (OT) under realistic combat conditions, which includes end-to-end testing with operational users across the intended operational envelope and within the context of the system-of-systems in which it will operate.

The Deputy Assistant Secretary of Defense (DASD) Developmental Test and Evaluation (DT&E) conducts an assessment of all Major Defense Acquisition Programs and special interest programs prior to their OT; this DT&E assessment reports on a system's demonstrated ability to meet its Key Performance Parameters and assesses the risk of the system's ability to successfully complete OT. The DT&E assessment is based on capabilities demonstrated during developmental testing (DT), early OT, and criteria from the Test and Evaluation Master Plan and requirements documents. The DT&E community engages with program offices early and often throughout a program's acquisition cycle, observing both contractor and government DT. The DT and early OT events provide the program manager opportunities to discover and correct problems that could prevent a system from delivering its required combat capability. As such, the test events should include as much operational realism as possible, and also include military operators and maintainers whenever possible. The early test events should also provide information to the requirements and resource sponsors for the system to ensure that the documented requirements are still relevant and feasible. By the time of the Initial Operational Test and Evaluation (IOT&E), discovery of significant issues affecting combat capability should be rare, and lingering problems from DT should have been resolved.

Last year, I added a new section to my Annual Report assessing systems under my oversight in 2010-2011 with regard to problem discovery during testing. My assessment fell into two categories: systems with significant issues observed in OT that should, in my view, have been discovered and resolved prior to the commencement of OT, and systems with significant issues observed during early testing that, if not corrected, could adversely affect my evaluation of those systems' effectiveness, suitability, and survivability during IOT&E. This year, I am providing an update to the status of those systems identified last year, as well as my assessment of systems under my oversight in 2012 within those two categories.

Last year, I reported that four of the seven Assessments of Operational Test Readiness (AOTRs) that I received from the DASD(DT&E) recommended that the programs not proceed to IOT&E, but that the program proceeded anyway. Regardless of the AOTR recommendation, six of those seven programs experienced significant issues in their IOT&Es: the C-5 Reliability Enhancement and Re-Engining Program (RERP); RQ-4B Global Hawk Blocks 20 and 30; Standard Missile-6 (SM-6); Multi-functional Information Distribution System (MIDS) Joint Tactical Radio System (JTRS); Stryker Nuclear, Biological, and Chemical Reconnaissance Vehicle (NBCRV); and Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) Rifleman Radio.

I have received 12 additional assessments from DASD(DT&E) since my report last year; these are listed in the table below. Of the 12 reports, 2 recommended not proceeding to IOT&E: MQ-1C Gray Eagle and JTRS HMS Manpack Radio. Despite the recommendation, both of these systems proceeded to IOT&E. The JTRS HMS Manpack Radio performed poorly in the IOT&E, as predicted by the AOTR; however, the MQ-1C Gray Eagle performed well in IOT&E despite DT results suggesting poor reliability that would affect the test outcome. In fact, the Gray Eagle IOT&E demonstrated that the modeling assumptions that established the reliability requirements thresholds were not valid. As a result, the Army is reassessing whether those reliability thresholds should be changed. Additionally, as discussed in this section last year, the Warfighter Information Network – Tactical (WIN-T) Increment 2 had both performance and reliability issues during early testing, but these issues were not assessed by the DT&E AOTR. Two of the systems listed below are still in-test: P-8 and Joint Space Operations Center (JSpOC) Mission System (JMS) Increment 1.

DASD(DT&E) Assessments of Operational Test Readiness (AOTRs)	
AIM-9X Air-to-Air Missile Upgrade	Joint Space Operations Center (JSpOC) Mission Systems (JMS) Increment 1
Apache Block III	Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) Manpack Radio
B-2 Extremely High Frequency (EHF)	MQ-1C Gray Eagle Unmanned Aircraft System (UAS)
C-130 Avionics Modernization Program (AMP)	P-8
E-2D Advanced Hawkeye	Space-Based Infrared System (SBIRS)
HC/MC-130J	Warfighter Information Network – Tactical (WIN-T) Increment 2

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PROGRESS UPDATES ON DISCOVERIES REPORTED LAST YEAR

Last year, I identified 23 systems that had significant issues in early testing that should be corrected prior to IOT&E. The following table provides an update on the progress those systems made in implementing fixes to those problems.

FY11 DISCOVERIES IN EARLY TESTING THAT SHOULD BE CORRECTED PRIOR TO IOT&E			
Fixes Implemented and Demonstrated in OT	**Fixes Implemented; Currently in OT or Planning OT**	**Some Fixes Implemented; Testing Constrained Pending Future Acquisition Decisions**	**No Fixes Planned**
Apache Block III	Aegis Modernization	Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) Manpack Radio	Defense Enterprise Accounting and Management System (DEAMS)
EProcurement	AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM)	RQ-4B Global Hawk Block 30 High-Altitude, Long-Endurance Unmanned Aerial System (UAS)	LHA-6
Joint Tactical Radio System (JTRS) Network Enterprise Domain (NED)	AN/TPQ-53 Radar (formerly the Enhanced AN/TPQ-36 Radar System (EQ-36))	Vertical Take-Off and Landing Unmanned Aerial Vehicle (VTUAV)	Littoral Combat Ship (LCS) Mission Modules
MQ-1C Gray Eagle Unmanned Aircraft System (UAS)	E-2D Advance Hawkeye		MQ-9 Reaper Armed Unmanned Aircraft System (UAS)
Spider XM7 Network Command Munition	Joint High Speed Vessel (JHSV)		
	Miniature Air-Launched Decoy – Jammer (MALD-J)		
	Mk 48 Advanced Capability (ADCAP) Mod 7 Common Broadband Advanced Sonar System (CBASS)		
	Mk 54 Lightweight Torpedo		
	P-8A Poseidon		
	Surveillance Towed Array Sensor System (SURTASS) with Compact Low Frequency Active (CLFA)		
	Warfighter Information Network – Tactical (WIN-T)		

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Last year, I identified 17 systems that had significant issues in IOT&E that should have been discovered and resolved prior to commencement of operational testing. The following table provides an update on the status of those systems, as well as the progress those systems have made in implementing fixes to the problems.

FY11 DISCOVERIES IN IOT&E THAT SHOULD HAVE BEEN RESOLVED PRIOR TO OPERATIONAL TEST			
Fixes Implemented and Demonstrated in FOT&E	**Fixes Implemented; But New Issues Discovered**	**Fixes Implemented; Currently in OT**	**No Fixes Planned**
C-130J	AGM-88E Advanced Anti-Radiation Guided Missile (AARGM)	LPD-17	Force XXI Battle Command Brigade and Below (FBCB2) Joint Capabilities Release (JCR)
Common Aviation Command and Control System (CAC2S)	Standard Missile-6 (SM-6)	Nett Warrior	Stryker Nuclear, Biological, and Chemical Reconnaissance Vehicle (NBCRV)
CV-22 Osprey			Vertical Launch Anti-Submarine Rocket (VLA) with Mk 54 Mod 0 Lightweight Hybrid Torpedo
Department of the Navy (DoN) Large Aircraft Infrared Countermeasures (LAIRCM)			
Financial Information Resource System (FIRST)			
Multi-functional Information Distribution System (MIDS) Joint Tactical Radio System (JTRS)			
Navy Multiband Terminal (NMT)			
Space-Based Space Surveillance (SBSS)			
Additionally, 2 of 17 programs were cancelled: Early Infantry Brigade Combat Team (E-IBCT) and Joint Tactical Radio System (JTRS) Ground Mobile Radio (GMR).			

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PROBLEMS DISCOVERED DURING OPERATIONAL TEST AND EVALUATION THAT SHOULD HAVE BEEN DISCOVERED DURING DEVELOPMENTAL TEST AND EVALUATION

SIGNIFICANT DISCOVERIES IN FY12 IOT&E	
AGM-88E Advanced Anti-Radiation Guided Missile (AARGM)	Key Management Infrastructure (KMI) Increment 2
ALR-69 Radar Warning Receiver (RWR)	Mine Resistant Ambush Protected (MRAP) Caiman Multi-Terrain Vehicle (CMTV)
Battle Control System – Fixed (BCS-F) Release 3.2	Mine Resistant Ambush Protected (MRAP) Dash Ambulance
Distributed Common Ground System – Army (DCGS-A)	Miniature Air-Launched Decoy – Jammer (MALD-J)
E-2D Advanced Hawkeye	MV-22 Osprey
E-3 Airborne Warning and Control System (AWACS) Block 40/45 Upgrade	Standard Missile-6 (SM-6)
Joint Mission Planning System – Air Force (JMPS-AF) Mission Planning Environment (MPE) E-8	*Virginia* Class Submarine Modernized with the APB-09 Acoustic Rapid Commercial Off-the-Shelf (COTS) Insertion (A-RCI) Sonar System and AN/BYG-1 Combat Control System
Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) Manpack Radio	Warfighter Information Network – Tactical (WIN-T) Increment 2
Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) Rifleman Radio	

AGM-88E Advanced Anti-Radiation Guided Missile (AARGM)

The AARGM program spent most of FY11 correcting hardware and software deficiencies discovered in DT and during its first IOT&E attempt. Once IOT&E began the second time, the Navy provided requirements changes in response to deficiencies identified since the first IOT&E attempt was terminated, and hence, the test scenarios were less stressing than originally planned. Additionally, new anomalies were discovered:

- AARGM Guidance Section/Control Section communication failures caused a significant number of operational mission failures. The problem occurred during specific IOT&E threat scenarios, but the system deficiency identified is one that should have been identified with adequate DT&E.
- A classified deficiency in performance required an adjusted threat representation.

ALR-69 Radar Warning Receiver (RWR)

The Air Force began operational flight testing in May 2012, knowing that the system would likely not meet several thresholds based on DT that occurred between February and May 2011. Additional deficiencies were observed in OT:

- Threat symbol splitting (when one threat signal received by the system produces multiple threat symbols at different azimuths on the cockpit display) degraded the aircrew's situational awareness as to which displayed threats are "real," where those real threats are located, and inhibited the aircrew's ability to appropriately react to the threat(s) in a timely manner. The threat symbol splitting deficiency did not occur during DT. The program believes it was strictly a software timing problem, and they modified the software and demonstrated the fix in the laboratory after the IOT&E. No flight testing has been accomplished to verify the fix.

Battle Control System – Fixed (BCS-F) Release 3.2

The Air Force conducted OT of BCS-F from April through August 2012, at the System Support Facility (SSF) and all four U.S. operational air defense sectors.

- A critical deficiency was discovered during OT at the Eastern Air Defense Sector. Random tracks were not being passed from the BCS-F system to the Joint Air Defense Operations Center at Bolling Air Force Base, Washington, D.C. This deficiency causes a loss of situational awareness for the operators conducting surveillance of the National Capital Region and results in an inaccurate air picture. The problem with the forwarding of tracks could not be identified at the

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SSF during DT&E since the SSF cannot replicate sector link architecture.

Distributed Common Ground Station – Army (DCGS-A)

The Army conducted the DCGS-A Software Baseline 1.0 IOT&E from May through June 2012 at Fort Stewart, Georgia. DOT&E found the system not operationally effective, not operationally suitable, and not survivable because of deficiencies identified in the OT:

- Effective workflow is inhibited for the development of intelligence products to support operations because the system configuration as tested placed the fusion capability in the Secret Compartmented Information (SCI) (high) side even though most of the data necessary for fusion are in the Secret (low) side. Additionally, collection management tools are on the high side, but collection managers need to work closely with the brigade operations staff on the low side. Human intelligence tools are split between the high side and low side, but human intelligence analysts manage and interview their sources on the low side. Developmental testing and Early User Testing were conducted in a laboratory environment that did not replicate the physical separation and security barriers of the deployed configuration.
- The targeting software in the SCI enclave used first known location rather than the last known location. The DT showed the target algorithm to be correct, but was not robust enough to discover this deficiency.
- DCGS-A was not reliable because of a large number of software problems. The program has not rigorously tracked metrics identifying trends in software maturity, such as the number of new software problems opened and the number of software problems closed.

E-2D Advanced Hawkeye

The Navy conducted the E-2D IOT&E from February to September 2012. The evaluation is currently ongoing, but the following deficiencies were revealed:

- Cooperative Engagement Capability (CEC) software deficiencies associated with the CEC system generating multiple tracks for the same contact were outstanding upon entering IOT&E; thus, CEC was decoupled from the E-2D IOT&E. Corrections to the CEC system have continued throughout 2012. The system is now in test. It is likely that current E-2D fixes will not address all shortfalls in the current CEC system. Ongoing work is required, some of which is required for other systems separate from E-2D and CEC.
- Radar track re-labeling was observed in DT, but the full magnitude of the problem only manifested itself under the conditions of IOT&E.

E-3 Airborne Warning and Control System (AWACS) Block 40/45 Upgrade

The Air Force conducted a 24-flight IOT&E operating from the E-3 main operating base, Tinker Air Force Base, Oklahoma City, Oklahoma, between March and June 2012. The two operational Block 40/45 E-3 aircraft participated in several large force exercises. The test included flights working with assets from all four Services in training areas on both coasts as well as over land. The Block 40/45 AWACS was not ready to enter IOT&E, in addition to aircrews and maintainers not having representative training.

- The mission planning system and mission computing start-up checklist were never tested in DT&E and were used for the first time in IOT&E.
- The system was designed to the interoperability standards in place when the development contract was written. The aircraft does not provide Link 16 capabilities that are equivalent to the legacy Block 30/35 it replaces. Many of the tactical datalink deficiencies were caused by the Air Force not modifying the system design to reflect changes in interoperability standards during Block 40/45 development. The satellite communications terminal did not provide an operationally useful capability to receive digital information.

Joint Mission Planning System – Air Force (JMPS-AF) Mission Planning Environment (MPE) E-8

The Air Force paused the IOT&E of the E-8 MPE, the representative test platform for JMPS-AF Increment IV, in September 2011 to allow the Program Office to develop and integrate corrective actions to deficiencies identified during OT. Following additional development and regression testing, the Air Force certified E-8 MPE version 1.3 ready for resumed OT. The Air Force intends to re-execute the entire IOT&E in early FY13. DOT&E's assessment of the paused IOT&E noted significant deficiencies that were not identified during DT&E:

- The time needed for E-8 MPE software installation was lengthy, due in large part to anomalies in the software functionality and installation process
- Threat database information was not easily accessible or usable; training for intelligence specialists was inadequate
- Inability to transfer mission plans to the aircraft
- Critical calculation errors of the magnetic variation for user-specified waypoints
- Could not plan missions with in-flight delays

Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) Manpack Radio

Although the DASD(DT&E) AOTR stated the Manpack radio was not sufficiently mature to enter the planned Multi-Service Operational Test and Evaluation (MOT&E), the Army proceeded to conduct the test as a part of the Network Integration Evaluation (NIE) 12.2. DOT&E assessed the Manpack as not operationally effective due to the poor performance of the Single Channel Ground and Airborne Radio System (SINCGARS) waveform and not operationally suitable due to a failure to meet reliability or availability requirements. The Manpack radio AOTR had outlined these major MOT&E deficiencies prior to OT. In September 2012, the Army conducted a Government Development Test (GDT) 3 to demonstrate improvements in

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MOT&E deficiencies. During GDT 3, the Manpack radio demonstrated:

- Improved performance of the SINCGARS waveform that met requirements of mounted and dismounted transmission range, voice quality, and call completion rates under benign conditions of developmental test.
- Poor reliability with the Solider Radio Waveform (SRW) waveform demonstrating 177 hours Mean Time Between Essential Function Failure compared to the Manpack radio requirement of 477 hours. This translates to a 66 percent chance of completing a 72-hour mission compared to a requirement of 86 percent.

Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) Rifleman Radio

From October to November 2011, the Army Test and Evaluation Command conducted the Rifleman Radio IOT&E at White Sands Missile Range, New Mexico, as part of the Army's NIE 12.1. Operational units tested the Rifleman Radio using the Soldier Radio Waveform Network Manager (SRWNM) to plan and load SRW network configurations into the radios. From February through March 2012, the Army conducted the Rifleman Radio GDT 2.3 at the Electronic Proving Ground at Fort Huachuca, Arizona. The Army conducted this GDT to complete DT that the Army should have completed prior to IOT&E. In April 2012, the Army conducted a follow-on developmental test, GDT 2.3a. The Army used this follow-on event to confirm fixes to deficiencies observed during GDT 2.3.

- The SRWNM was not employed with the Rifleman Radio prior to IOT&E. The poor performance of the SRWNM adversely affected the performance of the Rifleman Radio.
- The software version used in the Rifleman Radio for IOT&E was not the final version to include all the security features required by the National Security Agency (NSA) certification. The NSA requirements updated software caused numerous essential function failures during GDT 2.3, which followed IOT&E. GDT 2.3 reliability was so poor that the Army executed a GDT 2.3a to reassess DT reliability with installed security fixes. If the DT had been conducted prior to IOT&E, the Army would have produced a more reliable radio for operational test.
- Problems with reliability, range, battery life, and thermal characteristics were found in early OT.
- Prior to the IOT&E, problems with the communications security retention battery would have negatively affected suitability.
- Post-IOT&E, additional problems were found with the Rifleman Radio including spontaneous self-initiated shutdown, failures to transmit and receive, and the SRW network not healing in a timely manner after radios that had separated from the network rejoined. These deficiencies have been fixed and demonstrated in DT.
- All deficiencies have been shown to be fixed or improving (reliability still not met) but should still be confirmed in a formal GDT prior to the competitive IOT&E-2.

Key Management Infrastructure (KMI) Increment 2

The Joint Interoperability Test Command conducted an IOT&E from July until August 2012. The results were a marked improvement over previous operational assessments; however, there were still several operational effectiveness and suitability problems uncovered during the testing event that must be corrected before continued deployment. The KMI program and vendor regression testing of software was problematic and inconsistent. Lacking thorough regression, software fixes in newer releases often broke previously functioning components.

- OT identified some problems that were missed by DT, including problems with Electronic Key Management System (EKMS) to KMI transition, High Assurance Internet Protocol Encryptor (KG-250) configuration, virtual private network establishment, and data error handling. The developmental test environment was initially limited because of no operational data from the legacy system; however, this has now been corrected.
- The transition process from EKMS to KMI functioned in DT, but was inadequate once implemented in the operational environment on live networks. The controlled test environment did not account for multiple network configuration; and therefore, the test team was forced to perform rapid diagnosis, on-the-fly troubleshooting, and resolution as the OT&E was underway.

Mine Resistant Ambush Protected (MRAP) Caiman Multi-Terrain Vehicle (CMTV)

Another major capability insertion during FY12 included the Independent Suspension System for the CMTV. Endurance testing of the CMTV is ongoing at Yuma Proving Ground, Arizona, in all conditions.

- Based on performance during DT, the CMTV cannot stop following sustained operations in muddy terrain. The program suspended DT until the program identifies and implements a materiel solution to fix the brake system.
- The CMTV experienced problems associated with air conditioner, tire, and cab mount cracking failures.

Mine Resistant Ambush Protected (MRAP) Dash Ambulance

The MRAP program continues to acquire and test enhanced capabilities to integrate across the MRAP family of vehicles. In FY12, a major capability insertion included the ambulance kits for the Navistar Dash. The Dash Ambulance is not operationally effective and not operationally suitable because of the deficiencies listed below:

- The patient compartment of the vehicle is small and the litter births are not long enough to safely accommodate litter patients taller than 5 feet 11 inches. A unit equipped with the Dash Ambulance cannot provide safe emergency medical care and transport for tall casualties in close proximity to enemy forces. This problem should have been corrected prior to the Limited User Test (LUT).
- The small interior of the Dash Ambulance does not provide sufficient space for medical equipment and inhibits the ability

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of the medic to maneuver within the compartment to properly treat patients.

Miniature Air-Launched Decoy (MALD) and Jammer (MALD-J)

The MALD variant (without the jammer) completed IOT&E in 2011 and was found operationally effective for combat, but not operationally suitable due to poor materiel reliability. In July 2011, the Air Force identified a fault with the missile's radio frequency connector that caused it to separate from the missile during long-endurance carriage flights. The Air Force has repaired the fault and conducted further reliability testing; however, MALD's operational reliability of 78 percent remains below the 93 percent threshold requirement. The Air Force began IOT&E for the MALD-J variant in August 2012.

MV-22 Osprey

The Navy conducted Follow-On Operational Test and Evaluation (FOT&E) in June 2012 of the latest Block C software and six other minor enhancements.

- The Traffic Advisory System (TAS) became saturated during formation flight, preventing the display of potentially hazardous traffic external to the mission aircraft. Intended to warn pilots of impending collision with approaching aircraft, the TAS does not distinguish between approaching aircraft and aircraft in formation. Additional development is needed to address operational test findings and improve the utility of TAS for the MV-22 fleet.

Standard Missile-6 (SM-6)

The Navy completed SM-6 Phase 2 IOT&E in July 2012. Phase 2 was an extensive modeling and simulation effort that examined SM-6 battlespace not covered in the flight tests completed in July 2011. As discussed last year, there were two classified performance anomalies in the flight test portion of the IOT&E that a more rigorous DT&E should have discovered earlier.

- The Phase 2 modeling and simulation trials confirmed the classified performance deficiency observed in flight test. The Navy is exploring corrective actions; however, implementation and testing of these corrective actions are not scheduled.
- The uplink/downlink antenna debris anomaly was discovered during DT and carried forward to IOT&E without corrective action being fully implemented on all missiles; thus, there were additional occurrences during IOT&E. The Navy conducted high-temperature wind tunnel tests, which examined if changes to the antenna sealant material and insulation bonding manufacturing process would eliminate the debris. The trials recorded no anomalies against these fixes; however, the unexpected discovery of insulation inter-layer delamination on three of five wind tunnel test articles raises questions regarding the efficacy of the Navy's corrective actions.
- First observed in DT, the Mk 54 Safe-Arm Device anomaly carried forward into IOT&E with additional occurrences. While initially viewed as anomalous, there is not enough evidence at this time to determine whether the Mk 54 behavior, as seen in testing, has a connection to the burst mode of the SM-6. However, the Phase 2 modeling and simulation trials confirmed that the missile lethality is sensitive to the combination of the burst mode, target, and engagement conditions.

***Virginia* Class Submarine Modernized with the APB-09 Acoustic Rapid Commercial Off-the Shelf (COTS) Insertion (A-RCI) Sonar System and AN/BYG-1 Combat Control System**

- A series of *Virginia* class FOT&E events examined the mission performance changes as a result of the modernization of the sonar and combat control system. These tests were combined with the operational evaluations of the latest variants of the A-RCI Sonar System, the AN/BYG-1 Combat Control System, and the Mk 48 Advanced Capability torpedo. One of the primary focus areas of the new combat control system software was the improvement of the Wide Aperture Array's processing and displays for the operators.
- The Wide Aperture Array demonstrated poor performance during the OT period, and operators chose not to use it to aid in completing their missions. The Navy investigated the problems after the OT period was complete, developed new software fixes, and fielded the new software following some limited DT. No OT has been completed to evaluate the new software or the effects on mission performance.
- These problems are recurring and likely a result of the Navy's time-based process for upgrading electronics systems.
- Many other systems on the *Virginia* class submarine exhibited the same failure modes in FOT&E as in IOT&E.

Warfighter Information Network – Tactical (WIN-T) Increment 2

In May 2012, the Army conducted the WIN-T Increment 2 IOT&E at Fort Bliss, Texas; White Sands Missile Range, New Mexico; Fort Campbell, Kentucky; Fort Riley, Kansas; and Fort Gordon, Georgia. DOT&E assessed the WIN-T Increment 2 as supportive of voice, video, and data communications at-the-halt and on-the-move. However, the network needs improvement in the following areas:

- Reliability
- Stability of the terrestrial Highband Networking Waveform network to support on-the-move communications
- Performance of the Soldier Network Extension
- Information Assurance

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PROBLEMS DISCOVERED DURING EARLY TESTING THAT, IF NOT CORRECTED, COULD ADVERSELY AFFECT MY ASSESSMENT OF OPERATIONAL EFFECTIVENESS, SUITABILITY, AND SURVIVABILITY DURING INITIAL OPERATIONAL TEST AND EVALUATION (CONDUCTED WITHIN THE NEXT TWO YEARS)

DISCOVERIES IN EARLY TESTING IN FY12 THAT SHOULD BE CORRECTED PRIOR TO IOT&E	
Bradley Engineering Change Proposal (ECP)	Littoral Combat Ship (LCS) Increment 2
F-15E Radar Modernization Program (RMP)	Multi-Static Active Coherent (MAC) System
Joint Standoff Weapon (JSOW) C-1	Patriot Advanced Capability-3 (PAC-3)

Bradley Engineering Change Proposal (ECP)

In September 2012, the Army conducted two underbody blast tests at the Aberdeen Test Center on the M2A3 Infantry Fighting Vehicle with ECP1 components to characterize the system's vulnerability.

- Severe vehicle and occupant vulnerabilities were observed during early testing. If these vulnerabilities are not corrected the system will likely be assessed as not survivable against realistic underbody threats.

F-15E Radar Modernization Program (RMP)

F-15E RMP developmental flight testing began in January 2011 and IOT&E was expected to begin in late FY12. The planned FY12 IOT&E start did not occur due to challenges in maturing system software to meet the user's functional requirements.

- Software stability is crucial to operational effectiveness and suitability. However, the program experienced software maturation challenges and was unable to complete DT in 2012. Unanticipated software performance shortfalls led to multiple radar software releases and associated regression testing to mature radar mode functionality. At the end of FY12, RMP performance had not yet met the user's requirements. Achieving the Air Force RMP software stability requirement by IOT&E may not be feasible.

Joint Standoff Weapon (JSOW) C-1

The Navy completed DT and initiated integrated testing of the AGM-154C-1 JSOW variant during FY12. The JSOW C-1 integrated testing completed in early FY13, with OT to begin in mid-FY13.

- JSOW C-1 reliability is well below the threshold primarily because of software-driven problems. Achieving an adequate assessment of Mean Flight Hour between Operational Mission Failure during OT is an area of high risk.
- The pilot-vehicle interface is excessively complicated and could prevent successful mission execution.

Littoral Combat Ship (LCS)

The Navy conducted shore-based testing of the MH-60S Block 2 Airborne Mine Countermeasures System, which is intended to support LCS mine countermeasures. Additionally, the Navy commenced a Quick Reaction Assessment (QRA) of the gun systems on LCS 1. Testing indicated shortfalls in performance:

- The Navy determined the MH-60S helicopter cannot safely tow the AN/AQS-20A Sonar Mine Detecting Set (AQS-20A) or the Organic Airborne Sweep and Influence System because the helicopter is underpowered for these operations. The MH-60S helicopter will no longer be assigned these missions operating from any ship, including LCS.
- Preliminary evaluation of test data collected during the operational assessment (OA) of the MH-60S Block 2 Airborne Laser Mine Detection System indicates that the system does not meet Navy requirements for False Classification Density and has low reliability.
- Results from the QRA of the LCS gun systems revealed performance, reliability, and operator training deficiencies for both the 30 mm and 57 mm guns.

Multi-Static Active Coherent (MAC) System

The Navy conducted DT in 2012 and plans to begin OT in early FY13.

- No significant problems have been observed in DT to date; however, little realistic DT has been conducted, and the test construct used for DT contained target requirements that may support model verification but were not operationally realistic or translatable to operationally realistic conditions. The Navy plans to waive two known problems that will likely affect mission performance.

Patriot Advanced Capability-3 (PAC-3)

The Army completed DT of the Post-Deployment Build-7 (PDB-7) and began a LUT operational test in FY12.

- Data analysis is ongoing, but preliminary results indicate that Patriot training remains inadequate to prepare operators for complex Patriot engagements. This was true during the PDB-6.5 and PDB-6 LUTs as well. This problem was exacerbated in the PDB-7 LUT because many of the experienced Patriot operators in the test unit were understandably transferred to deploying units prior to the LUT, resulting in many inexperienced users and a high variability in Soldier proficiency across the test unit.

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- The Patriot system did not meet its reliability requirements during the PDB-7 DT. DOT&E is investigating the possibility of using field data to improve the estimates of Patriot system reliability such as Mean Time Between Critical Mission Failure. However, critical field data including total operating hours and numbers of critical mission failures for each Patriot battery major end item may not be accurate.

CONCLUSION

Previously, Congress has expressed concerns that significant weapons acquisition program problems are discovered during OT&E that should have been discovered during DT. Last year, I documented 40 systems with significant discovery during OT during 2010-2011; 23 of those systems had discovery in early OT, of which 19 implemented fixes that were either verified by successful IOT&E or are currently in IOT&E. Of the 17 programs that discovered significant issues during their IOT&E in 2010-2011, 12 have implemented fixes that were either verified in successful FOT&E or are planning additional OT periods; 2 of the remaining 5 programs were cancelled. Thus, while significant issues are being discovered late in the programs' acquisition cycle, most programs are addressing the discoveries and verifying fixes in FOT&E. In 2012, 17 programs had significant discoveries in IOT&E or FOT&E, while 7 programs had significant discovery in early testing.

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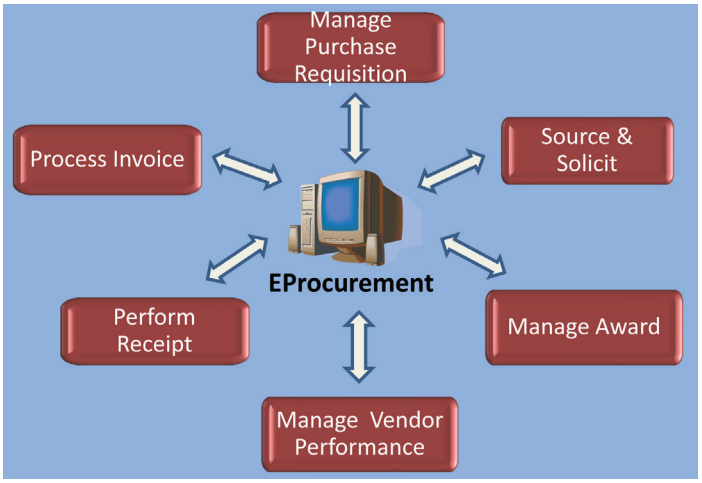
EProcurement

Executive Summary

- The Joint Interoperability Test Command (JITC) conducted a DOT&E-directed Operational Assessment (OA) of Release 1.2 in January 2012. EProcurement demonstrated significantly improved maturity over the previous Release 1.1. Users could successfully employ the system to execute all phases of procurement mission tasks with few problems. However, user perception of training adequacy, system usability, and system timeliness remained poor.
- JITC conducted the IOT&E of Release 1.2 between February and April 2012.
- EProcurement is operationally effective. The effectiveness evaluation concentrated on the users' ability to use EProcurement in six areas: manage purchase requisitions, source and solicit goods and services, manage awards, process receipts and invoices, create reports, and maintain system data (data cleansing and conversions). JITC observed users performing day-to-day operations and recorded 1,350 successful transactions and 13 failed transactions (99 percent success rate).
- EProcurement is operationally suitable, but with deficiencies. Improvements are required in the areas of training, usability, Help Desk operations, and supportability.
- EProcurement is secure from an Information Assurance perspective. At the end of IOT&E, only one moderate impact, and two low impact deficiencies remained open, with minimal effect on system security and operations. The Defense Information Systems Agency (DISA) and the Defense Logistics Agency (DLA) created a plan of action and milestones to address resolution of these deficiencies. However, DOT&E was unable to verify that DLA has a robust theft and fraud prevention and detection program.
- The Deputy Chief Management Officer (DCMO) approved the Full Deployment Decision (FDD) of EProcurement on August 23, 2012. As a part of the FDD approval, DLA agreed to employ a Red Team to conduct a pilot assessment in accordance with the rules of engagement established by the results of the DCMO-sponsored Massachusetts Institution of Technology Theft/Fraud Red Team study. DLA also agreed to continue the effort to demonstrate automated regression testing as a potential standard model for the DoD.

System

- DLA developed EProcurement to provide enterprise-level procurement capabilities to replace legacy procurement systems (Pre-Award Contracting System, Electronic Contract Folder, Procurement Automated Contract Evaluation, and Base Operations Support System).
- The Intended functions of EProcurement include: manage purchase requisition, source and solicit, manage award, manage vendor performance, perform receipt, and process invoice. Receipts and invoices are processed via the DLA Wide Area Workflow System or manually.
- EProcurement is based on a suite of commercial off-the-shelf (COTS) software applications purchased from the Systems Applications and Products Corporation that operates on COTS computing hardware.
- The Defense Enterprise Computing Center (DECC) in Ogden, Utah, which is operated and maintained by DISA, is the production environment for EProcurement. EProcurement is one of the programs in the overall DLA Enterprise Business System Infrastructure hosted by the Ogden DECC. The back-up site is located at the DECC in Mechanicsburg, Pennsylvania.



Mission

DLA users will use EProcurement to procure and provide the full spectrum of consumables, services, and depot-level repairables to the Army, Navy, Air Force, Marine Corps, other federal agencies, and combined and allied forces.

Major Contractor

Accenture – Reston, Virginia

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Activity

- JITC conducted an OA of Release 1.2 in January 2012, in accordance with a DOT&E-approved OA plan. JITC conducted the OA at the DLA Aviation facility in Richmond, Virginia.
- JITC conducted the IOT&E of EProcurement Release 1.2 from February through April 2012. JITC executed the test at DLA locations in New Cumberland, Pennsylvania; Mechanicsburg, Pennsylvania; Battle Creek, Michigan; Fort Belvoir, Virginia; and Richmond, Virginia, in accordance with a DOT&E-approved IOT&E plan.
- Information Assurance testers from JITC along with members of the DISA Field Security Operations (FSO) and DLA Computer Emergency Response Team (CERT) conducted penetration test events at the DECC in Ogden, Utah, during both the OA and IOT&E.

Assessment

- During the Release 1.2 OA, EProcurement demonstrated significantly improved maturity over the previous Release 1.1. Users successfully used the system to execute all phases of procurement mission tasks with few problems. However, user training, system usability, and system timeliness still require improvement.
- Based on the IOT&E results, EProcurement is operationally effective.
  - The effectiveness evaluation concentrated on the users' ability to use EProcurement to: manage purchase requisitions, source and solicit goods and services, manage awards, process receipts and invoices, create reports, and maintain system data (data cleansing and conversions), which included all major system functionality.
  - JITC observed users performing day-to-day operations and recorded 1,350 successful transactions and 13 failed transactions, which achieved a 99 percent success rate and exceeded the 90 percent requirement.
  - EProcurement is interoperable. JITC interoperability testers evaluated 52 interfaces to assess the data exchanges between EProcurement and other systems, with no failures reported in the more than 400 transactions evaluated.
- EProcurement is operationally suitable but has deficiencies in the areas of training, usability, Help Desk operations, and supportability.
  - DOT&E considers EProcurement reliable, available, and maintainable. DLA reported one site specific outage at Battle Creek, Michigan, lasting 1 hour and 55 minutes, but it appears to have been an isolated event.
  - EProcurement training, training aids, and system documentation need improvement. None of these areas met the 80 percent threshold of acceptability by the users surveyed. Users report that EProcurement is not user friendly and is difficult to master.
  - Help Desk trouble tickets take a long time to resolve. Analysis of the closure rates for the tickets shows that the average time required to resolve trouble tickets was approximately 8.5 days, with resolution times ranging from less than 5 minutes to nearly 40 days.
  - The supportability of EProcurement needs improvement as DLA does not have an automated test capability to perform thorough regression testing on new software releases.
- EProcurement meets Information Assurance security thresholds. JITC Information Assurance testers, along with members of the DISA FSO and DLA CERT, conducted a series of penetration test events primarily at the Ogden DECC.
  - Following IOT&E, only one moderate impact, and two low impact deficiencies remained open, with minimal effect on system security and operations. DISA and DLA created a plan of action and milestones to address resolution of these deficiencies.
  - DLA did not implement a robust theft and fraud prevention and detection program. DLA asserts that by using role separations, at least two to three people would need to be involved in any theft or fraud activity and that while large-scale theft or fraud was not impossible, it would be difficult. DLA also indicated that bi-annual audits and other accounting controls are in place to further mitigate such activities. While DOT&E acknowledges that some level of prevention and detection is available at DLA, the extent of the financial threat vulnerability is yet to be determined and is pending the outcome of a financial theft and fraud test.

Recommendations

- Status of Previous Recommendations. The program manager satisfactorily addressed three of the five FY11 recommendations. The program manager partially addressed recommendations concerning operational realism of developmental testing and the use of automated test tools; these recommendations remain valid.
- FY12 Recommendations.
  1. DLA should employ a Theft and Fraud Prevention and Detection Red Team to conduct a pilot assessment in accordance with the rules of engagement established by the results of the Deputy Chief Management Officer-sponsored Theft and Fraud Red Team study.
  2. DLA should continue with ongoing efforts to implement automated regression testing.
  3. DLA should improve the quality of training, training aids, and other system documentation for the users, and include role-specific training in the future when DLA transitions users to EProcurement at the remaining DLA sites.
  4. DLA should modify the method of managing trouble tickets to allow for better query capabilities. DLA should also periodically track the resolution times of system problems to aid DLA management in identifying potential problem areas so that DLA can implement mitigation strategies before productivity is affected.
  5. DLA should periodically administer the System Usability Scale survey to a random sample of all EProcurement users

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through full deployment to see whether user satisfaction does improve with increased system use and to pinpoint any inherent deficiencies with system usability.

6. In future testing, JITC and DLA should evaluate all untested interfaces that will be part of the full deployment.
7. Although only minor deficiencies remained after the last Information Assurance test event, the DISA FSO and DLA CERT should periodically reevaluate the security posture of the system as part of the overall defense-in-depth security strategy.

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F-35 Joint Strike Fighter (JSF)

Executive Summary

- The F-35 Joint Strike Fighter (JSF) program continues to have a high level of concurrency among production, development, and test. Approximately 34 percent of the total planned flight testing, based on test points completed through November 2012, has now been accomplished as the program initiates the fifth of 11 initial production lots. Durability testing is ongoing on all three variants, with only the F-35A test article having completed a full lifetime of testing. The program will not complete the two lifetimes of durability testing currently planned on any variant until the last quarter of 2014.
- Through November 2012, the flight test teams were able to exceed the flight rate planned for flight sciences in the F-35B and F-35C variants, but were slightly behind the plan for the F-35A. The program did not accomplish the intended progress in achieving test objectives (measured in flight test points planned for 2012) for all variants. Certain test conditions were unachievable due to unresolved problems and new discoveries. The need for regression testing of fixes (repeat testing of previously accomplished points with newer versions of software) displaced opportunities to meet flight test objectives.
- The flight rate of the mission systems test aircraft also exceeded the planned rate during the year, but overall progress in mission systems was limited. This was due to delays in software delivery, limited capability in the software when delivered, and regression testing of multiple software versions (required to fix problems, not add capability). Test points accomplished for the year included Block 1 verification, validation of limited capabilities for early lot production aircraft, baseline signature testing, and Block 2 development. No combat capability has been fielded.
- The lag in accomplishing the intended 2012 flight testing content defers testing to following years, and in the meantime, will contribute to the program delivering less capability in production aircraft in the near term.
- The tables on the following page present the actual versus planned test flights and test points conducted as of the end of November 2012.
- The program submitted Revision 4 of the Test and Evaluation Master Plan (TEMP) for approval, which included changes to the program structure brought about by the previous year's Technical Baseline Review and subsequent re-planning of testing. However, the TEMP contained an unacceptable overlap of development with the start of operational test activity for IOT&E.
- The Air Force began the F-35A training Operational Utility Evaluation (OUE) in September 2012 and completed it in mid-November. During the OUE, four pilots completed training in the system familiarization portion of the syllabus, which included no combat capabilities. Because of the immaturity of the system, which is still largely under development, little can be learned about operating and sustaining the F-35 in combat operations from this evaluation.



- The program completed two of the eight planned system-level ballistic test series.
  - The first series confirmed the built-in redundancies and reconfiguration capabilities of the flight-critical systems. The second series indicated that ballistic damage introduced no measurable degradation in the F-35B propulsion system performance and that the damage would be undetectable by the pilot. Ongoing analysis will evaluate whether these tests stressed the vulnerabilities unique to ballistic damage to the F-35 (e.g., interference or arcing between 270 Volt, 28 Volt, and signal lines and/or damage to lift fan blade sections).
  - The first test series confirmed Polyalphaolefin (PAO) coolant and fueldraulic systems fire vulnerabilities. The relevant protective systems were removed from the aircraft in 2008 as part of a weight reduction effort. A Computation of Vulnerable Area Tool analysis shows that the removal of these systems results in a 25 percent increase in aircraft vulnerability. The F-35 Program Office may consider reinstalling the PAO shutoff valve feature based on a more detailed cost-benefit assessment. Fueldraulic system protection is not being reconsidered for the F-35 design.
- The program's most recent vulnerability assessment showed that the removal of fueldraulic fuses, the PAO shutoff valve,

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and the dry bay fire suppression, also removed in 2008, results in the F-35 not meeting the Operational Requirements Document (ORD) requirement to have a vulnerability posture better than analogous legacy aircraft.
- Tests of the fuel tank inerting system in 2009 identified deficiencies in maintaining the required lower fuel tank oxygen levels to prevent fuel tank explosions. The system is not able to maintain fuel tank inerting through some critical portions of a simulated mission profile. The program is redesigning the On-Board Inert Gas Generating System (OBIGGS) to provide the required levels of protection from threat and from fuel tank explosions induced by lightning.

Actual versus Planned Test Metrics through November 2012

TEST FLIGHTS					
	All Testing	Flight Sciences			Mission Systems
	All Variants	F-35B Only	F-35A Only	F-35C Only	
2012 Actual	1,092	374	263	233	222
2012 Planned	927	244	279	211	193
Difference from Planned	+18%	+53%	–6%	+10%	+15%
Cumulative Actual	2,533	963	709	425	436
Cumulative Planned	2,238	820	651	404	363
Difference from Planned	+13%	+17%	+9%	+5%	+20%

TEST POINTS								
	All Testing	Flight Sciences			Mission Systems			
	All Variants	F-35B Only	F-35A Only	F-35C Only	Block 1*	Block 2	Block 3	Other
2012 Baseline Accomplished	4,711	1,075	1,338	1,060	358	457	0	423
2012 Baseline Planned	6,497	1,939	1,923	1,327	336	448	0	524
Difference from Planned	–28%	–45%	–30%	–20%	+7%	+2%	0	–19%
Added Points	1,720	292	565	253	0	610	0	0
Points from Future Year Plans	2,319	992	431	896	0	0	0	0
Total Points Accomplished**	8,750	2,359	2,334	2,209	358	1,067	0	423
Cumulative SDD Actual***	20,006	7,480	5,664	4,330	899	457	0	1,176
Cumulative SDD Planned	19,134	7,057	6,102	3,748	667	488	0	1,072
Difference from Planned	+5%	+6%	–7%	+16%	+35%	–6%		+10%
Test Points Remaining	39,579	12,508	8,321	10,316	8,434 (All Blocks and Other Mission Systems Activity)			

* Includes Block 0.5 and Block 1 quantities
** Total Points Accomplished = 2012 Baseline Accomplished + Added Points + Points from Future Year Plans
*** SDD – System Design and Development

System
- The F-35 JSF program is a tri-Service, multi-national, single-seat, single-engine family of strike aircraft consisting of three variants:
  - F-35A Conventional Take-Off and Landing (CTOL)
  - F-35B Short Take-Off/Vertical-Landing (STOVL)
  - F-35C Aircraft Carrier Variant (CV)
- It is designed to survive in an advanced threat (year 2012 and beyond) environment using numerous advanced capabilities. It is also designed to have improved lethality in this environment compared to legacy multi-role aircraft.
- Using an Active Electronically Scanned Array (AESA) radar and other sensors, the F-35 is intended to employ precision-guided bombs such as the Joint Direct Attack Munition (JDAM) and Joint Standoff Weapon, AIM-120C radar-guided Advanced Medium-Range Air-to-Air Missile (AMRAAM), and AIM-9 infrared-guided short-range air-to-air missile.
- The program provides mission capability in three increments: Block 1 (initial training), Block 2 (advanced), and Block 3 (full).
- The F-35 is under development by a partnership of countries: the United States, Great Britain, Italy, the Netherlands, Turkey, Canada, Australia, Denmark, and Norway.

Mission
- A force equipped with F-35 units should permit the Combatant Commander to attack targets day or night, in all weather, and in highly defended areas of joint operations.
- F-35 will be used to attack fixed and mobile land targets, enemy surface units at-sea, and air threats, including advanced cruise missiles.

Major Contractor
Lockheed Martin, Aeronautics Division – Fort Worth, Texas

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Test Strategy, Planning, and Resourcing

- The JSF Program Office, in coordination with the operational test agencies, worked to develop Revision 4 of the TEMP. As part of the Milestone B recertification in March 2012, the USD(AT&L) tasked the program to submit a revised TEMP for approval prior to the September In-Progress Review by the Defense Acquisition Board.
- The TEMP included a schedule for IOT&E that assumed the final preparation period prior to IOT&E could fully overlap with the air-worthiness certification phase of development, which occurs after the final developmental test events. DOT&E identified to the program and the JSF Operational Test Team that without analysis showing this overlap is feasible, the TEMP could not be approved. DOT&E concluded that this final preparation period should be scheduled to begin at a later point, no earlier than the Operational Test Readiness Review, and budgets should be adjusted accordingly.
- This report reviews the program by analyzing the progress of testing and the capability delivered as a function of test results. The program plans a specific set of test points (discrete measurements of performance under specific test conditions) for accomplishment in a given calendar year. In this report, test points planned for a given calendar year are referred to as baseline test points. In addition to baseline test points, the program accomplishes test points added for discovery and regression. Cumulative System Design and Development (SDD) test point data refer to the total progress towards completing development at the end of SDD.

F-35A Flight Sciences

Flight Test Activity with AF-1, AF-2, and AF-4 Test Aircraft

- F-35A flight sciences testing focused on:
  - Expanding the flight envelope (achieved 700 knots calibrated airspeed [KCAS]/1.6 Mach test point in March and achieved 50,000 feet, the designed altitude limit, in November)
  - Evaluating flying qualities with internal stores (GBU-31 JDAM, GBU-12 Laser-guided Bomb, and AIM-120 AMRAAM) and external stores (AIM-9X short-range missile)
  - Characterizing subsonic and supersonic weapons bay door and environment
  - Expanding the air-refueling envelope and investigating tanker-to-F-35A connection/disconnection problems
  - Engine air-start testing
  - High (greater than 20 degrees) angle-of-attack testing
- The test team began weapons separation testing in October with the first safe separation of an inert GBU-31 JDAM, followed by the first AIM-120 safe separation later in the month.
- The program released two revisions of the air vehicle systems software (R27.1 and R27.2.2) in 2012 to improve flying qualities, correct air data deficiencies observed during F-35A envelope expansion, and to address various software deficiencies.
- Through the end of November 2012, the test team was able to sustain a sortie rate of 8.0 flights per aircraft per month, compared to the goal of 8.5 sorties per month. The overall annual sortie total was only 6 percent short of the goal (263 sorties completed, 279 planned).

Flight Sciences Assessment

- By the end of November, the progress against planned baseline test points for 2012 lagged by over 30 percent (accomplishing 1,338 baseline F-35A flight sciences test points of 1,923 planned through November 2012, for a completion rate of 70 percent). The test team could not execute this portion (30 percent) of planned 2012 baseline test points for the following reasons:
  - Aircraft operating limitations, which prevented the extended use of afterburner needed to complete high-altitude/high-airspeed test points.
  - Higher than expected loads on the weapon bay doors, which required additional testing and thus limited the amount of testing with weapons loaded on the aircraft.
  - Deficiencies in the air-refueling system, which reduced testing opportunities.
- To compensate for not being able to achieve the baseline test points planned for 2012, the test team moved up test points planned for completion in later years, and was thereby able to nearly keep pace with overall cumulative SDD test point objectives. For example, the Block 2B flight envelope includes operations with the weapons bay doors open. The program discovered dynamic flight loads on portions of the open doors were higher than expected, requiring additional instrumentation and testing. The test team substituted other test points, which were available from Block 3 envelope plans for 2013 that did not require the doors open. For F-35A flight sciences, the test team had accomplished 93 percent of the overall planned number of cumulative test points scheduled for completion by the end of November (5,664 cumulative points accomplished against a goal of 6,102 points).
- Weight management of the F-35A variant is important for meeting air vehicle performance requirements. The program generates monthly aircraft weight status reports for all variants and computes weights as a sum of measured weights of components or subassemblies, calculated weights from approved design drawings released for build, and engineering weight estimates of remaining components. The program has managed to keep F-35A weight estimates nearly constant for the last year. The latest F-35A weight status report from November 2012 showed the estimated weight of 29,098 pounds to be within 273 pounds (0.94 percent) of the projected maximum weight needed to meet the technical performance required per contract

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specifications in January 2015. This small margin allows for only 0.42 percent weight growth per year for the F-35A. The program will need to continue rigorous weight management through the end of SDD to avoid performance degradation and operational impacts.
- The program announced an intention to change performance specifications for the F-35A, reducing turn performance from 5.3 to 4.6 sustained g's and extending the time for acceleration from 0.8 Mach to 1.2 Mach by 8 seconds. These changes were due to the results of air vehicle performance and flying qualities evaluations.
- Discoveries included:
  - Delayed disconnects during air refueling required the program to implement restrictions on the F-35A fleet and conduct additional testing of the air refueling capability. The program added instrumentation to isolate root causes.
  - Horizontal tail surfaces are experiencing higher than expected temperatures during sustained high-speed/high-altitude flight, resulting in delamination and scorching of the surface coatings and structure. All variants were restricted from operations outside of a reduced envelope until the test team added instrumentation to the tailbooms to monitor temperatures on the tail surfaces. The program scheduled modification of one flight sciences aircraft of each variant with new skin coatings on the horizontal tail to permit flight testing in the currently restricted part of the high-speed/high-altitude flight envelope. The test team is adding more flight test instrumentation to help quantify the impacts of the tail heating to support necessary design changes. The program scheduled modifications on one aircraft (AF-2) to be completed in early 2013 to allow flight testing of the new skin design on the horizontal tails to proceed.

F-35B Flight Sciences

Flight Test Activity with BF-1, BF-2, BF-3, BF-4, and BF-5 Test Aircraft

- F-35B flight sciences focused on:
  - Expansion of the vertical-lift operations envelope testing of the newly designed auxiliary air inlet door
  - Engine air-start testing
  - Expansion of the flight envelope with weapons loaded on the aircraft
  - Fuel dump operations
  - Regression testing of new vehicle systems software
- The test team accomplished radar signature testing on BF-5 after the aircraft was returned to the plant for four months for final finishes.
- The test team began weapon-separation flight tests in August when BF-5 accomplished a successful safe separation of an inert GBU-32 JDAM.
- As of the end of November, the sortie rate for the F-35B flight sciences test aircraft was 6.8 sorties per aircraft per month, compared to the goal of 4.4. The program accomplished 153 percent of the planned F-35B flight sciences sorties, completing 374 vice 244 planned.

Flight Sciences Assessment

- Although the program exceeded the objectives planned for sortie rate through the end of November, the progress against planned baseline test points for 2012 lagged by 45 percent with 1,075 test points accomplished against 1,939 planned. This was primarily a result of higher-than-expected loads on weapon bay doors, which prevented planned envelope expansion test points and required additional unplanned testing.
- To compensate for not being able to accomplish the planned envelope expansion test points, the test team pulled an additional 992 points from testing planned for 2013 back into 2012 and added 292 points for regression testing of new software. As of the end of November, the program had accomplished 2,359 total test points for the year. By pulling test points to 2012 that were originally planned for execution in later years, the test team was able to keep pace with the program's overall cumulative SDD test point objectives. Like the F-35A, loads on the weapons bay doors prevented test point accomplishment for internally-loaded weapons; test points with external stores were accomplished instead. For F-35B flight sciences, the test team had completed 106 percent of the planned quantity of cumulative SDD test points scheduled for completion by the end of November (7,480 cumulative points accomplished against a goal of 7,057 points).
- The test team continued investigations into the impact of transonic roll-off and transonic buffet in the F-35B; these investigations are not complete. The program introduced new F-35B vehicle systems software to reduce rudder and flaperon hinge moment in the transonic/supersonic region. The program expected to see improvements in transonic wing roll-off with these changes, but results were not available at the end of November 2012.
- The following table, first displayed in the FY11 Annual Report, describes the observed door and propulsion problems by component and identifies the production cut-in, if known. A significant amount of flight test and validation of an adequate final STOVL-mode configuration (doors and propulsion system) remains to be accomplished.

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F-35 B Door and Propulsion Problems				
Category	**Component**	**Problem**	**Design Fix and Test Status**	**Production Cut-In**
Subsystems	Upper Lift Fan Inlet Door Actuators	High actuator failure rates.	Root cause analysis is complete and failure modes are limited to open position (i.e., failure to close); the doors have not failed to open when commanded, which allows lift fan operations. New actuator design is complete and testing is entering final stage of qualification.	BF-38 Low-Rate Initial Production (LRIP) 6 2014
Structure	Auxiliary Air Inlet Door (AAID)	Inadequate life on door locks, excessive wear and fatigue due to the buffet environment, inadequate seal design.	Redesigned door undergoing testing on BF-1. Loads testing completed and verified. Static testing on ground test article (BG-1) is complete, fatigue testing started in November.	BF-38 LRIP 6 2014
Structure	Lift Fan Door Actuator Support Beam	Cracks occurring earlier than predicted. Root cause analysis showed fastener location incorrectly inserted in design.	BF-1, BF-2, and BF-4 modifications are complete. BF-3 will not be modified (will not be used for STOVL Mode 4 operations). BF-4 has resumed Mode 4 operations. Design fix is on BF-5 and subsequent aircraft and new configuration is to full life.	BF-5 LRIP 2 2012
Structure	Roll Control Nozzle (RCN) Doors	Doors separated from aircraft BF-2 and BF-3 during flight; door loads not well understood, aero pressures higher than expected. Impact not limited to STOVL mode operations – flight not to exceed 400 KCAS below 18K ft and 0.5 minimum g-load.	BF-2 and BF-3 were modified with an interim design, instrumented, and flown to verify the updated loads used to develop the interim and final design doors. The Program Office is reviewing a redesign to support production in LRIP 6.	BF-38 LRIP 6 2014
Structure	3 Bearing Swivel Nozzle Door	Door attachment wear/damage found on BF-1 (6/11) requiring new inspection interval every 25 Mode-4 (vertical-lift-fan-engaged) flights. During Slow Landing flight testing, measured door loads exceeded limits.	Interim mod complete on BF-1 and BF-2, instrumentation added and flight test is ongoing. Production redesign is in progress.	BF-44 LRIP 7 2015
Structure	Main Landing Gear (MLG) Doors	Door cracking observed on BF-1, -2, and -4 aft door adjacent to aft lock.	Instrumentation added to BF-2 and flight loads testing complete. Models correlated and root cause confirmed. Modification of the rest of the SDD fleet is in work; production redesign is in progress. MLG door modification will be concurrent with AAID modification.	BF-44 LRIP 7 2015
Propulsion	Drive Shaft	Lift fan drive shaft undergoing a second redesign. Original design inadequate due to shaft stretch requirements to accommodate thermal growth, tolerances, and maneuver deflections.	Full envelope requirements are currently being met on production aircraft with an interim design solution using spacers to lengthen the early production drive shaft. Due to the heavy maintenance workload associated with the spacers, the Program Office is pursuing an improved design that does not require class spacers. The initial improved driveshaft design failed qualification testing. A new design is under development.	BF-44 LRIP 7 2015
Propulsion	Clutch	Lift fan clutch has experienced higher than expected drag heating during conventional (up and away) flight.	Testing completed to determine root cause of drag heating. Fix includes clutch plate width reduction on LRIP 5 and 6 aircraft, at the expense of reduced life (engagements) to the clutch. The Program Office is investigating alternate plate material to meet engagement requirement on subsequent LRIPs.	BF-44 LRIP 7 2015
Propulsion	Roll Post Nozzle Actuator	Roll post nozzle bay temperatures exceed current actuator capability. Actuator failure during Mode 4 operations.	Insulation between the roll post nozzle bay and the actuator has been installed and testing completed through the STOVL flight envelope. All LRIP aircraft have been fitted with insulation to reduce heat transfer into the bay and wear on current actuator. A newly designed, more heat tolerant actuator is scheduled to begin testing in early 2013.	TBD, depending on testing and production of redesigned actuator; retrofit of early production fleet will occur by attrition.
Propulsion	Bleed Air Leak Detectors	Nuisance overheat warnings to the pilot are generated because of poor temperature sensor design; overheats are designed to be triggered at 460 degrees F, but have been annunciated as low as 340 degrees F.	More accurate temperature sensors in the bleed air leak detectors have been designed and delivery for production aircraft started in January 2012.	Detectors on early LRIP aircraft will be replaced by attrition.
Propulsion	Auxiliary Air Inlet Door Aft down-lock seal doors (aka "saloon doors")	Doors are spring-loaded to the closed position and designed as overlapping doors with a 0.5 inch gap. The gap induces air flow disturbance and make the doors prone to damage and out-of-sequence closing. Damage observed on BF-5.	Seal doors are being redesigned with non-overlapping doors and stronger spring loads to ensure proper sequencing and full closure of the doors.	TBD

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- The status of F-35B door and propulsion deficiencies follows.
  - The upper lift fan inlet doors continue to fail to operate correctly due to poor actuator design. Crews have observed failure of the doors to close on flight test aircraft and the early LRIP aircraft at Eglin AFB during ground operations. Ground maintenance workaround procedures are in place to ensure correct door operation; however, standard maintenance procedures for fleet operations are not yet in place. Newly designed actuators will not be available for production cut-in until BF-38, a Lot 6 delivery in 2014.
  - Redesign of the auxiliary air inlet doors is complete. The test team accomplished flight testing of the aerodynamic loads on the BF-1 doors early in 2012, and modified the F-35B static test article with the new auxiliary air inlet doors in August 2012 in preparation for static and durability testing. The static load testing was completed in mid-November, followed by the start of durability testing. Results of the testing were not available as of the time of this report.
  - Testing and analysis continued on the three-bearing swivel nozzle doors. The test team added instrumentation on BF-1 in January to assess the dynamic loads on the door to support an engineering redesign. BF-2 was modified and flight testing of the design is ongoing as of the time of this report. Redesign for both the production cut-in and the retrofit plans is in review at the Program Office. Fleet restrictions will remain in effect (slow landings below 100 KCAS are prohibited) until the program modifies the nozzle doors.
  - Temperatures in the roll control nozzle actuator area exceeded the heat tolerance of the current actuator design during flight test, necessitating a redesign. The program is changing the insulation in the nozzle actuator area as an interim fix and redesigning the nozzle actuator to improve heat tolerance. The program plans to begin testing the newly designed nozzle actuator in early 2013.
  - After roll control nozzle doors separated in-flight in 2011, additional testing of the aerodynamic loads on the doors led to a door redesign. A production redesign currently under review with the Program Office increases the closing forces on the door to prevent aerodynamic loads opening and possibly damaging doors or causing door separation.
  - The material solution to unacceptably high clutch temperatures observed during developmental testing is to reduce the width of the clutch plates in later LRIP aircraft with the expectation of reducing the drag and associated heating during all modes of flight. Clutch temperatures are monitored by aircraft sensors, which alert the pilot when normal temperature limits are exceeded. The associated pilot procedures to reduce high clutch temperatures require changing flight regimes to a cooling envelope of lower altitude (below 11,000 feet) and lower airspeed (less than 280 knots); such a procedure during combat missions would likely increase the vulnerability to threats and cause the pilot to abort the mission. Further, a vertical landing under high clutch temperature conditions needs to be avoided if possible, making return to forward basing or ship-borne operations in the combat zone, where a vertical landing would be required, not practical.
  - The program added spacers to the lift fan driveshaft to address unanticipated expansion/stretching that takes place during flight. This is an interim solution while the program redesigns the driveshaft for better performance and durability.
- Weight management of the F-35B aircraft is critical to meeting the Key Performance Parameters (KPPs) in the ORD, including the vertical lift bring-back requirement. This KPP requires the F-35B to be able to fly an operationally representative profile and recover to the ship with the necessary fuel and balance of unexpended weapons (two 1,000-pound bombs and two AIM-120 missiles) to safely conduct a vertical landing.
  - Weight reports for the F-35B have varied little in 2012, increasing 14 pounds from either changes in the manufacturing processes or more fidelity in the weight estimate. Current estimates are within 231 pounds (0.71 percent) of the not-to-exceed weight of 32,577 pounds – the target weight of the aircraft in January 2015 to meet specification requirements and ORD mission performance requirements for vertical lift bring-back. The small difference between the current weight estimate and the not-to-exceed weight allows for weight growth of 0.32 percent per year.
  - Managing weight growth with such small margins will continue to be a significant program challenge. Since the program will conduct the technical performance measurement of the aircraft in January 2015, well before the completion of SDD, continued weight growth through the balance of SDD will affect the ability of the F-35B to meet the STOVL mission performance KPP during IOT&E. Additionally, production aircraft are weighed as part of the government acceptance process, and the early LRIP lot F-35B aircraft were approximately 150 pounds heavier than the predicted values found in the weight status report.
- The program announced an intention to change performance specifications for the F-35B, reducing turn performance from 5.0 to 4.5 sustained g's and extending the time for acceleration from 0.8 Mach to 1.2 Mach by 16 seconds. These changes were due to the results of air vehicle performance and flying qualities evaluations.
- Other discoveries included:
  - As with the F-35A, horizontal tail surfaces are experiencing higher than expected temperatures during sustained high-speed/high-altitude flight, resulting in delamination and scorching of the surface coatings and structure. The program modified the tail surfaces of BF-2 in September to permit flight testing at higher airspeeds. The coatings delaminated during flight,

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however, suspending further flight testing in the higher airspeed envelope until a new plan for the coatings can be developed.
- Fuel dump testing is ongoing on BF-4 after a redesign of seals on the lower trailing edge flaps. Previous testing with the original seals resulted in fuel penetrating the cove area behind the flaps and wetting the fuselage, allowing fuel to pool near the Integrated Power Package exhaust where the fuel is a fire hazard. Testing with the new seals has shown less fuel penetration with flaps fully retracted and with flaps extended to 20 degrees; however, fuel traces inside the flaperon cove were observed during post-flight inspections. The test team is also testing redesigned exit nozzles of different shape and cross-sectional areas. As of the end of November 2012, 11 relevant test flights have been accomplished; more flights will be necessary to resolve the deficiency.
- Planned wet runway testing, required to assess braking performance with a new brake control unit, has been delayed due to the inability to create the properly degraded friction conditions at the Patuxent River Naval Air Station (NAS), Maryland. The F-35B training aircraft at Eglin will be restricted to dry runway operations only until the wet runway testing is completed.

F-35C Flight Sciences

Flight Test Activity with CF-1, CF-2, and CF-3 Test Aircraft

- F-35C flight sciences focused on:
  - Verification of the basic flight envelope for the first production F-35C aircraft
  - Expansion of the flight envelope with external weapons loaded on the aircraft (AIM-9X short-range missile in subsonic flight)
  - Testing of arresting hook system modifications
  - Preparing for executing carrier landings in the simulated carrier environment at Lakehurst Naval Test Facility, New Jersey, including handling qualities at approach speeds at carrier landing weights
  - Surveying handling qualities in the transonic flight regimes
  - Regression testing of new air vehicle systems software
- As of November, the test team executed a sortie rate of 7.1 sorties per aircraft per month compared to the goal of 6.4. The program accomplished 110 percent of the planned F-35C flight sciences sorties, completing 233 vice 211 planned through the end of November.
- The program plans to deliver the final F-35C flight sciences aircraft, CF-5, in late 2012, followed soon by the first production F-35C from Lot 4. CF-5 flew its first company acceptance flight at the end of November.

Flight Sciences Assessment

- The program completed 80 percent of the baseline test points planned though November 2012, accomplishing 1,060 test points of a planned 1,327. Flight restrictions blocked accomplishment of a portion of the planned baseline test points until a new version of vehicle systems software became available.
- The test team flew an additional 253 test points from flight test requests and pulled 896 test points forward from work planned for 2013.
- By accomplishing envelope test points planned for completion in later years, the test team was able to keep ahead of the cumulative SDD test point objectives, as was the case in F-35A and F-35B flight sciences. While awaiting new vehicle systems software required to complete planned envelope testing in 2012, the test team accomplished points in other areas of the flight envelope. For F-35C flight sciences, the test team had accomplished 116 percent of the planned number of cumulative test points scheduled for completion by the end of November (4,330 cumulative points accomplished against a goal of 3,748 points).
- Weight management of the F-35C variant is important for meeting air vehicle performance requirements. F-35C weights have generally decreased in the monthly estimates during 2012. The latest weight status report from November 2012 showed the estimated weight of 34,522 pounds to be within 346 pounds (1.0 percent) of the projected maximum weight needed to meet technical performance requirements in January 2016. This margin allows for 0.31 percent weight growth per year. The program will need to continue rigorous weight management through the end of SDD to avoid performance degradation and operational impacts.
- The program announced an intention to change performance specifications for the F-35C, reducing turn performance from 5.1 to 5.0 sustained g's and increasing the time for acceleration from 0.8 Mach to 1.2 Mach by at least 43 seconds. These changes were due to the results of air vehicle performance and flying qualities evaluations.
- Discoveries included:
  - Due to the difference in wing design, transonic buffet becomes severe in different portions of the flight envelope and is more severe in the F-35C than the other variants. The program is making plans for investigating how to reduce the impact of transonic roll off in the F-35C with the use of wing spoilers; however, detailed test plans are not complete.
  - As with the F-35A and F-35B, horizontal tail surfaces are experiencing higher than expected temperatures during sustained high-speed/high-altitude flight, resulting in delamination and scorching of the surface coatings and structure. In August, the test team installed new coatings on CF-1 horizontal tails, designed to prevent scorching and delaminating during prolonged use of afterburner pursuing high airspeed test points. However, portions of the coatings dis-bonded during flight, suspending further testing of the high airspeed portion of the envelope.
  - The test team investigated alternative trailing edge flap settings to improve flying qualities during carrier landing approach. While pilot surveys showed handling qualities were improved with a 15-degree flap setting, flight test data to date have shown that 30 degrees of flaps are required to meet the KPP for maximum approach speed of 145 knots at required carrier landing weight.

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Mission Systems

Flight Test Activity with AF-3, AF-6, AF-7, BF-17, and BF-18 Test Aircraft and Software Development Progress

- Mission systems are developed and fielded in incremental blocks of capability.
  - Block 1. The program designated Block 1 for initial training capability and allocated two increments: Block 1A for Lot 2 (12 aircraft) and Block 1B for Lot 3 aircraft (17 aircraft). No combat capability is available in either Block 1 increment. (Note: Remaining development and testing of Block 0.5 initial infrastructure was absorbed into Block 1 during the program restructuring in 2011.)
  - Block 2A. The program designated Block 2A for advanced training capability and associated this block with Lots 4 and 5. No combat capability is available in Block 2A.
  - Block 2B. The program designated Block 2B for initial, limited combat capability for selected internal weapons (AIM-120C, GBU-32/31, and GBU-12). This block is not associated with the delivery of any production aircraft. Block 2B software will be used to retrofit earlier production aircraft.
  - Block 3i. Block 3i is Block 2A capability re-hosted on an improved integrated core processor for Lots 6 through 8.
  - Block 3F. The program designated Block 3F as the full SDD capability for production Lot 9 and later.
- The Patuxent River test site accepted two early production aircraft from Lot 3 (BF-17 and BF-18) to support mission systems development and testing, in accordance with guidance following the Technical Baseline Review (TBR) in October 2010. Aircraft BF-17 ferried to Patuxent River on October 4th and BF-18, on November 8th. BF-17 began radar signature testing soon after arrival; BF-18 has yet to fly test sorties.
- The four mission systems flight test aircraft, three assigned to the Edwards AFB test center, and one BF-17 assigned to Patuxent River, flew an average rate of 5.0 sorties per aircraft per month through November, exceeding the planned rate of 4.4 by 14 percent. Mission systems test aircraft flew 115 percent of the test flights planned through the end of November (222 sorties completed compared to 193 planned).
- The test team accomplished 95 percent of the planned 2012 baseline test points by the end of November (1,238 baseline test points accomplished, 1,308 planned). The team also accomplished an additional 610 test points for regression testing of additional revisions of Block 2A software.

Mission Systems Assessment

- The program made limited progress in 2012 in fielding capability, despite relatively high sortie and test point completion rates.
  - Software delivery to flight test was behind schedule or not complete when delivered.
    - Block 1 software has not been completed; approximately 20 percent of the planned capability has yet to be integrated and delivered to flight test.
    - The first version of Block 2A software was delivered four months late to flight test. In eight subsequent versions released to flight test, only a limited portion of the full, planned Block 2A capability (less than 50 percent) became available and delivered to production. Block 2A has no combat capability.
    - Block 2B software was planned to be delivered to flight test by the end of 2012, but less than 10 percent of the content was available for integration and testing as of the end of August. A very limited Block 1B software version was delivered to the Cooperative Avionics Test Bed aircraft in early November for integration testing.
    - The program made virtually no progress in the development, integration, and laboratory testing of any software beyond 2B. Block 3i software, required for delivery of Lot 6 aircraft and hosted on an upgraded processor, has lagged in integration and laboratory testing.
  - The test team completed 1,238 (95 percent) of the planned 1,308 baseline test points by the end of November. The team also completed an additional 610 points for regression of multiple versions of software. Although the test team accomplished test points in 2012 as planned, little flight testing of advanced mission systems capability has taken place. Additionally, current planning of baseline test points results in shortfalls in production aircraft capabilities that will persist into 2014. Only 2,532 (23 percent) of the 10,966 total mission systems test points planned for SDD have been accomplished as of the end of November 2012. Of those completed, 54 percent supported testing of basic mission systems capabilities, such as communications, navigation, and basic radar functions, with the remaining 46 percent being comprised of radar signature testing (which does not involve or require any mission systems capability), software maturity demonstrations, and verification of capabilities for early production aircraft delivery.
- Although all Lot 2 and Lot 3 aircraft – in the Block 1 configuration – were either delivered to the Services or awaiting final delivery as of the time of this report, the test team had accomplished only 54 percent (738) of the 1,371 test points in the original Block 1 test plan. This resulted in the Lot 2 and Lot 3 aircraft being accepted by the Services with major variances against the expected capabilities and added to a bow wave of test points that will have to be completed in the future.
  - For example, when six F-35A and six F-35B Lot 2 aircraft were delivered to the training center in the Block 1A configuration, only 37 of 51 Block 1A capabilities on contract were delivered. Subsequently, the program delivered ten Lot 3 aircraft to the training center in 2012 in a partial Block 1B configuration (three F-35As, five F-35Bs, and two F-35Bs produced for the United Kingdom).

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  - The Block 1B configuration was designed to provide an additional 35 capabilities; however, the program delivered only 10 prior to the delivery of the first Lot 3 aircraft. The program is in the process of upgrading Block 1A aircraft to the 1B configuration; however, no additional capabilities were delivered with the Block 1B configuration. Examples of expected capabilities that were not delivered include air vehicle and off-board prognostic health management tools, instrument landing system (ILS) for navigation, distributed aperture system (DAS) video displaying in the helmet, corrosion data recording capability, and night vision imaging integration with the helmet.
- The Services began accepting Lot 4 aircraft in the Block 2A configuration in November with major variances against the expected capabilities. The program plans to continue to develop and test the incomplete and remaining Block 2A capabilities using incremental versions of Block 2A software and update the aircraft previously delivered with partial capabilities in late 2013. The continued development and testing of Block 2A software will be accomplished concurrently with the Block 2B software capabilities.
- Simultaneous development of new capabilities, associated with the next blocks of software, competes with the flight test resources needed to deliver the scheduled capability for the next lot of production aircraft.
  - For example, the testing needed for completion of the remaining 20 percent of Block 1 capabilities and 50 percent of Block 2A capabilities will have to be conducted while the program is introducing Block 2B software to flight test. Software integration tasks supporting Block 2B (and later increments) were delayed in 2012 as contractor software integration staff were needed to support Block 2A development, test, and anomaly resolution.
  - This process forces the program to manage limited resources, including the software integration labs, the cooperative avionics test bed aircraft, and the mission systems test aircraft, to address the needs of multiple versions of software simultaneously. The demand on flight test to complete test points for verification of capability for production software releases, while simultaneously accomplishing test points for expanding development of capability will continue to challenge the test team and add to the inherent concurrency of the program. The program intends Block 3i to enter flight test in mid-2013, which will be conducted concurrently with the final 15 months of Block 2B flight test. The program intends for Block 3F to enter a 33-month developmental flight test period in early 2014.
- Recognizing the burden and challenges caused by the concurrency of production and flight test, the Program Office is developing a capability management plan and review board to evaluate priorities and trades of capabilities within blocks and for deferral out of SDD if necessary.
- Shortfalls in the test resources required to test mission systems electronic warfare capabilities under operationally realistic conditions were identified by DOT&E in February. The needed resources and funding were being considered by the Department at the time of this report.
- Discoveries included:
  - The test team continued to work through technical problems with the helmet-mounted display system, which is deficient. The program was addressing five problems at the time of this report. Jitter, caused by aircraft vibrations and exacerbated by aircraft buffet, makes the displayed information projected to the pilot hard to read and unusable under certain flight conditions. Night vision acuity is not meeting specification requirements. Latency of the projected imagery from the DAS is currently down to 133 milliseconds, below the human factors derived maximum of 150 milliseconds, but still requires additional testing to verify adequacy. Boresight alignment between the helmet and the aircraft is not consistent between aircraft and requires calibration for each pilot. Finally, a recently discovered technical problem referred to as “green glow” has been experienced when light from the cockpit avionics displays leaks into the helmet-mounted display and degrades visual acuity through the helmet visor under low ambient light conditions. The test team is planning additional, dedicated ground and flight testing to address these technical problems.
  - Electronic warfare antenna performance of the first three production lots of aircraft was not meeting contract specification requirements. Poorly designed connectors created signal distortion in the six antenna apertures embedded in the aircraft. The Program Office determined that 31 aircraft are affected and require additional testing of each antenna. Testing of the apertures began on SDD aircraft at Edwards AFB in November. Progress in verifying the performance of the electronic warfare system will be affected until additional testing of the apertures in the aircraft is completed and any necessary retrofits accomplished on the mission systems test aircraft.
  - Helmet-mounted display video imagery needed to successfully analyze and complete portions of the mission systems test plans cannot be reliably recorded on either the portable memory device or the data acquisition recording and telemetry pod. The program began testing fixes in August. Until resolved, the overall impact is 336 total mission systems test points that are not achievable.
  - The program projects utilization rates for the two processors that support the panoramic cockpit display to be greater than 100 percent when assessed against Block 3 capabilities. The program initiated plans to optimize the core processor software to reduce these rates.
  - The program is tracking mission system software stability by analyzing the number of anomalies

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observed as a function of flight time. Current program objectives for early mission system software in flight test are to have integrated core processor and Communications/Navigation/Identification Friend or Foe (CNI) anomaly rates be 15 hours or more between events. Recent reports for the latest mission systems software in flight test – version 2AS2.8 – show a rate of 6.3 hours between anomalies based on 88 hours of flight test.

Weapons Integration

- Weapons integration includes flight sciences, mission systems, and ground maintenance support. Testing includes measuring the environment around the weapon during carriage (internal and external), handling characteristics of the aircraft, safe separation of the weapon from the aircraft, and weapons delivery accuracy events.
- In 2012, the program conducted detailed planning of the weapons integration events necessary to complete SDD. This planning yielded a schedule for completing weapons integration for Block 2B and Block 3F combat capability.
- The test team conducted the flight sciences loads, flutter, and environmental testing necessary to certify a limited Block 2B carriage envelope of the F-35A and F-35B aircraft for Joint Direct Attack Munition, GBU-12 laser guided bomb, and the AIM-120 air-to-air missile to enable the start of active flight testing. As of the end of October, this testing had achieved captive carriage and first safe separation of an inert AIM-120 missile (on the A model) and inert Joint Direct Attack Munition (on both the A and B model). However, to date, weapons integration has been limited by the following deficiencies:
  - Instrumentation
  - Data recording shortfalls
  - Deficient mission systems performance in radar, Electro-Optical Targeting System (EOTS), fusion, and the helmet
  - Lack of radar fusion support to the AIM-120 air-to-air missile
  - EOTS inability to accurately track and designate targets for the air-to-ground munitions,
  - Deficient fused situational awareness presentation to the pilot
- The successful execution of the detailed schedule developed this year was dependent on:
  - The ability of the program to deliver mission systems capability required to start weapons integration in April 2012
  - Adequate margin in the test schedule to accommodate repeated testing, cancellations due to weather, range assets, and operational support
  - Reliable instrumentation and range support
- None of these assumptions have proven true, adding risk to the execution of the overall schedule. Deferrals of mission systems capabilities to later blocks and delays for corrections to test instrumentation and data recording have removed the schedule margins. The impact of these delays will potentially require an additional 18 months added to the schedule for weapons integration events.

Static Structural and Durability Testing

- Durability testing on the ground test articles of all three variants continued in 2012; progress is measured in aircraft lifetimes. An aircraft lifetime is defined as 8,000 Equivalent Flight Hours (EFH), which is a composite of time under different test conditions (i.e., maneuver and buffet for durability testing). In accordance with the SDD contract, all three variants will complete two full lifetimes, or 16,000 EFH of durability testing. The completion dates for the second aircraft lifetimes are late 2014 for the F-35B and early 2015 for the F-35A and F-35C. Plans for a third lifetime of durability testing for all three variants are under development.
- The F-35A ground test article, AJ-1, completed the first of two planned aircraft lifetimes in August, as planned. F-35A durability testing continued into the second planned aircraft lifetime at the time of this report, completing 9,117 EFH as of December 5, 2012.
- F-35B durability testing on BH-1 was restarted in January after a 16-month break caused by the discovery, analysis, and repair of a crack in a wing carry-through bulkhead at 1,055 EFH. Since restarting, an additional 5,945 hours of testing had been completed by the end of October, bringing the total test time to 7,000 EFH and putting the testing ahead of the restructured 2012 plan to complete 6,500 hours by the end of the year.
- F-35C durability testing began in March and the test article, CJ-1, had completed 4,000 EFH of fatigue testing as of October, as scheduled.
- Component durability testing for two lifetimes of the vertical tails was completed for the F-35A and F-35B during 2012. This testing was started in August for the F-35C. Component testing of the horizontal tail for the F-35C completed 8,000 EFH, or one lifetime, in May, and an additional 2,000 EFH by the end of October. (Component testing of the horizontal tails for the F-35A and F-35B completed two lifetimes of testing in 2011.)
- The program redesigned the F-35B auxiliary air inlet doors, required for STOVL operations, and began flight testing in 2012. Redesigned doors have been installed on the static loads test article (BG-1) and completed static loads testing in early November, followed by the start of durability testing. The report from the static testing is scheduled to be completed by the end of 2012; however, the results of the durability testing are not scheduled to be available until mid-2013. The program has already ordered, received, and begun installing retrofit kits for the auxiliary air inlet door modifications on fielded Lot 4 aircraft.
- Discoveries from durability testing included significant findings in both the F-35A and F-35B ground test articles.
  - In the F-35A, a crack was discovered on the right wing forward root rib at the lower flange (this is in addition to the crack found and reported in the FY11 Annual Report).

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Also, a crack was found by inspection in the right hand engine thrust mount shear web in February. Testing was halted while the crack was inspected and analyzed, then restarted to complete subsequent blocks of testing.
  - In the F-35B, the program halted testing in December 2012 after multiple cracks were found in a bulkhead flange on the underside of the fuselage during the 7,000-hour inspection. Root cause analysis, correlation to previous model predictions, and corrective action planning were ongoing at the time of this report. Other cracks were previously discovered in the B-model test article; one on the right side of the fuselage support frame in February and one at a wing pylon station in August, both of which were predicted by modeling. Another crack in the shear web tab that attaches to the support frame was discovered in March. Also, excessive wear was found on the nose landing gear retractor actuator lugs and weapons bay door hinges. All of these discoveries will require mitigation plans and may include redesigning parts and additional weight.
- The results of findings from structural testing highlight the risks and costs of concurrent production with development. The Program Office estimates of the weight changes to accommodate known limited life parts discovered so far from structural testing are shown in the table below. These weight increases are in the current weight status reports for each of the variants. Discoveries during the remaining two years of structural testing will potentially result in more life-limited parts and associated impacts to weight and design.

Variant	Number of Life Limited Parts	Retrofit Weight Increase to Early LRIP Aircraft (prior to production cut-in)	Production Weight Increase (cut-in varies from LRIP 4 to LRIP 7)
F-35A	19	38 pounds	20 pounds
F-35B	20	123 pounds	33 pounds
F-35C	7	5 pounds	1 pound

Modeling and Simulation

Verification Simulation (VSim)

- The Verification Simulation (VSim) is a man-in-the-loop, mission software-in-the-loop simulation developed to meet the operational test agencies' requirements for Block 2B OT&E and Block 3 IOT&E.
- The program continued detailed technical reviews of the VSim with the contractor and subcontractors supplying its component models during 2012. Sensor model reviews took place for the electronic warfare, radar, and DAS infrared sensors. The program held similar detailed reviews for the inertial navigation system (INS) and Global Positioning System (GPS) models, as well as for the VSim Battle Space Environment (BSE), a collection of background environment models with which the sensor and navigation system models interact.
- At the time of this report, the program was tracking 11 formal risks with regard to VSim, 4 of them characterized as high risk, the other 7 characterized as moderate. These 11 risks fall into 4 general categories:
  - Risks associated with timeliness of VSim software delivery, completeness with regard to modeled capabilities, and discrepancies between VSim and aircraft software due to mismatches in the software versions that are current in VSim and those that are current in the aircraft at any given time.
  - Risks associated with the timeliness, completeness, and production-representativeness of data from flight testing and other testing used to verify and validate VSim.
  - Risks regarding the time and manpower needed to analyze VSim validation data and perform accreditation assessments.
  - Fundamental risks regarding the ability of VSim to faithfully replicate all aspects of F-35 and threat systems performance.
- In addition to the risks cited by the Program Office, DOT&E has highlighted shortfalls in the test resources needed to gather key elements of data required for validation of the VSim for IOT&E, in particular for electronic warfare performance. These shortfalls are a function of limitations in the test assets currently available to represent threat systems. DOT&E has made formal recommendations to address the shortfalls.

Other Models and Corporate Labs Activity

- The Program Office has accredited 7 of the 28 models and simulations currently planned to support verification of the F-35.
- The program accredited three models intended for use in contract specification verification in 2012. These are the Ejection Seat Model, the Support Enterprise Model (SEM), and the Automatic Dynamic Analysis of Mechanical Systems (ADAMS) model. A fourth model, Prognostic Health Management (PHM) Coverage Analysis Tool (PCAT), is in final accreditation review at the Program Office at the time of this report.
  - The Ejection Seat Model is used to verify the terrain clearance requirements of the F-35 ejection seat under different flight conditions.
  - SEM is used to assess the logistics infrastructure requirements of the fielded F-35 Air System.
  - ADAMS is used to assess weapon store-to-aircraft clearances and interfaces during loading, carriage and separation, evaluating weapon arming and de-arming, and other weapons system separation functions.
  - PCAT is a spreadsheet-based application that rolls-up probabilities of fault isolation and fault detection to various line replaceable units.
- The program plans to accredit 6 models and simulations intended for use in requirements verification plan in 2013, with the remaining 15 accreditations due between 2014 and the end of SDD in 2017.
- The Program Office has identified challenges for 2013 with respect to obtaining and analyzing, in a timely fashion, the

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validation data needed to accredit the GPS System Model Simulation (GSMS) and Modeling System for Advanced Investigation of Countermeasures (MOSAIC) infrared countermeasures effectiveness models.

- In 2011, the Air Force airworthiness authorities identified the pilot escape system installed in the early LRIP aircraft as a serious risk. Validation of expected performance of the F-35 escape system is supported by modeling the ejection seat as well as the effectiveness of the transparency removal system for the canopy during the ejection sequence.
  - For the ejection seat model, the program used data from sled testing under straight and level conditions to predict performance of the ejection seat under non-zero angle-of-bank (including inverted) conditions. Interactions between the pilot, the ejection seat, and the canopy during the ejection sequence, however, are not well understood, particularly during other than straight and level ejection conditions.
  - Testing of the transparency removal system under off-nominal conditions to better understand these interactions was scheduled for March 2012. The program expects this testing to take place in December 2012.

Training System

- The program initiated flight operations at the Integrated Training Center, Eglin AFB, Florida, in 2012 with both the F-35A and F-35B aircraft.
  - The Air Force accepted six F-35A aircraft from production Lot 2 in 2011 at Eglin in the Block 1A configuration, but did not commence flight operations until March 2012 when the Air Force airworthiness authorities provided the necessary flight clearance, which limited operations to previously qualified F-35 pilots. In July, the Air Force changed the flight clearance to allow pilots not previously qualified to fly at Eglin, which paved the way for F-35A pilot training to begin later in the year.
  - The program delivered six F-35B aircraft from production Lot 2 to Eglin between January and May 2012. Also in May, Navy airworthiness authorities provided a flight clearance for F-35B flight operations to begin at Eglin.
  - The program added 10 production Lot 3 aircraft – all in the Block 1B configuration – to Eglin by the end of October 2012 to support flight training: 3 F-35A aircraft between July and August and 7 F-35B aircraft (5 for the Marine Corps and 2 for the United Kingdom) between July and October. These deliveries were later than planned due to late availability of an adequate Autonomous Logistics Information System (ALIS) at Eglin to support the Block 1B aircraft configuration.
- In July 2012, DOT&E recommended to the Air Force, the operational test agencies, and the JSF Program Office that the training OUE be delayed until the system matures and possesses some combat capability relevant to an operational evaluation.
  - DOT&E identified seven indicators which highlighted a lack of overall system maturity: abort rates higher, and trending flat, than the Air Force risk assessment identified for a maturing system; the trend in discovery as indicated by the rate of new Deficiency Reports; the high number of "workarounds" needed to support maintenance and sortie generation activities (including engineering support from the contractor); lack of a water-activated parachute release system (qualification testing is delayed until 2013); incomplete testing of the escape/ejection system; low overall availability rates; and no new information or plans to address deficiencies in the Integrated Caution and Warning System.
  - The Air Force elected to begin the training OUE in early September 2012, and concluded it in mid-November 2012. The system under test had no combat capability. Flight training events were limited to basic aircraft maneuvers called for in the "familiarization" pilot transition syllabus, which is a six-flight module of training. Pilots were trained in basic ground procedures, take-off, approach/landing, and formation flight. Radar, electronic warfare, countermeasures, and weapons capabilities were not included in the syllabus as they were either restricted from being used or were not available. Flight maneuvering was restricted to 5.5 g's, 550 knots, 18 degrees angle-of-attack, and below 39,000 feet altitude, and was further constrained by numerous aircraft operating limitations that are not suitable for combat. The maintenance environment and support systems are still immature. Sortie generation was dependent on contractor support personnel, maintenance personnel had to use workarounds to accommodate shortfalls in ALIS, and the Joint Technical Data was incomplete. DOT&E will provide an independent report on the evaluation in early 2013.
- As of the end of OUE in November, 276 sorties and 366 hours had been flown in the F-35A aircraft at Eglin, with the first flights in March, and 316 flights and 410 hours flown in the F-35B, since starting in May.
  - Aircraft availability rates for the F-35A varied from less than 5 percent to close to 60 percent in a given week from the first flights in March through October, with an average availability of less than 35 percent, meaning three of nine aircraft were available on average at any given time. For the F-35B, availability rates varied monthly as well from less than 5 percent to close to 50 percent, with similar average rates over the six months of flying.
  - Cumulative air abort rates over the same time period were also similar between the two variants with approximately five aborts per 100 flight hours observed (4.7 for the F-35A and 5.3 for the F-35B). In 2010, the Air Force used air abort rate as an objective metric for assessing the maturity needed to start flight training, with a goal of 1.0 air abort per 100 flight hours as a threshold to start an evaluation of the system's readiness for training. Ground abort rate was one ground abort in seven scheduled sorties (0.14) for the F-35A and one in eight (0.13) for the F-35B.
- The center conducted maintenance training for experienced maintenance personnel for both the F-35A and F-35B

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during 2012. As of the end of November, 542 personnel had completed training in one or more of the maintenance courses. Graduates from the maintenance courses at the training center will support initial service bed down and training locations.

Air System-Ship Integration and Ship Suitability Testing

F-35B

- The Program Office continued planning efforts to support the next F-35B developmental testing deployment to USS *Wasp* in August 2013. Through the middle of November, the test team had accomplished 79 vertical landings in 2012 (358 total to date) and 212 short takeoffs (631 to date). Control law changes were made to the vehicle system software as a result of flying qualities observed during the first deployment to USS *Wasp* in 2011. Regression testing of the control law changes was accomplished in 2012.
- Discoveries affecting F-35B operations on L-class ships include:
  - Assessment of ship capabilities were inconclusive in determining whether there would be adequate storage requirements for lithium battery chargers and spares, gun pods, and the ejection seat carts as some of the support equipment and spares from legacy systems may no longer be required. Additional data are required to determine a path forward.
  - Propulsion system module containers do not meet all shipboard requirements. Due to the fragility of certain propulsion system components, there is significant risk to engines during transport to and from ships, using the current containers. The Program Office is coordinating a propulsion system fragility analysis which is expected to lead to a container redesign.
  - Concept of operations for managing and using the classified materials area remains to be resolved.

F-35C

- A redesign of the arresting hook system for the F-35C to correct the inability to consistently catch cables and compensate for greater than predicted loads took place in 2012. The redesign includes modified hook point shape to catch the wire, one-inch longer shank to improve point of entry, addition of damper for end-of-stroke loads, increased size of upswing damper and impact plate, addition of end-of-stroke snubber. In 2012, the following occurred:
  - Initial loads and sizing study completed showed higher than predicted loads, impacting the upper portion of the arresting hook system (referred to as the "Y frame," where loads are translated from the hook point to the aircraft) and hold down damper (January 2012)
  - Risk reduction activities, including cable rollover dynamics testing at Patuxent River (March 2012), deck obstruction loads tests at Lakehurst (April 2012)
  - Flight tests with CF-3 using new hook point and new hold down damper design at Lakehurst (August 2012)
  - 72 of 72 successful roll-in tests with MK-7 and E-28 gear
  - 5 of 8 successful fly-in tests; 3 of 8 bolters (missed wire)
  - Preliminary design review of updated design completed (August 15, 2012)
- Analysis by Service and program ship integration teams identified several aircraft-ship interface problems for resolution.
  - Deficient capability to transfer recorded mission data to ship intelligence functions for analysis, in particular video data recorded by the JSF.
  - Ships are unable to receive and display imagery transmitted via Link 16 datalink by JSF (or other aircraft).
  - The design of the JSF Prognostic Health Maintenance downlink is incomplete, creating concerns for sufficient interfaces with ship systems and Information Assurance.

Live Fire Test and Evaluation

System-Level Test Series

- The program completed two of the eight system-level test series. The first, LF-19D Flight-Critical System-Level test series, was conducted on the first F-35A flight test aircraft to assess the ballistic tolerance of the flight control system and its supporting systems (e.g., power thermal management, vehicle management, and electrical power systems).
- This test series targeted components of the redundant vehicle management and electrical power systems, demonstrating their ability to automatically reconfigure after damage, and to continue to operate with no obvious effect on the ability of the aircraft to remain in controlled flight.
- The Live Fire Test team is assessing the aircraft vulnerability damage thresholds and whether testing properly explored the intended ballistic damage modes (e.g., interference or arcing between 270 Volt, 28 Volt, and signal lines; loss of flight actuator stiffness; and/or impact to singularly vulnerable components such as the flight actuator ram cylinder).
- One test in this series, LF-19D-27, demonstrated aircraft vulnerabilities to fires associated with leaks from the PAO system. The aircraft uses flammable PAO in the avionics coolant system, which has a large footprint on the F-35. The threat in this ballistic test ruptured the PAO pressure line in the area just below the cockpit, causing a sustained PAO-based fire with a leak rate of 2.2 gallons per minute (gpm).
  - The program assessed that a similar event in flight would likely cause an immediate incapacitation and loss of the pilot and aircraft. The test article, like the production design, lacks a PAO shutoff system to mitigate this vulnerability.
  - In 2008, the JSF Executive Steering Board (JESB) directed the removal of PAO shutoff valves from the F-35 design to reduce the aircraft weight by 2 pounds. Given the damage observed in this test, the JESB directed the program to re-evaluate installing a PAO shutoff system through its engineering process based on a cost/benefit analysis and the design performance capabilities. The ballistic test results defined the significance of this vulnerability. However, the test also showed that a shutoff system needs

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to outperform other fielded systems. To be effective, it must trigger on smaller leak rates, down to 2 gpm versus the 6 gpm typical of other aircraft designs, without causing excessive false alarms.
  - The program is currently working to identify a low leak rate technical solution. The Program Office will consider operational feasibility and effectiveness of the design, along with cost, to decide if PAO shutoff valves will be reinstated as part of the production aircraft configuration.
- Another test in this series, LF-19D-16, identified the vulnerability associated with fuel fires from fueldraulic system leaks. The fueldraulic system is a fuel-based hydraulic system used to control the engine exhaust nozzle. It introduces a significant amount of fuel plumbing to the aft end of the engine and, consequently, an increased potential for fire.
  - This test confirmed the increase in vulnerability. The original aircraft design included flow fuses, also known as excess flow check valves, to cutoff fuel flow when a leak is sensed due to downstream fuel line damage or failure. As a result of the weight-reduction initiative, the JESB directed removal of fueldraulic fuses from the production design in 2008 to provide weight saving of 9 pounds. Fuses, however, were still part of the non-weight-optimized F-35A test article used in this test.
  - While a ballistic test with fragment threats demonstrated that the fueldraulic system poses a fire-related vulnerability to the F-35, the leak rates generating the fire were insufficient to trigger the fuses. Since the fuses did not shut off the flow, the result was a sustained fuel-based fire.
  - The Program Office is accepting the increased vulnerability associated with the fueldraulic system and is currently not considering reinstating the fueldraulic fuses in the production aircraft configuration.
- A Computation of Vulnerable Area Tool analysis shows that the removal of the PAO coolant and fueldraulic systems results in a 25 percent increase in aircraft vulnerability.

Ballistic Analysis

- The program used a computational analysis, supported by single fragment test data, to evaluate the vulnerabilities of the F-35 to multiple missile warhead fragment hits for several encounter geometries.
  - Multiple missile warhead fragment hits are more combat-representative and will result in combined damage effects that need to be assessed. For example, aircraft may not be lost due to a fuel leak from a single missile fragment impact, but combined leakage from multiple impacts could prevent the aircraft from returning to base.
  - There are potentially other such combined effects that are not known or expected and that, due to the analysis limitations, cannot be identified. These limitations will introduce a level of uncertainty in the F-35 vulnerability assessment.
- The program used the results of the completed tests to assess the effects of ballistic damage on the capability of the aircraft to maintain controlled flight.
  - These estimates are typically expressed as a function of time intervals, i.e., 0 minutes ("catastrophic kill"), 30 seconds ("K-kill"), 5 minutes ("A-kill"), 30 minutes ("B-kill"), etc.; however, the program categorized them in terms that supported their specification compliance, i.e., "Loss of Aircraft" or the ability to "Return to Forward Line of Troops (FLOT)."
  - These limited categories do not provide detailed insight into the vulnerability of the aircraft. For example, with a Return to FLOT criterion of 55 minutes, if the aircraft could fly for 45 minutes it would still be classified as a Loss of Aircraft and no understanding is provided concerning the aircraft's actual capability to maintain controlled flight for those 45 minutes. Such an assessment does not provide insight into the actual operational survivability of the aircraft because it only focuses on the ability of the aircraft to fly for 55 minutes even though, in some instances, the pilot might need much less time to return to friendly territory.

STOVL Propulsion System Test Series

- The program completed most of the STOVL propulsion system test series. The Program Office temporarily suspended this test series due to budget constraints without notifying DOT&E. The remaining lift fan-to-clutch drive shaft and lift fan clutch static and dynamic tests have been postponed until FY13.
  - The LFT&E STOVL propulsion system tests confirmed that back-ups to hydraulic systems that configure the STOVL propulsion system for its various operating modes worked as intended.
  - The completed test events targeted the lift fan rotating and stator components while the fan was static. The program assumed that the lift fan would most likely be hit while in forward flight and that hits during STOVL flight were less likely. In most test events, the system was then run up to simulate a STOVL landing sequence.
  - The results indicated that test damage introduced no measurable degradation in STOVL propulsion performance, including cascading damage effects, and would be undetectable by the system and the pilot. However, due to concerns for catastrophic lift fan or drive train damage that would risk loss of the test article for subsequent tests, this test series did not include dynamic tests to the inboard portion of the lift fan blade, where the cross section is smaller and centrifugal forces are higher, making failure more likely.
  - The engine manufacturer is providing damage tolerance estimates for these threat-target conditions, which still need to be evaluated.

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Vulnerability Assessment

- The program completed an intermediate vulnerability assessment (the previous one was in 2008) incorporating results from ballistic tests conducted to date, a higher-fidelity target model, and modified blast and fire curves.
  - The ORD requires an analysis of two types of fragments, a 30 mm high explosive incendiary (HEI) round and a Man-Portable Air Defense System (MANPADS) missile. The analysis showed that none of the F-35 variants met the operational requirements for the HEI threat. The analysis also showed that the F-35A and F-35C have shortfalls to the two fragment threats. The F-35B variant is more resistant to these two threats, primarily due to less fuel carried and some additional shielding provided by the lift fan.
  - Reinstatement of the dry bay fire extinguishing system, in combination with the PAO shutoff valve, and the fueldraulic fuses could make all F-35 variants compliant for all four specified ballistic threats, as currently defined in the ORD.

OBIGGS Redesign

- The program is redesigning OBIGGS to address deficiencies identified in earlier fuel system simulator test series (LF-09B) to meet the vulnerability requirements during all critical segments of a combat mission and to provide an inert tank atmosphere for internal lightning protection.
- The program reported several design changes during the Phase II Critical Design Review to:
  - Fix the vent-in-during-dive problem, wherein fresh oxygen-laden air is drawn into the fuel tanks in a dive
  - More uniformly distribute the nitrogen enriched air (NEA) throughout the fuel tanks
  - Ensure NEA quality
  - Inform the pilot when the system is not inerting the ullage
- The program will conduct verification and certification testing and analyses to confirm the performance of the new OBIGGS design on all three aircraft variants. These tests are expected to begin in FY13.
- Additionally, the current fuel tank venting design is inadequate to vent the tanks during a rapid descent. As a result of the related OBIGGS and tank venting deficiencies, flight operations are currently not permitted within 25 miles of known lightning conditions. Moreover, below 20,000 feet altitude, descent rate is restricted to 6,000 feet/minute. Dive rates can be increased to up to 50,000 feet/minute but only if the maneuver includes 4 minutes of level flight for fuel tank pressurization purposes. Neither restriction is acceptable for combat or combat training.

Chemical/Biological Survivability

- The F-35 Chemical Biological Warfare Survivability Integrated Product Team built and demonstrated a prototype full-scale shelter-liner for chemical/biological containment. The demonstration did not evaluate effectiveness, and the program determined the design was too complex for field use.
- The team is working on a lighter, more robust and less complex redesign. The integration of the new shelter-liner with the chemical and biological agent decontamination support system is ongoing with a full-up demonstration test planned for FY14.

Issues Affecting Operational Suitability

- Overall suitability performance demonstrates the lack of maturity in the F-35 as a system in developmental testing and as a fielded system at the training center.
- Reliability requirements are identified for system maturity (50,000 fleet hours), but the program predicts a target at each stage of development that projects growth toward the maturity requirement.
  - Analysis of data through May 2012 shows that flight test and Lots 1 through 3 aircraft demonstrated lower reliability than those predictions. Demonstrated Mean Flight Hours Between Critical Failure for the F-35A was 5.95 hours, for the F-35B was 4.16 hours, and for the F-35C was 6.71 hours, which are 60, 70, and 84 percent of the level predicted by the program for this point in development of each variant, respectively.
  - Although reliability results appear to indicate improvement over those reported in last year's report (2.65 for F-35A, 2.05 for F-35B, and 2.06 for F-35C, reflecting data through September 2011), too few flight hours have accrued (approximately 1.5 percent of the flight hours required to achieve reliability maturity) for these results to be predictive, and although they are based on a rolling three-month measure of reliability, have shown great variation between measurement periods.
- In 2012, the program updated the reliability growth plan for the first time since 2006. Significant contributors to low reliability by variant are:
  - F-35A – power and thermal management system, CNI, lights, fuel system, landing gear, fire control and stores, integrated air vehicle architecture, and electrical power system
  - F-35B – electrical power system, power and thermal management system, integrated air vehicle architecture (which includes the Integrated Core Processing system and the cockpit displays including the HMDS), access doors and covers, landing gear, oxygen system, stabilizers, lift fan system, crew escape and safety, and flight control system
  - F-35C – engine controls, power and thermal management system, electrical power system, landing gear, and integrated air vehicle architecture
- The amount of time spent on maintenance, or measures of maintainability, of flight test and Lots 2 and 3 aircraft exceeds that required for mature aircraft.

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- Mean corrective maintenance time for critical failures by variant are:
  - F-35A – 9.3 hours (233 percent of the requirement of 4.0 hours)
  - F-35B – 8.0 hours (178 percent of the requirement of 4.5 hours)
  - F-35C – 6.6 hours (165 percent of the requirement of 4.0 hours)
- Mean times to repair by variant are:
  - F-35A – 4.2 hours (168 percent of the requirement of 2.5 hours)
  - F-35B – 5.3 hours (177 percent of the requirement of 3.0 hours)
  - F-35C – 4.0 hours (160 percent of the requirement of 2.5 hours)
- Maintainability of the system hinges on improvements and maturation of Joint Technical Data (JTD), and the ALIS functions that facilitate flight line maintenance.

• The program is developing and fielding the ALIS in incremental capabilities, similar to the mission systems capability in the air vehicle. It is immature and behind schedule, which has had an adverse impact on maintainability, and delays delivery of aircraft.
- ALIS 102 is a limited capability and is the version fielded only at the Eglin training center. It was required for receiving and operating the early Lot 2 and Lot 3 aircraft, as well as for conducting initial aircrew and maintenance training. This version of ALIS operates with independent subsystems and requires multiple workarounds to support sortie generation and maintenance activities.
- ALIS 103 is intended to provide the initial integration of ALIS subsystems. The program intended to make it available for the fielding of Lot 3 and Lot 4 production aircraft at new operating locations in 2012: Edwards AFB, California, and Yuma Marine Corps Air Station (MCAS), Arizona. The program discovered problems with ALIS security in February 2012, which in turn delayed the delivery of Lot 3 and Lot 4 aircraft from July to late in 2012. A formal evaluation of ALIS 103 was delayed until September 2012, and was completed in October. The first F-35B was delivered to Yuma MCAS on November 16, 2012, and the first F-35A to Edwards AFB is delayed to December 2012. These aircraft were ready for delivery as early as July 2012. A version of ALIS 103 has been fielded at Yuma MCAS for use with ground operations of the three Lot 4 F-35Bs delivered in November. Flight operations at Yuma are expected to start in early 2013. Similarly, ALIS 103 has been fielded at Edwards AFB and is expected to provide support delivery of aircraft and flight operations in early 2013.
- Future versions of ALIS will complete the integration of subsystems. In 2012, the program made limited progress toward the development of a deployable unit-level version of ALIS by demonstrating only half of the unclassified functionality on representative hardware. The deployable version will weigh approximately 700 pounds less than the existing 2,466-pound system, and will be modular to enable transportation. Funding for development is being secured by the Program Office.

• The program continued the process of verifying JTD, the set of procedures used to operate and maintain the aircraft.
- As of the end of September 2012, the program had verified 38 percent of the technical data modules (6,879 out of an estimated 17, 922), which is close to the planned schedule. The program plans to have approximately 11,600 (65 percent) of all the modules verified by the end of FY13.
- Although the program has improved plans and dedicated effort for verifying and fielding JTD, the lack of JTD causes delays in maintenance actions that consequently affect the availability of aircraft.

• Data Quality and Integration Management (DQIM) are essential parts of the overall Autonomic Logistics Global Sustainment process for the F-35. Experiences with early production aircraft indicate an immature database that contains missing or incorrect part numbers, serial numbers, and missing scheduling rules for inspections. Effective data quality and integration management require that part numbers, serial numbers, and inspection requirements for each aircraft be loaded into ALIS for mission debrief or maintenance actions to occur.

Progress in Plans for Modification of LRIP Aircraft

• The program and Services continued planning for modifications of early LRIP aircraft to attain planned service life and the final SDD Block 3 capability.
- In January, the aircraft assembly plant received the first production wing parts, which the program redesigned as a result of life limits imposed by structural analyses. The assembly plant received the first F-35A forward root rib in January for in-line production of AF-31, the first Lot 5 F-35A aircraft, which is scheduled to deliver in 2013.
- The operational test agencies worked with the Services and the Program Office to identify modifications required. Due to the extension of the program, which resulted in very early procurement (relative to the end of SDD) of the aircraft planned for IOT&E, there is high risk that the Service plans for updating the aircraft intended for IOT&E will not be production-representative. Activities to study the depth of the problem occurred in 2012; however, a comprehensive, funded plan that assures a production-representative set of aircraft for OT&E is not yet available. This is a significant and fundamental risk to an adequate IOT&E.
- The first set of depot-level modifications for the F-35A aircraft are scheduled to begin at Hill AFB in early 2014. Initial F-35B modifications will be completed at the initial operating base at Yuma MCAS, Arizona. Modification of the Auxiliary Air Inlet Door, which is required for vertical landings, has begun on the first F-35B delivered to Yuma in November.

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Recommendations

- Status of Previous Recommendations. The program and Services are satisfactorily addressing four of seven previous recommendations. The remaining three recommendations concerning use of objective criteria for evaluating flight test progress, integrating flight test of an operational mission data load, restoring shut-off valves, and redesigning the OBIGGS are outstanding.
- FY12 Recommendations. The program should:
  1. Make the corrections to Revision 4 of the JSF TEMP, as described by DOT&E September 2012 memorandum disapproving the TEMP
     - Include the electronic warfare test annex that specifically required operationally-realistic threats
     - Include adequate criteria for entering the final preparation period prior to IOT&E
     - Schedule the start of the final preparation period prior to IOT&E to begin no earlier than the Operational Test Readiness Review, approximately 90 days prior to the end of the air-worthiness certification phase of development
  2. Conduct dedicated ALIS end-to-end developmental testing of each incremental ALIS version that supports the production aircraft.
  3. Assure modification and retrofit plans for OT aircraft make these aircraft fully production-representative.
  4. Ensure the contractor is meeting VSim requirements for operational testing and is addressing data requirements to support the validation, verification, and accreditation during developmental testing.
  5. Assure the schedules of record for weapons integration, VSim, and mission data load production/verification are consistent with the Integrated Master Schedule.
  6. Continue with the OBIGGS redesign efforts to ensure the system has the capability to protect the aircraft from threat and lightning induced fuel tank explosions while on the ground and during all phases of a combat mission without compromised maneuver limits.
  7. Continue the PAO system redesign efforts and reinstall a PAO shutoff valve to protect the aircraft from PAO-based fires.
  8. Reconsider the removal of the fueldraulic fuses. The program should design and reinstate an effective engine fueldraulic shutoff system to protect the aircraft from fuel-induced fires.
  9. Reconsider the removal of a dry bay fire extinguisher system from other than the Integrated Power Package dry bay. Prior F-35 Live Fire testing showed that the fire suppression system could be designed to successfully extinguish fires from the most severe ballistic threats.
  10. Provide a higher-resolution estimate on how long the aircraft could continue to maintain controlled flight after a ballistic event. Remaining flight time, expressed in smaller time intervals (e.g., 30 seconds, 5 minutes, 30 minutes, etc.) is a more informative metric than the current “Loss of Aircraft” or “Return to FLOT” metric.

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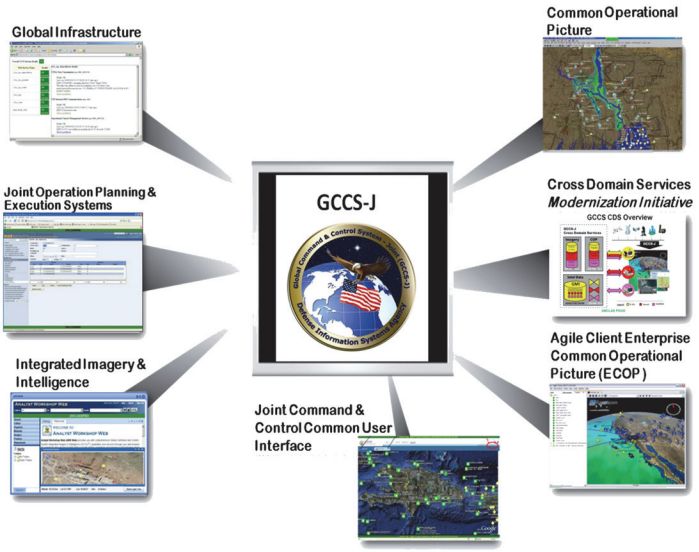
Global Command and Control System – Joint (GCCS-J)

Executive Summary

- Defense Information Systems Agency (DISA) development focused on implementing high priority capability enhancements, software corrections, and infrastructure improvements to both Global Command and Control System – Joint (GCCS-J) Global and Joint Operation Planning and Execution System (JOPES).

GCCS-J Global

- DISA developed GCCS-J Global v4.2.0.9 (Global v4.2.0.9) to provide operational enhancements, remediate security vulnerabilities, and correct Common Operational Picture (COP) and Integrated Imagery and Intelligence (I3) application deficiencies discovered while testing and operating previous Global releases. DISA expended significant effort to ensure Global v4.2.0.9 would be acceptable for fielding into the Air Operations Centers (AOCs) that support the Joint Force Air Component Commanders. Global v4.2.0.9 testing occurred at both the Combatant Command (CCMD) and AOC levels.
- CCMD-level testing:
  - The Joint Interoperability Test Command (JITC) conducted CCMD-level operational testing in December 2011, revealing substantially fewer defects than OT&E conducted during the past two years. However, due to known and encountered test limitations, operational testing was insufficient to determine operational effectiveness and suitability for both the CCMD and higher-echelon environments in which Global v4.2.0.9 will be used.
  - Regression testing of Global v4.2.0.9 Updates 1 and 2 conducted by DISA in 2012 showed the release was acceptable at CCMD and higher echelons. Four Category I deficiencies and 15 Category II deficiencies remain. Testing in the more demanding AOC environment is required to fully evaluate Global v4.2.0.9 corrections.
- AOC-level testing:
  - DOT&E used data collected during AOC-level developmental and operational testing, which implemented Global 4.2.0.9 in a more complex configuration, to assess Global v4.2.0.9 performance at lower echelons.
  - The Air Force conducted developmental testing at Langley AFB, Virginia, of Air Operations Center – Weapon System (AOC-WS) 10.1 Recurring Event (RE)11, which used Global v4.2.0.9 as a significant portion of RE11.
  - The 605th Test and Evaluation Squadron (TES) conducted a Force Development Evaluation (FDE) of RE11 with Global v4.2.0.9 Update 1, which revealed that most critical deficiencies had been fixed, but faster servers would be required to process the data demands of the AOC environment. Global v4.2.0.9 Update 1 testing occurred on upgraded servers, and showed a four-fold improvement in processing speed, satisfying AOC data demands.
  - 605th TES integrated developmental/operational testing of RE12 with Global v4.2.0.9 Update 2 in December 2012 is expected to address the remaining 4 Category I and 15 Category II deficiencies of Global v4.2.0.9 within the AOC environment.



GCCS-J JOPES

- DISA developed GCCS-J JOPES v4.2.0.2 (JOPES v4.2.0.2) to provide the initial framework for the Transportation Tracking Account Number (TTAN), to upgrade JOPES Data Network Services (JDNETS) software to reduce dependency on the Deliberate and Crisis Action Planning and Execution Segment (DCAPES) and support enhanced system monitoring, to resolve existing problem reports, and to upgrade commercial off-the-shelf (COTS) software.
- JITC conducted low-risk operational testing in February and March 2012 of JOPES v4.2.0.2 at five CCMD sites, three Service sites, the Joint Staff Support Center, and at the DISA Headquarters facility laboratories at Fort George G. Meade, Maryland. JOPES operational users validated the JOPES v4.2.0.2 capabilities during the execution of an end-to-end Time-Phased Force Deployment Data scenario.
  - The scenario demonstrated the ability to identify high-level mission requirements, source operational forces and materials, verify force and material availability and mission readiness, and schedule transportation to move those forces and materials.

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- Decoupling of database exchanges between DCAPES and JOPES allowed each program to upgrade without affecting the other.
- Enhanced system monitoring allowed JOPES system administrators to better track JOPES system performance, such as transaction queues and query backlogs, across all four enclaves and deployable servers.

System

- GCCS-J is a command and control system utilizing communications, computers, and intelligence capabilities. The system consists of hardware, software (COTS and government off-the-shelf), procedures, standards, and interfaces that provide an integrated near real-time picture of the battlespace necessary to conduct joint and multi-national operations. GCCS-J consists of a client/server architecture using open systems standards, government-developed military planning software, and an increasing use of World Wide Web technology.
- GCCS-J consists of two main components:
  - Global v4.2.0.9 (Force Protection, Situational Awareness, Intelligence applications)
  - JOPES v4.2.0.2 (Force Employment, Projection, Planning, and Deployment/Redeployment applications)

Mission

- Joint Commanders utilize the GCCS-J to accomplish command and control.

GCCS-J Global

- Commanders use GCCS-J Global:
  - To link the National Command Authority to the Joint Task Force, Component Commanders, and Service unique systems at lower levels of command
  - To process, correlate, and display geographic track information integrated with available intelligence and environmental information to provide the user a fused battlespace picture
  - To provide I3 capabilities
  - To provide a missile warning and tracking capability
- The AOC uses GCCS-J Global:
  - To build the air picture portion of the COP and maintain its accuracy
  - To correlate or merge raw track data from multiple sources
  - To associate raw Electronics Intelligence data with track data
  - To perform targeting operations

GCCS-J JOPES

- Commanders use GCCS-J JOPES:
  - To translate policy decisions into operation plans (OPLANs) to meet U.S. requirements for the employment of military forces
  - To support force deployment, redeployment, retrograde, and reposturing
  - To conduct contingency and crisis action planning

Major Contractors

- Government Integrator: DISA
- Software Developers:
  - Northrop Grumman – Arlington, Virginia
  - SAIC – Arlington, Virginia
  - Pragmatics – Arlington, Virginia

Activity

GCCS-J Global

- DISA developed Global v4.2.0.9 to provide operational enhancements, remediate security vulnerabilities, and correct COP and I3 application deficiencies discovered while testing and operating previous Global releases. DISA expended significant effort to ensure Global v4.2.0.9 would be acceptable for fielding into the AOCs that support the Joint Force Air Component Commanders.
- Global 4.2.0.9 is a critical upgrade urgently needed by the AOC-WS program and the operational AOCs. The AOC-WS baseline uses legacy Global v4.0.2 and cannot employ critical I3 capabilities due to outstanding Category I problems when used in the AOC operational environment. Global v4.2.0.9 testing occurred at both the CCMD and AOC levels.
- CCMD-level testing:
  - JITC conducted operational testing of Global v4.2.0.9 at U.S. European Command and U.S. Southern Command in December 2011 in accordance with a DOT&E-approved test plan.
  - DISA conducted a regression test of Global v4.2.0.9 Update 1 in January and February 2012, after correction of deficiencies.
  - DISA conducted a regression test of Global v4.2.0.9 Update 2 in June 2012 after making corrections to additional deficiencies identified during Update 1 and RE11 testing.
- AOC-level testing:
  - The Air Force performed developmental testing of RE11 in January 2012 at Langley AFB, Virginia. A significant portion of this testing involved additional testing of the Global v4.2.0.9 baseline as it was approved by DISA for fielding within an AOC environment.
  - The 605th TES performed an FDE of RE11, to include the corrections in Global v4.2.0.9 Update 1, at Langley AFB in March 2012. Additional testing of

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Global v4.2.0.9 Update 1, modified to work on newer, more powerful servers, occurred at Langley AFB in May 2012. During RE11, the 605th TES implemented Global v4.2.0.9 in a more complex configuration. This configuration has more live interfaces and the ability to load up to 30,000 active tracks into the battlespace picture, which was significantly more demanding than previous operational testing.
  - The 605th TES plans to test Global v4.2.0.9 Update 2 in an AOC environment in December 2012.

GCCS-J JOPES

- DISA developed JOPES v4.2.0.2 to provide the initial framework for TTAN, to upgrade JDNETS software to reduce dependency on DCAPES and support enhanced monitoring, to resolve existing problem reports, and to upgrade COTS software.
- JITC, in conjunction with the GCCS-J Program Office, conducted low-risk operational testing of JOPES v4.2.0.2 at five CCMD sites, three Service sites, the Joint Staff Support Center, and at the DISA Headquarters facility laboratories at Fort George G. Meade, Maryland. Testing occurred in February and March 2012.

GCCS-J SORTS

- DISA transitioned the GCCS-J Status of Resources and Training System (SORTS) component to the Defense Readiness Reporting System Implementation Office in late October 2011.

Assessment

GCCS-J Global

- DOT&E approved the JITC plan for operationally testing Global v4.2.0.9 for fielding to CCMD and higher-echelon locations, but not for fielding at lower-echelon sites such as AOCs. DOT&E is using operational test data collected during RE11 to adequately assess Global v4.2.0.9 performance at lower echelons.
- CCMD-level testing:
  - Results of JITC operational testing demonstrated significant improvement relative to past testing. Substantially fewer defects were discovered during the CCMD testing than was the case in nearly every OT&E conducted during the past two years. However, the aggregate of known and encountered test limitations rendered this test insufficient to determine operational effectiveness and suitability for both the CCMD and higher-echelon environments in which Global v4.2.0.9 will be used.
  - Many Global v4.2.0.9 interfaces were not available or tested at the two CCMD test locations, and stress levels for the COP and intelligence portion of GCCS-J are not operationally representative for AOC usage.
  - The CCMD COP loading was well below the 30,000 and 35,000 active tracks, with missile events, expected within the AOC environment.
  - Each CCMD location had only three to six intelligence users participating in the test, whereas lower-echelon locations may have over 100 users.
  - Regression testing in May 2012 showed that Global v4.2.0.9 Update 1 was acceptable at CCMD and higher echelons, albeit with 4 Category I and 15 Category II deficiencies requiring correction before fielding to AOCs. Regression testing on Update 1 demonstrated the ability of Global v4.2.0.9 Update 1 to handle the more demanding track loads experienced in the AOC environment.
  - DISA conducted regression testing of Global v4.2.0.9 Update 2 to validate corrections for 1 of 4 Category I and 10 of 15 Category II AOC deficiencies identified during Update 1 and RE11 testing. However, testing in an AOC environment is required to fully evaluate Global v4.2.0.9 corrections.
- AOC-level testing:
  - DOT&E used data collected at Langley AFB, Virginia, during developmental and operational testing of RE11, which used Global v4.2.0.9 as a significant portion of RE11, to assess Global v4.2.0.9 performance at lower echelons. RE11 offered a test environment more operationally representative of AOC usage and is expected to provide the remaining operational data needed to adequately assess the system once testing is complete.
  - Developmental testing of the RE11 revealed several critical deficiencies with the Global v4.2.0.9 baseline. JITC did not find these deficiencies during the earlier operational testing at the two CCMD sites due to test limitations. AOC users applied more stress to the Global COP and I3 application suite than was experienced at the CCMD test sites.
  - The FDE of RE11 with Global v4.2.0.9 Update 1 revealed that the most critical deficiencies had been fixed, but that faster servers would be required to process the data demands experienced in the AOC environment. Global v4.2.0.9 Update 1 was tested on upgraded servers, showing a four-fold improvement in processing speed and satisfying AOC data demands.
  - 605th TES integrated developmental/operational testing of RE12 with Global v4.2.0.9 Update 2 in December 2012 is expected to address the remaining 4 Category I and 15 Category II deficiencies of Global v4.2.0.9 within the AOC environment.

GCCS-J JOPES

- JOPES operational users validated the JOPES v4.2.0.2 capabilities during the execution of an end-to-end Time-Phased Force Deployment Data scenario. JITC also observed DISA testers perform functional testing of the system to verify that system changes did not introduce new errors to the previously fielded software.

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- The supported CCMD identified high-level requirements for forces and materials to accomplish a particular OPLAN.
- CCMD users sourced operational forces and materials to support the OPLAN, along with required timelines and locations.
- CCMD users verified forces and material were available and mission-ready.
- U.S. Transportation Command users scheduled transportation for the operational forces and materials to meet the supported CCMD requirements.

• TTAN implementation added new data fields, providing operational users with an initial capability to track the status of individuals and pieces of equipment for improved situational awareness. Upgrades to JDNETS web services did not adversely affect users' ability to monitor, plan, and execute mobilization, deployment, employment, and sustainment activities associated with joint operations. The upgrades to JDNETS improved JOPES administrator system-monitoring capabilities with an enhanced dashboard. Users successfully installed COTS software upgrades, following installation procedures, with no discrepancies noted.

Recommendations

• Status of Previous Recommendations. DISA addressed all previous recommendations.

• FY12 Recommendation.

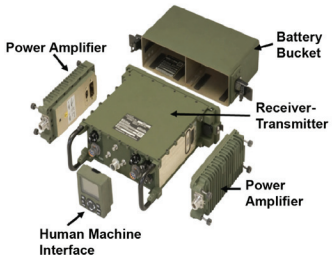
1. Operational testing of significant Global v4.2.0.9 upgrades will require testing by both CCMD and AOC communities to successfully address the significant test limitations encountered at the CCMD locations. Operational testing needs to include operationally representative stress levels by users, significant COP data processing of dynamically updating tracks, and live data flowing across all critical interfaces.

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Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) Manpack Radio

Executive Summary

- In May 2011, the Defense Acquisition Executive (DAE) approved a Milestone C Low-Rate Initial Production (LRIP) decision of 100 Manpack radios.
- In June 2011, the Army conducted a Manpack Limited User Test (LUT) as a part of its 2011 Network Integration Evaluation (NIE) 11.2. The Manpack radio demonstrated poor reliability, transmission range, and voice quality that restricted the unit's ability to accomplish its mission. These same problems were observed during previous developmental testing.
- In May 2012, the Deputy Assistant Secretary of Defense, Developmental Test and Evaluation (DASD DT&E) published a Manpack Assessment of Operational Test Readiness (AOTR) that stated the radio was not sufficiently mature to enter the planned Manpack Multi-Service Operational Test and Evaluation (MOT&E). DASD DT&E recommended that the Manpack radio not proceed to MOT&E to allow for corrective actions and additional developmental testing.
- In May 2012, the Army Test and Evaluation Command (ATEC) conducted the Manpack radio MOT&E as a part of its NIE 12.2. DOT&E assessed the Manpack radio as not operationally effective due to the poor performance of the Single Channel Ground and Airborne Radio System (SINCGARS) waveform and not operationally suitable due to a failure to meet reliability or availability requirements. The Manpack radio AOTR had outlined these major MOT&E deficiencies prior to operational test.
- In September 2012, the Army conducted a Government Development Test (GDT) 3 to demonstrate improvements in MOT&E deficiencies to support a planned 1QFY13 second LRIP decision.
- In October 2012, the DAE approved a second LRIP decision for 3,726 Manpack radios.
- The Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) program is schedule-driven and has reduced developmental testing to support an aggressive operational test schedule. Operational testing continues to reveal problems that developmental testing should have identified and fixed.
- The Army continues preparation for a future Manpack radio MOT&E-2, which will include competition of Program of Record and alternate vendors.







System

- JTRS is a family of software-programmable and hardware-configurable digital radios intended to provide increased interoperability, flexibility, and adaptability to support numerous tactical communications requirements.
- The JTRS HMS program provides handheld and two-channel Manpack radios supporting Army, Marine Corps, Navy, and Air Force operations. The program develops Small Form Fit (SFF) radio configurations that include the stand-alone Army Rifleman Radio and embedded SFF variants that serve in Army host platforms such as the SFF-B (Shadow Unmanned Aerial Vehicle), SFF-B (V)1 (Nett Warrior), and the SFF-D (Small Unmanned Ground Vehicle).
- The program strategy has two phases of HMS production. The JTRS HMS program developed the Rifleman Radio as part of its Phase 1 effort to provide software programmable radios with National Security Agency (NSA) Type 2 encryption of unclassified information that could operate a networking waveform. Phase 2 consists of developing the Manpack radio to provide software programmable radios with NSA Type 1 encryption of classified information.
- The Manpack radio is a two-channel radio with military GPS that:
  - Is capable of operating at various transmission frequencies using the Soldier Radio Waveform (SRW), the SINCGARS waveform, and current military satellite communications waveforms. The JTRS HMS program intends to host the Mobile User Objective Satellite waveform on the Manpack radio as an objective capability.
  - Operates up to 20 watts at maximum power output.
  - Allows Soldiers to participate in doctrinal networks and transmit Position Location Information.

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Mission

Commanders from the Army, Marine Corps, Navy, and Air Force use Manpack radios to:

- Communicate and create networks to exchange voice, video, and data using legacy waveforms or the SRW during all aspects of military operations.
- Integrate JTRS SFF variants into host platforms to provide networked communications capabilities for users engaged in land combat operations to support voice, video, and data across the air, land, and sea battlespace.

Major Contractor

General Dynamics, C4 Systems – Scottsdale, Arizona

Activity

- The Army conducted four developmental tests of the Manpack radio:
  - Manpack Customer Test, conducted at Fort Benning, Georgia, February 7 – 11, 2011.
  - Manpack GDT, conducted at the Electronic Proving Ground (EPG), Fort Huachuca, Arizona, April 15 – 22, 2011 (originally planned for 45 days).
  - Manpack GDT 2, conducted at the EPG, Fort Huachuca, Arizona, March 2 – 30, 2012.
  - Manpack GDT 3, conducted at the EPG, Fort Huachuca, Arizona, September 19 through October 3, 2012.
- In May 2011, the DAE approved a Milestone C LRIP decision to procure 100 Manpack radios of a total acquisition objective of 71,814 radios. The Manpack radio LRIP is intended to support future developmental and operational tests.
- In June 2011, the Army conducted the Manpack LUT as part of its NIE 11.2 at White Sands Missile Range, New Mexico. The Army used the LUT to assess the performance of the Manpack radio under numerous mission scenarios executed by a cavalry troop.
- In March 2012, the program conducted GDT 2 to assess the Manpack radio and verify fixes of deficiencies highlighted during the 2011 LUT.
- In May 2012, ATEC conducted the Manpack radio MOT&E as part of the Army's NIE 12.2 at White Sands Missile Range, New Mexico. ATEC tested the Manpack radio under various missions conducted by a motorized infantry company. Soldiers used the Joint Enterprise Network Manager to plan, load, and monitor the Manpack radio waveforms. The test was conducted in accordance with a DOT&E-approved test plan.
- The Army conducted a Manpack radio GDT 3, from September through October 2012. The test was intended to verify fixes to reliability and performance deficiencies found during the MOT&E and GDT 2.
- On October 11, 2012, the DAE approved a second LRIP for an additional 3,726 Manpack radios to increase the total LRIP procurement to 5 percent of the total acquisition objective.
- The Army is developing a JTRS HMS Manpack Radio Acquisition Strategy Report and Test and Evaluation Master Plan. These documents are required for future developmental and operational testing.

Assessment

- The Army reduced the first Manpack GDT (April 2011) from a scheduled 45 days to 8 days in order to place radios into the NIE 11.2 Manpack LUT.
- Both the Manpack Customer Test and GDT highlighted deficiencies in performance and poor reliability. The Army determined that the Manpack radio's SINCGARS waveform was not ready for test and therefore did not test it during the shortened GDT.
- During the NIE 11.2 Manpack LUT, the radio demonstrated the following:
  - Ability to transmit and receive on two channels
  - Ability to distribute Position Location Information throughout the network
  - Poor reliability
  - Poor transmission range performance of the SRW and SINCGARS waveforms that constricted the operational area of the cavalry troop
  - Inconsistent voice quality
  - SINCGARS waveform did not support unit operations and was immature for operational test
- The NIE 11.2 Manpack LUT reliability data collection was not adequate and not conducted in accordance with the DOT&E-approved test plan.
- The Manpack radio in GDT 2 demonstrated improved performance of the SRW, but the performance of the SINCGARS waveform and reliability were poor.
- In May 2012, DASD DT&E published a Manpack radio AOTR that stated the radio was not sufficiently mature to enter the planned MOT&E due to developmental test deficiencies that included poor reliability and an immature SINCGARS waveform. DASD DT&E recommended that the Manpack radio not proceed to MOT&E to allow for corrective actions and more developmental testing.
- Based on the NIE 12.2 Manpack radio MOT&E, DOT&E made the following assessment:
  - Not operationally effective due to the poor voice quality and limited range of the SINCGARS waveform compared to legacy SINCGARS radios. Since the SINCGARS performance was poor, the company leadership resorted to using satellite-based chat communications of the Blue Force Tracker.

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- The SRW performance was good and the Soldiers were able to employ the Manpack radio for intra-company voice and data communications.
- Not operationally suitable due to a failure to meet reliability and availability thresholds.
- No waveform met the Army's reliability requirement. The SRW was the most used waveform and demonstrated a reliability of 163 hours Mean Time Between Essential Function Failure (MTBEFF) compared to the radio's revised requirement of 477 hours. This translates to a 63 percent chance of completing a 72-hour mission compared to a requirement of 86 percent.
- No waveform met the availability requirement. The SRW achieved an operational availability of 0.86 compared to a 0.96 requirement.
- The radio's design allowed Soldiers to accidentally zero the Manpack radio. This action erases all radio presets and communications security, and requires 20 – 25 minutes to restore the Manpack radio to operation.
- The Army's integration of the radios into Mine Resistant Ambush Protected vehicles was poor and reduced the radio's performance. The program did not test vehicle integration in developmental testing prior to the MOT&E.

• During GDT 3, the Manpack radio demonstrated:
- Improved performance of the SINCGARS waveform that met requirements of mounted and dismounted transmission range, voice quality, and call completion rates under benign conditions of developmental test.
- Poor reliability with the SRW waveform demonstrating 177 hours MTBEFF compared to the Manpack requirement of 477 hours. This translates to a 66 percent chance of completing a 72-hour mission compared to a requirement of 86 percent.

• The Army continues preparation for a future Manpack radio MOT&E-2, which will include competition of Program of Record and alternate vendors.
• The JTRS HMS program is schedule-driven and has reduced time for developmental testing to support an aggressive operational test schedule.

Recommendations

• Status of Previous Recommendations. The JTRS HMS program did not address the previous recommendations to perform adequate developmental testing prior to operational testing and to complete necessary documentation to support developmental and operational testing.
• FY12 Recommendations. The Army should:
1. Ensure that adequate developmental testing is performed prior to future operational tests.
2. Correct any JTRS HMS deficiencies noted at the May 2012 Manpack radio MOT&E prior to the scheduled MOT&E-2.
3. Perform a holistic reliability growth analysis to rigorously assess Manpack radio maturity and to provide the information needed to develop a detailed plan for achieving required reliability.
4. Complete necessary Manpack radio documentation to support future developmental and operational testing.

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Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) Rifleman Radio

Executive Summary

- In January 2011, the Army conducted a Verification of Correction of Deficiencies (VCD) test with a redesigned version of the Rifleman Radio. During the VCD test, Soldiers demonstrated that the redesigned Rifleman Radio corrects most of the radio's deficiencies and provides some improvement to reliability.
- In May 2011, the Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) program received a Milestone C Low-Rate Initial Production (LRIP) decision based upon the improved performance the Rifleman Radio demonstrated during the VCD. The Defense Acquisition Executive (DAE) approved the Rifleman Radio LRIP quantity of 6,250 radios.
- In November 2011, the Army conducted a Rifleman Radio IOT&E intended to support a Full-Rate Production decision as a part of the Network Integration Evaluation 12.1. DOT&E assessed the Rifleman Radio to be operationally effective with poor reliability.
- From February through April 2012, the Army conducted Governmental Developmental Test (GDT) 2.3 and GDT 2.3a to complete developmental testing normally completed prior to IOT&E. During GDT 2.3, the Rifleman Radio demonstrated new failures not observed in IOT&E. The program performed a software update and demonstrated fixes during GDT 2.3a. The Rifleman Radio showed improvement but did not meet its reliability requirement.
- In May 2012, the DAE decided to pursue a competitive Full-Rate Production decision and approved a second LRIP decision for 13,077 radios.
- The JTRS HMS program is schedule-driven and did not complete developmental testing prior to IOT&E to support an aggressive operational test schedule. Operational testing has continued to reveal problems that should have been discovered and fixed during developmental testing.

System

- JTRS is a family of software-programmable and hardware configurable digital radios intended to provide increased interoperability, flexibility, and adaptability to support numerous tactical communications requirements.
- The JTRS HMS program provides handheld and two-channel Manpack radios supporting Army, Marine Corps, Navy, and Air Force operations. The program develops Small Form Fit (SFF) radio configurations that include the stand-alone Army Rifleman Radio and embedded SFF variants that serve in Army host platforms such as the SFF-B (Shadow Unmanned Aerial Vehicle), SFF-B (V)1 (Nett Warrior), and the SFF-D (Small Unmanned Ground Vehicle).
- The program strategy has two phases of HMS production. The JTRS HMS program developed the Rifleman Radio as part of its Phase 1 effort to provide software programmable radios with National Security Agency (NSA) Type 2 encryption of unclassified information that could operate a networking waveform. Phase 2 consists of developing the Manpack radio to provide software programmable radios with NSA Type 1 encryption of classified information.
- The Rifleman Radio is a one-channel radio with commercial GPS that:
  - Is capable of operating at various transmission frequencies using the Soldier Radio Waveform (SRW)
  - Operates at 5 watts maximum power output
  - Allows Soldiers to participate in Army doctrinal voice networks and transmit Position Location Information



Mission

Army leaders and Soldiers use Rifleman Radios to communicate and create networks to exchange voice, video, and data using the SRW during all aspects of military operations.

Major Contractor

General Dynamics, C4 Systems – Scottsdale, Arizona

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Activity

- The JTRS HMS program completed a redesign of the Rifleman Radio hardware and improved its software to address deficiencies identified during the 2009 Limited User Test. The redesigned Rifleman Radio features improvements in size, weight, battery life, and increased radio frequency power output.
- In January 2011, the Army conducted a Rifleman Radio VCD test at Fort Benning, Georgia, to demonstrate improvements in the redesigned radio.
- In May 2011, the DAE approved a Milestone C LRIP decision to procure 6,250 Rifleman Radios of a total acquisition objective of 193,279 radios.
- From October to November 2011, the Army Test and Evaluation Command conducted the Rifleman Radio IOT&E at White Sands Missile Range, New Mexico, as part of the Army's Network Integration Evaluation 12.1. The test was conducted in accordance with a DOT&E-approved test plan. Operational units tested the Rifleman Radio using the Soldier Radio Waveform Network Manager (SRWNM) to plan and load SRW network configurations into the radios. Two platoons of infantry engaged in a variety of mission scenarios employed the Rifleman Radio. An additional baseline infantry platoon, equipped with legacy radios, completed similar missions for comparison purposes.
- February through March 2012, the Army conducted the Rifleman Radio GDT 2.3 at the Electronic Proving Ground at Fort Huachuca, Arizona. The Army conducted this GDT to complete developmental testing that the Army should have completed prior to IOT&E.
- In April 2012, the Army conducted a follow-on developmental test, GDT 2.3a. The Army used this follow-on event to confirm fixes to deficiencies observed during GDT 2.3.
- On May 23, 2012, the DAE approved a second LRIP for an additional 13,077 Rifleman Radios to increase the total LRIP procurement to 10 percent of the total acquisition objective.
- The Army continues preparation for a future Rifleman Radio IOT&E-2 that will include competition of Program of Record and alternate radio vendors.

Assessment

- During the 2009 Rifleman Radio Limited User Test, DOT&E assessed the radio as useful during mission preparation, movement, and reconnaissance activities. The radio demonstrated poor performance during combat operations and poor reliability.
- During the 2011 Rifleman Radio VCD test, the redesigned radio demonstrated the following improvements:
  - Operational reliability of 277 hours Mean Time Between Essential Function Failure (MTBEFF) compared to the revised requirement of 477 hours. This translates to a 92 percent chance of completing a 24-hour mission compared to a requirement of 95 percent.
  - Transmission range met the radio's requirement of 2,000 meters in an urban setting and 1,000 meters in dense vegetation.
  - Radio battery life exceeded the radio's revised 8-hour requirement.
- During the 2011 Rifleman Radio IOT&E, the production-representative radio demonstrated the following:
  - Usefulness in supporting combat leaders and Soldiers in a wide variety of missions.
  - Enhanced ability for Soldiers to execute mission command and communicate using voice and data.
  - Increased effective radio transmission range relative to legacy radios.
  - Reduced reliability of 161 hours MTBEFF compared to the requirement of 477 hours. This translates to an 86 percent chance of completion of a 24-hour mission compared to a requirement of 95 percent.
  - Vulnerabilities in Information Assurance and electronic warfare.
- During the 2011 Rifleman Radio IOT&E, the SRWNM did not support the unit's mission in planning and loading radios in a timely manner due to cumbersome software and poor training provided to Soldiers.
- During the 2012 GDT 2.3, the Rifleman Radio demonstrated reliability of 157 hours MTBEFF. This reduced reliability was due to new failures (not observed in IOT&E) that included spontaneous reboots, loss of the ability to transmit, or loss of the ability to receive. The program attributed these failures to software updates. The JTRS HMS program updated the software and performed GDT 2.3a to demonstrate fixes.
- The Rifleman Radio during the GDT 2.3 and 2.3a demonstrated the following results:
  - Estimated reliability of the Rifleman Radio is 310 hours MTBEFF, which is a 93 percent chance of completing a 24-hour mission against a 95 percent requirement.
  - Message completion rate of 84 percent and a call completion rate of 95 percent. The Army's requirement for both is 90 percent.
  - The radio met its requirements for Position Location Information updates, size, weight, power, and retention of cryptographic information.
- The Rifleman Radio program is schedule-driven. As a result, the Army did not perform the necessary developmental testing required to ensure success during the Rifleman Radio IOT&E. Although the first developmental test event was conducted prior to IOT&E, the Army conducted the remaining two developmental test events several months after the operational test.

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Recommendations

- Status of Previous Recommendations. The JTRS HMS program did not address the previous recommendations to perform adequate developmental testing prior to operational testing and to complete necessary documentation to support future developmental and operational testing.
- FY12 Recommendations. The Army should address the previous recommendations and:
  1. Ensure that adequate developmental testing is performed prior to future operational tests.
  2. Complete necessary Rifleman Radio documentation to support future developmental and operational testing.

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Joint Tactical Radio System (JTRS) Network Enterprise Domain (NED) Network Managers

Executive Summary

- Joint Tactical Radio System (JTRS) Enterprise Network Manger (JENM) runs both the JTRS Wideband Networking Waveform (WNW) Network Manager (JWNM) and the Soldier Radio Waveform (SRW) Network Manager (SRWNM). JENM allows signal personnel to manage the networks of JTRS software-defined radio sets.
- Of the JENM management functions (planning, loading, monitoring, controlling, and reporting) SRWNM and JENM/SRWNM testing examined the planning, loading, and monitoring functions.

SRWNM

- The Navy's Commander, Operational Test and Evaluation Force (COTF) conducted operational testing from October through November 2011. Based on results from testing, DOT&E issued an Operational Assessment report in August 2012 assessing SRWNM as not capable of supporting the unit's mission and unreliable in supporting JTRS Rifleman Radio. The SRWNM lacks the capability needed for Soldiers to use it quickly and effectively to configure a network. The Army had not developed the tactics, techniques, and procedures needed for Soldiers to employ the SRWNM in support of units using Rifleman Radios during combat operations.

JENM/SRWNM

- In a July 2012 Operational Assessment report, DOT&E assessed JENM/SRWNM as effective and suitable in support of JTRS Manpack radios operating the SRW in part due to applying the lessons learned from the SRWNM IOT&E. Soldiers also used JENM/SRWNM to successfully load Rifleman Radios as part of the Army's Network Integration Evaluation (NIE) activities. Lessons learned from the SRWNM IOT&E applied during the JENM/SRWNM IOT&E included improvements to Soldier training, development and validation of the network plan, and concept of operations for loading and configuring the Manpack radios for the MOT&E.
- The test unit successfully used JENM/SRWNM to import a network plan, load the radios, and monitor the SRW network. However, Soldiers reported the monitoring capability had limited utility.

System

- JTRS Network Enterprise Domain (NED) software applications allow the JTRS software-defined radio sets to provide communications to tactical forces. The software applications include waveforms, enterprise networking services (route and retransmission among waveforms), and enterprise network management.



- The waveforms and enterprise networking services software are integrated into and are considered part of a JTRS radio set, and their performance is part of that reported for the JTRS Handheld, Manpack, and Small Form Fit (HMS); and Airborne, Maritime, and Fixed Station (AMF) radio products.
- The enterprise network management software is separate from the JTRS radio sets and is deployed on designated commercial off-the-shelf laptop computers.
  - The current network manager products are: JWNM for managing WNW networks; and SRWNM for managing SRW networks of JTRS software-defined radio sets.
  - In FY12, the JTRS NED Program Office integrated SRWNM onto the JENM. In the near future, the Program Office intends to integrate both JWNM and SRWNM onto a single JENM laptop computer.
  - Enterprise network management functions include planning, loading, monitoring, controlling, and reporting.
  - The planning function develops the network parameters and creates a Radio Mission Data Set file.
  - The loading function transfers the Radio Mission Data Set file into the HMS or AMF radio sets to configure them.
  - The monitoring function provides a near real-time display of the WNW or SRW network status and the conditions of the radios.
  - The controlling function allows the signal Soldier to make changes to the network, to include sending commands to the radio operator, changing the configuration parameters

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of the radio sets, or conducting cryptographic functions (rekey, zeroize, and transfer).
- The reporting function records all network management events and makes the data available for analysis.

Mission
- Forward-deployed military forces use JTRS radios to communicate and create networks to exchange voice, video, and data during all aspects of tactical military operations.
- Signal staffs use the JENM to plan, load, monitor, control, and report on network operations involving JTRS HMS and AMF software-defined radio sets, as well as non-developmental item radios, running WNW and SRW.

Major Contractors
- The Boeing Company, Phantom Works Division – Huntington Beach, California (the JWNM and JENM developer)
- ITT Electronics Systems Division – Clifton, New Jersey (the SRWNM developer)

Activity
- DOT&E approved the JTRS NED Test and Evaluation Master Plan in July 2011.

SRWNM
- DOT&E approved the SRWNM IOT&E plan on October 7, 2011.
- COTF conducted the SRWNM IOT&E in support of the Rifleman Radio IOT&E from October through November 2011. Problems with the network plan and use of SRWNM began to affect the start date for the Rifleman Radio IOT&E. Contractor support was used to correct the plan and reload the radios to ensure the Rifleman Radio test would start on time. As a result, the SRWNM test was not conducted in accordance with the DOT&E-approved test plan.

JENM/SRWNM
- DOT&E approved the JENM/SRWNM IOT&E plan on March 29, 2012.
- COTF conducted the JENM/SRWNM IOT&E as described in the DOT&E-approved test plan in support of the Army's NIE 12.2 and Manpack radio IOT&E in April and May 2012.
- The JTRS NED Program Office integrated the SRWNM software onto the JENM platform following the Rifleman Radio IOT&E (referred to as JENM/SRWNM).

JENM
- The JTRS NED Program Office continues development of the JENM, which will integrate the JWNM and SRWNM into a single network management product in FY13.

Assessment

SRWNM
- SRWNM developmental testing in FY11 confirmed the system's capability to plan networks, create mission data sets, and then load mission data sets for the Rifleman Radios loaded with the SRW. Per the Army concept of operations, there is no requirement for SRWNM to monitor the Rifleman Radio/SRW network, so this function was not demonstrated in the SRWNM IOT&E.
- DOT&E assessed SRWNM as not capable of supporting the unit's mission and the system demonstrated poor reliability in support of the Rifleman Radio. Soldiers could not use SRWNM to quickly and effectively configure a network. The Army had not developed adequate training or the necessary tactics, techniques, and procedures for Soldiers to employ the SRWNM in support of units using Rifleman Radios during combat operations.
- Shortfalls in the capability and use of SRWNM include the following:
  - Lack of troubleshooting procedures
  - Lack of a network plan validation event or process
  - Excessive time needed to load Rifleman Radios
  - Lack of procedures to distribute configured radios by mission
  - Lack of flexible radio configurations to support changing missions
- The single signal Soldier in the company was overwhelmed by the sheer amount of communications equipment he was responsible for operating and maintaining.

JENM/SRWNM
- DOT&E assessed JENM/SRWNM as effective and suitable in support of Manpack radios operating the SRW.
- Lessons learned from the SRWNM IOT&E were applied to the training, development, and validation of the network plan and concept of operations for loading and configuring Manpack radios. Soldiers using JENM/SRWNM also demonstrated the ability to successfully load Rifleman Radios as part of NIE activities.
  - The test unit successfully used JENM/SRWNM to import a network plan, load the radios, and monitor the SRW network. However, Soldiers reported the monitoring capability had limited utility.
  - Operational challenges with the use of JENM/SRWNM still exist. The process for planning and loading a network is cumbersome and time consuming (about 20-25 minutes per radio). This time includes several steps that include radio start up, loading the plan, loading the crypto keys, and checking the communications link. For the test, the company had 46 Manpack radios and 96 Rifleman Radios. In total, it took two Soldiers two to three days to load and check all the radios.

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- Dynamic task organization remains an operational deficiency because of the length of time it takes to change radio presets to match the task organization. The brigade estimated it would take 48 hours to modify the radio presets in the plan and reload all the radios with the new plan to allow the task organization of a single platoon to a different company.
- The JENM/SRWNM had no significant reliability problems. The JENM/SRWNM IOT&E results demonstrated that the software and hardware improvements corrected the deficiencies noted in the previous SRWNM IOT&E. Training was much better than that experienced in the previous SRWNM IOT&E based on Soldier input, but Soldiers reported that they would like to see more practical exercises and documented processes in future training.
- The single signal Soldier in the company was overwhelmed by the sheer amount of communications equipment he was responsible for operating and maintaining.
- Development and verification of the JTRS networks is a significant undertaking. The Army must determine who is going to develop the SRW network architecture/communication plans and translate those into JENM files and radio configuration files for the multi-Service units to be equipped with Manpack radios. It is not clear whether the Program Office can sustain the level of effort required to construct the needed inputs for each unit as JTRS radios are fielded across the force.

Recommendations

- Status of Previous Recommendations. The Army addressed two of the three recommendations for FY11. There is still no movement on developing an integrated test methodology for JENM developmental and operational testing. With the closing of the JTRS Joint Program Executive Office and the radio programs now all under separate program management, resolving this FY11 recommendation is critical to ensure JENM is properly tested.
- FY12 Recommendations. The Army should:
  1. Evaluate the force structure implications of adding JTRS radios and network management responsibilities into company-level organizations. The single signal Soldier in the company was overwhelmed by the sheer amount of communications equipment he was responsible for operating and maintaining.
  2. Determine who is going to develop the WNW and SRW network architecture/communications plans, and then translate those into JENM files and radio configuration files for the multi-Service units to be equipped with Manpack, Rifleman, and AMF radios.

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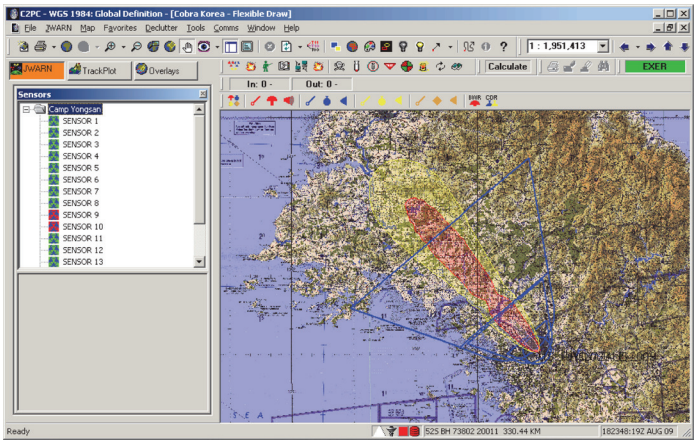
Joint Warning and Reporting Network (JWARN)

Executive Summary

- Joint Warning and Reporting Network (JWARN) software hosted on Global Command and Control System (GCCS) – Maritime is an operationally effective automated Chemical, Biological, Radiological, and Nuclear (CBRN) warning, reporting, and analysis tool for Navy operations to send warning reports to units at risk from a CBRN hazard in time to take protective action when the units are more than 10 kilometers downwind. The Navy should upgrade the GCCS – Joint version currently employed at its Maritime Operations Centers to GCCS – Joint with Plain Language Address (PLA) capability to utilize JWARN to send timely warning messages between battle groups and to other Services when ships are employing emissions control procedures.
- Based on FOT&E results, JWARN software hosted on GCCS – Maritime is operationally suitable and reliable. Operators with JWARN new equipment training are able to successfully execute basic-level analysis and reporting scenarios. During FOT&E, JWARN operators lost situational awareness during more complex CBRN attack scenarios and did not send appropriate and timely hazard warning reports.
- The JWARN Program Office should develop and field computer-based training that includes basic to advanced scenario exercises to increase operator skills and provide sustainment training.

System

- JWARN is a joint automated CBRN warning, reporting, and analysis software tool that resides on joint and Service command and control systems such as the GCCS – Army, GCCS – Joint, GCCS – Maritime, and Command and Control Personal Computer/Joint Tactical Common Workstation, or stand-alone computers.
- JWARN software automates the NATO CBRN warning and reporting process to increase the speed and accuracy of information sharing to support force protection decision making and situational awareness.
- JWARN uses the Common Operating Picture of the host command and control network to display ground maps; unit locations; location of CBRN events; and the predicted or actual location of hazards to support the Commanders' situational awareness and response capability.



Mission

JWARN operators in command cells support CBRN force protection, battlefield management, and operational planning by predicting chemical, biological, and nuclear hazard areas based on sensor and observer reports, identifying affected units and operating areas, and transmitting warning reports.

Major Contractor

Northrop Grumman Mission Systems – Orlando, Florida

Activity

- The Army Test and Evaluation Command and the Navy's Commander, Operational Test and Evaluation Force conducted follow-on operational testing of the JWARN hosted on GCCS – Maritime from June 25 – 29, 2012, at the Space and Naval Warfare Systems Center Pacific computer laboratory, in accordance with the DOT&E-approved operational test plan.
- DOT&E approved an updated Test and Evaluation Master Plan on March 19, 2012, to address follow-on developmental and operational testing of the JWARN when hosted on GCCS – Maritime.
- The program conducted developmental and reliability growth testing to demonstrate readiness for follow-on operational testing at the Space and Naval Warfare Systems Center Pacific computer laboratory in San Diego, California, from November to December 2011 with JWARN hosted on GCCS – Maritime and GCCS – Joint with PLA.
- DOT&E approved the JWARN follow-on operational test plan on June 5, 2012.

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Assessment

- JWARN software hosted on GCCS – Maritime provides an operationally effective automated CBRN warning, reporting, and analysis tool to send warning reports to units at risk from a CBRN hazard in time to take protective action if the units are more than 10 kilometers downwind for the initial hazard.
- During normal operations, U.S. Navy Expeditionary Strike Groups can exchange CBRN hazard warnings and reports with Navy Maritime Operations Centers for communication across the naval fleet and Services using JWARN and GCCS host e-mail capability. When ships are employing emissions control procedures to avoid being located by the enemy, e-mail capability is shut down. Ships in emissions control mode are able to send CBRN JWARN hazard warnings and reports using GCCS-Maritime PLA text messaging capability.
- The version of GCCS – Joint used by Navy Maritime Operations Centers does not have PLA capability. JWARN is not compatible with the current legacy software used by Navy Maritime Operations Centers to send PLA text messages. Personnel at the Navy's Maritime Operations Centers must manually enter information from JWARN reports into a legacy system with PLA capability to send CBRN warnings and reports to ships employing emission control procedures. This presents an opportunity for transcription errors and creates a delay that may cause CBRN warning messages to reach ships at risk too late to implement effective protective actions.
- During FOT&E, operators using JWARN demonstrated interoperability with a developmental version of GCCS – Joint with PLA capability. Fielding GCCS – Joint with PLA capability at Navy Maritime Operations Centers would speed delivery of CBRN warning messages when ships are implementing emissions control measures and are unable to receive e-mail communications.
- JWARN software hosted on GCCS – Maritime is operationally suitable. The JWARN software hosted on GCCS – Maritime is reliable. Operators with new equipment training are able to successfully execute basic-level analysis and reporting scenarios. However, JWARN operators require advanced training in order to successfully execute CBRN analysis and reporting when faced with complex CBRN attack scenarios.

Recommendations

- Status of Previous Recommendations. The program manager addressed all previous recommendations.
- FY12 Recommendations.

1. The Navy should work with the GCCS program to coordinate deployment of GCCS – Joint with PLA capability to Maritime Operations Centers with deployment of GCCS – Maritime (with JWARN).
2. The program manager should develop and field computer-based training that includes basic to advanced scenario exercises to increase operator skills and provide sustainment training.

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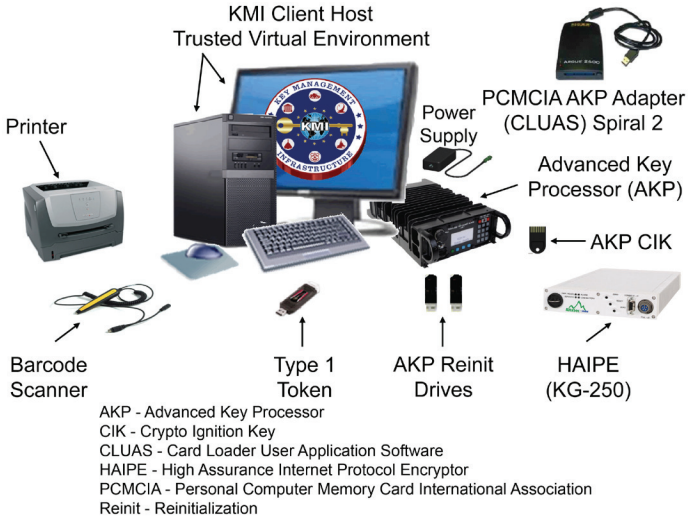
Key Management Infrastructure (KMI)

Executive Summary

- In January 2012, the Key Management Infrastructure (KMI) Program Management Office (PMO) and DoD Chief Information Officer (CIO) declared an acquisition cost and schedule threshold breach, resulting in a Critical Change Review of the program. Subsequently, the Chairman of the Joint Chiefs of Staff declared KMI essential to national security and OSD recertified the program to Congress.
- The Joint Interoperability Test Command (JITC) conducted an IOT&E from July until August 2012. The results were a marked improvement over previous operational assessments; however, there were still several operational effectiveness and suitability problems uncovered during the testing event that must be corrected before continued deployment.
- The KMI transition process and Services' fielding concepts must be matured to ensure an accurate and smooth migration from the legacy Electronic Key Management System (EKMS) to KMI. Configuration management controls and training of personnel at the KMI operational support site need improvement to eliminate system inconsistencies.
- The new Type 1 token hardware and its stability are an improvement over previous tokens, but its reliability is deficient and further product refinement and testing is necessary for a suitability determination.
- KMI is potentially operationally effective once significant transition problems are resolved. Security is undetermined, pending a Red Team's assessment. KMI is interoperable and received full certification for Spiral 1; however, KMI was determined to be unsuitable due to the lack of help desk preparedness for operational support, deficient token reliability, and immature Configuration Control Board and configuration management processes.
- Despite problems identified during operational testing, the KMI program continues to show progress toward delivering a useful cryptographic capability for system managers and users. Operational users in the IOT&E reviewed the system capabilities positively, once the transition process completed.

System

- KMI is intended to replace the legacy EKMS to provide a means for securely ordering, generating, producing, distributing, managing, and auditing cryptographic products (e.g., asymmetric key, symmetric keys, manual cryptographic systems, and cryptographic applications).
- KMI Spiral 1 consists of core nodes that provide web operations at a single site operated by the National Security Agency (NSA), as well as individual client nodes distributed globally to provide secure key and software provisioning services for the DoD, intelligence community, and agencies. Spiral 2 will provide improved capability through software enhancements to the Spiral 1 baseline.



- KMI combines substantial custom software and hardware development with commercial off-the-shelf (COTS) computer components. The custom hardware includes an Advanced Key Processor for autonomous cryptographic key generation and a Type 1 user token for role-based user authentication. The COTS components providing user operations include a client host computer, High Assurance Internet Protocol Encryptor (KG-250), monitor, keyboard, mouse, printer, and barcode scanner.

Mission

- Combatant Commands, Services, DoD agencies, other Federal government agencies, coalition partners, and allies will use KMI to provide secure and interoperable cryptographic key generation, distribution, and management capabilities to support mission-critical systems, the Global Information Grid, and initiatives such as Cryptographic Modernization.
- Service members will use KMI cryptographic products and services to enable security services (confidentiality, non repudiation, authentication, and source authentication) for diverse systems such as Identification Friend-or-Foe, GPS, Advanced Extremely High Frequency Satellite System, Joint Tactical Radio System, and Warfighter Information Network – Tactical.

Major Contractors

- SAIC – Columbia, Maryland (Spiral 2 Prime)
- General Dynamics Information Assurance Division – Needham, Massachusetts (Spiral 1 Prime)
- BAE Systems – Linthicum, Maryland
- L3 Systems – Camden, New Jersey
- SafeNet – Belcamp, Maryland
- Praxis Engineering – Annapolis Junction, Maryland

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Activity

- DOT&E published the KMI Operational Assessment-2 report in mid-October 2011. Based on that report, the DoD CIO approved Milestone C and authorized the KMI program to enter the Production, Deployment, and Sustainment phase for Capability Increment 2 in late October 2011.
- In January 2012, the KMI PMO and DoD CIO declared an acquisition cost and schedule threshold breach, resulting in a Critical Change Review of the program. Subsequently, the Chairman of the Joint Chiefs of Staff declared KMI essential to national security and OSD recertified the program to Congress.
- With the DoD CIO certification of the program, the KMI Program Office moved forward with Spiral 1 IOT&E preparations and Spiral 2 Contract Award.
- In accordance with the Acquisition Decision Memorandum, the KMI program manager implemented a token reliability growth program and conducted accelerated life testing of 120 tokens in order to increase confidence in token reliability. The tokens achieved 86,000 combined hours of testing while undergoing temperature and vibration cycles to demonstrate a 10,000-hour Mean Time Between Failure with 80 percent confidence.
- The KMI program and JITC conducted an IOT&E in accordance with a DOT&E-approved plan from July 9 through August 10, 2012, at 17 separate Service and Agency locations across the United States.
- DOT&E published the KMI IOT&E report in mid-October 2012.

Assessment

- KMI is potentially operationally effective once significant transition problems are resolved. Security is undetermined, pending a Red Team's assessment. KMI is interoperable and received full certification for Spiral 1; however, KMI was determined to be unsuitable due to the lack of help desk preparedness for operational support, deficient token reliability, and immature Configuration Control Board and configuration management processes.
- Successful completion of IOT&E was required for a Spiral 1 client node fielding decision.
  - The program's major hardware developmental item, the Advanced Key Processor, is performing well and exceeds its expected reliability.
  - The Service and agency users perceived KMI as a major qualitative improvement over the legacy EKMS.
- KMI is significantly more stable and usable than in previous test events, although there are still effectiveness and suitability problems with transition and backend support.
- Based on the IOT&E, problems with system performance, data errors, manual KG-250 and virtual private network tunnel configurations, and network connectivity associated with account transition affected the efficacy and speed of migrating cryptographic products from EKMS to KMI. This caused significant delays in account migration across Services and agencies.
- The 5 percent token failure rate observed during the test period is not acceptable. While observations indicate that token reliability is improved, additional token reliability testing to gain more usage hours, square wave (power cycling), and mechanical insertion testing is required.
- Symmetric cryptographic key ordering is working well in KMI; however, asymmetric keys are ordered within KMI but their production is accomplished external to the system. While this is an early delivery solution to support Service needs, operational users can still effectively perform their duties.
- Suitability concerns persist with the system and logistical support documentation. These products are improved, but they require refinement to support a fully operational capability.
- KMI help desk and system administration personnel were not adequately prepared to support a fully operational KMI system.
  - The monitoring capabilities and knowledge base are immature and not well-exercised. Critical support personnel were not prepared to support the user community during transition and day-to-day operations.
  - The backend support is not prepared for a KMI full fielding effort. Significant effort must be made to refine the technical support processes before the system is fully deployed to hundreds of user accounts and client systems.
- The Configuration Control Board processes and procedures for updating and implementing system builds and maintaining a consistent software baseline are not refined or effectively implemented to support the Services and agencies.
- The KMI transition process and Services' fielding concepts must be matured to ensure an accurate and smooth migration from the legacy EKMS to KMI. Configuration management controls and training of personnel at the KMI operational support site needs improvement to eliminate system inconsistencies.
- KMI system documentation, procedures, and training for technical staff and help desk personnel are inadequate. However, KMI operational users indicated the training was thorough but too compressed. The Services have limited training blocks to two weeks because of Reservist and National Guard requirements.
- Despite some problems identified during operational testing, the KMI program continues to show steady progress toward delivering a useful cryptographic capability for system managers and users. Operational users in the IOT&E reviewed the system capabilities positively, once the transition process completed.
- Based on the IOT&E results, the KMI PMO scheduled an FOT&E for January 2013.

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Recommendations

- Status of Previous Recommendations. The KMI PMO satisfactorily addressed seven of nine previous recommendations. Additional PMO effort is required to adequately address regression testing for system builds and their deployment and more time is necessary to provide adequate KMI training.
- FY12 Recommendations. The KMI PMO should:
  1. Require the developmental contractors to routinely demonstrate system readiness through regression testing before releasing software upgrades and system builds, and then only as approved by the Configuration Control Board for distribution to Services and agencies.
  2. Review Service and agency deployment methods and work jointly to automate transition functions, such as KG-250 and virtual private network tunnel configurations, to reduce problems and minimize network setup changes and remote troubleshooting from the KMI support site.
  3. Capture and refine documentation of all KMI process adjustments for incorporation in system and user-level operating guides.
  4. Assure that KMI training includes sufficient hands-on equipment time to allow users to gain more system familiarity, knowledge, and proficiency. Additional user and manager-level training is needed to ensure that users can understand the KMI processes and operate the system.
  5. Conduct additional token reliability testing incorporating more usage hours, square wave (power cycling), and mechanical insertion tests.

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Mine Resistant Ambush Protected (MRAP) Family of Vehicles

Executive Summary

- The program procured 250 Navistar Dash Ambulances to fulfill an urgent need to provide protected transport and urgent medical treatment for Army units in Afghanistan.
- The Army Test and Evaluation Command (ATEC) completed the Limited User Test (LUT) of the Dash Ambulance with the Independent Suspension System (ISS) in November 2011 at Yuma Proving Ground, Arizona, in accordance with the DOT&E-approved test plan.
- DOT&E provided an Operational Assessment of the Dash Ambulance in August 2012.
- The Dash Ambulance is not operationally effective and not operationally suitable.
  - The patient compartment of the vehicle is small and the litter births are not long enough to safely accommodate litter patients taller than 5 feet 11 inches. A unit equipped with the Dash Ambulance cannot provide safe emergency medical care and transport for tall casualties in close proximity to enemy forces.
  - The small interior of the Dash Ambulance does not provide sufficient space for medical equipment and inhibits the ability of the medic to maneuver within the compartment to properly treat patients.
  - Loading patients in the Dash Ambulance is hampered due to difficulty aligning and securing the litter onto the litter rail system.
- The Dash Ambulance is reliable. During the Dash Ambulance LUT, the vehicle demonstrated 796 Mean Miles Between Operational Mission Failure (MMBOMF) versus its operational requirement of 600 MMBOMF. The vehicle can be maintained by Soldiers and is recoverable.
- The Dash Ambulance is survivable. The vehicle met the MRAP Capabilities Document version 1.1 threshold underbody and under-wheel blast requirements.
- The MRAP program procured 2,071 Caiman Multi-Terrain Vehicle (CMTV) rolling chassis with ISS and Caiman Underbody Blasts Kits to address crew vulnerability and mobility deficiencies. This variant is undergoing developmental testing. Underbody blast testing of an early version of the CMTV showed a significant reduction of the crew to injuries over the baseline Caiman.
- The Joint Program Office MRAP will transfer management responsibilities to the Services on October 2013.



NAVISTAR Dash Ambulance



BAE Caiman Multi-Terrain Vehicle Category II

System

- MRAP is a family of vehicles designed to provide increased crew protection and vehicle survivability against current battlefield threats, such as IEDs, mines, and small arms. The DoD initiated the MRAP program in response to an urgent operational need to meet multi-Service ground vehicle requirements. MRAP vehicles provide improved vehicle and crew survivability over the High Mobility Multi-purpose Wheeled Vehicle (HMMWV). The MRAPs are employed by units in current combat operations in the execution of missions previously accomplished with the HMMWV. This report covers two MRAP vehicles:
  - Navistar Dash Ambulance with ISS
  - BAE CMTV Category II
- The Navistar Dash ISS Ambulance variant is designed to transport up to two litter patients or four ambulatory casualties.
- The BAE CMTV Category II is designed to transport 10 persons plus 1 gunner.
- MRAP vehicles incorporate current Service command and control systems and counter-IED systems. MRAP vehicles have gun mounts with gunner protection kits capable of mounting any one of a variety of weapons systems such as the M240B medium machine gun, the M2 .50 caliber heavy machine gun, and the Mk 19 grenade launcher.

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Mission

Units equipped with CMTV conduct small unit combat operations such as mounted patrol, convoy security, troop, and cargo transportation. The unit equipped with the MRAP Dash Ambulance variant supports the conduct of medical treatment and evacuation.

Major Contractors

- BAE Tactical Vehicle Systems (TVS) – Sealy, Texas
- Navistar Defense – Warrenville, Illinois

Activity

- The MRAP program continued to acquire and test enhanced capabilities to integrate across the MRAP family of vehicles. In FY12, the major capability insertions include the ambulance kits for the Navistar Dash and the ISS for the BAE CMTV.
- The MRAP program procured 2,071 CMTV rolling chassis with ISS and Caiman Underbody Blasts Kits to address crew vulnerability and mobility deficiencies. This variant is undergoing developmental testing. Live Fire testing of the CMTV will commence in 2QFY13.
- The program procured 250 Navistar Dash Ambulances.
- In November 2011, ATEC completed a LUT of the Dash Ambulance with ISS at Yuma Proving Ground, Arizona, in accordance with the DOT&E-approved test plan.
- DOT&E provided an Operational Assessment of the Dash Ambulance in August 2012.
- The program is developing, procuring, and integrating the Army network capabilities onto MRAP vehicles.
- The Joint Program Office MRAP will transfer management responsibilities to the Services in October 2013.

Assessment

- The Dash Ambulance is not operationally effective and not operationally suitable. The patient compartment of the vehicle is small and the litter births are not long enough to safely accommodate litter patients taller than 5 feet 11 inches. A unit equipped with the Dash Ambulance cannot provide safe emergency medical care and transport for tall casualties in close proximity to enemy forces. This problem should have been corrected prior to the LUT.
- The small interior of the Dash Ambulance does not provide sufficient space for medical equipment and inhibits the ability of the medic to maneuver within the compartment to properly treat patients.
- Loading patients in the Dash Ambulance is hampered due to difficulty aligning and securing the litter onto the litter rail system.
- The Dash Ambulance is reliable. During the Dash Ambulance LUT, the vehicle demonstrated 796 MMBOMF versus its operational requirement of 600 MMBOMF. The vehicle can be maintained by Soldiers and is recoverable
- The Dash Ambulance is survivable. The vehicle met the MRAP Capabilities Document version 1.1 threshold underbody and under-wheel blast requirements.
- Based on performance during developmental testing, the CMTV cannot stop following sustained operations in muddy terrain. The program suspended developmental testing until the program identifies and implements a materiel solution to fix the brake system.
- Endurance testing of the CMTV is ongoing at Yuma Proving Ground, Arizona, in all conditions except wet off-road. Underbody blast testing of an early version of the CMTV showed a significant reduction of the crew to injuries over the baseline Caiman. The CMTV experienced problems associated with air conditioner, tire, and new cab mount cracking failures. The program should resolve these problems prior to conducting FOT&E.
- Planning for Live Fire testing of the CMTV is ongoing and testing will commence in FY13.

Recommendations

- Status of Previous Recommendations. The Army has not addressed the recommendation to improve the cross-country mobility and system reliability of the Navistar MRAP Recovery Vehicle.
- FY12 Recommendations for the Dash Ambulance and the CMTV. Prior to conducting FOT&E, the program should:
  1. Redesign the Dash Ambulance to accommodate litter patients taller than 5 feet 11 inches. Review the installed medical equipment with the objective of providing additional internal space and reducing patient loading time.
  2. Fix the CMTV brake system to allow the vehicle to stop in muddy conditions and improve the overall reliability of the CMTV.

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Mine Resistant Ambush Protected (MRAP) All-Terrain Vehicle (M-ATV)

Executive Summary

- The Mine Resistant Ambush Protected (MRAP) All-Terrain Vehicle (M-ATV) with Underbody Improvement Kit (UIK) participated in the Dash MRAP Ambulance Limited User Test (LUT) in November 2011 at Yuma Proving Ground, Arizona, in accordance with the DOT&E-approved test plan.
- DOT&E provided an Operational Assessment of the M-ATV with UIK in August 2012.
- The M-ATV with UIK is operationally effective, operationally suitable, and survivable.
  - A unit equipped with the M-ATV with UIK can accomplish tactical transport missions.
  - The M-ATV with UIK provides sufficient armored mobility to conduct missions over the type of terrain typically found in Afghanistan.
  - The M-ATV with UIK demonstrated off-road mobility and maneuver capability similar to the base M-ATV during the MRAP Dash Ambulance LUT. The M-ATV with UIK met its reliability, operational availability, and maintainability requirements based on the LUT.
  - The M-ATV with UIK meets the level for improved protection against underbody blast threats specified in the Joint Urgent Operational Need Statement.
- In October 2014, the Joint Program Office (JPO) MRAP will transition management of the of the Special Operations Forces (SOF) M-ATV fleet to the Services.
- United States Special Operations Command (USSOCOM) is planning an FOT&E of the SOF M-ATV in 2QFY13.

System

- The M-ATV is designed for five passenger positions including a gunner. The vehicle incorporates current Service command and control and counter-IED systems. The M-ATV includes gun mounts with gunner protection kits capable of mounting a variety of weapons systems such as the M240B medium machine gun, the M2 .50 caliber heavy machine gun, and the Mk 19 grenade launcher.



M-ATV with Underbody Improvement Kit (UIK)



Special Operations Forces M-ATV UIK

- The M-ATV has the capability to add protection against attacks by explosively formed penetrators, and rocket-propelled grenades to support mounted patrols, reconnaissance, security, and convoy protection.
- USSOCOM required modifications to the Army M-ATV to support SOF missions. The modifications included five passenger positions including a gunner, protection for the cargo area, rear area access, and some other improvements for human factors.
- The M-ATV with UIK and SOF M-ATV UIK are designed to provide improved underbody blast protection to the M-ATV variants.

Mission

Multi-service and special operations units equipped with the M-ATV conduct mounted patrols, convoy patrols, convoy protection, reconnaissance, and communications, as well as command and control missions to support combat and stability operations in highly restricted rural, mountainous, and urban terrain.

Major Contractor

Oshkosh Defense – Oshkosh, Wisconsin

Activity

- The M-ATV with UIK participated in the Dash MRAP Ambulance LUT in November 2011 at Yuma Proving Ground, Arizona, in accordance with the DOT&E-approved test plan.
- In FY12, the program integrated the SOF-specific UIK onto the SOF M-ATV fleet to improve SOF M-ATV underbody blast protection.
- DOT&E provided an Operational Assessment of the M-ATV with UIK in August 2012.
- USSOCOM completed the developmental test weapons firing event of the SOF M-ATV with the Common Remotely Operated Weapon Station (CROWS) at Fort Campbell, Kentucky, in April 2012 to examine the capability to fire the

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Mk 19 grenade machine gun with the CROWS integrated on the SOF M-ATV in an operational environment.
- The program is developing, procuring, and integrating the Army network capabilities onto base M-ATVs.
- The SOF M-ATV UIK Live Fire testing was completed in August 2012.
- In October 2014, the JPO MRAP will transition management of the SOF M-ATV fleet to the Services.
- USSOCOM is planning an FOT&E of the SOF M-ATV in 2QFY13.

Assessment
- The M-ATV with UIK is operationally effective, operationally suitable, and survivable. A unit equipped with the M-ATV with UIK can accomplish tactical transport missions. The M-ATV with UIK provides sufficient armored mobility to conduct missions over the type of terrain typically found in Afghanistan.
- The M-ATV with UIK demonstrated off-road mobility and maneuver capability similar to the base M-ATV during the MRAP Dash Ambulance LUT. The M-ATV with UIK met its reliability, operational availability, and maintainability requirements based on the LUT.
- The M-ATV with UIK meets the level for improved protection against underbody blast threats specified in the Joint Urgent Operational Need Statement.
- During developmental test weapons firing of the SOF M-ATV, no CROWS/SOF M-ATV integration failures were observed after firing approximately 480 rounds of high-explosive dual-purpose ammunition. Four weapon-firing failures were attributed to operator error indicating more CROWS and weapon proficiency training is needed before FOT&E.

Recommendations
- Status of Previous Recommendations. USSOCOM has addressed two of the three previous SOF M-ATV recommendations. USSOCOM did not address the recommendation related to improving the visibility of the SOF passenger by installing larger rear windows in SOF M-ATV.
- FY12 Recommendation.
  1. USSOCOM should continue to plan and conduct the SOF M-ATV FOT&E.

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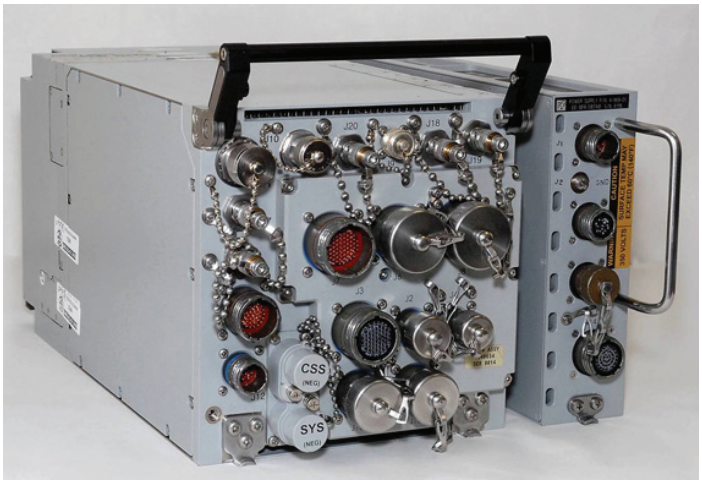
Multi-functional Information Distribution System (MIDS) Joint Tactical Radio System (JTRS)

Executive Summary

- The Navy completed the Verification of Correction of Deficiencies (VCD) operational test of the Multi-functional Information Distribution System Joint Tactical Radio System (MIDS JTRS) core terminal as integrated into the F/A-18E/F in December 2011.
- DOT&E published a MIDS JTRS VCD report in March 2012. DOT&E determined that testing was adequate to indicate that the MIDS JTRS, integrated into the F/A-18E/F, was now operationally effective and operationally suitable. Major deficiencies discovered during the 2010 IOT&E, including ineffective Link 16 message exchange and fine synchronization, as well as terminal and host platform integrated system reliability, have been resolved.
- The Air Force completed operational testing of the MIDS JTRS core terminal integration into the E-8C Joint Surveillance and Target Attack Radar System (JSTARS) aircraft in September 2011. DOT&E assessed that MIDS JTRS as integrated in the E-8 JSTARS is operationally effective and suitable with limitations.
- The Navy is continuing development of two major increments of MIDS JTRS capability that will improve datalink performance: Link 16 four-channel Concurrent Multi-Netting with Concurrent Retention Receive (CMN-4) and Tactical Targeting Networking Technology (TTNT). These new capabilities may require significant hardware and software design changes to the MIDS JTRS core terminal, as well as modifications to host platforms. DOT&E and the Navy are formulating the test strategies for these new MIDS JTRS terminal designs and their integration into host platforms.

System

- When integrated into a host platform, MIDS JTRS provides Link 16 digital datalink, Link 16 digital voice communications, and Tactical Air Navigation (TACAN) capabilities, plus three additional programmable channels capable of hosting additional JTRS Software Communications Architecture-compliant waveforms in the 2 to 2,000 Megahertz radio frequency band. In addition, MIDS JTRS is intended to provide the capability for Link 16 enhanced throughput and Link 16 frequency re-mapping.
- Link 16 digital datalink is a joint and allied secure anti-jam high-speed datalink that uses standard messages to exchange information among flight or battle-group host platforms or between combat platforms and command and control systems.



Link 16 digital voice provides host platforms with a secure anti-jam voice line-of-sight communications capability. TACAN is a legacy aircraft navigation system used in many military aircraft with air-to-air as well as air-to-ground modes of operation.

- The system includes the MIDS terminals and the host platform components and interfaces such as controls, displays, antennas, high-power amplifiers, and any radio frequency notch filters.
- The MIDS JTRS terminals developed to conduct Concurrent Multi-Net Reception are intended to have improved digital receivers, improved buffering, and faster processors to allow host aircraft to receive more Link 16 messages during periods of high message exchange demand.
- The Navy intends for the MIDS JTRS terminals under development to utilize the multiband capability of the MIDS JTRS to provide Link 16 and TTNT to the host platform. The Navy intends for TTNT to provide a larger throughput with lower latency, thereby enabling faster updates of precise information than Link 16 with expanded radio frequency coverage. The Navy intends to use TTNT as one of the communications enablers for the Naval Integrated Fire Control – Counter Air capability.

Mission

U.S. Services and many allied nations will deploy aircraft, ships, and ground units equipped with MIDS JTRS in order to provide military commanders with the ability to communicate with their forces by voice, video, and data during all aspects of military

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operations. MIDS JTRS-equipped units are intended to exchange information including air and surface tracks, identification, host platform fuel, weapons, mission status, engagement orders, targeting data, and engagement results.

Major Contractors
- ViaSat, Inc. – Carlsbad, California
- Data Link Solutions – Wayne, New Jersey and Cedar Rapids, Iowa

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Activity
- The Navy's Commander, Operational Test and Evaluation Force completed the VCD test of the MIDS JTRS, as integrated on the F/A-18E/F, operating from the Naval Air Warfare Center China Lake, California, and during deployed detachments to Naval Air Station Fallon, Nevada, during December 2011.
- The Air Force's 605th Test and Evaluation Squadron (TES) conducted a Force Development Evaluation of the JSTARS Communications and Network Upgrade Phase 1, which includes the MIDS JTRS integration, from June to September 2011. This evaluation took place at Patuxent River Naval Air Station, Maryland, in the U.S. Southern Command Joint Interagency Task Force – South area of responsibility, and at the JSTARS Test Force and Northrop Grumman Corporation facilities in Melbourne, Florida. All testing was conducted in accordance with DOT&E-approved Test and Evaluation Master Plans and operational test plans. DOT&E published a MIDS JTRS VCD report in March 2012.
- DOT&E and the Navy are formulating the test strategies and revising TEMPs for new MIDS JTRS terminal designs and their integration into host platforms. These designs include Link 16 four-channel Concurrent Multi-Netting with CMN-4 and TTNT.

Assessment
- The FY12 DOT&E MIDS JTRS VCD indicated improved Link 16 message exchange compared to the 2010 IOT&E result. DOT&E determined that the MIDS JTRS, as integrated into the F/A-18E/F, was now operationally effective and operationally suitable.
- Testing indicated that Link 16 messages provided situational awareness of friendly force positions and intentions. These messages were consistently and accurately exchanged with 100 percent success during air-to-air missions. The test data also indicated a 99 percent successful ability to obtain Link 16 fine synchronization compared to the IOT&E result of 84 percent.
- The test data indicated that terminal and host platform integration reliability had improved relative to IOT&E. System reliability improved to 21.6 hours between critical failures compared to 8.1 hours during the IOT&E. Operational availability had improved to 99 percent compared to 68 percent during the IOT&E.
- The built-in test false alarm rate of 1 false alarm every 5.9 flight hours failed to meet the threshold requirement of 1 false alarm every 113 flight hours.
- DOT&E found the integration of the MIDS JTRS core terminal into the E-8C JSTARS operationally effective and operationally suitable with limitations. The system was effective in transmitting Link 16 datalink and voice communications. JSTARS had no MIDS JTRS terminal failures in 114.3 hours accumulated during testing, but terminal operators experienced display anomalies. The JSTARS Program Office plans to fix the display anomalies in the next upgrade cycle.
- New capabilities such as Link 16 four-channel Concurrent Multi-Netting with CMN-4 and TTNT may require significant hardware and software design changes to the MIDS JTRS core terminal, as well as modifications to host platforms to integrate the new TTNT capability.

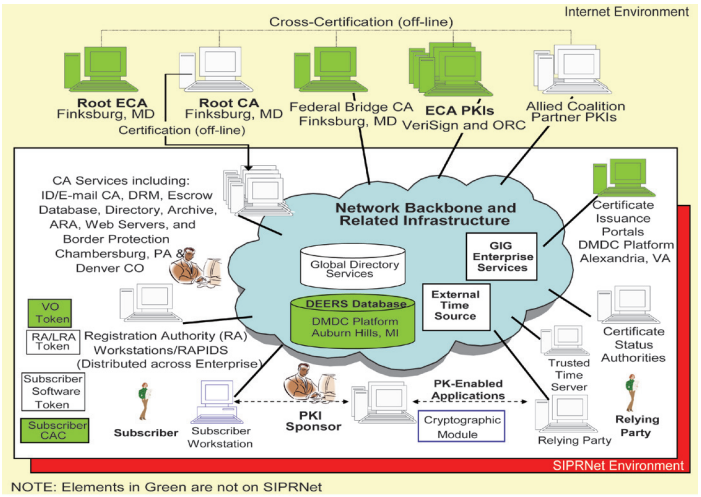
Recommendations
- Status of Previous Recommendations. The Navy and the MIDS Program Office made satisfactory progress on the previous recommendations related to the correction of deficiencies identified during the IOT&E.
- FY12 Recommendations. The Navy should:
  1. Continue software design efforts to reduce the incidence of built-in test false alarms and plan a maintenance demonstration to include an exhaustive evaluation of failure diagnostics prior to the start of the operational test of the Link 16 Concurrent Multi-Net Reception capability.
  2. Adopt a Design of Experiments approach to the test strategies and include a reliability growth analysis/plan as TEMP revisions occur for future MIDS JTRS capability increments. Conduct a thorough review of the manufacturing process of the terminal with new capabilities to verify the new production-representative terminals will be stable during operational testing.

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Public Key Infrastructure (PKI)

Executive Summary

- DoD Public Key Infrastructure (PKI) Increment 2 provides authenticated identity management via password-protected Secret Internet Protocol Routing Network (SIPRNET) tokens to enable DoD members and others to access the SIPRNET securely and encrypt and digitally sign e-mail. Full implementation will enable authorized users and non-person entity (NPE)-enabled devices (e.g., servers and workstations) to access restricted websites and enroll in online services.
- An IOT&E in 2011 exposed significant logistics deficiencies due to undefined processes for procuring, distributing, and tracking SIPRNET tokens. The Defense Manpower Data Center, which currently handles the common access card (CAC) logistical processes on the Non-secure Internet Protocol Router Network (NIPRNET), is actively working with the DoD PKI Program Management Office (PMO) to take on similar responsibilities for the SIPRNET tokens.
- In October 2011, the DoD Chief Information Officer (CIO) directed the military Services and agencies to implement PKI on the SIPRNET and deploy tokens DoD-wide to approximately 500,000 users by December 31, 2012. As of mid-October 2012, military Services and agencies had issued approximately 78,300 tokens to users, falling far short of the pace needed to achieve the 500,000 goal by end of year. This status reflects growing backlogs in registering, enrolling, and getting SIPRNET tokens out to users, suggesting only nominal improvements toward overall SIPRNET security.
- In January 2012, the DoD CIO approved full fielding of PKI to the SIPRNET and tactical environments and the acquisition of the necessary tokens, card readers, and software to support fielding. The DoD CIO called for an operational retest of end-to-end logistical processes to address outstanding suitability deficiencies.
- In September 2012, the Joint Interoperability Test Command (JITC) conducted an operational test of a bulk token formatting and issuance capability intended to improve the speed of token issuance. JITC found the formatter to be effective and suitable, fulfilling its intended purpose by providing the Registration Authorities the ability to simultaneously complete multiple tasks. Fifteen SIPRNET token bulk formatters are currently being used by the Services and an additional 35 units are being procured.
- Capabilities to correct logistic shortfalls with token inventory and accounting are delayed and awaiting operational testing. A previously scheduled FOT&E slipped from 3QFY12 until 2QFY13 to verify correction of logistics deficiencies found during the IOT&E. JITC intends to conduct an operational test to verify whether the new Inventory Logistics System (ILS) can successfully track tokens by serial number and location throughout their lifecycle from ordering, through shipping, issuing, and return. Future enhanced reporting capabilities to improve token accounting and reporting will not be available for operational testing until 1QFY14.



NOTE: Elements in Green are not on SIPRNet

ARA - Auto-key Recovery Agent
CA - Certification Authority
CAC - Commom Access Card
DEERS - Defense Enrollment Eligibility Reporting System
DMDC - Defense Manpower Data Center
DRM - Data Recovery Manager
ECA - Enterprise Certification Authority
GIG - Global Information Grid
ID - Identification
LRA - Local Registration Authority
ORC - Operational Research Consultants, Inc.
PK - Public Key
RA - Registration Authority
RAPIDS - Real-Time Automated Personnel Identification System
SIPRNet - SECRET Internet Protocol Router Network
VO - Verifying Official

System

- DoD PKI is a critical enabling technology for Information Assurance (IA). It supports the secure flow of information across the Global Information Grid as well as secure local storage of information.
- DoD PKI provides for the generation, production, distribution, control, revocation, recovery, and tracking of Public Key certificates and their corresponding private keys.
- DoD PKI is comprised of commercial off-the-shelf hardware and software, and other applications developed by the National Security Agency (NSA).
  - The Defense Enrollment Eligibility Reporting System (DEERS) and the Secret DEERS provide the personnel data for certificates imprinted on NIPRNET CACs and SIPRNET tokens respectively.
  - DoD PKI Certification Authorities for the NIPRNET and SIPRNET tokens reside in the Defense Information Systems Agency (DISA) Enterprise Service Centers in Chambersburg, Pennsylvania, and Oklahoma City, Oklahoma.
  - DISA and NSA are jointly developing DoD PKI in multiple increments. Increment 1 is complete and

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deployed on the NIPRNET. Increment 2 is being developed and deployed in three spirals on the SIPRNET and NIPRNET to deliver the infrastructure, PKI services and products, and logistical support for Spiral 1 (tokens), Spiral 2 (tactical and austere environments), and Spiral 3 (NPE PKI, Federal and coalition capabilities).
- The NPE development effort provides certificates for devices, automated and manual enrollment, and the infrastructure means for credential checking to insure NPE-enabled devices (e.g., domain controllers, web servers, and workstations) are authorized to exist on DoD networks.

Mission
- Military operators, communities of interest, and other authorized users will use DoD PKI to securely access, process, store, transport, and use information, applications, and networks regardless of technology, organization, or location.
- Commanders at all levels will use DoD PKI to provide authenticated identity management via personal identification number-protected CACs or SIPRNET tokens to enable DoD members, coalition partners, and others to access restricted websites, enroll in online services, and encrypt and digitally sign e-mail.

Major Contractors
- General Dynamics Information Technology – Needham, Massachusetts (Prime)
- 90Meter – Newport Beach, California
- SafeNet – Belcamp, Maryland

Activity
- In September 2011, the PKI PMO signed a Memorandum of Agreement with the Defense Manpower Data Center to develop an ILS to handle SIPRNET token ordering, shipping, and distribution.
- In October 2011, the DoD CIO directed the military Services and Agencies to implement PKI on the SIPRNET and deploy tokens DoD-wide to all users by December 31, 2012.
- The JITC and PMO executed an automated failover in December 2011. The failover between the PKI systems in Chambersburg, Pennsylvania, and Oklahoma City, Oklahoma, demonstrated continuity of operations after the planned failover.
- DOT&E issued the PKI Increment 1, Spirals 1 and 2 IOT&E report on December 6, 2011.
- In January 2012, the DoD CIO approved full fielding of PKI to the SIPRNET and tactical environments and the acquisition of the necessary tokens, card readers, and software to support fielding. The DoD CIO called for an operational retest of end-to-end logistical processes to address outstanding suitability deficiencies.
- The PKI PMO continues to work on the underlying suitability problems, focusing on the ILS and Token Management System to address scalability. However, no significant PKI capabilities were delivered and operationally tested in FY12. Suitability retesting is ready but on hold due to errors in reconciling token inventory status for tokens already issued.
- Test planning and preparations are ongoing for conducting an operational test of Increment 2, Spiral 3 backend capabilities in December 2012.
- With approval from the DoD CIO, the PKI PMO further delayed the NPE capability delivery and operational assessment until 3QFY13 due to security and user concerns that the proposed capability will not satisfy current mission requirements. Security mitigations are being developed and plans for testing the proposed NPE capability are being put in place.

Assessment
- The PKI Increment 2, Spirals 1 and 2 IOT&E were conducted in 4QFY11 in accordance with a DOT&E-approved test plan.
- The DOT&E report in December 2011 found the system to be operationally effective and secure, but not operationally suitable with logistical improvements needed to support full deployment. The system was available, reliable, maintainable, and relatively easy to use. However, critical logistical support deficiencies were found in the processes for distributing and accounting for hardware tokens, token readers, and middleware. Specific logistics deficiencies found include the following:
  - The lack of a robust token reliability tracking program for ensuring failure rates are acceptable.
  - A centralized token inventory system for ensuring tokens are procured and distributed according to Service and agency demands and for tracking tokens that are reissued to different users.
  - The need for more customized searching and reporting through the Token Management System portal interface to enable Services and Agencies to better report on token issuance status.
  - The lack of bulk formatting and issuance capabilities to improve token distribution time and reduce manpower costs.
- While logistics improvements have been made since the IOT&E report, to include delivery of a bulk formatting and issuance capability, a final tested robust logistics process for token procuring, distributing, tracking, and reporting is not in place. Delays in the delivery of the centralized logistics inventory system coupled with the Services' need to meet the DoD CIO's SIPRNET token deployment directive are hampering the transition from previous operations.
- There are over 530,000 SIPRNET tokens distributed to the Services and Agencies but only 78,300 tokens in use as of mid-October 2012. This status reflects the significant backlog in registering, enrolling, and deploying SIPRNET tokens. The

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Service and agency registration authorities responsible for issuing tokens currently do not have the manpower needed to support the FY13 NPE operational test activities. Additionally, stakeholders do not have enough confidence in the NPE capability because it has not been adequately demonstrated via developmental testing. Ongoing missions and operations are precluding the Services and agencies from being able to commit critical devices to operational assessments and testing.

- Overall, the PKI system and technical capabilities are sound, but the SIPRNET standard operating procedures, training, logistical support, and lifecycle sustainment lack maturity. While procedures for middleware and card reader distribution and support have improved, the new process supporting the token ILS has not yet been demonstrated. Additional duties are being defined within the PKI program for Service and agency token warehouse and issuance site managers to ensure that tokens are properly tracked by the new system. With more than 100 issuance sites, there is a significant risk that the ILS process will not be uniformly adopted in a timely manner, which is necessary to provide a complete and accurate inventory status and to enable production of tokens based on issuance site requirements.
- The NPE capability delays continue to plague the Program Office. The NPE delivery is now amassed into the Increment 2, Spiral 3 set of capabilities, which also include enhancements to the existing SIPRNET and NIPRNET infrastructures. While the NPE Release 3 provides some automation improvements, it adds a substantial manpower support requirement for the Services to accomplish the large volume of DoD NPE devices, especially given the loose DoD guidance stating that all devices require medium assurance certificates. The registration authorities and system administrators ultimately responsible for approving and enrolling devices into the system have major concerns with the system and the workload it will entail. Although the PKI PMO has attempted to refine guidance to enable NPE certificate deployment to be prioritized based on risk that a device can be compromised by information attacks, the community has not established a clear path forward for deploying NPE certificates across DoD devices.
- The developmental test program is inadequate to support integrated test planning efforts. Processes and procedures directed in both the Test and Evaluation Master Plan and System Engineering Plan have not been implemented, which has resulted in limited visibility into actual performance of the system. Better coordination between the test teams, and improved test planning and reporting are required to support operational test readiness assessments.
- Overly aggressive testing event dates continue to waste critical user and test resources by forcing the assessment of PKI capabilities that are not ready to be assessed.

Recommendations

- Status of Previous Recommendations. The PKI PMO satisfactorily addressed five of seven recommendations from the FY11 Annual Report for Increment 2, Spirals 1 and 2. The recommendations concerning correction of token testing and scheduling deficiencies remain.
- FY12 Recommendations.
  1. The PKI program needs to improve coordination with the stakeholders, provide better capability definition, and recognize schedule impossibilities early to provide sound acquisition management for testing and delivering the PKI capabilities for the DoD.
  2. The PKI program needs to adhere to both the System Engineering Plan and Test and Evaluation Master Plan, which provide specific direction on how the development and testing of the PKI capabilities should be executed.
  3. The PKI acquisition community needs clear guidance on the intended NPE devices. Any directives for issuing NPE certificates must take into consideration Service and agency manpower and resource constraints. If such guidance is not timely, the PKI acquisition program baseline should be restructured such that tests are driven based on capability maturity, readiness, and mission need and not to satisfy program schedule requirements.
  4. The PMO should work to establish a more realistic timeline for PKI development, delivery, and capability testing that better supports milestone decisions. The program must better manage expectations of those with PKI equities by avoiding recurring schedule slips caused by capability delivery delays.

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Army Programs

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Network Integration Evaluation (NIE)

In FY12, the Army continued execution of a series of Network Integration Evaluations (NIEs), which began in FY11 with NIE 11.2. The purpose of the NIEs is to provide a venue for operational testing of Army acquisition programs, with a particular focus on the integrated testing of programs related to tactical mission command networks. Additionally, the NIEs are intended to serve as a venue for evaluating emerging capabilities that are not formal acquisition programs. This fiscal year the Army executed two NIEs, both at Fort Bliss, Texas, and White Sands Missile Range, New Mexico. NIE 12.1 was conducted from October through November 2011 and NIE 12.2 was conducted from April through May 2012.

The intended objective of the NIE to test and evaluate network components together in a combined event is sound. The NIE events should allow for a more comprehensive evaluation of an integrated mission command network, instead of piecemeal evaluations of individual network components. Conducting NIEs two times a year creates an opportunity for event-driven operational testing as opposed to schedule-driven testing. For example, if a system was not developmentally ready to enter operational testing at one NIE event, it would have the opportunity to enter testing in a subsequent NIE event.

The Army intends to conduct NIE events approximately every six months for the foreseeable future.

NIE 12.1.
During NIE 12.1, the Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) Rifleman Radio underwent an IOT&E. The Army also executed an operational assessment of the AN/PRC-117G radio. (Individual articles providing assessments of the Rifleman Radio and the AN/PRC-117G can be found later in this Annual Report).



During NIE 12.1, the Army conducted evaluations of 47 additional systems in various stages of development. These systems, termed by the Army as "systems under evaluation" (SUEs), are not acquisition programs of record, but rather systems that may offer value for future development.

NIE 12.2
During NIE 12.2, the Army conducted a Multi-Service Operational Test and Evaluation (MOT&E) for the JTRS HMS Manpack radio and IOT&Es for Warfighter Information Network – Tactical (WIN-T) Increment 2 and JTRS Enterprise Network Manager. (Individual articles on these programs are provided later in this Annual Report.) The Army also conducted assessments of 36 SUEs.

NIE ASSESSMENT

Overall, the Army's execution of the NIEs has shown steady improvement since NIE 11.2, which was reported on in the FY11 Annual Report. The Army has incorporated lessons learned from previous events. This was reflected in NIE 12.2, which was the best planned and executed NIE of the three conducted to date.

Operational Scenarios and Test Design. The Brigade Modernization Command, in conjunction with the Army Test and Evaluation Command's Operational Test Command, continues to develop realistic, well designed operational scenarios for use during NIEs. NIE 12.2 contained the most challenging mission set to date, including Combined Arms Maneuver for the first time in any significant way. NIE 12.2 stressed brigade and battalion command and control to a much greater degree than did previous NIEs. Unlike in previous NIEs, all Tactical Operations Centers and command posts in NIE 12.2 displaced multiple times. Additionally, as part of the WIN-T Increment 2 testing, NIE 12.2 included units not located at Fort Bliss or White Sands Missile Range, with the 101st Airborne Division operating from Fort Campbell, Kentucky, serving as the division headquarters.

In contrast to NIE 12.2, NIE 12.1 focused on Wide Area Security missions executed predominately at the company level. Brigade and battalion tactical operations centers and company command posts operated from fixed sites and were dependent upon a fixed aerial tier of 100-foot towers and aerostats in order to establish network connectivity.

Threat Operations. The Army continues to improve threat operations during NIEs. NIE 12.2 was the first NIE in which

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threat information operations, such as electronic warfare and computer network operations, were fully integrated into the threat commander's scheme of maneuver. An aggressive, adaptive threat intent on winning the battle is an essential component of good operational testing. The Army should continue to ensure that future NIEs contain a robust threat force, to include threat information warfare capabilities.

Schedule-Driven Programs. The Army remains schedule-driven to meet NIE objectives, vice pursuing an event-driven schedule appropriate to acquisition system development.

In NIE 12.1 the Army proceeded to the Rifleman Radio IOT&E despite unfinished developmental testing. Developmental testing conducted prior to the IOT&E indicated that the Rifleman Radio was demonstrating reliability of roughly one-half its intended requirement (277 hours of Mean Time Between Essential Function Failure (MTBEFF) compared to a requirement of 477 hours). Predictably, Rifleman Radio's reliability demonstrated during the IOT&E fell far short of the requirement, demonstrating a 161-hour MTBEFF.

In NIE 12.2, the Army proceeded with the Manpack radio MOT&E despite developmental testing results indicating that the Manpack radio Single Channel Ground and Airborne Radio System (SINCGARS) waveform performance was not satisfactory and that the Manpack radio was falling short of its reliability requirements. The OSD's Deputy Assistant Secretary of Defense for Developmental Test and Evaluation in its Assessment of Operational Test Readiness (AOTR) identified these developmental testing deficiencies prior to the start of the MOT&E. The Manpack radio MOT&E results confirmed both the SINCGARS waveform deficiency and reliability shortfall previously identified in developmental testing. Furthermore, Manpack radio vehicle integration was poorly executed and not adequately tested prior to the MOT&E, resulting in poor vehicular-mounted radio performance in the MOT&E. The AOTR also identified insufficient developmental testing to assess vehicle integration prior to the MOT&E.

According to system development best practices, the Army should not proceed to IOT&E with a system until it has completed developmental testing and the program has corrected any identified problems. Otherwise, the Army runs the risk of conducting costly operational tests that only serve to confirm developmental testing conclusions about poor system performance, without affording the Program Office the opportunity to fix system shortfalls.

Too Many Systems. The Army continues to insert a large number of immature systems into NIEs. The 25 SUEs contained in the NIE 11.2 stressed the Army's evaluation capacity, indicating a need to reduce the number of SUEs in later NIEs. Nevertheless, NIE 12.1 contained 47 SUEs and NIE 12.2 included 36 SUEs. Too many immature systems in the NIE challenges the Army's capacity to employ appropriate instrumentation, collect relevant data, and conduct full and adequate assessments, detracting from the Army's capability to perform focused evaluations. Having this large number of SUEs in the NIE stresses the test unit's capacity to adequately train operators on the new systems. In addition, it strains the unit's ability to understand the systems' intended concepts of operations and to integrate the systems into unit operations. These limitations make it challenging to thoroughly examine the capabilities of each SUE. Finally, much of the NIEs' overall cost can be attributed to the inclusion of these SUEs. Whether the knowledge gained of the SUEs justifies the overall cost is unclear.

Logistics. NIEs are still not replicating realistic battlefield maintenance and logistical support operations for systems under test. Field Service Representative (FSR) support plans, maintenance and repair parts stockage, and the quantity and management of system spares, do not accurately reflect what a unit will observe upon fielding. For example, the JTRS HMS Manpack System Support Package provided by the Program Office for use in the MOT&E did not accurately reflect expected system support after fielding. The density of contract FSRs and spare radios far exceeded what is likely to be the case within fielded brigades. Easy access and over reliance on FSR support resulted in the test unit not having to realistically execute its field-level maintenance actions. Failure to accurately replicate "real world" maintenance and logistics support cause operational availability rates and ease of maintenance to be overestimated in NIEs.

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AN/PRC-117G

Executive Summary

- The Army intends tactical units to employ the AN/PRC-117G as a data radio. The radio will be used as an interim commercial off-the-shelf (COTS) solution until the Multi-Tier Networking Vehicle Radio (MNVR) is developed and fielded. The MNVR is intended to replace the cancelled Joint Tactical Radio System Ground Mobile Radio (JTRS GMR) program.
- The AN/PRC-117G radio is not a Program of Record. As a result, there is no acquisition strategy, documented requirements, or Test and Evaluation Master Plan. The Army has used an existing General Services Administration contract to purchase the AN/PRC-117G.
- The Army Test and Evaluation Command conducted an operational assessment of the AN/PRC-117G from October through November 2011 at Fort Bliss, Texas, and White Sands Missile Range, New Mexico, in conjunction with the Army's Network Integration Evaluation (NIE) 12.1.
- The AN/PRC-117G performed satisfactorily in transmitting digital Position Location Information. However, full AN/PRC-117G capability was not exercised or evaluated. AN/PRC-117G demonstrated satisfactory reliability and interoperability with the Rifleman Radio and its corresponding Soldier Radio Waveform (SRW) network.



System

- The AN/PRC-117G radio is a single channel voice and data radio that is capable of operating in a frequency range of 30 Megahertz to 2 Gigahertz. It can be configured for manpack, vehicular-mounted, or base station operations. The primary AN/PRC-117G waveform is the Advanced Networking Wideband Waveform (ANW2), which is a Harris Corporation proprietary waveform. The AN/PRC-117G is capable of simultaneously transmitting both Voice over Internet Protocol (VoIP) and digital data on a single channel. Digital data include file transfers, chat, streaming video, and position location reports. ANW2 allows units to use internet protocol routing to transmit medium to high bandwidth data traffic over tactical Very High Frequency, Ultra High Frequency, and L-band radio networks.
- The AN/PRC-117G radio is not a Program of Record. As a result, there is no acquisition strategy, documented requirements, or Test and Evaluation Master Plan.

Mission

The Army intends for tactical units to employ the AN/PRC-117G as a data radio. AN/PRC-117G will be an interim COTS solution until the MNVR is developed and fielded. The MNVR is intended to replace the cancelled JTRS GMR program.

Major Contractor

Harris Corporation – Rochester, New York

Activity

- The Army is purchasing the AN/PRC-117G as a COTS item to fill a capability gap for a tactical digital radio. With the October 2011 cancellation of JTRS GMR, the Army sought an interim solution to fill Brigade Combat Teams as a part of Capability Set 13. The Army has used an existing General Services Administration contract to purchase the AN/PRC-117G.
- The Army Test and Evaluation Command conducted an operational assessment of the AN/PRC-117G from October through November 2011 at Fort Bliss, Texas, and White Sands Missile Range, New Mexico, in conjunction with the Army's NIE 12.1. During this event, a cavalry squadron equipped with Mine Resistant Ambush Protected vehicles executed typical cavalry missions in an Afghanistan-like scenario. A total of 26 AN/PRC-117Gs were used. These radios ran both the ANW2 and SRW.
- DOT&E has placed the AN/PRC-117G on oversight.

Assessment

- During the NIE event, the AN/PRC-117G performed satisfactorily in transmitting digital data. However, full AN/PRC-117G capability was not exercised or evaluated. The test unit only employed the AN/PRC-117G to transmit limited types of digital Joint Variable Message Format (JVMF) messages. The vast majority of the digital traffic was automated position location reports, with a small number

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of other JVMF messages pertaining to mortar fire missions. The unit did not employ the radio's voice capability, except in the case of the Rifleman Radio-equipped platoon. The AN/PRC-117G's capabilities for file transfer, transmitting streaming video, and chat were not employed in NIE 12.1, as the Army did not give the test unit the capability or opportunity to do so.

- The SRW successfully ran on several AN/PRC-117Gs, which allowed the Rifleman Radio-equipped platoon to transmit to the AN/PRC-117G the position location reports generated by Rifleman Radio-equipped Soldiers. From the AN/PRC-117G, these position locations crossed over to the ANW2 in the platoon leader's vehicle, enabling these position locations to be displayed at the troop and squadron level. This troop also successfully used the AN/PRC-117G running SRW for VoIP with Rifleman Radio-equipped platoon members.
- The AN/PRC-117G demonstrated a point estimate Mean Time Between Essential Function Failure (MTBEFF) of 511 hours, which exceeds the JTRS GMR single channel requirement of 477 hours MTBEFF. This result is over five times greater than the JTRS GMR reliability demonstrated in NIE 11.2.

Recommendations

- Status of Previous Recommendations. This is the first annual report for this program.
- FY12 Recommendation.
  1. The Army should conduct sufficient government developmental and operational testing to fully characterize system performance. A future operational assessment should be executed in which the test unit employs the system to its full capability, including streaming video, file transfers, chat, and VoIP.

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Apache Block III (AB3) Upgrade

Executive Summary

- The Army conducted the Apache Block III (AB3) IOT&E at the National Training Center in Fort Irwin, California, March through April 2012. The test included training, force-on-force missions, live fire of all weapon systems, and threat penetration testing of AB3 computer networks. The IOT&E was preceded by four years of developmental testing that included analysis, modeling and simulation, component qualification testing, testing in extreme environments, system-level flight testing, weapons qualifications, and live fire testing.
- The Army completed LFT&E of AB3 flight critical and force protection components followed by vulnerability analyses to evaluate aircraft ballistic survivability.
- In August 2012, DOT&E submitted a Combined Initial Operational Test and Evaluation and Live Fire Test and Evaluation report to Congress evaluating:
  - AB3 as operationally effective. It has improved flight performance compared to legacy Apache Block II (AB2) aircraft. When aided by real-time unmanned aircraft system (UAS) video containing actionable intelligence, AB3 teams demonstrated target acquisition ranges, Hellfire missile engagement ranges, and mission success rates greater than the legacy AB2 aircraft.
  - AB3 as operationally suitable. The aircraft exceeded reliability thresholds with statistical confidence and met all current maintainability requirements. Overall, flight safety is enhanced by the aircraft's ability to operate with increased power margins.
  - AB3 as at least as survivable as legacy AB2 aircraft. New AB3 subsystems met survivability requirements and demonstrated ballistic tolerance similar to legacy AB2 aircraft.



System

- The AB3 is a modernized version of the AH-64D Attack Helicopter with which the Army intends to sustain the Apache fleet through the year 2040. The Army intends to organize the AB3 in Attack/Reconnaissance Battalions assigned to the Combat Aviation Brigades. Each Battalion will have 24 aircraft.
- The Army acquisition objective is to procure 690 AB3 aircraft: 634 remanufactured and 56 new build aircraft. Remanufactured and new build AB3 aircraft are built on the same assembly line in Mesa, Arizona, and are essentially the same aircraft.
- The AB3 aircraft capability improvements include:
  - Levels 2 through 4 UAS control by the AB3 aircrew
    - Level 2 receives and displays UAS data/video feed
    - Level 3 receives and displays UAS data/video feed and enables the aircrew to control the UAS payload (sensor)
    - Level 4 receives and displays UAS data/video feed and enables the aircrew to control the flight path of the UAS and the payload
  - Improved Radar Electronic Unit to provide radio frequency interferometer passive ranging, extended fire control radar range, and maritime targeting capability
  - Improved aircraft performance with 701D engines, composite main rotor blades, weight reduction through processor and avionic upgrades, and an improved rotor drive system
  - Enhanced survivability with integrated aircraft survivability equipment and additional crew and avionic armoring
  - Enhanced communication capability, which includes satellite communication, Link 16 datalink, and an integrated communication suite to meet global air traffic management requirements
  - Improved reliability and maintainability using embedded system-level diagnostics, improved electronic technical manuals, and reduced obsolescence

Mission

The Attack/Reconnaissance Battalions assigned to the Combat Aviation Brigade will employ the AB3 to conduct the following types of missions:

- Attack
- Movement to contact
- Reconnaissance
- Security

Major Contractors

- Aircraft: The Boeing Company Integrated Defense Systems – Mesa, Arizona
- Sensors and UAS datalink: Longbow Limited – Orlando, Florida, and Baltimore, Maryland

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Activity

- The Army conducted the AB3 IOT&E in accordance with the DOT&E-approved test plan from March 16, 2012, through April 13, 2012, at the National Training Center in Fort Irwin, California. The IOT&E consisted of force-on-force missions with a dedicated opposing force; live fire of all weapon systems; and threat penetration testing of AB3 computer networks.
- Prior to the IOT&E, the test unit completed three weeks of classroom, simulator, and flight training at the Boeing facility in Mesa, Arizona. Legacy AB2 aircraft and aircrews conducted home-station training prior to deploying to the National Training Center.
- During IOT&E, five AB3 aircraft flew 367 flight hours. The five AB3 aircraft and five legacy AB2 aircraft conducted 28 force-on-force missions under varying conditions. The conditions were selected using Design of Experiments methodology with four factors: aircraft type (AB3 or AB2), mission type (reconnaissance or attack), UAS support (with or without), and light level (day or night). A single Gray Eagle UAS with associated flight crew and personnel provided mission support to the IOT&E from Edwards AFB, California.
- The Army conducted ballistic testing of production-representative AB3-improved drive system components and composite main rotor blades (CMRBs) from May through July 2011 at Aberdeen Proving Ground, Maryland.
- The Army conducted ballistic shots against 20 crew armor panels on December 7, 2010, to verify performance against the key performance parameter force protection threat.
- At the conclusion of ballistic testing, the Army completed a system-level vulnerability analysis using a modeling and simulation suite that models target-threat interaction for direct fire and small projectiles on air and ground systems.
- The Air Force approved the Mission Design Series request to designate the AB3 as the AH-64E on September 6, 2012.
- In August 2012, DOT&E submitted a Combined Initial Operational Test and Evaluation and Live Fire Test and Evaluation report to Congress.
- The USD(AT&L) conducted a Defense Acquisition Board on August 16, 2012. The key decisions include the following.
  - Approve full-rate production for the Apache Block IIIA (AB3A) Remanufacture program.
  - Authorize the procurement of up to 12 low-rate initial production aircraft in FY13 for the Apache Block IIIB (AB3B) New Build program.
  - The Army will fully fund the AB3A Remanufacture program to the Director of Cost Assessment and Program Evaluation-approved independent cost estimate.
  - Upon approval of the AB3A Remanufacture Acquisition Program Baseline, the AB3A Remanufacture and AB3B New Build programs will be designated as Acquisition Category 1C programs.

Assessment

- The AB3 is operationally effective. It has improved flight performance compared to legacy AB2 aircraft, and when aided by real-time UAS video containing actionable intelligence, AB3 teams demonstrated target acquisition ranges, Hellfire engagement ranges, and greater mission success rates than legacy AB2 aircraft teams.
- AB3 crews were consistently able to establish a datalink with Gray Eagle to receive UAS video. Crews had some difficulty establishing and maintaining control of the Gray Eagle sensor.
- There is a pilot confidence concern with the AB3 transmission design. It has a single tail rotor output pinion that provides power for the tail rotor, hydraulic pump, and electric generator. A failure of this one pinion could be catastrophic for the aircrew, as this would result in the simultaneous loss of the tail rotor, electric generator, and hydraulic power.
- AB3 is operationally suitable. The helicopter exceeded its reliability thresholds with statistical confidence and met all current maintainability requirements. The redesigned AB3 helmet offers improved comfort and performance compared to the legacy helmet. Overall, flight safety is enhanced by AB3's increased power margins relative to legacy AB2 aircraft.
- The AB3 is at least as survivable as the legacy AB2 aircraft. New AB3 subsystems met survivability requirements and demonstrated ballistic tolerance similar to legacy AB2 aircraft.
- Infrared countermeasures provide protection against most man-portable rocket system threats, but the Army should improve the laser and radar warning systems. Consistent with other DOT&E evaluations, the APR-39A(V)4 radar warning receiver was not effective during IOT&E. Radar warning receiver false alarms were so pervasive during the IOT&E that the pilots ignored or turned off all countermeasure warning systems.
- The AB3 is vulnerable to computer network attack. An Army threat computer network operations team conducted limited penetration testing of AB3 computer networks. The threat team considered three attack vectors to gain access to the AB3 networked systems: the Blue Force Tracker, the Aviation Mission Planning System, and aircraft maintenance ports. Threat team activities were limited to computer network scanning (passive and active) while the AB3 aircraft were on the ground, so as not to affect flight operations. The team was successful in gaining access to AB3 systems.
- The CMRB has very low vulnerability to most small arms threats. However, during another test, a larger threat impacted the blade spar and removed a substantial portion of the spar's cross-sectional area. The blade completed 30 minutes of operation, despite a loss of structural stiffness. While spinning, the centrifugal forces kept the blade straight, but as the blade rotation slowed after the shot, the blade folded downward at the damage location. It is uncertain if the observed damage would have resulted in catastrophic blade failure within 30 minutes under actual flight conditions, or if

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equivalent damage located at another spar location would have resulted in the same outcome.

Recommendations

- Status of Previous Recommendations. The Army continues to address all DOT&E recommendations from previous testing. Many of the recommendations, including the Fire Control Radar performance anomalies and the AB3 aviator helmet fit and visibility display, were addressed and changed prior to the IOT&E.
- FY12 Recommendations. The Army should:
  1. Continue to refine tactics, techniques, and procedures for teaming with UASs. Determine the root cause for datalink dropouts and improve the stability of the tactical command datalink for control of UAS sensors.
  2. Consider incorporating improvements to current threat warning systems as they are developed. Upgrade radar and laser warning systems and provide for adjustable controls for each warning system.
  3. Address pilot's confidence concerns with regard to the transmission design. Conduct physics of failure analysis to provide an independent analysis of the probability of failure of the new tail rotor pinion design. Investigate the feasibility of alternate transmission designs that provide automatic redundant hydraulic and electrical power in the event of loss of power to the tail rotor.
  4. Address the Information Assurance vulnerabilities identified.
  5. Perform a structural analysis of the CMRB to better understand the load carrying capabilities of the blade that was damaged during ballistic testing.

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Armored Tactical Vehicles – Army

Executive Summary

- DOT&E delivered the Family of Medium Tactical Vehicles (FMTV) LFT&E Report to Congress in October 2011.
- DOT&E provided an Operational Assessment to support the re-procurement decision of the Oshkosh FMTV. A transportation unit can accomplish line and local haul convoy missions using the Oshkosh FMTV in the same manner as the fielded FMTV.
- The Army is developing a Modernized Expanded Capacity Vehicle (MECV) High Mobility Multi-purpose Wheeled Vehicle (HMMWV) survivability test series to determine available enhanced protection capabilities. In a parallel effort, the Marine Corps is exploring a HMMWV sustainment modification initiative to restore lost reliability and mobility capabilities due to armoring vehicles.
- Emerging Heavy Equipment Transporter (HET) underbody test results indicate that the HET Underbody Improvement Kit (UIK) increases crew protection against under-vehicle threats.

System

FMTV

- The FMTV re-procurement is the fourth stage of FMTV progression. These vehicles consist of the following light and medium variants intended to operate on- and off-road:
  - The Light Medium Tactical Vehicle (LMTV) transports a 5,000-pound payload and a 12,000-pound towed load.
  - The Medium Tactical Vehicle (MTV) transports a 10,000-pound payload and a 21,000-pound towed load.

HMMWV

- The HMMWV is a general purpose tactical wheeled vehicle with light and heavy variants.
  - The Light Variant includes the light utility, weapon carrier, and ambulance with a required minimum payload of 2,600 pounds.
  - The Heavy Variant includes the heavy shelter carrier, light and heavy howitzer towing variant, and ambulance with a required minimum payload of 4,550 pounds.
- The MECV HMMWV effort is intended to identify improved underbody crew protection, scalable armor, and the ability to regain automotive performance.

HET

- The M1070 HET is an eight-wheeled tractor used to transport the M1 main battle tank and other large equipment weighing up to 70 tons to and from the battlefield.
- The HET UIK is designed to provide improved underbody blast protection to the fielded HETs. The vehicle seats were modified in conjunction with the UIK development.



FMTV
(Family of Medium Tactical Vehicles)



HMMWV
(High Mobility Multi-purpose Wheeled Vehicle)



HET
(Heavy Equipment Transporter)

Mission

FMTV

- The Army employs the FMTV to provide multi-purpose transportation and unit mobility vehicles in maneuver, maneuver support, and sustainment units.

HMMWV

- The HMMWV provides highly mobile light tactical wheeled transport for command and control, troops and light cargo, medical evacuation, and weapon platforms to division and below units. This vehicle is employed throughout the battlefield and operates in off-road and cross-country environments.

HET

- The M1070 HET is used to transport, deploy, recover, and evacuate combat-loaded tanks and other large tracked and wheeled vehicles.

Major Contractors

FMTV & HET

- Oshkosh Corporation – Oshkosh, Wisconsin

HMMWV

- AM General – South Bend, Indiana

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Activity

FMTV

- The Army completed the Production Verification Testing (PVT) of the Oshkosh FMTV Wrecker at Aberdeen Proving Ground, Maryland. The purpose of the PVT was to ensure that performance, reliability, and maintainability met the requirements for the vehicle.
- The Army Test and Evaluation Command completed the FMTV Developmental/Operational Test (DT/OT) at Aberdeen Proving Ground in June 2011 in accordance with the DOT&E-approved test plan.
- DOT&E delivered the FMTV LFT&E Report to Congress in October 2011.
- DOT&E provided an Operational Assessment in October 2011 to support the re-procurement decision of the FMTV by Oshkosh.

HMMWV

- In February 2012, the Army Test and Evaluation Command (ATEC) completed developmental testing and a user evaluation of the M997A3 HMMWV Ambulance at Aberdeen Proving Ground, Maryland, to support the procurement of 500 vehicles for the Army National Guard.
- The Army is developing an MECV HMMWV survivability test series to determine available enhanced protection capabilities. In a parallel effort, the Marine Corps is exploring a HMMWV sustainment modification initiative to restore lost reliability and mobility capabilities due to armoring vehicles.

HET

- ATEC conducted four system-level underbody blast tests against the HET UIK at the Aberdeen Test Center, Aberdeen, Maryland. The results compare the blast protection of the base and up-armored HET.
- The M1070 HET Live Fire test series included threats above Mine Resistant Ambush Protected All-Terrain Vehicle levels.
- The program procured 55 HET UIKs in August 2011.

Assessment

FMTV

- Based on DT/OT results, a transportation unit can accomplish line and local haul convoy missions using the Oshkosh FMTV in the same manner as the fielded FMTV.
- During PVT, the Oshkosh FMTV Wrecker demonstrated 8,000 Mean Miles Between Hardware Mission Failure (MMBHMF) versus its operational requirement of 5,000 MMBHMF. The Wrecker is capable of recovering and towing wheeled vehicles such as the HMMWV, 5-ton truck series, and FMTV vehicles over a variety of terrain and surfaces.

HMMWV

- Contractor results from the ballistic tests on the potential MECV designs demonstrated that improvements in survivability are feasible. The Army will retest these designs during the MECV HMMWV survivability test series.
- The M997A3 HMMWV Ambulance contributes to the accomplishment of the medical ground evacuation mission in support of Homeland Defense and Homeland Security operations based on the results of developmental testing and user evaluation. The medical crews effectively collected, provided en-route treatment, and transferred patients from simulated points of injury to a treatment facility utilizing the Ambulance. The M997A3 HMMWV Ambulance demonstrated a Mean Miles Between Operational Mission Failure of 3,053 miles during DT/OT versus the 1,637 miles requirement.

HET

- Emerging underbody test results indicate that the M1070 HET UIK increases crew protection against under-vehicle strikes.

Recommendations

- Status of Previous Recommendations. The Army addressed all previous recommendations.
- FY12 Recommendations. None.

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Bradley Engineering Change Proposal (ECP)

Executive Summary

- The Bradley Engineering Change Proposal (ECP) LFT&E was initiated to evaluate the vulnerability of ECP upgrades, which intend to restore ground clearance and integrate new network technologies and to evaluate the vulnerability of urgently fielded survivability kits, which are now part of the M2A3 configuration.
- In September 2012, the Army conducted two underbody blast tests on the M2A3 Infantry Fighting Vehicle with ECP1 components that revealed severe vehicle and occupant vulnerabilities. These two tests are not sufficient to address all of the critical survivability concerns with the Bradley Fighting Vehicle Systems (BFVS). Additional testing is required.

System

- The Bradley ECP1 intends to restore ground clearance with upgrades to the suspension and track and ECP2 intends to integrate network technologies as they become available for the following three variants of the BFVS:
  - M2A3 Infantry Fighting Vehicle
  - M3A3 Cavalry Fighting Vehicle
  - Bradley Fire Support Team with Fire Support Sensor System
- The Bradley Urban Survivability Kit I, II, and III and add-on-armor kit intend to improve vehicle and crew survivability. These kits were urgently fielded for Operation Iraqi Freedom and are now part of the M2A3 configuration.



Mission

Combatant Commanders employ BFVS-equipped Armor Brigade Combat Teams to provide protected transport of Soldiers; provide overwatching fires to support dismounted infantry and suppress an enemy; and perform missions to disrupt or destroy enemy military forces and control land areas.

Major Contractor

BAE Systems Land and Armaments – Sterling Heights, Michigan

Activity

- The Army initiated the Bradley Engineering Change Proposal (ECP) LFT&E to evaluate the vulnerability of ECP upgrades, which include an upgraded suspension, upgraded track, and new network technologies and to evaluate the vulnerability of urgently fielded survivability kits, now part of the M2A3 configuration.
- DOT&E approved the Phase 1 Bradley ECP LFT&E strategy in August 2012.
- In September 2012, the Army conducted two underbody blast tests at the Aberdeen Test Center on the M2A3 Infantry Fighting Vehicle with ECP1 components to characterize the system's vulnerability.
- The Program Office wrote a draft Test and Evaluation Master Plan (TEMP) that outlined the Bradley ECP1 operational and live fire test plans, test methods, resources, and evaluation plans. The draft TEMP is in staffing for review and approval. The Program Office will update the TEMP in 1QFY15 for ECP2.

Assessment

- Results from the first two underbody blast tests with realistic threats (as opposed to the outdated underbody requirement) conducted in September 2012 revealed severe vehicle and occupant vulnerabilities, which the Army plans to examine for possible improvement. The first two underbody tests are not sufficient to address all of the critical BFVS survivability concerns.
- Results from the first two underbody blast tests also demonstrate that survivability modifications to the Bradley Fighting Vehicle would be required if it is chosen as the platform for the Armored Multi-purpose Vehicle (AMPV) to meet the draft AMPV survivability requirement.

Recommendations

- Status of Previous Recommendations. This is the first annual report for this program.

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- FY12 Recommendations.
  1. The Army must provide a comprehensive live fire strategy for DOT&E approval, which includes plans for additional tests required to comprehensively evaluate the force protection and survivability provided by the Bradley Urban Survivability Kit I, II, and III; add-on-armor kit; ECP1; and ECP2 components.
  2. The Army should correct the vulnerabilities identified during underbody blast testing prior to using the vehicles in combat situations in which underbody threats are prevalent.

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Common Remotely Operated Weapon Station (CROWS)

Executive Summary

- The Army conducted an Initial Operational Test (IOT) in 2009.
- Early in FY12, the Army Acquisition Executive notified the USD(AT&L) that the CROWS program was expected to become a Major Defense Acquisition Program with the Army as the lead Service. This designation caused the program to come under DOT&E oversight.
- In June 2012, Program Executive Office (PEO) Soldier requested that DOT&E prepare an OT&E report to Congress to support a September 2012 production decision for the procurement of the final 1,212 CROWS systems.
- In September 2012, DOT&E provided Congress with an assessment of the operational effectiveness and operational suitability of the CROWS mounted on Up-Armored High Mobility Multi-purpose Wheeled Vehicles (UAHs) based upon the results of the IOT, developmental testing, and CROWS New Equipment Training (NET) at Fort Campbell, Kentucky.
- The CROWS system is operationally effective. The CROWS target acquisition and engagement capabilities enable units to detect and engage targets at long range while both on-the-move and stationary relative to non-CROWS equipped units. CROWS operators are provided protection over Objective Gunner Protection Kit (OGPK) gunners because of the CROWS ability to fire remotely. Nonetheless, CROWS has some limitations in comparison with the OGPK due in part to the limited fields of view of the CROWS daytime and nighttime sensors.
- The CROWS system is operationally suitable. During IOT, the CROWS exceeded its reliability requirement. The CROWS-equipped UAH demonstrated the capability to perform its mission essential functions of move, shoot, and communicate.

System

- CROWS is a gunner-operated system that provides the capability to remotely aim and fire the MK19 Grenade Machine Gun (GMG), M2 Machine Gun, M240 Machine Gun, or the M249 Machine Gun from a stationary platform or while on-the-move.
- The M153 CROWS consists of weapons cradles, traverse and elevation drives, weapon interface, weapon remote charger, ammunition container and feed system, laser range finder, day/night viewing and sighting unit, joystick, and remote fire control and display unit.



Mission

Gunners within a vehicle crew or in a stationary battle position use CROWS to improve their weapon's performance through enhanced target acquisition, identification, and engagement capabilities while firing remotely. Units equipped with CROWS include Infantry, Artillery, Armor, Cavalry, Engineer, Chemical, and Military Police.

Major Contractor

Kongsberg Defense Corporation – Johnstown, Pennsylvania

Activity

- The Army conducted an IOT in 2009. At the time the IOT was conducted, CROWS was an Acquisition Category (ACAT) II program and was not on DOT&E oversight. The Army Test and Evaluation Command (ATEC) was responsible for approving the test plan, conducting the IOT, and reporting its evaluation to the Army.
- ATEC conducted the IOT at Fort Carson, Colorado, from October – November 2009. For the IOT, the performance of a CROWS-equipped Military Police (MP) unit was compared to an MP platoon equipped with OGPKs. All four types of weapons were used during the test. Representatives from DOT&E visited the site during the conduct of the IOT in 2009 to monitor test execution adequacy.
- Early in FY12, the Army Acquisition Executive notified USD(AT&L) that the CROWS program was expected to reach an ACAT I funding level for the procurement year. In March 2012, the USD(AT&L) designated the CROWS

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program as an ACAT IC Major Defense Acquisition Program with the Army as the lead Service.
- In June 2012, PEO Soldier requested that DOT&E prepare an OT&E report to Congress to support a September 2012 production decision for the procurement of the final 1,212 CROWS systems.
- In August 2012, DOT&E observed the revised CROWS NET at Fort Campbell, Kentucky. Thirty-two Soldiers from different units at Fort Campbell participated.
- In September 2012, DOT&E provided Congress with an assessment of the operational effectiveness and operational suitability of the CROWS mounted on UAHs based upon the results of the IOT, developmental testing, and the revised CROWS NET.

Assessment
- Representatives from DOT&E monitored the Army's IOT at Fort Carson, Colorado, in 2009 and assessed that it was adequately executed.
- The CROWS system is operationally effective. The CROWS target acquisition and engagement capabilities enable units to detect and engage targets at long range while both on-the-move and stationary relative to non-CROWS equipped units.
  - The CROWS provides enhanced lethality and is more accurate while firing on-the-move at long ranges than a crew-served weapon fired by a gunner using the OGPK.
  - CROWS operators are provided protection over OGPK gunners because of the ability to remotely fire CROWS. A unit with CROWS-equipped vehicles can synchronize target acquisition, maneuver, and provide responsive fires during missions such as Convoy Security, Route Reconnaissance, and Overwatch.
- The shortcomings of CROWS identified during IOT were that the operator and crew struggled to detect enemy personnel close to the vehicle and to maintain situational awareness of their surroundings. Additionally, they were slower than the OGPK-equipped UAHs in determining the location of enemy fire as the CROWS operator and crew lacked the visual and auditory cues necessary to stay in the firefight.
- The CROWS daylight sight provides a 47-degree field of view and its minimum focus distance is 2 meters. The CROWS thermal sighting only provides a narrow 10-degree field of view. These capabilities limit the gunner/operator from rapidly acquiring dispersed targets, whereas a gunner operating the OGPK can rapidly scan for and detect close-in and widely dispersed targets.
- The CROWS system is operationally suitable. During IOT, the CROWS exceeded its reliability requirement. The CROWS-equipped UAH demonstrated the capability to perform its mission essential functions of move, shoot, and communicate.
- The revised 2012 NET is improved over that conducted in 2009. The new program of instruction (POI) incorporates expanded hands-on, situational awareness, safety, and gunnery live-fire exercises. The POI now includes lessons on the correct method to establish no-fire and no-traverse zone.

Recommendations
- Status of Previous Recommendations. This is the first annual report for this program.
- FY12 Recommendations. The CROWS program manager should:
  1. Conduct follow-on operational testing to evaluate the effectiveness and suitability of CROWS as it is integrated for use on combat vehicles in addition to the High Mobility Multi-purpose Wheeled Vehicle and Mine Resistant Ambush Protected vehicle.
  2. Investigate increasing the field of view of the CROWS daytime and thermal sights to improve CROW operator determination of enemy location. The CROWS imaging sights have limited field of view, which affects the crew's ability to acquire and engage the enemy.
  3. Test to confirm the updated fire tables corrective action improve the MK19 accuracy with CROWS in a desert environment.
  4. Validate that link guide corrective action deflects expended cartridge cases and links.

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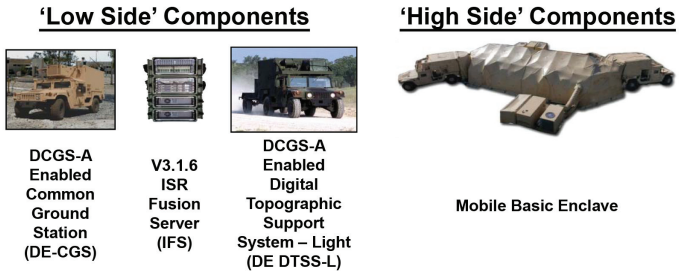
Distributed Common Ground System – Army (DCGS-A)

Executive Summary

- The Army Test and Evaluation Command (ATEC) conducted a Developmental Test/Early User Test (DT/EUT) on the Distributed Common Ground System – Army (DCGS-A) Software Baseline 1.0 (DSB 1.0) from August through September 2011, to provide information for the Milestone C decision in February 2012.
- DOT&E published a DCGS-A DSB 1.0 Operational Assessment Report in January 2012. ATEC conducted the test in a non-operationally representative laboratory environment. Based on the DT/EUT data, DOT&E evaluated DSB 1.0 to be sufficiently mature to enter production in preparation for IOT&E, but recommended improvements to Tactics, Techniques, and Procedures (TTPs); individual and collective training; and system reliability.
- ATEC conducted the DSB 1.0 IOT&E from May through June 2012, utilizing an operationally representative field configuration.
- DOT&E published a DCGS-A DSB 1.0 IOT&E Report in October 2012 that evaluated DSB 1.0 to be not operationally effective, not operationally suitable, and not survivable based on the IOT&E data.
  - During IOT&E, the physical configuration of DSB 1.0 forced unnecessary foot traffic and data exchange through the security cross-domain guard since most of the data needed for the fusion is Secret, but the fusion capability was only in the Sensitive Compartmented Information (SCI) enclave. Physical barriers and security procedures between the SCI enclave and the remainder of the DSB 1.0 system inhibited exchange and fusion of data to the point where DOT&E assessed the DSB 1.0 system to be not operationally effective.
  - Additionally, software faults within the SCI enclave were a primary factor in the evaluation of the DSB 1.0 system as not operationally suitable.
- The Army reconfigured DSB 1.0 without the SCI enclave to mitigate the effectiveness and suitability shortfalls identified in the IOT&E report and demonstrated fixes to the critical Information Assurance (IA) shortfalls that led to the evaluation that the system was not survivable. The reconfigured package is called Release 1.
- DOT&E released a memorandum in November 2012 that stated Release 1 will provide users with capabilities at least as good as those provided by the current systems.

System

- DSB 1.0 establishes the architecture that will provide an organic net-centric Intelligence, Surveillance, and Reconnaissance (ISR) capability. DSB 1.0 integrates three major existing systems and provides new SCI components to brigade combat teams. The major components include the following:
  - V3.1.6 ISR Fusion Server is the same as the currently fielded DCGS-A v3.1.6 and organizes and processes raw intelligence reports into coherent information at the Secret classification level.
  - DCGS-A Enabled Common Ground Station provides multisensory imagery intelligence data processing and evaluation capability.
  - DCGS-A Enabled Digital Topographic Support System – Light provides geospatial analysis and production capability.
  - Mobile Basic Enclave contains new components designed to provide signal intelligence capability and intelligence fusion and analysis capability for Top Secret information and SCI.
- DCGS-A allows users to collect, process, fuse, and display intelligence on six types of enemy entities: individuals, units, equipment, facilities, events, and organizations.
- DCGS-A is the information- and intelligence-processing centerpiece of the Army ISR framework and is the enabler for all intelligence functions at the Division, Brigade Combat Team, Maneuver Battalion, and Company levels.



Mission

Army intelligence analysts use DSB 1.0 to support six Mission Command Capabilities:

- Display and share relevant information
- Provide a standard and shareable geospatial foundation
- Collaborate in voice, text, data, and video modes
- Execute running estimates of enemy force progress
- Provide mission rehearsal and training support
- Interoperate across the joint, interagency, intergovernmental, and multinational forces

Major Contractor

Northrop Grumman Electronic Systems – Linthicum, Maryland

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Activity

- From August through September 2011, ATEC conducted the DT/EUT utilizing a non-operationally representative system configuration at the Intelligence Systems Integration Laboratory at Fort Huachuca, Arizona. In the laboratory configuration, the SCI enclave and the rest of the DSB 1.0 system were connected by a single secured door. Testing was conducted in accordance with a DOT&E-approved test plan.
- DOT&E published the DCGS-A DSB 1.0 Operational Assessment Report in January 2012 informing the Milestone Decision Authority on the test results of the DT/EUT.
- The Milestone Decision Authority signed the Acquisition Decision Memorandum in March 2012, approving limited deployment for IOT&E.
- From May through June 2012, ATEC conducted the IOT&E at Fort Stewart, Georgia, with the 4th Brigade Combat Team, 3rd Infantry Division operating the system in an operationally representative field configuration. In the fielded configuration, the SCI enclave and the rest of the DSB 1.0 system were separated physically and by security barriers (concertina wires and guarded entrances). Testing was conducted in accordance with a DOT&E-approved test plan.
- In October 2012, DOT&E provided an IOT&E report to the Milestone Decision Authority and Congress.
- The Army reconfigured the DSB 1.0 without the SCI enclave to mitigate the effectiveness and suitability shortfalls identified in the IOT&E report, and demonstrated fixes to the critical IA shortfalls. The reconfigured package is called Release 1.
- DOT&E released a memorandum in November 2012 that stated Release 1 will provide users with capabilities at least as good as those provided by the current systems.

Assessment

- The DT/EUT demonstrated that the DSB 1.0 system had shortfalls but was sufficiently mature to enter production in preparation for IOT&E.
  - During the DT/EUT, test data showed operators using DSB 1.0 could execute all key missions, although software limitations forced the users to manually fuse data on two of the six entity types. DSB 1.0 could perform fusion for unit, equipment, facility, and event entities, but not for individuals and organizations. The software modules to fuse data on each entity type are unique due to the different data sets associated with each entity.
  - DSB 1.0 was not reliable due to software problems. The Mean Time Between Essential Capability Failure (MTBECF) of 3.8 hours fell short of the 160-hour requirement. The primary cause for all reliability failures was software (44 of 49 for all failures, 15 of 16 for essential capability failures).
  - The TTPs and training were not mature and needed improvement prior to IOT&E. The TTP and training shortfalls during DT/EUT precluded comprehensive operational evaluation of the end-to-end mission sequence. These shortfalls channelized testers' attention and precluded identification of the non-trivial problems (discovered later during IOT&E) that were associated with the physical separation of the SCI enclave and the rest of the DSB 1.0 system.
  - The Army did not evaluate DSB 1.0 survivability against cyber threats during DT/EUT.
- The change from a laboratory configuration to the fully fielded configuration in IOT&E significantly altered the test results from those seen during DT/EUT. The IOT&E results showed DSB 1.0 is not operationally effective, not operationally suitable, and not survivable.
  - The system is not effective because it inhibits effective workflows for the development of intelligence products to support operations. The system configuration, as tested, placed the intelligence fusion capability in the SCI (high) enclave even though most of the data to be fused are contained in the Secret (low) side. Additionally, collection management tools reside in the high side, but collection managers need to work closely with the brigade operations staff on the low side. Human intelligence tools are split between the high side and low side, but human intelligence analysts manage and interview their sources on the low side. The need for constant collaboration between high and low side personnel and the utilization of fusion capabilities contained only on the high side, in addition to physical separation and security procedures, inhibited access to capabilities and ultimately severely degraded the ability to generate a single, fused intelligence plot.
  - The system is not suitable because operators performing key mission tasks are interrupted with server reboots or reliability failures, on average, every 8 hours, and operators frequently need to recreate lost work as a result of computer resets. Training for the targeting and signal intelligence analysts using the new capabilities is inadequate.
  - The system is not survivable against cyber threats and does not provide adequate protection and detection against them.
- As reconfigured, Release 1 provides useful capability for the Army users, but does not fully satisfy the Key Performance Parameters (KPPs) for DSB 1.0.
  - Release 1 does not fully meet the Net-Ready KPP since the information exchange requirement that involves the SCI component is not satisfied.
  - Release 1 does not fully meet the Fusion KPP since the software that performs semi-automated fusion was hosted on the SCI enclave. However, Army users can perform fusion with manual assist.
  - Release 1 critical IA shortfalls have been corrected.

Recommendations

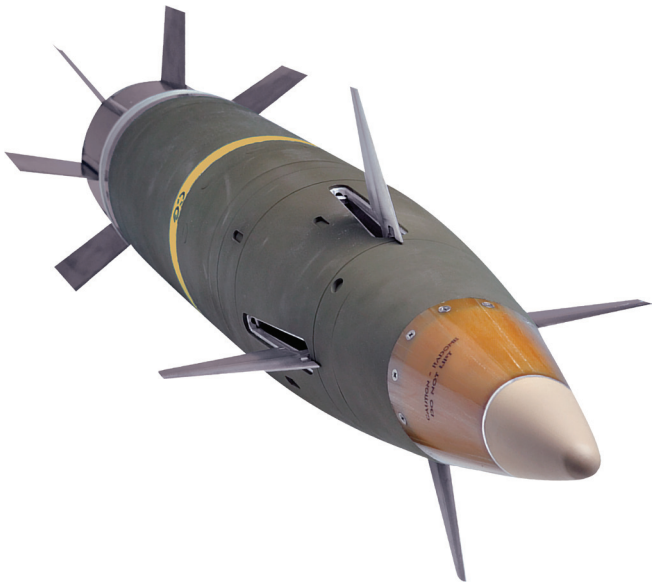
- Status of Previous Recommendations. This is the first annual report for this program.
- FY12 Recommendation.
  1. The Army should conduct operational testing of all releases of DCGS-A Increment 1 to be deployed for operational use.

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Excalibur XM92 Precision Engagement Projectiles

Executive Summary
- As of July 2012, the Army has fired 601 Excalibur Ia projectiles in operational theaters with the Program Office reporting 90 percent reliability.
- In February 2012, technical challenges with the Increment Ib projectiles caused reliability concerns with the base assembly. This resulted in the program changing the configuration of the Increment Ib projectiles.
- Excalibur Increment Ib is scheduled for a December 2012 Milestone C decision.

System
- Excalibur is a family of precision-guided, extended-range, 155-millimeter artillery projectiles. The projectiles are fin-stabilized and glide to their target.
- The Army plans to develop three Excalibur variants:
  - High-Explosive, Unitary (Block I)
  - Smart (Block II)
  - Discriminating (Block III)
- All variants use GPS and an Inertial Measurement Unit (IMU) to attack point targets with accuracy of less than 10 meters from the desired aim point (in an unjammed environment).
- The Army is developing the High-Explosive, Unitary (Block I) projectile in three spirals of increasing capability (Ia-1, Ia-2, and Ib). The Ia-1 projectiles use aerodynamic lift generated by canards to extend range out to 24 kilometers without the maximum propellant charge. The Ia-2 and Ib projectiles add base bleed technology and use of the maximum propellant charge to further increase range to beyond 35 kilometers. The Army intends for the Increment Ib projectiles to improve reliability and reduce cost.



Mission
- Field Artillery units use Excalibur to attack enemy targets in support of maneuver operations at a greater range and with increased accuracy than standard high-explosive munitions.
- Field Artillery units use Excalibur to support the close fight in urban and complex environments, striking critical targets that must be engaged at extended ranges or in areas where minimal collateral damage is desired.

Major Contractor
Raytheon Missile Systems – Tucson, Arizona

Activity

Increment Ia
- Units in Operation Enduring Freedom (OEF) have been using Excalibur Increments Ia-1 and Ia-2 since February 2008. As of July 2012, Field Artillery units have fired 601 Excalibur projectiles in either Operation Iraqi Freedom or OEF.

Increment Ib
- In February 2012, technical challenges with the Increment Ib projectiles caused reliability concerns with the base assembly. This resulted in the program changing the configuration of the Increment Ib projectiles, reverting to the Ia spinning base assembly and warhead design.
- In June 2012, the contractor fired six Increment Ib projectiles in the contractor Gun Hardening P2 (GH P2) test at Yuma Test Center (YTC), Arizona, for reliability and accuracy testing. All GH P2 test projectiles reached their targets with 2.9-meter median radial miss distance. All six projectiles reached their intended targets and detonated.
- In September 2012, YTC personnel fired 12 Increment Ib projectiles in developmental testing for Sequential Environmental Test-Safety 1 (SET-S1). All rounds completed environmental conditioning (logistic and tactical vibration and thermal soak) prior to firing, and were fired at pressures above the normal operational envelope. Two projectiles failed to guide and traveled to the ballistic impact point. Ten projectiles reached their targets with a 1.5-meter median radial miss distance.
- In October 2012, the Army fired 25 environmentally-conditioned projectiles at YTC to support validation of the ballistic firing tables, verify that Excalibur Increment Ib meets performance requirements, and provide

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live fire target assessment data (Sequential Environmental Test-Performance 1 (SET-P1)).
- The Increment Ib Milestone C decision is scheduled for December 2012, and the IOT&E is scheduled for April 2013.

Assessment

Increment Ia

- Excalibur Increment Ia-2 reliability in OEF is 90 percent (according to the Program Office) and Lot Acceptance Tests conducted in November and December 2011, and February 2012, had 24 of 24 reliable projectiles.

Increment Ib

- Increment Ib has the same base and warhead as Increment Ia-2, and is expected to have the same terminal ballistic characteristics and lethality as Increment Ia-2.
- Since the GH P2 median radial miss distance is comparable to the Increment Ia IOT&E (unjammed) miss distance (3 meters), Increment Ib is anticipated to meet the 10-meter accuracy requirement and be as accurate as Increment Ia.
- Since external differences between Excalibur Increments Ia and Ib are minor and units are expected to use the same tactics, techniques, and procedures, Increment Ib is anticipated to be as effective as Increment Ia.
- Of the 25 SET-P1 rounds fired, 22 hit the target with a median miss distance of 1.38 meters and 3 were duds. With regards to reliability, there were six failures in 31 rounds (including the GH-2 rounds). This gives a point estimate of 0.81 and a 21.8 percent confidence that they have met their growth curve target of 0.84. The program will need to complete root cause analysis before an assessment can be made as to whether the program can meet its 90 percent reliability requirement.

Recommendations

- Status of Previous Recommendations. The Army is addressing the previous recommendations.
- FY12 Recommendations.
  1. The Army should continue Increment Ib reliability growth through completion of the developmental test.
  2. The program will need to complete root cause analysis before an assessment can be made as to whether the program can meet its 90 percent reliability requirement.

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Global Combat Support System – Army (GCSS-Army)

Executive Summary

- The Global Combat Support System – Army (GCSS-Army) Release 1.1 is operationally effective, operationally suitable, and survivable against cyber threats. DOT&E recommendations from the June 2012 IOT&E report included continued test and evaluation for future upgrades, monitoring scalability as the user population increases, and achieving financial auditability no later than 2017.
- The Army Test and Evaluation Command (ATEC) will participate in the Lead Site Verification Test in January 2013 to evaluate GCSS-Army's operational effectiveness, operational suitability, and survivability for use by the Army National Guard, Army Reserves, and Directorate of Logistics.

System

- GCSS-Army is an information technology system made up of commercial off-the-shelf and non-developmental software and server hardware.
- The core functionality of GCSS-Army comes from the adaptation of a commercially-available Enterprise Resource Planning (ERP) system. The ERP system integrates internal and external management information across an entire organization, including finance/accounting, manufacturing, sales and service, and customer relationship management, and automates this activity with an integrated software application.
- The hardware component of GCSS-Army is limited to the production server in Redstone, Alabama, and the Continuity of Operation server in Radford, Virginia.
- The GCSS-Army program includes the Army Enterprise Systems Integration Program (AESIP) that provides the enterprise hub services, centralized master data management, and cross functional business intelligence and analytics for the Army ERP solutions, including the General Fund Enterprise Business System and Logistics Modernization Program.
- GCSS-Army executes finance actions and thus is subject to the 2010 National Defense Authorization Act requirements to be auditable by 2017.



Mission

Army logisticians will use this system to access information and exchange operational logistics data related to tactical maintenance, materiel management, property accountability, tactical financial management, and logistics planning.

Major Contractors

- ERP Solution Component: Northrop Grumman Space and Mission Systems Corporation – Carson, California
- AESIP Component: Computer Sciences Corporation – Falls Church, Virginia

Activity

- DOT&E published an IOT&E report on GCSS-Army Release 1.1 in June 2012 based on the following three test events. These events were conducted in accordance with the DOT&E-approved test plan.
  - ATEC Release 1.1 testing conducted from August through October 2011. The 2nd Heavy Brigade Combat Team, 1st Armored Division, at Fort Bliss, Texas, and Defense Finance and Accounting Office at Rome, New York, participated in the IOT&E.
  - The GCSS-Army Cyber Threat Test conducted by the U.S. Army Threat System Management Office from September 2011, and the Program Management Office's corrective actions up through March 2012.
  - A Continuity of Operation demonstration conducted by the GCSS-Army and AESIP product manager in November 2011, which evaluated the system's ability to restore operations in the event of a declared disaster at the production server in Redstone Arsenal, Alabama.

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- DOT&E and ATEC are planning to conduct or participate in a series of test events to address the recommended changes listed in the DOT&E-published IOT&E report.
  - Lead Site Verification Test at the National Guard, Army Reserve, and the Directorate of Logistics module in January 2013.
  - Test for scalability of GCSS-Army's ability to support the entire Army when the loading tool can be developed, verified, validated, and accredited.
  - Test for future upgrades as the program manager develops new functions. A Risk Assessment will determine the scope of the test in accordance with the DOT&E-published Guidelines for Operational Test and Evaluation of Information and Business Systems memorandum.

Assessment

DOT&E evaluated GCSS-Army Release 1.1 as operationally effective, operationally suitable, and survivable against cyber threats. DOT&E recommended the Army address the following.

- The Army conducted IOT&E with 545 users, compared to the total expected user population of 168,000 when fully deployed.
- The Army had not developed GCSS-Army versions for Army Reserve and National Guard units at the time of the IOT&E.
- The 2010 National Defense Authorization Act requires financial audibility by 2017. GCSS-Army had not achieved this requirement at the time of IOT&E.

Recommendations

- Status of Previous Recommendations. The Army is making progress implementing the previous recommendations.
- FY12 Recommendations.
  1. The Army needs to take steps to achieve financial auditability no later than 2017.
  2. The Army should continue to collect data for computational (server capacity, storage, and bandwidth) and human factors (help desk responsiveness, overhead labor and communication costs, and data noise) impacts of an increased user base. Use such data to establish a pattern of demand on the system, so that future demand can be adequately anticipated and resourced as more users come online.
  3. The Army should conduct test and evaluation when the software is developed for Army Reserve and National Guard units in accordance with the September 2010 DOT&E-published Guidelines for Operational Test and Evaluation of Information and Business Systems memorandum.

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Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS)

Executive Summary

- The Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS) program experienced a critical Nunn-McCurdy cost breach due to an FY12 budget decision to eliminate procurement of all production systems. USD(AT&L) directed the Army to continue with a limited development program using the two existing JLENS developmental orbits, but did not restore funding for production systems. The Army is continuing to plan and execute a reduced JLENS test program to evaluate JLENS technologies and capabilities as directed by USD(AT&L). The Army Test and Evaluation Command (ATEC) will conduct a limited assessment of JLENS operational capabilities and limitations in FY13.
- During the initial phases of contractor functional verification and government developmental testing in 2011, the JLENS demonstrated surveillance and fire control radar detection and tracking performance that exceeded system technical specifications for fixed-wing and cruise missile air-breathing targets in a controlled test environment. The system was operated and maintained by contractor personnel during these test events. Testing identified problems with operator controls and displays, non-cooperative target recognition, friendly aircraft identification, and fire control radar software and track stability; these problems require future improvement.
- During the developmental integrated fire control test phase in April 2012, an integrated JLENS orbit supported a series of simulated missile flight test engagements of airborne targets with an operational Army air defense missile system. This phase concluded with a successful live missile flight test that destroyed a fixed-wing target drone aircraft in a controlled test environment.
- The Army and Navy conducted a joint JLENS Navy Integrated Fire Control – Counter Air (NIFC-CA) missile flight test event at White Sands Missile Range, New Mexico, in late September 2012. The JLENS provided integrated fire control targeting information to a Navy Aegis-based missile system using Cooperative Engagement Capability (CEC) datalinks to successfully engage and destroy a surrogate cruise missile aerial target.
- Based on data collected during developmental testing, JLENS system-level reliability is not meeting program reliability growth goals. Both software and hardware reliability problems contribute to low system reliability.

System

- A JLENS orbit consists of separate surveillance and fire control radar systems individually mounted on 74-meter tethered aerostat balloons that operate at altitudes up to 10,000 feet above mean sea level.
- A 180,000-pound mobile mooring station and tether system is used to launch, recover, and secure each aerostat system. The aerostat tether system provides radar control and data transfer links to supporting ground control and data processing stations. JLENS is deployable to pre-planned operational sites that have been prepared to support mobile mooring station operations. Five days are required to transition between fully operational status and a transportable configuration. Operators control the radar, process data, and transmit radar track information from mobile communication and control stations co-located with the mobile mooring stations. A mobile power generation and distribution system and associated ground equipment support each JLENS orbit.



Mission

- Army air defense units equipped with the JLENS provide persistent air and missile threat warning to friendly forces, target identification, target cueing for airborne interceptor aircraft, and precision targeting information to ground-based air defense weapons systems.
- Primary JLENS air-breathing targets include all fixed- and rotary-wing aircraft, unmanned aerial vehicles, and land attack cruise missiles. Secondary targets include surface moving targets, large caliber rockets, and tactical ballistic missiles.

Major Contractor

Raytheon Integrated Defense Systems – Andover, Massachusetts

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Activity

- The JLENS program experienced a critical Nunn-McCurdy cost breach due to an FY12 budget decision to eliminate procurement of all production systems. Following a Nunn-McCurdy review, USD(AT&L) rescinded the JLENS Acquisition Program Baseline and directed the Army to continue with a reduced JLENS test program using the two existing JLENS developmental orbits. The focus of the reduced test program is to improve airborne and surface moving target capabilities in advance of possible JLENS participation in an FY14 Combatant Commander exercise. USD(AT&L) did not authorize the program to complete the previously planned system development program or to proceed to a Milestone C or production decision.
- Based on the USD(AT&L) direction, the Army revised the JLENS operational test strategy, transitioning from the previously planned Milestone C operational assessment to a limited Early User Test (EUT) in FY13. The purpose of the EUT event is to assess JLENS operational capabilities and limitations in advance of the potential FY14 Combatant Commander exercise. During this limited assessment, Soldier operators will conduct missions with contractor support. All system maintenance support will be provided by contractor personnel. The Army has scheduled execution of EUT operational flight test scenarios for November 2012, with additional modeling and simulation events planned in March 2013. Since no further JLENS production is currently authorized, a JLENS IOT&E event will not be required.
- The Army completed the first phase of JLENS contractor functional verification testing and government test phase in December 2011 at the Utah Test and Training Range (UTTR). This phase included contractor and government developmental testing of the surveillance radar and fire control radars installed on their individual aerostat systems. The primary focus of these test events was to develop an initial capability for the surveillance and fire control radars to independently detect, identify, and track airborne targets. This phase also provided initial information on system reliability.
- From February through April 2012, the Army conducted a series of developmental integrated fire control tests with both radars operating as a single, integrated orbit to support simulated air defense missile engagements using an operational Army air defense missile system. This test phase concluded with a live missile flight test engagement against a target drone.
- The program entered the second phase of developmental testing in August 2012. This phase focused on improving orbit-level stability and technical maturity for airborne and surface moving target detection, identification, and tracking, including operations in a basic electronic attack environment. New capabilities under development in this phase included interoperability with additional datalink systems such as CEC, Integrated Broadcast Service (IBS), Joint Range Extension Application Protocol C (JREAP C), and Tactical Voice Communications. The phase also included Soldier operator and maintenance training activities, although contractor personnel continued to operate and maintain the system. This test phase was completed in September 2012 and data analysis is in progress.
- In September 2012, the JLENS system supported a NIFC-CA Live Fire Demonstration missile flight test event at White Sands Missile Range.

Assessment

- During the initial phases of contractor functional verification and government developmental testing in 2011, the JLENS demonstrated surveillance and fire control radar detection and tracking performance that exceeded system technical specifications for fixed-wing and cruise missile air-breathing targets in a controlled test environment. Contractor personnel operated and maintained the system during these test events.
- Testing showed that the fire control radar consistently provided fire control quality tracking data that were sufficient to support air defense missile engagements. The system also demonstrated a limited target identification capability that partially met requirements and basic interoperability with other air defense systems using Link 16 data transfer systems. Testing included a successful demonstration of the fully-deployed aerostat tether system, including power and fiber-optic data transmission paths. The test also identified critical performance areas for improvement to include: non-cooperative target recognition, friendly aircraft identification capabilities, fire control radar software stability, and target track consistency. During this test phase, the system was operated primarily by contractor personnel using non-production representative engineering control systems and operator interfaces.
- During the developmental integrated fire control test phase in April 2012, an integrated JLENS orbit supported a series of simulated missile flight test engagements of airborne targets with an operational Army air defense missile system. These tests verified that JLENS detection and tracking technical performance continued to mature and were sufficient to support basic air defense missile engagements. This phase concluded with a successful live missile flight test that destroyed a target drone aircraft in a controlled test environment. During this phase, the JLENS system was operated primarily by contractor personnel using non-production representative engineering control systems and operator interfaces.
- During the joint JLENS NIFC-CA missile flight test at White Sands Missile Range, the JLENS provided integrated fire control targeting information to a Navy Aegis-based missile system using CEC datalinks to successfully engage and destroy a surrogate cruise missile aerial target.
- Based on data collected during developmental testing, JLENS system-level reliability is not meeting program growth goals. At the beginning of the DT-2 test phase in August 2012, the Army assessed orbit level reliability to be 21 hours Mean Time Between System Abort (MTBSA), well below the 108 hours MTBSA necessary to meet operational reliability

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and availability requirements. Both software and hardware reliability problems contribute to low system reliability.

Recommendations

- Status of Previous Recommendations. This is the first annual report for this program.
- FY12 Recommendations. The Army should:
  1. Complete the planned JLENS EUT and provide an operational capabilities and limitations report prior to initiating a Combatant Command exercise.
  2. Develop a reliability improvement plan to address poor system-level reliability prior to a JLENS fielding decision.

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Joint Light Tactical Vehicle (JLTV)

Executive Summary

- DOT&E approved the Joint Light Tactical Vehicle (JLTV) Test and Evaluation Master Plan (TEMP) in July 2012. The TEMP addresses the test and evaluation strategy to support the selection of a single vendor to produce JLTV low-rate initial production vehicles, and includes a reliability growth plan and adequate operational and live fire testing.
- In August 2012 the USD(AT&L) granted approval for the program to enter Engineering Manufacturing and Development (EMD) at Milestone B.
- Based on JLTV prototype performance in Technology Development (TD) phase tests, demonstrating the reliability threshold requirement of 2,400 Mean Miles Between Operational Mission Failure is dependent on the vendors designing reliability into vehicles and successfully integrating government-furnished mission equipment in the vehicles.
- The Army underbody threat size requirements are equivalent to those of the Mine Resistant Ambush Protected (MRAP) All-Terrain Vehicle (M-ATV) without an underbody improvement kit. The ability to achieve this level of protection while satisfying other JLTV requirements is not yet known.
- The program awarded contracts to Oshkosh Corporation, AM General, and Lockheed Martin for the EMD phase of the JLTV Family of Vehicles (FoV) program in August 2012. The program has allotted 33 months for the EMD phase. The contractors will deliver 22 full-up prototypes per contractor in the 12 months after the EMD contract is awarded for the 14-month government test program.



AM General JLTV



Lockheed Martin Systems JLTV



Oshkosh Defense JLTV

System

- The JLTV FoV is the Marine Corps and Army partial replacement for the High Mobility Multi-purpose Wheeled Vehicle (HMMWV). The Services intend the JLTV to provide increased crew protection against IED and underbody attacks, improved mobility, and higher reliability than the HMMWV.
- The JLTV FoV consists of two vehicle categories: the JLTV Combat Tactical Vehicle (CTV), designed to seat four passengers; and the JLTV Combat Support Vehicle (CSV), designed to seat two passengers.
- The JLTV CTV has a 3,500-pound payload and three mission package configurations:
  - Close Combat Weapons Vehicle
  - General Purpose Vehicle
  - Heavy Guns Carrier Vehicle
- The JLTV CSV has a 5,100-pound payload and two mission package configurations:
  - Utility Prime Mover
  - Shelter Carrier
- The JLTV program is using a competitive acquisition strategy. During the EMD phase, the program will test and assess at least three vendors' FoVs.

Mission

- Military units employ JLTV as a light tactical wheeled vehicle to support all types of military operations. JLTVs will be used by airborne, air assault, light, Stryker, and heavy forces as reconnaissance, maneuver, and maneuver sustainment platforms.
- Small ground combat units employ JLTV in combat patrols, raids, long-range reconnaissance, and convoy escort.

Major Contractors

- Oshkosh Corporation – Oshkosh, Wisconsin
- AM General – South Bend, Indiana
- Lockheed Martin Corporation – Dallas, Texas

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Activity

- The program completed TD phase testing in 4QFY11 in accordance with the DOT&E-approved Test and Evaluation Strategy (TES).
- In January 2012, the program released the Request for Proposal to industry to solicit vendor participation in the JLTV EMD phase.
- The Joint Requirements Oversight Council approved the JLTV Capability Development Document and designated the Army as lead Service for the program in March 2012.
- DOT&E approved the JLTV TEMP in July 2012. The TEMP addresses the TES to support the selection of a single vendor to produce JLTV low-rate initial production vehicles, and includes a reliability growth plan and adequate operational and live fire testing.
- The USD(AT&L) approved Milestone B in August 2012, which permitted the program to enter EMD.
- The program awarded contracts to Oshkosh Corporation, AM General, and Lockheed Martin for the EMD phase of the JLTV FoV program in August 2012. The program has allotted 33 months for the EMD phase. The contractors will deliver 22 full-up prototypes per contractor in the 12 months after the EMD contract is awarded for the 14-month government test program.

Assessment

- Based on JLTV prototype performance in TD phase tests, demonstrating the reliability requirement of 2,400 Mean Miles Between Operational Mission Failure during EMD is dependent on the vendors designing reliability into their vehicles and successfully integrating government-furnished mission equipment in the vehicles.
- The Army underbody threat size requirements are equivalent to the threat size requirements of the M-ATV without an underbody improvement kit. The ability to achieve this level of protection while satisfying other JLTV requirements is not yet known.
- The planned EMD reliability growth testing and corrective action periods have limited time to identify and resolve failure modes prior to initiation of the Limited User Test.
- The Limited User Test and live fire test programs have adequate quantities and variants of the JLTV prototypes to assess the JLTV FoV operational capabilities and survivability.

Recommendations

- Status of Previous Recommendations. The program addressed all previous recommendations.
- FY12 Recommendations. None.

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MQ-1C Gray Eagle Unmanned Aircraft System (UAS)

Executive Summary
- The Army conducted the Gray Eagle IOT&E at Edwards AFB, California, and the National Training Center (NTC), Fort Irwin, California, July 30 through August 17, 2012.
- The Army conducted the IOT&E in accordance with the DOT&E-approved Test and Evaluation Master Plan and test plan.
- DOT&E is completing a Beyond Low-Rate Initial Production (BLRIP) report supporting the Gray Eagle Full-Rate Production decision planned for April 2013. In that report, DOT&E concludes the Gray Eagle-equipped unit was effective at operating the MQ-1C system and has the potential to provide effective support to combat units, but the Army needs to continue to develop the tactics, techniques, and procedures; the training; and the doctrine required to effectively integrate this capability into combat operations. The Gray Eagle system is operationally suitable. The Gray Eagle meets its crew force protection survivability requirements by providing up-armored capability to the cab of the vehicles transporting the Ground Control Stations during company movement. The Gray Eagle aircraft is not survivable in a mid- to high-threat environment.

System
The Gray Eagle Unmanned Aircraft System (UAS) is composed of the following major components:
- Twelve unmanned aircraft each with a Common Sensor Payload (CSP) with an electro-optical/infrared with a Laser Range Finder/Laser Designator capability, a STARLite Synthetic Aperture Radar/Ground Moving Target Indicator (SAR/GMTI) sensor payload, and an Air Data Relay (ADR) control capability
- Each aircraft is equipped with a Standard Equipment Package that includes a communications relay package, Identification Friend-or-Foe equipment, and Air Traffic Control radios
- Each aircraft has the ability to carry up to four Hellfire P+ missiles
- Five Ground Control Stations designated as the One System Ground Control Station (OSGCS)



- Five Tactical Common Datalinks (TCDL) Ground Data Terminals
- One Satellite Communications (SATCOM) Ground Data Terminal
- Six SATCOM Air Data Terminals
- Two Automatic Take-off and Landing Systems, which consist of four Take-off and Landing System-Tracking Systems and antennas

Mission
Commanders employ Gray Eagle Companies to execute Reconnaissance, Surveillance, Security, Attack, and Command and Control missions in support of assigned Division Combat Aviation Brigade, Fires Brigade, Battlefield Surveillance Brigade, Brigade Combat Teams, and other Army and Joint Force units based upon the Division Commander's mission priorities.

Major Contractor
General Atomics Aeronautical Systems, Inc., Aircraft Systems Group – Poway, California

Activity
- The Gray Eagle UAS participated in the Apache Block 3 IOT&E in March through April 2012, at the NTC in Fort Irwin, California, to conduct Manned-Unmanned Teaming operations. A single Gray Eagle UAS with associated flight crew and personnel provided mission support to the IOT&E from Edwards AFB, California.
- In July 2012, and as a result of the direction received from the Low-Rate Initial Production (LRIP) III Acquisition Decision Memorandum, the project manager for UAS requested the Army Aviation Center seek a deferral of the requirement to meet the Reliability Key System Attributes (KSAs) and the Sustainment Key Performance Parameter (KPP) from IOT&E to FOT&E. The Army deferred the requirement of meeting the KSAs on August 16, 2012. The Joint Requirements Oversight Council approved the deferral of meeting the KPP on November 16, 2012.

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- The Army conducted the Gray Eagle IOT&E at Edwards AFB, California, and the NTC, Fort Irwin, California, July 30 through August 17, 2012, in accordance with the DOT&E-approved Test and Evaluation Master Plan and test plan. The Army based the IOT&E unit at Edwards AFB, and from there it conducted missions in support of the Brigade Combat Team conducting a training rotation at the NTC approximately 130 kilometers away. The IOT&E unit flew 1,090 flight hours and conducted missions at operational ranges exceeding 150 kilometers. The IOT&E unit routinely flew aircraft between 8,000 and 13,000 feet mean sea level (MSL) with a maximum altitude being flown of 24,500 feet MSL.
- There were eight Hellfire missile engagements during IOT&E. Six were cooperative engagements with Apache helicopters, meaning one aircraft provided the lasing of the target while the other aircraft launched the missile. Two engagements were autonomous, meaning the Gray Eagle provided the lasing of the target and launched the missile on its own. All eight missile engagements hit the intended target.
- DOT&E is completing a BLRIP report supporting the Gray Eagle Full-Rate Production decision planned for April 2013.

Assessment

- During IOT&E, the Gray Eagle-equipped unit was effective at operating the MQ-1C system and demonstrated the potential to provide effective support to combat units, but the Army has not effectively integrated this capability into combat operations. Army integration of Gray Eagle into employment concepts, and development of tactics, techniques, and procedures are not mature and training afforded to the IOT&E unit before the test was not complete. Soldiers did not receive training on fundamentals of reconnaissance, mission planning, set-up and operation of radios, distribution of video, STARLite SAR/GMTI capabilities and operation, or employment of Gray Eagle.
- The Gray Eagle system has more capability and functionality today than it demonstrated in previous operational tests. Increases in capability demonstrated during the 2012 IOT&E include:
  - The CSP providing the electro-optical/infrared with a Laser Range Finder/Laser Designator capability
  - A STARLite SAR/GMTI payload
  - The ability to conduct aircraft operations via encrypted TCDL, SATCOM datalink, as well as the ADR aircraft control capability
- The IOT&E unit completed 223 of 307 attempted missions during test, resulting in a mission success rate of 73 percent.
- The Gray Eagle system is operationally suitable. During IOT&E, the Gray Eagle unit demonstrated its ability to meet its operational tempo requirement to provide three simultaneous and continuous missions (24-hour continuous reconnaissance, 24-hour continuous armed reconnaissance, and two 5-hour attack missions in a 24-hour period). The Gray Eagle system demonstrated a Combat Availability of 81 percent, exceeding the Sustainment KPP requirement of 80 percent. The unit achieved the Combat Availability requirement in spite of failing to meet its reliability requirements. The IOT&E demonstrated that the modeling assumptions that established the reliability requirements thresholds were not valid. As a result, the Army is reassessing whether or not the reliability KSAs need to be changed. Those modified reliability requirements, if made, are planned to be tested in FOT&E.
- During the IOT&E, the Gray Eagle demonstrated KSA Mean Time Between System Abort (MTBSA) compared to the deferred MTBSA requirements of 44 hours versus 150 hours for the OSGCS, 55 hours versus 100 hours for the aircraft, 218 hours versus 500 for the CSP, and 97 hours versus 500 hours for the STARLite SAR/GMTI.
- The Gray Eagle Company depended heavily on the maintenance expertise of Contractor Field Service Representatives.
- During the IOT&E, remote video from the Gray Eagle to the One System Remote Video Terminal (OSRVT) was generally not available, not clear, and not reliable. Integration of the Gray Eagle with a reliable remote video display system is not complete.
- The IOT&E unit demonstrated effective target detection and recognition capability using the electro-optical/infrared sensor with Laser Range Finder/Designator.
- The Hellfire P+ missile is fully integrated into the Gray Eagle system when using the TCDL and SATCOM datalinks. The Army has not demonstrated Hellfire engagements via the ADR datalink in developmental or operational testing.
- The Automatic Take-off and Landing System worked as designed.
- The Gray Eagle is vulnerable to computer network attack.
- The Gray Eagle meets its crew force protection survivability KPP requirement by providing up-armored capability to the cab of the vehicles transporting the ground control stations during company movement. Testing indicates that the Gray Eagle aircraft is not survivable in a mid- to high-threat environment. The aircraft can be detected at operational altitudes visually, acoustically, by late-model man-portable air defense systems, and by threat radar systems.
- The operator's manual is not current and in some cases not accurate.
- The design of the OSGCS shelter has a number of features that reduce operator efficiency and increase operator stress and fatigue: volume control of radios, OSGCS start-up procedures, procedures for operators to establish SATCOM and ADR datalinks, work station climate control, and poor ergonomics of the OSGCS operator's joy stick controller.
  - Operators are not able to control the volume on any of the radios within the OSGCS. On numerous occasions during missions, the air traffic control radio calls would drown out the operator's ability to hear other communications on the tactical radio networks.
  - The OSGCS start-up procedures entail 191 checklist steps and require up to 2 hours to execute.

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- Procedures for operators to establish SATCOM and ADR datalinks are numerous and complex in nature. If the operator does not follow the prescribed sequence, they have to re-execute the procedure in its entirety, taking up to 45 additional minutes to complete the task.
- The computers and avionics within the OSGCS require air conditioning to maintain normal operation. Air conditioning controls have been improved; however, in order to stay warm, OSGCS operators continue to wear hats, gloves, and cold-weather gear even in hot weather environments.
- Operator controls are not efficient. OSGCS employs a joystick that has no triggers or buttons that would allow one-handed control of the payload or aircraft. Both hands are required for many basic tasks as the operator provides inputs to both the joystick and the keyboard while operating the system. A cyclic-type joystick, such as those found in Army helicopters, would allow for one-handed multifunction operation of the system.

Recommendations

- Status of Previous Recommendations. The Army addressed four of the seven previous recommendations. Outstanding previous recommendations include:
  1. The Army should develop, optimize, and publish standardized procedures for the OSRVT terminal.
  2. The Army should revise and expand the training program and update the operator's manual.
  3. The Army should improve the Ground Control Shelter design.
- FY12 Recommendations.
  1. The Army should:
     - Continue to develop doctrine; employment concepts; and tactics, techniques, and procedures to fully integrate the Gray Eagle unit into combat operations.
     - Train operators on fundamentals of reconnaissance, mission planning, set-up and operation of radios, distribution of video, and optimal employment of the Gray Eagle.
     - Continue to develop and publish standardized procedures for distribution of Gray Eagle video to OSRVT and institute training across the Army to facilitate integration of Gray Eagle into supported unit operations.
     - Revise and expand the training program for operators and update the operator's manual.
     - Modify the personnel plan to retain or offset the anticipated loss of Contractor Field Service Representative support.
     - Refine and train procedures for collection and exploitation of SAR/GMTI imagery.
  2. The Product Office should:
     - Simplify, and to the greatest extent possible, automate routine operator tasks. The 2-hour, 191 checklist steps required to start the Ground Control Station should be streamlined and be made less susceptible to operator errors.
     - Simplify procedures for operators to establish SATCOM and ADR datalinks.
     - Qualify the ADR datalink for employment of Hellfire missiles.
     - Improve OSGCS functionality by increasing operator control of radio volume, temperature, and joy stick functionality.

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Paladin Integrated Management (PIM)

Executive Summary

- DOT&E approved the Paladin Integrated Management (PIM) Engineering and Manufacturing Development Test and Evaluation Master Plan on March 5, 2012.
- In 1QFY12, PIM completed Phase I government developmental testing with five prototype howitzers and two prototype ammunition carriers. The howitzer reliability estimate from Phase I reliability, availability, and maintainability (RAM) missions was 45 hours Mean Time Between System Abort (MTBSA) compared to a requirement of 62 hours.
- In July 2012, PIM vehicles commenced Phase II developmental testing in preparation for a Limited User Test scheduled for October 31 through November 8, 2012, to support a June 2013 Milestone C decision.
- Testing to characterize the protection provided by M109 Family of Vehicles (FoV) armor configurations began in August 2012 and is scheduled to continue through the end of the year.
- In 2011, DOT&E raised concerns regarding the M109 FoV force protection and survivability requirements. As a result, the Army improved the systems' ballistic vulnerability requirements, and OSD directed the Army to design, develop, and test an underbelly kit to address operationally-relevant underbody blast threats.
- OSD also directed the Army to characterize the expected impact of the objective-level underbelly kit on howitzer performance and vehicle RAM by integrating such a kit into the PIM program's development and testing, and planned Production Qualification Testing.
- The program's current plans are schedule driven, with limited time for correction of deficiencies identified in developmental testing and little flexibility with individual component test schedules. The program must wait for the production of low-rate initial production (LRIP) vehicles before verifying most corrective actions.

System

- The M109 FoV PIM consists of two vehicles, the Self-Propelled Howitzer (SPH) and Carrier, Ammunition, Tracked (CAT).
- The M109 FoV SPH is a tracked, self-propelled 155 mm howitzer designed to improve sustainability over the legacy M109A6 howitzer fleet. The full-rate production howitzers will have a newly designed hull, modified Bradley Fighting Vehicle power train and suspension, and a high-voltage electrical system. Operated by a crew of 4, the howitzer is capable of achieving ranges of 22 kilometers using standard projectiles and 30 kilometers using rocket-assisted projectiles.
- The M109 FoV CAT supplies the howitzer with ammunition. The full-rate production ammunition carriers will have a common chassis with the SPH. The ammunition carriers are designed to carry 12,000 pounds of ammunition in various configurations and a crew of 4 Soldiers.
- The Army intends to employ the M109 FoV as part of a Fires Battalion in the Armored Brigade Combat Team and Artillery Fires Brigades with the capability to support any Brigade Combat Team.
- The Army plans to field 580 sets of the M109 FoV with full-rate production vehicles beginning in FY17.



Mission

Field Artillery units will use the M109 FoV to destroy, neutralize, or suppress the enemy by providing massed and precision indirect fire effects in support of maneuver units in multiple levels of conflict to include major combat operations and irregular warfare.

Major Contractor

BAE Systems – York, Pennsylvania

Activity

- In 1QFY12, PIM completed Phase I government developmental testing with five prototype howitzers and two prototype CAT platforms. Phase I SPH testing at Yuma Test Center, Arizona, included five RAM missions (firing 223 rounds and moving 17.4 miles per firing mission – equivalent

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to 1 combat day at the Paladin operational tempo), firing performance tests.
- Testers at the Aberdeen Test Center, Maryland, conducted Phase I testing of both vehicles to determine compliance with performance specifications. A 2,400-mile demonstration with the CAT was terminated early because of a transmission failure.
- In 2011, DOT&E raised concerns regarding the M109 FoV force protection and survivability requirements. As a result, the Army improved the systems' ballistic vulnerability requirements, and OSD directed the Army to design, develop, and test an underbelly kit to address operationally-relevant underbody blast threats.
- OSD also directed the Army to characterize the expected impact of the objective-level underbelly kit on howitzer performance and vehicle RAM by integrating such a kit into the PIM program's development and testing, and planned Production Qualification Testing.
- DOT&E approved the PIM Test and Evaluation Master Plan on March 5, 2012.
- Prototype SPHs completed refurbishment in June 2012, and entered Phase II government developmental testing, which completes production prove-out testing with prototype vehicles. Phase II included an additional 10 RAM missions using the Heavy Brigade Combat Team operational tempo, the logistics demonstration, and software verification. Phase II completed in mid-October 2012.
- Testing to characterize the protection provided by M109 FoV armor configurations began in August 2012 and is scheduled to continue through the end of the calendar year.
- The Army has scheduled a PIM Limited User Test for October 31 through November 8, 2012, to support a Milestone C decision in June 2013. The IOT&E is scheduled for 4QFY16.

Assessment
- The current program is schedule-driven, with limited time for correction of deficiencies identified in developmental testing and little flexibility in schedules for individual tests. Most corrective actions must wait for testing with LRIP vehicles to verify the corrective action.
- The howitzer reliability estimate from Phase I RAM missions, 45 hours MTBSA, is the initial point on a reliability growth curve designed to grow vehicle reliability above the 62-hour MTBSA needed to meet the reliability requirement.
- As Phase I RAM testing progressed, vehicle discrepancies increased as PIM subsystems had problems withstanding repeated gun shock. Legacy subsystems, including the Paladin Digital Fire Control System (PDFCS), demonstrated fewer gun-shock generated discrepancies.
- The PDFCS experienced frequent failures attributed to the Muzzle Velocity Radar System (MVRS). A software modification corrected a timing problem between MVRS and PDFCS, which is believed to have caused those failures.
- In Phase I testing, the PIM prototype SPH demonstrated the ability to conduct conventional fire missions, and verify compatibility with current 155 mm ammunition. In early testing with the initial transmission, the SPH failed to meet the climbing requirement. Subsequent testing has not demonstrated the ability to meet this requirement with confidence using correct fluid levels per the Technical Manual.
- Vehicle deficiencies were identified during Phase II RAM testing with the automotive subsystems of the SPH. These problems prevented the vehicle from conducting required short-duration survivability movements in a timely manner.
- After the critical design review, the program manager identified a number of corrective action, producibility, and obsolescence (CPO) engineering changes to the PIM design that will be implemented between LRIP and the IOT&E. The schedule for development, test, and implementation of those CPO changes is high-risk and challenging.

Recommendations
- Status of Previous Recommendations. This is the first annual report for this program.
- FY12 Recommendations. The Army should:
  1. Provide an LRIP-configured prototype as early as possible to continue characterizing armor performance, address critical ballistic vulnerability data voids, and provide time for implementation of corrective actions before entering full-up system-level testing.
  2. Ensure that CPO changes are fully qualified in system-level testing rather than relying solely on component-level qualification before implementing them in the LRIP vehicles scheduled for the IOT&E.

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Patriot Advanced Capability-3 (PAC-3)

Executive Summary

- The Army began the Post-Deployment Build-7 (PDB-7) Limited User Test (LUT) operational test in FY12. The PDB-7 LUT included hardware-in-the-loop (HWIL) testing, sustained operations testing, and a combined missile flight test that consolidated three individual missile flight tests into one campaign.
- The Army conducted five major developmental Patriot flight test missions and the PDB-7 Developmental Test and Evaluation (DT&E) in FY12.
- The Missile Defense Agency conducted an integrated flight test of the Ballistic Missile Defense System (BMDS) in October 2012, during which Patriot engaged and killed a cruise missile target and a tactical ballistic missile target in the debris field caused by another BMDS intercept.
- In the seven U.S. developmental and operational flight tests conducted in FY12, Patriot achieved successful intercepts of six short-range ballistic missile targets and five air-breathing threat/cruise missile targets using Patriot Advanced Capability-3 (PAC-3) and Guidance Enhanced Missile (GEM) missiles.
- The Army also conducted five flight tests for an international Foreign Military Sales (FMS) customer, during which Patriot intercepted four of five tactical ballistic missile targets and three of three air-breathing threat/cruise missile targets. The fifth FMS flight test concurrently successfully fulfilled a long standing PAC-3 Engineering Manufacturing and Development phase requirement.

System

- Patriot is a mobile air and missile defense system that counters missile and aircraft threats. The system includes the following:
  - C-band phased-array radars for detecting, tracking, classifying, identifying, and discriminating targets
  - Battalion and battery battle management elements
  - Communications Relay Groups and Antenna Mast Groups for communicating between battery and battalion assets
  - A mix of PAC-3 hit-to-kill missiles and PAC-2 blast fragmentation warhead missiles for negating missile and aircraft threats
- The newest version of the PAC-3 missile is the Cost Reduction Initiative (CRI) missile. In addition, the Army is developing the PAC-3 Missile Segment Enhancement (MSE) missile with increased battlespace defense capabilities and improved lethality.
- Earlier versions of Patriot missiles include the Patriot Standard missile, the PAC-2 Anti-Tactical Missile, and the GEM family (includes the GEM-T and GEM-C missile variants intended to counter tactical ballistic missiles and cruise missiles, respectively).
- DoD intended the Medium Extended Air Defense System (MEADS) to replace the Patriot system. The DoD has decided not to field MEADS and plans to conclude the design and development phase of the program in FY13.



Mission

Combatant Commanders use Patriot to defend deployed forces and critical assets from missile and aircraft attack and to defeat enemy surveillance air assets (such as unmanned aerial vehicles) in all weather conditions, and in natural and induced environments.

Major Contractors

- Raytheon Integrated Defense Systems – Tewksbury, Massachusetts
- Lockheed Martin Missile and Fire Control – Grand Prairie, Texas

Activity

- In accordance with the DOT&E-approved Test and Evaluation Master Plan, the Army began the PDB-7 LUT on May 31, 2012, at White Sands Missile Range (WSMR), New Mexico. The PDB-7 LUT is expected to end in November 2012 with the completion of the PDB-7 LUT regression test.

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- The Army conducted the PDB-7 LUT operational missile flight test (P7L-1/2/3) at WSMR in August 2012. During this test, Patriot:
  - Engaged and intercepted one tactical ballistic missile target with a ripple launch (firing of missiles in quick succession) of GEM-T/PAC-3 CRI missiles.
  - Engaged a second tactical ballistic missile target with a ripple launch of two PAC-3 missiles. This second tactical ballistic missile target self-destructed before the interceptors reached it; therefore, the endgame segment of the second tactical ballistic missile engagement was deemed a "No Test."
  - Engaged and intercepted a cruise missile target with a GEM-T missile in the debris field resulting from the destruction of the two tactical ballistic missile targets.
- The Army conducted the PDB-7 DT&E at WSMR from July 2011 to March 2012.
  - During PDB-7 flight test P7-4 in November 2011, Patriot engaged a short-range ballistic missile target with a ripple launch of two PAC-3 CRI missiles. The first PAC-3 missile intercepted the target.
  - During PDB-7 flight test P7-3 in November 2011, Patriot engaged a short-range ballistic missile target with a ripple launch of two GEM-T missiles. The first GEM-T missile intercepted the target.
  - During PDB-7 flight test P7-2 in November 2011, Patriot engaged two short-range ballistic missile targets with two ripple launches of GEM-T/GEM-C missiles. The first GEM-T missile of each ripple engagement intercepted its target.
  - During PDB-7 flight test P7-1 in March 2012, Patriot fired a GEM-T missile at one cruise missile target and a GEM-C missile at a second cruise missile target. Both Patriot missiles intercepted their targets.
- During the first Integrated Fire Control flight test (IFC-1) at the Utah Test and Training Range in April 2012, Patriot fired a PAC-3 CRI missile at a cruise missile target using a Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System cue. The PAC-3 missile intercepted the target.
- During the first MEADS flight test, the Launcher/Missile Characterization Test at WSMR in November 2011, MEADS fired an MSE missile at a simulated target.
- During the FMS G-2 missile flight test at WSMR in March 2012, Patriot intercepted a cruise missile target with a GEM-T missile.
- During the FMS P-1/P-2 missile flight test at WSMR in March 2012, Patriot engaged a short-range ballistic missile target with a ripple launch of two PAC-3 missiles. The first PAC-3 missile intercepted the target.
- During the FMS G-3/G-6/G-7 missile flight test at WSMR in May 2012, Patriot failed to intercept a short-range ballistic missile target during the G-3 portion of the mission because of a missile launch sequence failure. As a result, the G-3 portion of the mission was repeated using a backup short-range ballistic missile target, which Patriot intercepted using a GEM-T missile. This was followed by the launch of another short-range ballistic missile target, which Patriot engaged using a ripple launch of two GEM-T missiles. The first GEM-T missile intercepted the target.
- During the FMS G-4/G-5 missile flight test at Eglin AFB, Florida, in June 2012, Patriot performed near-simultaneous intercepts over water of two air-breathing targets using GEM-T missiles.
- During the FMS P-3/P-4 missile flight test at WSMR in September 2012, Patriot engaged a short-range ballistic missile target with a ripple launch of two PAC-3 CRI missiles. The first PAC-3 missile intercepted the target. This mission concurrently fulfilled a long standing PAC-3 Engineering Manufacturing and Development phase requirement.
- During Flight Test Integrated-01 (FTI-01) in October 2012 at the Reagan Test Site, Patriot performed a near-simultaneous engagement of a short-range ballistic missile target with two PAC-3 interceptors and a cruise missile target with another PAC-3 interceptor. FTI-01 was the first integrated flight test with multiple firing elements (Aegis Ballistic Missile Defense [BMD], Terminal High-Altitude Area Defense [THAAD], and Patriot) engaging multiple ballistic missile and air-breathing targets in a realistic BMDS-level architecture. Patriot successfully intercepted both of its targets.

Assessment

- The HWIL phase of the PDB-7 LUT was to have included equal numbers of runs with and without simulated MSE missiles. All planned runs without MSE missiles were completed, but Patriot system availability problems led to only 20 percent of the MSE runs being accomplished. As a result, the effectiveness assessment of the Patriot PDB-7 system with MSE missiles will be limited until the Army conducts a dedicated HWIL test with simulated MSE missiles. Additional HWIL testing with MSE missiles is planned as part of PDB-7 regression testing scheduled to complete in November 2012.
- Data analysis is ongoing, but preliminary results indicate that Patriot training remains inadequate to prepare operators for complex Patriot engagements. This was true during the PDB-6.5 and PDB-6 LUTs as well. This problem was exacerbated in the PDB-7 LUT because many of the experienced Patriot operators in the test unit were understandably transferred to deploying units prior to the LUT, resulting in many inexperienced users and a high variability in Soldier proficiency across the test unit.
- Calculation of Patriot system reliability such as Mean Time Between Critical Mission Failure using field data is being investigated. Critical field data including total operating hours and numbers of critical mission failures for each Patriot battery major end item may not be accurate.
- During the PDB-7 LUT operational missile flight test (P7L-1/2/3), Patriot demonstrated the capability to search, detect, track, engage, and intercept both a tactical ballistic missile target and a cruise missile target with GEM-T missiles. Patriot intercepted the cruise missile target in the debris field caused by the intercept of the first tactical ballistic missile target and the self-destruction of the second tactical ballistic

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missile target. However, the following problems were observed during this test:
  - Patriot was to have engaged the first tactical ballistic missile target with two GEM-T missiles, but the launcher incorrectly reported a missile count of zero after the first GEM-T missile launched so a PAC-3 missile was launched instead.
  - Patriot engaged the second tactical ballistic missile target with two PAC-3 missiles, but the target broke up before the missiles reached it. The cause of this target failure is under investigation.
  - Patriot was to have had two GEM-T missiles available to engage the cruise missile target, but one could not be armed. The backup missile was not needed however, as the first GEM-T missile launched successfully and intercepted the target.
  - Although the Patriot crews were not supposed to be notified when the targets were launched, a test conduct error led to them hearing the range communications network during the launches. It is unknown what effect, if any, this had on the test.
- The Patriot system met most of the test objectives during the PDB-7 DT&E. However, there were some incidents during the ground testing portion when Patriot did not properly transmit messages, had degraded track triangulation between batteries, was unable to isolate faults and had to be rebooted, selected a launcher with no available missiles, and selected less preferred missiles against threats (e.g., a GEM against a long-range tactical ballistic missile or a PAC-3 missile against a threat aircraft). The Patriot system did not meet its reliability requirements during this test.
- During PDB-7 flight test P7-4, Patriot demonstrated the capability to search, detect, track, engage, and intercept a tactical ballistic missile target with PAC-3 missiles in a ripple engagement. There were some discrepancies between the performance of the second PAC-3 missile during its initial turn and pre-flight simulations. The causes of these discrepancies are still under investigation. One of the two non-firing Patriot batteries did not collect data during the P7-4 flight test. The affected non-firing battery restarted the data collection system multiple times in an effort to fix the problem, but it was not resolved before the engagement.
- During PDB-7 flight test P7-3, Patriot demonstrated the capability to search, detect, track, engage, and intercept a tactical ballistic missile target with GEM missiles in a ripple engagement.
- During PDB-7 flight test P7-2, Patriot demonstrated the capability to detect, engage, and intercept short-range ballistic missile targets with GEM-T missiles. Patriot conducted the second engagement in the presence of the debris cloud caused by the first intercept.
- During PDB-7 flight test P7-1, Patriot demonstrated the capability to detect, engage, and intercept cruise missile targets in clutter with GEM-T and GEM-C missiles.
- During IFC-1, Patriot demonstrated the capability to use the Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System cuing data to engage a cruise missile with a PAC-3 missile. The PAC-3 missile intercepted the target.
- During the Launcher/Missile Characterization Test, an MSE missile was launched at a 70-degree angle, performed an out-of-plane maneuver, and followed the predicted flight path to the simulated target, which was 120 degrees off the launch axis. All test objectives were met.
- Patriot intercepted four of five tactical ballistic missile targets and three of three air-breathing threat/cruise missile targets during five FMS flight tests.
  - The original target in the FMS G-3 missile flight test was to be engaged with only one GEM-T missile, but the GEM-T missile had a launch sequence failure and there was not an active back-up missile that could launch in its place. After this failure, a back-up tactical ballistic missile target and back-up GEM-T missile were activated. The back-up GEM-T missile engaged and intercepted the back-up tactical ballistic missile target.
  - The FMS G-6/G-7 missile flight test was a GEM-T ripple engagement of another tactical ballistic missile target in the debris caused by the G-3 intercept. The first GEM-T had a launch sequence failure. However, there was a live back-up missile for this engagement so two GEM-T missiles were launched, the first of which intercepted the target.
- During FTI-01, Patriot demonstrated the capability to detect, track, engage, intercept, and kill both a tactical ballistic missile target and a cruise missile target with PAC-3 missiles. There was a Patriot radar fault between the cruise missile and ballistic missile engagements, but the system recovered and was able to conduct a nominal engagement. The root cause of the radar fault is under investigation. All PAC-3 missile subsystems performed as expected. The Patriot engagements were conducted in the debris field from the THAAD intercept and Patriot debris mitigation was nominal. Aegis BMD failed to intercept its ballistic missile target during FTI-01. The Missile Defense Agency did not set up the flight test so Patriot could intercept targets that Aegis or THAAD missed, although DOT&E had recommended this be a feature of BMDS flight testing (previous recommendation #6 below).
- Continuing obstacles to adequate T&E of the Patriot system include:
  - Limitations to the lethality information available for aircraft, cruise missile, and air-to-surface missile threats used to assess end-to-end system effectiveness.
  - The lack of a robust interoperability event during PDB-7 testing.
  - The lack of a robust Force Development Experiment, preventing the Army from thoroughly examining tactical standard operating procedures prior to developing Patriot PDB-7 tactics, techniques, and procedures. As a result, the engagement procedures used during the PDB-7 LUT against some threats may have led to decreased system performance.

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Recommendations

- Status of Previous Recommendations. The Army satisfactorily addressed 10 of the previous 18 open recommendations. The Army should still address the following recommendations:
  1. Conduct Patriot testing during joint and coalition exercises.
  2. Upgrade the Patriot HWIL systems to model electronic countermeasures and identification friend-or-foe systems.
  3. Conduct a Patriot flight test against an anti-radiation missile target to validate models and simulations.
  4. Review the risks of not conducting all flight tests against ballistic missile targets using two interceptors.
  5. Improve Patriot training.
  6. Have Patriot participate with live interceptors in THAAD flight testing.
  7. Conduct all operational testing regression tests with representative Soldier operators.
  8. Conduct a robust Force Development Experiment prior to the PDB-8 IOT&E to ensure that tactics, techniques, and procedures are adequate to support a successful operational test.
- FY12 Recommendations. In addition to addressing the above recommendations, the Army should:
  1. Collect reliability data on Patriot systems in the field, including total operating hours and numbers of critical mission failures for each Patriot battery major end item, so that the Mean Time Between Critical Mission Failure can be calculated.
  2. Ensure that test units for future Patriot operational tests have operationally representative distributions in Soldier proficiency by limiting transfers of experienced personnel to other units before the end of testing.
  3. Conduct future operational flight tests with unannounced target launches within extended launch windows to improve operational realism.

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Precision Guidance Kit (PGK)

Executive Summary

- In January 2011, the Army restructured the Precision Guidance Kit (PGK) Increment 1 program to address any necessary schedule changes due to reliability test failures that occurred in August 2010.
- Baseline reliability testing in August 2011 demonstrated that the contractor and program manager resolved the system's main reliability problems identified in 2010.
- In March 2012, the program received approval to accelerate fielding to Operation Enduring Freedom in FY13. The program currently has two tracks – the restructured baseline Program of Record and the Urgent Materiel Release (UMR).
- The program is currently undergoing government qualification testing and is revising the PGK Test and Evaluation Master Plan to support a Milestone C decision.
- In late October 2012, as part of the UMR program, the Army conducted an Early User Assessment that provided Soldiers their first opportunity to fire the PGK. The howitzer crew performed their tasks successfully in six operationally realistic end-to-end missions firing a total of 20 PGKs from an M777A2 howitzer. Preliminary data indicate that the PGK's accuracy is well within requirements.
- The PGK experienced two reliability failures. The program is investigating potential modifications to the GPS antenna and the ballistic parameters used to compute the firing mission when firing an M549A1 projectile.



System

- The PGK is a combined fuze and GPS guidance kit that improves the ballistic accuracy of the current stockpile of field artillery projectiles.
- The Army plans to develop PGK in two increments:
  - Increment 1. Provide 155 mm High-Explosive projectiles (M795 and M549A1) with 50 meter Circular Error Probable (CEP).
  - Increment 2. Improve delivery accuracy to 30 meters (threshold) and 20 meters (objective) CEP, as well as add anti-jam capability as a threshold requirement.
- The PGK will operate with existing and developmental artillery systems that have digital fire control systems and inductive fuze setters such as the M777A2 Lightweight Towed Howitzer and the M109A6 Paladin Self-Propelled Howitzer.

Mission

Field Artillery units will use PGK to provide indirect fire support with 30 – 50 meters accuracy to combat maneuver units in all types of weather and terrain. Artillery units will use PGK to achieve comparable effects of conventionally fuzed projectiles using fewer rounds and thus reducing collateral damage.

Major Contractor

Alliant-Techsystems Advanced Weapons Division – Plymouth, Minnesota

Activity

- In January 2011, the Army restructured the PGK Increment 1 program to address schedule changes due to the reliability test failures that occurred in August 2010. The restructured program features a Milestone C decision in 2QFY13, an Initial Operational Test (IOT) in 1QFY14, a Full-Rate Production decision in 2QFY14, and an Initial Operational Capability in 3QFY14.
- The PGK Increment 1 has three Milestone C entrance criteria: interoperability, reliability, and accuracy. The program successfully demonstrated interoperability during DOT&E-approved testing in 2009.
- In August 2011, the Army tested a modified PGK to address known failure modes in order to demonstrate satisfactory

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baseline reliability to support entrance into the next phase of Engineering and Manufacturing Development.
- In March 2012, the program received approval to accelerate fielding to Operation Enduring Freedom in FY13. Thus, the program currently has two tracks – the baseline Program of Record and the UMR.
- The program is currently undergoing government qualification testing, which includes Sequential Environmental Tests for safety and performance.
- The program is revising the PGK Test and Evaluation Master Plan to support a Milestone C decision in 2QFY13. Following Milestone C, the program intends to begin the manufacturing of fuzes for the IOT and the validation of the production line to support the Full-Rate Production decision. The program plans to conduct an IOT in 1QFY14 at Yuma Proving Ground, Arizona.
- In late October 2012, as part of the UMR program, the Army conducted an Early User Assessment that provided Soldiers their first opportunity to fire the PGK. The howitzer crew performed their tasks successfully in six operationally realistic end-to-end missions firing a total of 20 PGKs from an M777A2 howitzer. These firings provided both accuracy and reliability as input to the UMR decision planned for 2QFY13.

Assessment
- In August 2011, the Baseline Reliability testing of 48 fuzes to support entrance into the next phase of Engineering and Manufacturing Development demonstrated 84 percent reliability with 80 percent confidence, exceeding the required 83 percent with 80 percent confidence. This was the target reliability for a successful program and approval of an accelerated fielding effort.
- This reliability estimate is on the reliability growth curve for the program leading to the Capability Production Document requirement of 92 percent by Initial Operational Capability. However, in the July 2012 Sequential Environmental Test – Safety, three rounds fell significantly short of the target. This indicates a possible new failure mode. These failures are currently undergoing failure analysis. The Army will determine the effect of these failures on the program schedule upon completion of the failure analysis.
- The program is meeting accuracy requirements for the M795 and the M549A1 155 mm high-explosive projectiles at low- and mid-firing angles. The program has focused considerable resources and is making some progress in enhancing the PGK accuracy at higher firing angles.
- Results from the operational Early User Assessment of 20 fuzes in October 2012 indicate that the PGK demonstrated an 85 percent reliability with a lower 80 percent confidence bound of 74 percent. Two of the three failures in the small sample replicated a known failure mode with a planned corrective action in the Program of Record track but not in the initial UMR lots. Preliminary accuracy data indicate that overall, the PGK's accuracy met the threshold requirement of 50 meters CEP, demonstrating a 32-meter CEP although there was considerable variability in the errors – ranging from 9 meters to 131 meters. The program is investigating modifications to the GPS antenna and the ballistic parameters used to compute the firing mission when firing an M549A1 projectile. A change to the digital fire control software is in progress, which should be implemented with the upcoming UMR fielding.

Recommendations
- Status of Previous Recommendations. The Army has satisfactorily addressed all previous recommendations.
- FY12 Recommendations. The Army should:
  1. Continue to closely monitor developmental testing to ensure that the identified corrective actions for the known deficiencies are satisfactory and do not adversely affect other performance parameters prior to Milestone C.
  2. Determine the root cause of the rounds that fell short of the target and implement corrective action prior to Milestone C.
  3. Determine the causes of the substantial variance in accuracy observed in the Early User Assessment.

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Q-53 Counterfire Target Acquisition Radar System

Executive Summary
- In February 2012, the Army selected Lockheed Martin as the primary contractor for the Q-53 Program of Record. The Army plans to buy 136 Q-53 radars as part of the Program of Record.
- The Army contracted with Lockheed Martin to build 38 Quick Reaction Capability (QRC) radars to support an Urgent Materiel Release. The QRC production buy was completed in March 2012. Five QRC systems are operating in Afghanistan.
- The Army completed the first reliability test of the Program of Record radar. The radar's system abort rate was better than the rate observed in the system demonstration prior to the February 2012 Milestone C update. However, the demonstrated reliability rate is below the predicted rates needed to reach reliability requirements by the IOT&E.

System
- The Army changed the designation of the Enhanced AN/TPQ-36 (EQ-36) radar to the AN/TPQ-53 (Q-53) radar in September 2011.
- The Q-53 is a mobile radar system designed to detect, classify, and track projectiles fired from mortar, artillery, and rocket systems using a 90-degree or continuous 360-degree sector search.
- The radar provides target location of threat indirect fire systems with sufficient accuracy for effective counterfire.
- The Q-53 is designed to operate with the Counter – Rocket, Artillery, Missile (CRAM) system and the future Indirect Fire Protection Capability System.
- The Army intends to field the Q-53 radar to the sensor platoons in Brigade Combat Teams and Fire Brigades to replace the legacy AN/TPQ-36 and AN/TPQ-37 Firefinder Radars.
- The Q-53 is operated by a crew of four Soldiers and transportable by C-17 aircraft, with battlefield mobility provided by two Family of Medium Tactical Vehicle trucks.



- The Army contracted with Lockheed Martin Missile Systems and Sensors to develop and field 38 QRC radars to support an Urgent Material Release. Fielding began in 2010 with five systems operating in Afghanistan.
- The Army intends to produce 136 Program of Record Q-53 radars.

Mission
Field Artillery units protect friendly forces by employing the Q-53 radar to determine timely and accurate location of threat rocket, artillery, and mortar systems for defeat with counterfire engagements. Air Defense Artillery units will use the Q-53 radar integrated into the CRAM and Indirect Fire Protection Capability System to warn friendly forces and to engage incoming threat indirect fires.

Major Contractor
Lockheed Martin Missile Systems and Sensors – Syracuse, New York

Activity
- The Army conducted a Milestone C update on February 27, 2012. The Army selected Lockheed Martin as the primary contractor.
- The Army purchased 33 systems as part of the Milestone C update decision.
- The Army intends to purchase an additional 18 systems after the Limited User Test (LUT) scheduled for October 22 through November 8, 2012, and the remaining 85 systems at the 4QFY14 Full-Rate Production decision following the IOT&E in 1QFY14.
- The Army completed the first Program of Record reliability and performance tests at Yuma Proving Ground, Arizona, from May 15 through August 17, 2012. The contractor-operated radars completed 1,662 test hours. The two radars operated continuously in 72-hour cycles and made moves representative of the distances and terrain expected in an operational environment.
- Environmental chamber testing began at White Sands Missile Range, New Mexico, in August 2012. It will be completed by the end of 2012.

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Assessment

- Based on developmental testing at Yuma Proving Ground, the radar's reliability has improved since the system demonstration, but is below the growth projections needed to reach the reliability requirement at IOT&E.
- During the system demonstration in 2011, the radar averaged 1 system abort every 30 hours. During 2012 developmental testing, the Program Office made three significant configuration changes to address system aborts.
- During the first 2 configuration changes, the radars averaged 1 system abort every 103 hours and 1 system abort every 238 hours, respectively.
- During limited testing of the final configuration (298 test hours), the radars averaged a system abort every 75 hours.
- To reach the reliability threshold, the Program Office expected the radar to average 1 system abort every 257 hours. The Army determined two of the four system aborts during testing of the final configuration were due to problems with the user manual and training deficiencies, unrelated to the final configuration. The user manual and training will be updated prior to the LUT. The remaining two system aborts were software related and will not be addressed prior to the LUT.
- The radar met performance requirements during limited developmental testing in FY12. More extensive performance testing is planned for the LUT in October and November 2012.

Recommendations

- Status of Previous Recommendations. The Army satisfactorily addressed all of the FY11 recommendations.
- FY12 Recommendations. The Army should:
  1. Conduct future developmental reliability tests with trained civilian crews and limited contractor involvement.
  2. Continue dedicated reliability testing focusing on system aborts.

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Spider XM-7 Network Command Munition

Executive Summary
- The Army uses Spider instead of persistent landmines to comply with the requirements of the 2004 National Landmine Policy.
- The Army fielded Spider Low-Rate Initial Production (LRIP) systems to deployed and non-deployed units during 2012.
- At the request of the Army, DOT&E published a Beyond Low-Rate Initial Production (BLRIP) report in February 2012 to support a Full-Rate Production (FRP) decision in 2012. Following publication of this report, the Army postponed the Spider FRP decision until 3QFY13.
- The Army continued corrective actions to address Spider deficiencies with system reliability, complexity, and training reported in the February 2012 DOT&E Spider BLRIP Report.
- DOT&E will report on the operational effectiveness, suitability, and survivability of the Spider system early in 2013 following a third FOT&E. Based on analysis conducted to date, Spider has demonstrated effectiveness and lethality with poorly demonstrated suitability.

System
- The Army intends to use Spider as a landmine alternative to satisfy the anti-personnel munition requirements outlined in the 2004 National Landmine Policy that directs the DoD to:
  - End use of persistent landmines after 2010
  - Incorporate self-destructing and self-deactivating technologies in alternatives to current persistent landmines
- A Spider munition field includes:
  - Up to 63 Munition Control Units, each housing up to 6 miniature grenade launchers or munition adapter modules for remote electrical and non-electrical firing capabilities
  - A remote control station, used by the operator to maintain "man-in-the-loop" control of all munitions in a field
  - A communications relay device known as a "repeater" for use in difficult terrain or at extended ranges
- Spider incorporates self-destructing and self-deactivating technologies to reduce residual risks to non-combatants.



Mission
Maneuver or engineer units employ Spider to establish a force protection obstacle or as a stand-alone force protection system in all environments and in all terrains in order to accomplish the following missions:
- Protect the Force
- Shape the Battlefield
- Provide Early Warning
- Delay and Attrite Enemy Forces

Major Contractors
- Command and Control hardware and software: Textron Defense Systems – Wilmington, Massachusetts
- Munition Control Unit and Miniature Grenade Launcher: Alliant-Techsystems, Advanced Weapons Division – Plymouth, Minnesota

Activity
- The Army continued fielding Spider LRIP systems to deployed and non-deployed units. Home Station, Combat Training Center, and in-theater training were provided by the materiel and combat developers as part of the fielding package. In January 2012, the Army Milestone Decision Authority approved the production of additional LRIP systems to support continued fielding prior to an FRP decision.
- Based on demonstrated performance in the May 2010 Spider FOT&E and the June 2011 Spider Limited User Test, the Army requested DOT&E publish a BLRIP report in February 2012. Following publication of the report, the Army postponed the Spider FRP decision until 3QFY13.
- The Army continued corrective actions to address Spider deficiencies with system reliability, complexity, and training reported in the February 2012 DOT&E Spider BLRIP Report.
- The Army and DOT&E finalized planning for the third FOT&E in October 2012 to demonstrate corrective actions in an operationally realistic environment.

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- In October 2012, DOT&E approved an updated Test and Evaluation Master Plan. The update addressed the scope and execution of a comprehensive FOT&E to demonstrate Spider operational effectiveness and suitability in support of an Army FRP decision.

Assessment

- The Army conducted the Spider XM7 Limited User Test in accordance with the DOT&E-approved test plan in June 2011 at White Sands Missile Range, New Mexico.
- DOT&E intends to publish an updated evaluation on Spider XM7 early in FY13 based on the October 2012 FOT&E.
- DOT&E made the following assessment based on the BLRIP report in February 2012:
  - Spider provides the following enhanced capabilities not previously available with anti-personnel land munition systems:
    - "Man-in-the-loop" positive control of both lethal and non-lethal munitions
    - Remote electrical and non-electrical firing capabilities for munitions and demolitions to a range of 4 kilometers
    - Capability to fire a single munition or multiple munitions simultaneously
    - Capability to collect situational awareness information through tripline activation by threat personnel
  - Spider has demonstrated effectiveness and lethality.
    - A properly trained unit can successfully emplace and operate a Spider munition field in order to provide doctrinal protective obstacle effects – warn of threat activity and mitigate or prevent threat actions.
    - Units employing Spider can utilize both non-lethal and lethal munitions to achieve desired force escalation capabilities.
  - Spider has demonstrated poor suitability.
    - Spider is more complex than its predecessor system and requires Soldiers to receive extensive initial and sustainment training to maintain proficiency.
    - The Spider system's Munition Control Unit has not demonstrated the required reliability in a comprehensive operationally realistic environment.
    - Extensive battery management requirements and increased unit transportation requirements create a logistics planning challenge for units employing Spider.
- The Spider program demonstrated in contractor and government testing corrective actions to address reliability, complexity, and training deficiencies reported in the February 2012 DOT&E Spider BLRIP Report. These corrective actions are ready for further testing in an operationally realistic environment.

Recommendations

- Status of Previous Recommendations. The Army initiated actions to address the previous recommendations.
- FY12 Recommendation.
  1. The Army should closely monitor the results of the October 2012 FOT&E and be prepared to address shortcomings and deficiencies as necessary to support a 3QFY13 FRP decision.

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Stryker Mobile Gun System (MGS)

Executive Summary
- During the December 2010 Stryker Double-V Hull (DVH) Configuration Steering Board, the Army decided not to pursue full-rate production for the flat-bottom Stryker Mobile Gun System (MGS).
- Developmental tests have failed to replicate the coaxial machine gun deficiency in which brass and links falling into the ammunition storage box cause the low ammunition sensor to fail to activate. This deficiency was noted in the August 2011 Engineering Change Order Block III validation gunnery and has been noted by MGS crews returning from Afghanistan and during their training gunneries.
- Live fire testing indicates performance deficiencies in the protection provided by the Stryker Reactive Armor Tiles (SRAT) II configuration for MGS. The details are classified.

System
- The Stryker Family of Vehicles consists of two variants on a common vehicle platform: Infantry Carrier Vehicle and the MGS. There are eight configurations of the Infantry Carrier Vehicle variant.
- The MGS mission equipment includes the following:
  - The system integrates the Driver's Vision Enhancer and Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance components as government-furnished equipment.
  - The MGS provides the three-man crew with varying levels of protection against small-arms, fragmenting artillery, mines, and rocket-propelled grenades (RPGs). Add-on slat armor (high hard steel arranged in a spaced array) provides RPG protection.
- The MGS mission equipment includes the following:
  - M68A2 105 mm cannon system with an ammunition handling system
  - Coaxial 7.62 mm machine gun and a secondary M2HB, .50-caliber machine gun



  - Full solution fire control system with two-axis stabilization
  - Low-profile turret meant to provide survivability against specified threat munitions

Mission
- The Stryker Brigade Combat Team uses the MGS to create openings in walls, destroy bunkers and machine gun nests, and defeat sniper positions and light armor threats. The primary weapon systems are designed to be effective against a range of threats up to T-62 tanks.
- The MGS operates as a three-vehicle platoon organic to the Stryker infantry company or as a single vehicle in support of a Stryker infantry platoon.

Major Contractor
General Dynamics Land Systems – Sterling Heights, Michigan

Activity
- During the December 2010 Stryker DVH Configuration Steering Board, the Army decided not to pursue full-rate production for the Stryker flat-bottom MGS. The Army determined it could not integrate the DVH design onto the MGS platform without the Stryker Modernization program to resolve weight and power shortfalls.
- A total of 142 MGSs have been produced and fielded. Three MGSs have been total losses as a result of battle damage so the current fleet has 139.
- Testing in the August 2011 Engineering Change Order Block III validation gunnery confirmed the low ammunition sensor deficiency as part of the larger deficiency, inadequate ready load for the 7.62 coaxial machine gun. This is 1 of the 5 remaining deficiencies of 23 identified in the July 2008 Acquisition Decision Memorandum.
- During 2012, the contractor was not able to replicate the coaxial machine gun low ammunition sensor deficiency in

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which brass and links falling into the ammunition storage box inadvertently triggered the low ammunition sensor.
- The Army executed multiple components of the LFT&E program for the MGS with SRAT II, including tests to characterize the protection provided by the add-on armor and full-up system-level testing to characterize SRAT II integration effects on the MGS mission equipment.
- The Army, in coordination with DOT&E, submitted the seventh report to Congress in December 2011, updating the status of actions taken by the Army to correct or mitigate all Stryker MGS deficiencies, as directed in Section 115 of the FY09 Duncan Hunter National Defense Authorization Act. The Army will issue their next report when the remaining five deficiencies are corrected.

Assessment
- The Army has yet to correct the coaxial machine gun low ammunition sensor deficiency via material fix or crew workaround. The program manager has designed a chute modification with follow-on testing to take place in December.
- Live fire testing indicates performance deficiencies in the protection provided by the SRAT II configuration for MGS. The details are classified.
- In the 2007 Beyond Low-Rate Initial Production report, DOT&E assessed the MGS as not operationally effective when operating in a degraded capacity. DOT&E assessed that the gun pod can be easily disabled, causing the MGS to operate in a degraded capacity, thereby making the MGS not operationally effective. Lack of adequate gun pod protection makes the MGS vulnerable to widely proliferated threats including RPGs, which increases the likelihood of the MGS operating in a degraded capacity. The Army has no plans to improve gun pod protection.
- The C-130 Transportability Key Performance Parameter is a design constraint that limits MGS capabilities. Because of size and weight constraints for transporting equipment on the C-130, there is a limitation on the size and weight of the MGS. This limit results in several survivability deficiencies, including protection of the Commander's Weapon Station, protection of 105 mm ammunition, gun pod protection, and hydraulic circuit separation. If this program moves forward, a Stryker modernization program will have the opportunity to address these deficiencies.

Recommendations
- Status of Previous Recommendations. The Army addressed the one new recommendation from FY11.
- FY12 Recommendations. As part of our coordination with the Army, as directed in Section 115 of the FY09 National Defense Authorization Act, DOT&E recommended that the Army:
  1. Increase gun pod protection.
  2. Provide a close out report to Congress when the RPG protection deficiency and the coaxial low ammunition sensor deficiency is corrected.

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Stryker Double-V Hull (DVH)

Executive Summary

- The Army rapidly developed, tested, and fielded the Stryker Double-V Hull (DVH) in response to needs from commanders in Operation Enduring Freedom (OEF) regarding Stryker force protection/survivability shortfalls against underbody IEDs and blast threats. Testing and analysis confirm that the Stryker DVH configurations improve Stryker vehicle protection against IEDs; the details are classified.
- All configurations of the Stryker DVH are operationally effective for deployment into Afghanistan.
- All configurations of the Stryker DVH are operationally suitable.
- DOT&E published six classified reports on FY12 activity for the following variants: the Stryker DVH Commander's Vehicle (CVV), Infantry Carrier Vehicle – Scout (ICVV-S), Mortar Carrier Vehicle (MCVV), Medical Evacuation Vehicle (MEVV), Engineer Squad Vehicle (ESVV), and Anti-Tank Guided Missile Vehicle (ATVV).
- The Army Test and Evaluation Command (ATEC) continues to develop the System Evaluation Plan in support of testing for Stryker DVH worldwide fielding.

System

- The Stryker DVH Infantry Carrier Vehicle (ICVV) is the base variant for seven additional DVH configurations:
  - Anti-Tank Guided Missile Vehicle (ATVV)
  - Commander's Vehicle (CVV)
  - Engineer Squad Vehicle (ESVV)
  - Fire Support Vehicle (FSVV)
  - Mortar Carrier Vehicle (MCVV)
  - Medical Evacuation Vehicle (MEVV)
  - ICVV-Scout (ICVV-S)
- The ICVV-S is a new configuration to permit internal stowage of the Long-Range Advance Scout Surveillance System.
- The DVH configuration consists of a redesigned lower hull, energy attenuating seats, and an up-armored driver station. An upgraded suspension and driveline are incorporated because of the additional weight.
- At this time, the Army does not plan to purchase Stryker DVH versions of the Stryker Reconnaissance Vehicle; Mobile Gun System; or the Nuclear, Biological, Chemical Reconnaissance Vehicle.

Mission

- Combatant Commanders employ a DVH-equipped Stryker Brigade Combat Team (SBCT) as a decisive action combat force that conducts operations (offensive, defensive, stability, and defense support of civil authorities) against conventional or unconventional enemy forces in all types of terrain and climate conditions. In addition, it operates across the range of military operations (major operations and campaigns, crisis response and limited contingency operations, military engagement, security cooperation, and deterrence).
- The DVH-equipped SBCT has the same mission profile as a non DVH-equipped SBCT. The Army intends to use the DVH as Theater Provided Equipment in Afghanistan, and provide the Army with a long-term worldwide capability to simultaneously deploy SBCTs into a non-permissive environment.
- The Army intends for the Stryker DVH to provide improved survivability against IEDs and blast threats, beyond the protection provided by current flat-bottom Stryker vehicles with OEF kits.


XM1256 Infantry Carrier Vehicle


XM1257 Engineer Squad Vehicle


XM1255 Commanders Vehicle


XM1256 Infantry Carrier Vehicle - Scout


XM1251 Fire Support Vehicle


XM1254 Anti-Tank Guided Missile Vehicle


XM1252 Mortar Carrier Vehicle


XM1253 Medical Evacuation Vehicle

Major Contractor

General Dynamics Land Systems – Sterling Heights, Michigan

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Activity

- The Army executed all live fire and operational testing in accordance with DOT&E-approved test plans.
- The Army executed multiple series of full-up system-level live fire events against the following DVH versions: ESVV, CVV, MCVV, MEVV, ATVV, and ICVV-S. The purpose of the follow-on DVH LFT&E program was to compare each DVH configuration's IED protection to existing OEF-kitted Stryker vehicles, as well as to identify any configuration-unique vulnerabilities to underbody IED and blast threats.
- ATEC completed developmental, operational, and live fire testing of the following Stryker DVH variants: ICVV-S, CVV, FSVV, MCVV, MEVV, and ATVV through 3QFY12 to characterize any degradation to reliability, availability, maintainability, and cross-country mobility, and compare DVH performance to the Strykers currently used in OEF. ATEC conducted operational testing of the MCVV at Yuma Proving Ground, Arizona, and integrated testing of the MEVV at Aberdeen Proving Ground, Maryland.
- DOT&E published classified reports on the CVV, ICVV-S, MCVV, MEVV, ESVV, and ATVV variants on FY12 activity.
- The Army corrected suitability shortfalls with the driver's station identified during the initial ICVV operational test through an initiative called the Driver's Station Enhancement II (DSE II). The Army executed suitability and survivability testing of the DSE II March to July 2012 at Fort Lewis, Washington; Aberdeen Proving Ground, Maryland; and Yuma Proving Ground, Arizona.
- ATEC continues to develop the System Evaluation Plan to support testing measures for worldwide use of Stryker DVH.

Assessment

- Stryker DVH systems were rapidly developed, tested, and fielded in response to needs from commanders in OEF. Testing and analysis confirm that DVH systems improve Stryker vehicle protection against IEDs. The details can be found in the classified DOT&E LFT&E report on the CVV (January 2012) and Operational Assessment/LFT&E reports for ICVV-S (January 2012), MCVV (May 2012), and MEVV (July 2012).
- All configurations of the Stryker DVH are operationally effective for deployment into Afghanistan. There were no significant differences between the Strykers currently used in OEF and DVH Strykers regarding mobility and the ability of units equipped with the two types of vehicles to accomplish the mission.
- All configurations of the Stryker DVH are operationally suitable to include the driver's station. The Stryker DVH demonstrated better reliability and maintainability than the OEF variant.

Recommendations

- Status of Previous Recommendations. The Army addressed the previous recommendations.
- FY12 Recommendations. None.

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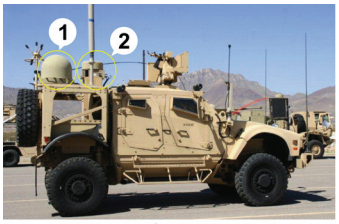
Warfighter Information Network – Tactical (WIN-T)

Executive Summary

- In 2011, the Army conducted a Warfighter Information Network – Tactical (WIN-T) Increment 2 developmental test that assessed a network of more than 70 WIN-T Increment 2 communications nodes. In benign developmental test conditions, WIN-T Increment 2 met its performance requirements, but did not meet its Army-defined reliability requirements.
- In May 2012, the Army conducted a WIN-T Increment 2 IOT&E as a part of the Network Integration Evaluation (NIE) 12.2. The Soldier Network Extension (SNE), Tactical Relay-Tower (TR-T), and High-Band Networking Waveform (HNW) were not effective. All other configuration items and the Net-Centric Waveform (NCW) were effective.
- DOT&E provided details of the IOT&E test results in the WIN-T Increment 2 Beyond Low-Rate Initial Production (BLRIP) Report issued on September 25, 2012.
- WIN-T Increment 2 is not suitable due to poor reliability and maintainability and not survivable due to deficiencies noted in the classified annex to the DOT&E BLRIP report.
- In September 2012, the Defense Acquisition Executive (DAE) authorized the Army to procure an additional 538 WIN-T Increment 2 communication nodes. The DAE directed the Army to conduct an FOT&E to demonstrate improvement of the SNE and HNW, and to provide evidence that each WIN-T Increment 2 configuration item is on track to meet reliability and maintainability requirements. The DAE directed the Army to provide an updated growth plan with growth curves to achieve reliability and maintainability requirements for each WIN-T Increment 2 configuration item.
- The program plans to conduct an FOT&E on the system during NIE 13.2 in May 2013.

System

- The Army designed the WIN-T as a three-tiered communications architecture (space, terrestrial, and airborne) to serve as the Army's high-speed and high-capacity tactical communications network.
- The Army intends WIN-T to provide reliable, secure, and seamless communications for units operating at theater level and below.
- The WIN-T program consists of four increments.
  - Increment 1: "Networking At-the-Halt" enables the exchange of voice, video, data, and imagery throughout the tactical battlefield using a Ku- and Ka-satellite-based network. The Army has fielded WIN-T Increment 1 to its operational forces.



Point of Presence



Soldier Network Extension

1 - Net-Centric Waveform Antenna
2 - High-Band Networking Waveform Antenna



Tactical Comms Node

  - Increment 2: "Initial Networking On-the-Move" provides command and control on-the-move down to the company level for maneuver brigades and implements an improved network security architecture. WIN-T Increment 2 supports on-the-move communications for commanders with the addition of the Point-of-Presence (PoP) and the SNE and provides a mobile network infrastructure with the Tactical Communications Node (TCN).
  - Increment 3: "Full Networking On-the-Move" provides full mobility command and control for all Army field commanders, from theater to company level. Network reliability and robustness are enhanced with the addition of the air tier transport layer, which consists of networked airborne communications relays.
  - Increment 4: "Protected Satellite Communications On-the-Move" includes access to the next generation of protected communications satellites while retaining all previous on-the-move capabilities.

Mission

Commanders at theater level and below will use WIN-T to:

- Integrate satellite-based communications capabilities into an everything-over-Internet Protocol network to provide connectivity, while stationary, across an extended, non-linear battlefield and at remote locations (Increment 1).

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- Provide division and below maneuver commanders with mobile communications capabilities to support initial command and control on-the-move (Increment 2).
- Provide all maneuver commanders with mobile communications capabilities to support full command and control on-the-move, including the airborne relay and protected satellite communications (Increments 3 and 4).

Major Contractor
General Dynamics, C4 Systems – Taunton, Massachusetts

Activity
- In 2011, the Army conducted a developmental test that assessed a WIN-T Increment 2 network containing more than 70 communications nodes. The Army conducted the test at Aberdeen Proving Ground, Maryland, and the contractor's facility in Taunton, Massachusetts.
- In January 2012, the Army conducted cold weather developmental testing at the Cold Weather Natural Environmental Testing, Fort Greeley, Alaska.
- In February 2012, the Army approved a revised requirement that lowered WIN-T Increment 2's reliability requirement by 30 – 60 percent based upon an updated operational mission summary/mission profile.
- In May 2012, the Army Test and Evaluation Command (ATEC) conducted the WIN-T Increment 2 IOT&E using the following units employed under operationally realistic mission scenarios.
  - 2nd Brigade, 1st Armored Division, Fort Bliss, Texas, and White Sands Missile Range, New Mexico
  - 101st Airborne Division, Fort Campbell, Kentucky
  - Sustainment Brigade, Fort Riley, Kansas
  - Network Service Center – Training, Fort Gordon, Georgia
- The WIN-T Increment 2 IOT&E included a fully equipped brigade and division headquarters dispersed over a wide geographic area to assess WIN-T Increment 2's capability to support the unit's at-the-halt and on-the-move mission in desert, forest, and urban terrain. ATEC conducted IOT&E in accordance with a DOT&E-approved Test and Evaluation Master Plan and test plan.
- On September 2012, the DAE chaired the WIN-T Increment 2 Defense Acquisition Board (DAB) to consider whether to approve the system for full-rate production and published an Acquisition Decision Memorandum (ADM) detailing the results. DOT&E provided a BLRIP report to support the DAB.

Assessment
- During the 2011 developmental test, the Army's developmental test efforts assessed that WIN-T Increment 2 met its performance requirements under benign conditions. WIN-T Increment 2 did not meet its reliability requirements and did not demonstrate planned reliability growth.
- During the Army's January 2012 cold weather testing, WIN-T Increment 2 met its cold weather requirements. During testing, the PoP demonstrated reduced bandwidth throughput (up to 10 percent) when the configuration item switched between terrestrial HNW and satellite NCW.
- DOT&E assessed the following WIN-T Increment 2 items as effective based upon performance demonstrated during IOT&E:
  - **TCN.** The TCN improved mission performance by sustaining a mission command network, and providing voice and data access to the network while on-the-move.
  - **PoP.** The PoP provided voice and data support for commanders while on-the-move and at-the-halt.
  - **Network Operations and Security Center (NOSC).** The NOSC supported the unit's network management mission at division and brigade, but needed additional Soldiers and tools at battalion and company.
  - **Colorless Core.** The Colorless Core supported multiple security levels and improved bandwidth allocation.
  - **NCW.** Given sufficient satellite bandwidth, the NCW connected TCNs and PoPs to the network and provided sufficient data flow while at-the-halt and on-the-move.
  - **Satellite Tactical Terminal + (STT+).** The STT+ demonstrated simultaneous connections of its satellite waveforms in support of the unit's mission.
  - **Vehicle Wireless Package (VWP).** The VWP was useful at the brigade and division levels, but should be installed in different vehicles at battalion level to better support command post movements.
  - **Joint Gateway Node (JGN).** The JGN allows WIN-T to connect to a variety of external networks.
  - **Modular Communications Node – Basic (MCN-B).** The MCN-B allowed the unit to extend subscriber services from an adjacent TCN.
- DOT&E assessed the following WIN-T Increment 2 items as not effective based upon performance demonstrated during the IOT&E:
  - **SNE.** The SNE did not support commanders while on-the-move but served as an alternate communications means while at-the-halt.
  - **HNW.** The HNW terrestrial line-of-sight waveform demonstrated poor transmission range in vegetation and routing problems that decreased the WIN-T Increment 2 network's performance.
  - **TR-T.** The single TR-T employed at brigade was not able to keep the HNW network from fragmenting when the unit dispersed.

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- DOT&E assessed the WIN-T Increment 2 as not suitable due to poor reliability and poor maintainability:
  - The VWP and MCN-B met their reliability requirements. The TCN, PoP, SNE, TR-T, and NOSC did not meet their reliability requirements. The WIN-T Increment 2 on-the-move platforms (TCN, PoP, and SNE) reliability estimates demonstrated during IOT&E are less than one third of the Army requirement.
  - The VWP and JGN met their maintainability requirements, while the remaining configuration items did not meet the Mean Time to Repair requirement. The IOT&E hosted twice the number of Field Service Representatives to perform maintenance (relative to the Army's support plan). Even with increased Field Service Representatives present at IOT&E, repair times for half of the configuration items took two to four times longer than the Army's requirement.
- As a result of IOT&E, DOT&E assessed WIN-T Increment 2 as not survivable due to significant Information Assurance vulnerabilities that would degrade a unit's ability to succeed in combat. These vulnerabilities are discussed in a classified annex to the DOT&E BLRIP report.
- On September 26, 2012, the DAE signed an ADM that:
  - Authorized the Army to procure an additional 538 WIN-T Increment 2 communication nodes as a second Low-Rate Initial Production.
  - Directed the Army to conduct an FOT&E to demonstrate operational effectiveness and suitability of the SNE and HNW.
  - Provide evidence that each configuration item is on track per approved growth curves to meet reliability and maintainability requirements.
- The Army plans to conduct an FOT&E during NIE 13.2 in May 2013 to demonstrate that WIN-T Increment 2 has addressed the operational effectiveness and suitability deficiencies noted in the DOT&E BLRIP report as directed by the September ADM.

Recommendations

- Status of Previous Recommendations. The program successfully addressed one of the three FY10 recommendations. The program still needs to correct deficiencies identified during the WIN-T Increment 2 LUT, complete requirements documents for Increment 3, update the Increment 2 TEMP, and develop an Increment 3 TEMP.
- FY12 Recommendations. The Army should:
  1. Create a reliability growth plan to improve the poor WIN-T Increment 2 reliability highlighted during IOT&E. Reliability improvements should be demonstrated during a future operational test event.
  2. Identify the root causes of the SNE deficiencies, correct the poor performance, and demonstrate its effectiveness in a future operational test event.
  3. Improve HNW and NCW to address deficiencies noted during the IOT&E. Waveform improvements should be demonstrated during a future operational test event.
  4. Complete a post full-rate production TEMP and ensure funding is available to conduct a future operational test to demonstrate improvements in WIN-T Increment 2.

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Navy Programs

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Acoustic Rapid Commercial Off-the-Shelf Insertion (A-RCI)

Executive Summary

- The Navy completed FOT&E of Acoustic Rapid Commercial Off-the-Shelf Insertion (A-RCI) Advanced Processor Build 09 (APB-09) in early FY12.
- DOT&E issued a classified FOT&E report for the A-RCI APB-09 system in November 2012, and found the APB-09 system provides performance similar to previous APBs (not improved or degraded).
- The processing and display for the Wide Aperture Array (WAA), a primary focus for APB-09 software upgrades, suffered from significant technical problems that were discovered during initial operational testing. The Navy developed new WAA software intended to fix the problems, conducted limited additional development testing, and issued the new software to the fleet without operational testing.
- The Navy is completing development of the APB-11 version and operational testing is planned to begin in FY13.

System

- A-RCI is an open-architecture sonar system intended to maintain an advantage in acoustic detection of threat submarines.
- A-RCI uses legacy sensors and replaces central processors with commercial off-the-shelf (COTS) computer technology and software. The program includes the following:
  - A sonar system for the *Virginia* class submarine
  - A replacement sonar system retrofitted into *Los Angeles*, *Ohio*, and *Seawolf* class submarines
  - Biannual software upgrades (called Acoustic Processor Builds (APBs)) and hardware upgrades (called Technology Insertions (TIs)). While using the same process and nomenclature, these APBs and TIs are distinct from those used in the AN/BYG-1 Combat Control System program.
- The Navy intends for the A-RCI upgrades to provide expanded capabilities for Anti-Submarine Warfare (ASW), high-density contact management, and mine warfare, particularly in littoral waters and against diesel submarines.
- A-RCI processes data from the submarine's acoustic arrays (i.e., spherical array, hull array, WAA, and high-frequency arrays) along with the submarine's two towed arrays (i.e., the fat line array consisting of the TB-16 or TB-34 and the thin line array consisting of the TB-23 or TB-29).



- The APB-09 introduced upgraded processing on the high frequency array and the ability to process new pulse types. It also introduced advanced signal processing to improve both detection and display performance for the WAA. The Navy intends for the new software to improve ASW search through attack performance with new enhanced narrowband processing algorithms, to improve performance avoiding threat mines, and to improve situational awareness and contact managements for all missions.

Mission

The Navy's intent for submarine crews equipped with the A-RCI sonar is to complete the following submarine force missions:

- Search, detect, and track submarine and surface vessels in open-ocean and littoral sea environments without being counter-detected
- Search, detect, and avoid mines and other submerged objects
- Covertly conduct intelligence, surveillance, and reconnaissance
- Covertly execute Naval Special Warfare missions
- Perform under-ice operations

Major Contractor

Lockheed Martin Maritime Systems and Sensors – Washington, District of Columbia

Activity

- The Navy completed FOT&E of A-RCI APB-09 in early FY12 in accordance with a DOT&E-approved test plan. The Navy combined testing with the AN/BYG-1 Combat Control System, the *Virginia* class submarine, and the Mk 48 Mod 6 Advanced Common Torpedo (ACOT) and Mk 48 Advanced Capability (ADCAP) Mod 7 Common Broadband Advanced

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Sonar System (CBASS) programs. Coordinating these tests provided testing efficiencies while enabling an end-to-end evaluation of mission performance.
- DOT&E issued a classified combined test report for the *Virginia* class submarine, the A-RCI sonar, and the AN/BYG-1 Combat Control system in November 2012 that evaluated the effectiveness and suitability of the A-RCI APB-09 system.
- The Navy began drafting a Test and Evaluation Master Plan (TEMP) for the APB-11 and APB-13 A-RCI variant APBs, and expects to issue it by early FY13. As part of these efforts, DOT&E requested the Navy investigate new methods of land-based testing and onboard simulated target injection methods to augment at-sea operational tests. Operational testing of the APB-11 variant of A-RCI is expected to begin in FY13.

Assessment
- The DOT&E classified FOT&E report for the A-RCI APB-09 system concluded the following regarding test adequacy and system performance:
  - Given the data available and the limitations of the test, DOT&E concluded that no evidence existed to change the conclusions about mission performance from previous reports on A-RCI (not improved or degraded). Specifically,
    - For ASW, A-RCI passive sonar capability is effective against older classes of submarines in some environments, but is not effective in all environments or against modern threats.
    - A-RCI is not effective in supporting operator situational awareness and contact management in areas of high-contact density.
    - A-RCI high-frequency mine performance is not effective for some types of minefields, but meets threshold requirements against some mine types under certain environmental conditions.
  - Testing to examine ASW-Attack and situational awareness in a high-surface-ship density environment was adequate for the system tested but not adequate for the software version fielded. The A-RCI processing for the WAA suffered from system development and software problems, which led to poor performance during the operational testing. The Navy investigated this issue after operational testing was completed and subsequently issued software intended to fix the problems. The Navy conducted some limited developmental testing to confirm functionality; however, the Navy has not conducted operational testing to evaluate the updated software or potential changes to mission performance.
  - Test execution to examine the Precision Underwater Mapping capability was not adequate.
  - Several mine shapes in the Navy's training minefield used for the operational testing were severely corroded, damaged, or buried. DOT&E considered the condition of the mine shapes in evaluating high-frequency sonar detection performance and assessed the testing was adequate for some types of threat minefields.
  - A-RCI continues to be not suitable due to problems with reliability and operator training. For APB-09, the Navy lowered the reliability requirements below the previously measured APB reliability. The Navy also refocused the system's new reliability requirements on the minimum system functions necessary for at-sea operations vice what system functions are required for the mission. While APB-09 met the revised lower reliability requirements, the APB-09 system's reliability was significantly below the sonar reliability demonstrated on *Virginia* class submarines during the IOT&E. For other submarine classes, measured sonar APB reliability is statistically unchanged from previous APBs. After operational testing, the Navy reported that software changes were made to the APB-09 software intended to fix the reliability problems identified in testing; these changes have not been evaluated.
  - The Navy revised the Capability Development Document/Capability Production Document performance requirements for A-RCI APB-09. The revised requirements metric focuses development and testing on the time between the A-RCI system displaying acoustic energy and the operator identifying the target. This new metric favors shorter range detections; therefore, a poorly-performing sonar system (shorter range detections) has the potential of scoring better than a long-range detecting system.
- Due to the A-RCI biannual software and hardware development cycle, the Navy generates and approves the A-RCI requirements documents and TEMPs in parallel with APB development and installation. As a result, the fleet assumes additional risk, since most operational testing is not completed before the system is initially deployed.
- The Navy's schedule-driven process prevents operational test results from directly supporting development of the follow-on APBs. For example, the Navy completed operational testing of the A-RCI APB-09 system in early FY12. Due to the combination of the late completion of testing and the Navy's practice of issuing an updated version every two years, data from APB-09 operational testing could not be included in the development of APB-11.
- The development and testing of APB-09 is an example of the high-risk of schedule-driven development and fielding; operational testing revealed significant performance failures with the WAA that were not discovered in developmental testing. Although the Navy issued new software intended to fix the identified problems after the operational test, submarines deployed with a version of A-RCI that the Navy has not operationally tested.

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Recommendations

- Status of Previous Recommendations. The Navy is making progress in addressing 23 of the 30 recommendations contained in the APB-00 to APB-07 OT&E reports. The significant remaining unclassified recommendations are:
  1. Improve the detection and localization performance for submarines operating in high-density surface ship environments. Consider investing in automation that will assist the operator in processing the large amount of constantly changing contact data and determining which contacts pose an immediate collision or counter-detection threat.
  2. Improve operator training such that operators understand and effectively employ new APB functionality when fielded. Many of the newly introduced features in APBs that were designed to improve mission performance were not used consistently during the test.
  3. Evaluate the covertness of the high-frequency sonar during a future submarine-on-submarine test.
  4. Investigate the software reliability problems and institute measures to improve system reliability.
  5. Conduct future ASW testing against a high-end diesel-electric submarine (SSK) target to enable a more complete assessment of A-RCI and BYG-1 performance.
- FY12 Recommendations. The Navy should:
  1. Consolidate the A-RCI and AN/BYG-1 TEMPs into an Undersea Enterprise Capstone document.
  2. Re-evaluate operational effectiveness and suitability of A-RCI on a submarine with the new WAA software.
  3. Address the 21 recommendations for the A-RCI and the AN/BYG-1 systems contained in DOT&E's FOT&E report on A-RCI APB-09. Some of the significant unclassified recommendations are:
     - The Navy should improve its developmental testing processes and metrics used to determine if a system potentially improves effectiveness and suitability and to ensure that the system is ready for operational testing and subsequent fielding.
     - Search rate is an important metric for evaluating the ASW search performance. Recently, the Navy issued revised requirements for A-RCI and did not update the platform search rate metric. The new metrics, which assess the difference between the initial operator and post-test laboratory detection times, could improperly result in a poorly performing system (short-range detections) scoring better than a long-range detecting sonar system. DOT&E recommends the Navy re-evaluate the new metrics to improve their robustness under varying environmental conditions and to focus on earlier and longer range operator detections. Also, the Navy should update the operational and environmental conditions for the search rate metric to reflect current threats and threat areas.
     - If future minefield testing requires the use of existing fleet training minefields, a minefield video survey to evaluate the condition and location of the mines should be conducted prior the decision to use the minefield for testing.

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Aegis Modernization Program

Executive Summary

- The Navy completed operational testing of Aegis guided missile cruisers (CG-52 through CG-58) upgraded with Aegis Warfare System (AWS) Advanced Capability Build 2008 (ACB08) and Aegis guided missile destroyers (DDG-103 through DDG-112) upgraded with AWS Baseline 7.1R in 1QFY12. The Navy did not scope the ACB08/Baseline 7.1R testing to provide a comprehensive evaluation of effectiveness and suitability. The purpose of these tests was to verify the recent updates did not degrade AWS performance. Based upon operational testing in FY12, the ACB08/Baseline 7.1R AWS performance is consistent with the performance of previous AWS versions, which DOT&E assessed as effective and suitable.
- Operational testing of the ACB08/Baseline 7.1R did not support a full assessment of Aegis effectiveness in the area defense mission. The introduction of AWS Baseline 9 in FY14 introduces new requirements and fields new performance capabilities that are intended to support such an assessment.
- The analysis of test data collected during AWS Baseline 7.1R operational testing and the remaining air defense and suitability portions of AWS ACB08 operational testing is ongoing. DOT&E will issue a formal test report in 2QFY13.

System

- The Navy's Aegis Modernization program provides updated technology and systems for existing Aegis guided missile cruisers (CG-47) and destroyers (DDG-51). This planned, phased program provides similar technology and systems for new destroyers.
- The AWS, carried on DDG-51 guided missile destroyers and CG-47 guided missile cruisers, integrates the following components:
  - AWS AN/SPY-1 three-dimensional (range, altitude, and azimuth) multi-function radar
  - SQQ-89 Undersea Warfare suite that includes the AN/SQS-53 sonar, SQR-19 passive towed sonar array (DDG-51 through DDG-78, CG-52 through CG-73), and the SH-60B or MH-60R Helicopter (DDG-79 and newer have a hangar to allow the ship to carry and maintain its own helicopter)
  - Close-In Weapon System
  - Five-inch diameter gun
  - Harpoon anti-ship cruise missiles (DDG-51 through DDG-78, CG-52 through CG–73)
  - Vertical Launch System that can launch Tomahawk land-attack missiles, Standard surface-to-air missiles, Evolved SeaSparrow Missiles, and Vertical Launch Anti-Submarine Rocket missiles
- The AWS on Baseline 2 Aegis guided missile cruisers (CG-52 through CG-58) was upgraded with commercial off-the-shelf hardware running the AWS software ACB08.
- The AWS on new construction Aegis guided missile destroyers (DDG-103 through DDG-112) is Baseline 7.1R.



Mission

The Joint Force Commander/Strike Group Commander employs AWS-equipped DDG-51 guided missile destroyers and CG-47 guided missile cruisers to:

- Conduct area and self-defense Anti-Air Warfare in defense of the Strike Group
- Conduct Anti-Surface Warfare and Anti-Submarine Warfare
- Conduct Strike Warfare when armed with Tomahawk missiles
- Conduct offensive and defensive warfare operations simultaneously
- Operate independently or with Carrier or Expeditionary Strike Groups, as well as with other joint or coalition partners

Major Contractors

- General Dynamics Marine Systems Bath Iron Works – Bath, Maine
- Northrop Grumman Shipbuilding – Pascagoula, Mississippi
- Lockheed Martin Maritime Systems and Sensors – Moorestown, New Jersey

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Activity

- The Navy conducted all portions of the planned operational test of AWS ACB08 in FY10, with the exception of air defense and suitability testing, which it completed in 1QFY12. All testing was conducted in accordance with a DOT&E-approved Test and Evaluation Master Plan and test plan.
- The Navy conducted all portions of the planned operational test of AWS Baseline 7.1R concurrently with the last phase of ACB08 testing in 1QFY12.
- The Navy repaired and examined critical software faults discovered during operational testing of AWS ACB08 in 4QFY12. This testing was conducted in accordance with a DOT&E-approved test plan.
- The Navy continued to deploy AWS ACB08-equipped cruisers and AWS Baseline 7.1R-equipped destroyers in FY12 in advance of operational testing.
- The Navy is preparing an update to the Test and Evaluation Master Plan to incorporate AWS baseline ACB 2012 (ACB12). ACB12 will provide existing and new construction Aegis destroyers an Integrated Air and Missile Defense (IAMD) capability that includes Ballistic Missile Defense (BMD). Current plans will also provide an enhanced Air Defense capability to selected Aegis cruisers without BMD (CGs-59, -60, -62, and -71).

Assessment

- The Navy did not scope the ACB08/Baseline 7.1R testing to provide a comprehensive evaluation of effectiveness and suitability. The purpose of these tests was to verify that the recent updates did not degrade AWS performance. Based upon operational testing in FY12, the ACB08/Baseline 7.1R AWS performance is consistent with the performance of previous AWS versions, which DOT&E assessed as effective and suitable. Analysis of the test data indicates the following:
  - The Air Warfare performance of Aegis cruisers and destroyers, in self-defense posture, is consistent with that of ships with earlier Aegis baselines. Testing did not focus on the area defense capability of the ACB08/7.1R AWS. The Navy intends to conduct an assessment of area defense effectiveness with the introduction of ACB12/AWS Baseline 9 in FY14.
  - The Undersea Warfare performance of Aegis cruisers with AWS ACB08 is consistent with that of ships with earlier Aegis baselines.
  - The Surface Warfare performance of Aegis cruisers and destroyers is consistent with that of ships with earlier Aegis baselines. As previously assessed, Aegis ships have limited ability to counter high-speed surface threats in littoral waters.
- Operational testing of ACB08/Baseline 7.1R in a multi-ship, Cooperative Engagement Capability environment revealed shortcomings in crew proficiency and training not observed in earlier testing that adversely affected Air Warfare performance.
- The analysis of data collected during follow-on testing of AWS ACB08 is still in progress. DOT&E will report on the corrective action in the ACB08 test report in 2QFY13.

Recommendations

- Status of Previous Recommendations. The Navy satisfactorily completed all FY11 recommendations.
- FY12 Recommendations. The Navy should:
  1. Continue to improve Aegis ships' capability to counter high-speed surface threats in littoral waters.
  2. Synchronize future baseline operational testing and reporting with intended ship-deployment schedules to ensure that testing and reporting is completed prior to deployment.
  3. Ensure Aegis crews are proficient in operation of the AWS when in a multi-ship, network environment.

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AGM-88E Advanced Anti-Radiation Guided Missile (AARGM) Program

Executive Summary

- The AGM-88E Advanced Anti-Radiation Guided Missile (AARGM) program completed IOT&E and conducted an additional Verification of Correction of Deficiencies (VCD) test period during FY12.
- During FY11/12 operational testing, the Navy completed 185 sorties, accumulating 558 hours of missile operating time. The Navy executed 396 captive-carry runs and fired a total of 12 missiles at actual and simulated threat targets and emitters.
- DOT&E published a classified IOT&E report in 4QFY12.
- AARGM is operationally suitable.
- AARGM is not operationally effective. Although AARGM has the potential to eventually provide some improved combat capability against enemy air defenses, the current weapon configuration has multiple performance shortfalls that largely negate its ability to accomplish its mission.
- The Navy expects the AARGM Block 1 Upgrade to address significant performance shortfalls and provide Full Operational Capability, with the associated FOT&E scheduled to commence in FY14.
- Due to deferred capabilities and IOT&E deficiencies, DOT&E anticipates that AARGM FOT&E requirements exceed the program's currently allocated resources for operational testing. A shortage of AARGM telemetry kits is already identified as a potential hindrance to adequate Block 1 testing.

System

- The AGM-88E AARGM is the follow-on to the AGM-88B/C High-Speed Anti-Radiation Missile (HARM) using a modified HARM body and fins. The Navy intends to employ AARGM on F/A-18C/D/E/F and EA-18G platforms.
- AARGM Block 0, intended for Initial Operational Capability, incorporates digital Anti-Radiation Homing (ARH), GPS, and Millimeter Wave (MMW) guidance, and a Weapon Impact Assessment transmitter.
  - ARH improvements over HARM include an increased field of view and larger frequency range.
  - The GPS allows position accuracy in location, time, and weapon impact assessment transmissions.



  - MMW radar technology allows target discrimination and guidance during the terminal flight phase.
- The Navy expects the AARGM Block 1 Upgrade to deliver Full Operational Capability, including Block 0 capability improvements, as well as an Integrated Broadcast Service Receiver (enables reception of national broadcast data), and software changes to provide deferred capability requirements and address deficiencies identified during IOT&E.

Mission

Commanders employ aircraft equipped with AARGM to conduct pre-planned, on-call, and time-sensitive reactive anti-radiation targeting for the suppression, degradation, and destruction of radio frequency enabled surface-to-air missile defense systems. Commanders receive real-time Weapons Impact Assessments from AARGM via a national broadcast data system.

Major Contractor

Alliant Techsystems, Defense Electronics Systems Division – Woodland Hills, California

Activity

- In 2QFY10, the Navy issued a change to the AARGM Capability Production Document (CPD) due to limitations discovered during developmental testing. This CPD change delayed the start of IOT&E until 3QFY10 to allow correction of system deficiencies; deferred a Key Performance Parameter target requirement to FOT&E; and clarified the acceptable target environment and reactive targeting constraints for IOT&E.
- In accordance with the DOT&E-approved Operational Test Plan (OTP), the Navy's Commander, Operational Test and

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Evaluation Force (COTF) commenced AARGM IOT&E in June 2010, but in September 2010, the Navy de-certified AARGM from IOT&E after the program suffered six operational mission failures during initial captive-carry flight tests.

- The AARGM program spent most of FY11 correcting hardware and software deficiencies discovered in developmental testing and during its first IOT&E attempt. In July 2011, DOT&E approved an updated AARGM OTP and the Navy re-initiated dedicated IOT&E in August 2011.
- Immediately following the restart of IOT&E, COTF initiated changes to the OTP that were driven by the 2010 CPD change and deficiencies identified since the first IOT&E attempt was terminated. DOT&E approved the requested changes in October 2011.
- The Navy postponed two live-missile test events scheduled for October 2011 due to an emergent anomaly that caused a communication failure between the AARGM Guidance and Control Sections (GS/CS). The Navy identified a short-term solution for this problem and conducted the live-missile events during 2QFY12.
- Immediately preceding a February 2012 test event involving two other live-missile shots, the Navy notified DOT&E that the planned threat scenario would likely result in mission failure due to a classified AARGM deficiency (details available in the classified DOT&E IOT&E report). Without DOT&E consent, the Navy modified the approved test scenario to alleviate the classified deficiency and proceeded with live-missile testing. DOT&E disagreed with the adjusted threat representation and subsequently assessed these events as operational failures.
- COTF completed IOT&E events in 2QFY12, with initial results indicating AARGM was neither operationally effective nor operationally suitable.
- The Navy subsequently completed software changes to address the two most significant deficiencies identified during IOT&E (GS/CS communication failure and a classified performance shortfall) and subsequently conducted a VCD test period during 3QFY12. DOT&E approved the VCD test plan and included the associated data in its IOT&E assessment.
- During operational testing, the Navy fired a total of 12 missiles at actual and simulated threat targets and emitters. As required by DOT&E, low-rate initial production (LRIP) missiles were used for all events.
- In accordance with DOT&E-approved test plans, the Navy completed 185 operational test sorties, accumulating 558 hours of missile operating time. These totals include sorties and hours accrued during integrated testing that DOT&E considered operationally representative, with the exception of the modified threat scenario mentioned above.
- DOT&E published a classified IOT&E report in 4QFY12.
- The Navy's Milestone Decision Authority (MDA) conducted a Full-Rate Production (FRP) Decision Review during 4QFY12. At that review, the Navy authorized AARGM Block 0 for FRP; however, only the first lot of FRP missiles was approved. Due to AARGM operational effectiveness concerns, the MDA stipulated that a review of FRP and Block 1 progress shall occur before the end of FY13. The MDA intends to base its authorization for another FRP lot on this follow-on review, even though no additional operational testing is planned during FY13.
- The AARGM program hosted an initial T&E Working-level Integrated Product Team meeting in late 4QFY12 to start identifying and coordinating AARGM Block 1 FOT&E requirements. Additional coordination meetings are planned for 1QFY13.

Assessment

- AARGM Block 0 testing was adequate to support an evaluation of the weapon system's operational effectiveness and operational suitability. With the exception of the modified threat scenario mentioned above, the Navy completed testing in accordance with the DOT&E-approved Test and Evaluation Master Plan, OTP, and VCD test plan.
- AARGM Block 0 is operationally suitable. Although the weapon demonstrated poor reliability during IOT&E, the program addressed the primary deficiency affecting reliability and satisfactorily demonstrated this during the VCD test period.
- AARGM Block 0 is not operationally effective. Although AARGM has the potential to eventually provide some improved combat capability against enemy air defenses, the weapon as tested has multiple deficiencies. The details of these deficiencies are detailed in the classified DOT&E IOT&E report. The numerous performance shortfalls identified largely negate AARGM's ability to accomplish its primary mission.
- The Navy expects AARGM Block 1 Upgrade to address significant performance shortfalls and provide Full Operational Capability, with the associated FOT&E scheduled to commence in FY14. DOT&E anticipates that Block 1 FOT&E captive-carry and live-missile firing requirements will exceed the program's currently allocated resources for operational testing. Operational testers have already identified a shortage of AARGM telemetry kits as a potential hindrance to adequate Block 1 testing.

Recommendations

- Status of Previous Recommendations. The two FY11 recommendations remain valid and open. DOT&E requires FOT&E to verify the correction of integrated testing and IOT&E deficiencies and to adequately assess previously deferred capabilities.
- FY12 Recommendations. The Navy should:
  1. Limit FRP quantities until operational effectiveness is properly demonstrated during AARGM Block 1 FOT&E and documented in a DOT&E report.
  2. Ensure adequate inventory of AARGM telemetry kits are available for AARGM FOT&E.

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AIM-9X Air-to-Air Missile Upgrade

Executive Summary

- The Navy completed AIM-9X Block II Integrated Testing in March 2012. The Navy assessed 8 of 12 missile shots conducted before the Operational Test Readiness Review (OTRR) as "hits." Developmental testing also included 83 captive-carry missions with telemetry analyzed in detail, and more than 3,700 captive-carry hours for quantifying reliability.
- The Navy and Air Force began IOT&E on April 27, 2012. During operational testing to date, the Navy has completed 10 of 22 planned captive-carry events and 2 of 9 live missile shots. The Air Force has completed 10 of 22 captive-carry flights and 4 of 8 live missile shots. Four of the six live missile shots have passed within lethal radius of the target. The Services plan to complete IOT&E in July 2013.
- As of mid-November 2012, the Services had accomplished 5,460 total captive-carry hours and had 23 failures resulting in a Mean Time Between Captive-Carry Failure (MTBCCF) of 237 hours. The current system reliability is slightly below the value on the reliability growth curve consistent with reaching the requirement of 500 hours MTBCCF at 80,000 hours.



System

- AIM-9X is the latest generation short-range, heat-seeking, air-to-air missile. The currently fielded version of the missile is AIM-9X Block I, Operational Flight Software (OFS) 8.220, which includes limited lock-on-after-launch, full envelope off-boresight capability without a helmet-mounted cueing system, and improved flare rejection performance.
- AIM-9X is highly maneuverable, day/night capable, and includes the warhead, fuze, and rocket motor from the previous AIM-9M missile.
- AIM-9X added a new imaging infrared seeker, vector controlled thrust, digital processor, and autopilot.
- F-15C/D, F-16C/D, and F/A-18C/F aircraft can carry the AIM-9X.
- The AIM-9X Block II is the combination of AIM-9X-2 hardware and OFS 9.3.
  - AIM-9X-2 is the latest hardware version and is designed to prevent parts obsolescence and provide processing capability for the OFS 9.3 upgrade. The AIM-9X-2 missile includes a new processor, a new ignition battery for the rocket motor, an electronic ignition safety/arm device, and the DSU-41/B Active Optical Target Detector (AOTD) fuze/datalink assembly.
  - OFS 9.3 is a software upgrade that is intended to add trajectory management to improve range, datalink with the launching aircraft, improved lock-on-after-launch, target re-acquisition, and improved fuzing.

Mission

Air combat units use the AIM-9X to:

- Conduct short-range offensive and defensive air-to-air combat
- Engage multiple enemy aircraft types with passive infrared guidance in the missile seeker
- Seek and attack enemy aircraft at large angles away from the heading of the launch aircraft

Major Contractor

Raytheon Missile Systems – Tucson, Arizona

Activity

- The Navy completed AIM-9X Block II (AIM-9X-2 with OFS 9.3) developmental testing in March 2012. Developmental testing consisted of 12 free flight shots, 4 of which were conducted with the final software version (OFS 9.311). It also included 83 captive-carry missions with telemetry analyzed in detail, and more than 3,700 captive-carry hours for quantifying reliability.
- The Navy conducted an OTRR in April 2012, and certified readiness for AIM-9X Block II IOT&E under the DOT&E-approved June 2011 TEMP and March 2012 test plan.

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- The Navy and Air Force began IOT&E in April 2012. During operational testing to date, the Navy has completed 10 of 22 planned captive-carry events and 2 of 9 live missile shots. The Air Force has completed 10 of 22 captive-carry flights and 4 of 8 live missile shots.
- The Services plan to complete IOT&E in July 2013, with a Full-Rate Production decision in April 2014 and Initial Operational Capability planned for September 2014.

Assessment

- During developmental testing, 9 of 12 total missile shots guided to within lethal radius of the drone. One of those nine missiles did not receive a fuze pulse, resulting in no detonation within proximity of the drone. Therefore, the Navy assessed 8 of 12 shots conducted before the OTRR as "hits."
- All captive-carry missions were nominal, but the Air Force highlighted one performance discrepancy with AIM-9X Block II Helmet-less High Off-Boresight (HHOBS) performance. It is possible that Block II is slower to acquire targets in HHOBS than Block I. The Capability Production Document (CPD) requires the AIM-9X Block II performance be equal to or better than baseline AIM-9X performance.
- At the OTRR, reliability was 232 hours MTBCCF and is projected to reach 316 hours at the end of IOT&E. As of mid-November 2012, the Services had accomplished 5,460 total captive-carry hours and had 23 failures resulting in an MTBCCF of 237 hours. The current system reliability is slightly below the value on the reliability growth curve consistent with reaching the requirement of 500 hours MTBCCF at 80,000 hours. DOT&E will track reliability through IOT&E.
- All Navy and Air Force IOT&E captive-carry sorties to this point have achieved mission objectives. As of November 15, 2012, 4 of 6 live missile shots have been successful. The AIM-9X Block II did not achieve a hit on the fourth shot by the Air Force, attempted in September 2012. It was a lock-on-after-launch shot, which initially locked on the target but then lost track and did not re-acquire. The Navy's first shot, attempted in October 2012, was also unsuccessful. It was another lock-on-after-launch shot that did not acquire the target. Data results are still pending for both unsuccessful attempts. To date, the Air Force and Navy have not reported any weapon system deficiencies during IOT&E.

Recommendations

- Status of Previous Recommendations. The Navy satisfactorily addressed previous recommendations.
- FY12 Recommendation.
  1. The Navy should address the Air Force's concern of HHOBS performance. It should gather data to verify or disprove AIM-9X Block II performance slip during HHOBS performance. If Block II performance is worse than that of Block I in HHOBS, consider a software modification to improve HHOBS performance and comply with the CPD requirement of achieving performance equal to or greater than Block I.

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AN/BYG-1 Combat Control System

Executive Summary

- The Navy completed FOT&E of AN/BYG-1 Advanced Processor Build 09 (APB-09) in early FY12.
- DOT&E issued a classified FOT&E report for the AN/BYG-1 APB-09 system in November 2012 and found the APB-09 system provides performance similar to previous APBs (not improved or degraded).
- The processing and display for the Wide Aperture Array (WAA) suffered from significant technical problems that were discovered during operational testing. The WAA is a sonar input to the BYG-1 intended to provide bearing and ranges data to the system. The Navy developed new software intended to fix the WAA problems, conducted limited development testing, and issued the new software to the fleet without further operational testing.
- The Navy is completing development of the APB-11 version and operational testing is planned to begin in FY13.

System

- AN/BYG-1 is an open-architecture submarine combat control system for analyzing and tracking submarine and surface ship contacts, providing situational awareness, as well as the capability to target and employ torpedoes and missiles.
- AN/BYG-1 replaces central processors with commercial off-the-shelf (COTS) computer technology. The Navy installs improvements to the system via an incremental development program. The program includes the following:
  - A combat control system for the *Virginia* class submarine
  - A replacement combat control system back-fit into *Los Angeles*, *Ohio*, and *Seawolf* class submarines
  - Biannual software upgrades (called Advanced Processor Builds (APBs)) and hardware upgrades (called Technology Insertions (TIs)). While using the same process and nomenclature, these APBs and TIs are distinct from those used in the Acoustic Rapid COTS Insertion (A-RCI) program.
- The Navy intends improvements to provide expanded capabilities for Anti-Submarine (ASW) and Anti-Surface Warfare (ASUW), high-density contact management, and the targeting and control of submarine weapons.
- The Navy is also developing AN/BYG-1 for use on the Royal Australian Navy *Collins* class diesel electric submarines.



Mission

Submarine crews equipped with the AN/BYG-1 combat control system are able to complete the following submarine force missions:

- Analyze submarine sensor contact information to track submarine and surface vessels in open ocean and littoral sea environments
- Employ heavyweight torpedoes against submarine and surface ship targets
- Receive strike warfare tasking, plan strike missions, and employ Tomahawk land-attack cruise missiles
- Receive and synthesize all organic sensor data and external tactical intelligence to produce an integrated tactical picture

Major Contractors

- General Dynamics Advanced Information Systems – Fairfax, Virginia
- General Dynamics Advanced Information Systems – Pittsfield, Massachusetts

Activity

- The Navy completed FOT&E of AN/BYG-1 APB-09 in early FY12 in accordance with a DOT&E-approved test plan. The Navy combined testing with the AN/BQQ-10 A-RCI Sonar System, the *Virginia* class submarine, and the Mk 48 Mod 6 Advanced Common Torpedo (ACOT) and Mk 48 Advanced Capability (ADCAP) Mod 7 Common Broadband Advanced Sonar System (CBASS) programs. Coordinating these tests provided testing efficiencies and enabled an end-to-end evaluation of mission performance.
- DOT&E issued a classified combined operational test report in November 2012 that evaluates the effectiveness and suitability of the AN/BYG-1 APB-09 system.
- The Navy began drafting a Test and Evaluation Master Plan (TEMP) for the APB-11 and APB-13 variants of AN/BYG-1, and expects to issue it by early FY13. Operational testing of the APB-11 variant of AN/BYG-1 is expected to begin in FY13.

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Assessment

- The Navy's schedule-driven process prevents operational test results from directly supporting development of the follow-on APBs. The Navy completed operational testing of the AN/BYG-1 APB-09 system in 2011. Due to the combination of late completion of testing and the Navy's practice of issuing an updated software and hardware version every two years, data from APB-09 operational testing have not been included in the development of APB-11, which is nearing completion.
- The DOT&E classified combined report to Congress for the *Virginia* class submarine, A-RCI APB-09, and AN/BYG-1 APB-09 systems concluded the following regarding AN/BYG-1 test adequacy and system performance:
  - Given the data available, no evidence exists to change the conclusions about mission performance from previous reports on AN/BYG-1 (not improved or degraded). Specifically,
    - APB-09 is not effective in supporting operator situational awareness and contact management in areas of high-contact density.
    - APB-09 did not meet the Navy's requirements for target localization; however, the targeting solutions were often sufficient for a trained crew to provide the torpedo an opportunity to detect the target. Nevertheless, the APB-09 variant remains not effective in ASW scenarios.
    - DOT&E's overall assessment of Information Assurance was unchanged from the APB-07 variant (not effective), although the new software represents an improvement in Information Assurance over previous systems.
    - APB-09 is operationally suitable and continues to exhibit excellent reliability and availability; however, the Navy needs to improve APB training.
  - Testing to examine missions involving ASW-Attack, situational awareness, and contact management in areas of high-contact density was adequate for the system tested but not adequate for the software version fielded on *Virginia* class submarines. The AN/BQQ-10 A-RCI processing for the WAA suffered from system development problems, which led to poor performance during the operational testing. AN/BYG-1's contribution to the ASW mission performance and submarine mission operations in areas of high-contact density was hindered due to these problems. The Navy investigated the WAA issues after operational testing was completed and subsequently issued software fixes intended to correct the problems. The Navy conducted some limited developmental testing to confirm functionality; however, the Navy has not completed operational testing to evaluate the updated WAA software effects on BYG-1 performance. DOT&E assesses that the completed operational testing allows for an adequate assessment of the performance on *Los Angeles* class and *Ohio* class submarines that do not have a WAA.
  - The new BYG-1 route planning tools were unable to be fully evaluated due to the lack of required databases and crew training.

Recommendations

- Status of Previous Recommendations. The Navy has made progress in addressing four of the seven outstanding recommendations contained in previous annual reports and test reports. The remaining significant unclassified recommendations are:
  1. Improve the detection and localization performance for submarines operating in high-density surface ship environments. Consider investing in automation that will assist the operator in processing the large amount of constantly changing contact data and determining which contacts pose an immediate collision or counter-detection threat.
  2. Improve operator training such that operators understand and effectively employ new APB functionality when fielded.
  3. Conduct future ASW testing against high-end targets simulating modern threat diesel-electric submarines (SSK) to enable a more complete assessment of A-RCI and BYG-1 performance. Since acoustic sensors and environmental conditions effect the system's performance, testing should be conducted using the Navy's tactical sensor combinations and in a variety of threat-like environments.
- FY12 Recommendations.
  1. DOT&E published a classified APB-09 FOT&E report in November 2012. That report identifies 21 recommendations that the Navy should address for the A-RCI sonar system and the AN/BYG-1 combat control systems. In particular, the Navy should re-evaluate operational effectiveness on a submarine with a repaired WAA.
  2. The Navy should consolidate the A-RCI and AN/BYG-1 TEMPs and test plans into an Undersea Enterprise Capstone document to permit efficiencies in testing.
  3. The Navy should improve its developmental testing processes and metrics used to determine if a system potentially improves effectiveness and suitability and to ensure that the system is ready for operational testing and subsequent fielding.

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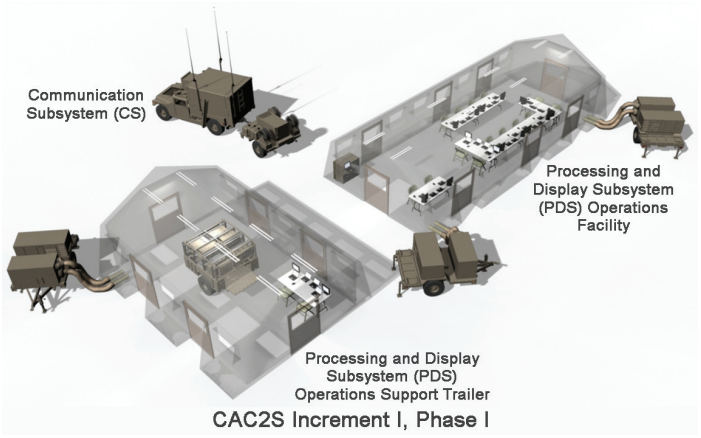
Common Aviation Command and Control System (CAC2S)

Executive Summary

- In September 2011, DOT&E assessed that the Common Aviation Command and Control System (CAC2S) Phase 1 IOT&E was not adequate due to test venue limitations and insufficient data collection. As a result, DOT&E could not determine CAC2S operational effectiveness and suitability.
- In September 2011, the Assistant Secretary of the Navy, Research, Development, and Acquisition, as the Milestone Decision Authority (MDA), led the Full Deployment Decision Review. The MDA subsequently approved Phase 1 full deployment of CAC2S and directed the CAC2S program manager to conduct additional testing to address recommendations by DOT&E and the Marine Corps Test and Evaluation Activity (MCOTEA) based on deficiencies identified during the IOT&E.
- In June 2012, the Marine Corps completed a Limited User Evaluation (LUE) for CAC2S Increment 1, Phase 1 that satisfactorily addressed previously identified key DOT&E and MCOTEA deficiencies.
- Based on data collected during the LUE combined with that from the IOT&E, DOT&E assessed CAC2S Increment 1, Phase 1 as operationally effective and operationally suitable in an October 2012 Major Automated Information System report for CAC2S Increment 1, Phase 1.

System

- CAC2S is designed to provide Marine Corps operators with the ability to share mission-critical voice, video, sensor, and command and control data and information in order to integrate aviation and ground combat planning and operations in support of the Marine Air-Ground Task Force (MAGTF).
- CAC2S consists of tactical shelters, software, and common hardware. The hardware components are expeditionary, common, modular, and scalable, and may be freestanding, mounted in transit cases, or rack-mounted in shelters and/or general purpose tents that are transported by organic tactical mobility assets.
- CAC2S Increment 1 is comprised of three functional subsystems to be delivered in two phases.
  - Phase 1:
    - Processing and Display Subsystem (PDS) – Provides the operational command post and functionality to support mission planning, decision making, and execution tools for all aspects of Marine Aviation.
    - Communication Subsystem (CS) – Provides the capability to interface with internal and external communication assets and the means to control their operation.
  - Phase 2:
    - Sensor Data Subsystem (SDS) – Provides an open-architecture interface capable of integrating emerging active and passive sensor technology for organic and non-organic sensors of the Marine Air Command and Control System (MACCS).
- CAC2S Phase 1 includes the PDS and CS to establish the baseline Direct Air Support Center (DASC) for the Marine Air Support Squadron and limited Tactical Air Operations Center (TAOC) mission functionality for the Marine Air Control Squadron. During Phase 2, SDS is intended to enhance the CAC2S and meet remaining MACCS aviation battle management command and control requirements to include fusion of real-time data.



CAC2S Increment I, Phase I

Mission

- The MAGTF Commander will employ CAC2S to integrate Marine Corps aviation into joint and combined air/ground operations in support of Operational Maneuver from the Sea, Sustained Operations Ashore, and other expeditionary operations. The CAC2S will support the MAGTF command and control concept and will provide an expeditionary and common joint air command and control capability.
- The MAGTF Commander will execute command and control of assigned assets afloat and ashore in a joint, allied, or coalition operational environments by using CAC2S capabilities to:
  - Display a common, real and near real-time integrated tactical picture with the timeliness and accuracy

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necessary to facilitate the control of friendly assets and the engagement of threat aircraft and missiles
- Access theater and national intelligence sources from a single, multi-function command and control node
- Standardize Air Tasking Order (ATO) and Airspace Control Order generation, parsing, interchange, and dissemination throughout the MAGTF and theater forces by using the joint standard for ATO interoperability

Major Contractors
- Phase 1
  - Government Integrator: Naval Surface Warfare Center – Crane, Indiana
  - Component Contractor: Raytheon-Solipsys – Fulton, Maryland
  - Component Contractor: General Dynamics – Scottsdale, Arizona
- Phase 2: General Dynamics – Scottsdale, Arizona

Activity
- In September 2011, DOT&E assessed that the CAC2S Phase 1 IOT&E was not adequate due to test venue limitations and insufficient data collection. As a result, DOT&E could not determine CAC2S operational effectiveness and suitability.
- In September 2011, the Assistant Secretary of the Navy, Research, Development, and Acquisition, as the MDA, led the Full Deployment Decision Review. The MDA subsequently approved Phase 1 full deployment of CAC2S and directed the CAC2S program manager to conduct additional testing to address test inadequacies and deficiencies identified by DOT&E and MCOTEA during the IOT&E.
- The Marine Corps conducted an LUE in accordance with a DOT&E-approved test plan to address prior limitations in test adequacy and to test corrections for CAC2S deficiencies identified during the IOT&E. The test was divided into two phases. The Marine Corps conducted Phase 1 testing during the Weapons and Tactics Instructor's Course (WTI) exercise at Marine Corps Air Station Yuma, Arizona, in April 2012. The Marine Corps conducted Phase 2 testing at the Marine Corps Tactical Systems Support Activity in June 2012.
- The Marine Corps began test planning for Phase 2 of CAC2S in FY12. IOT&E is scheduled for FY15.

Assessment
- The primary objectives of LUE Phase 1 testing were to assess the TAOC mission in an operationally realistic environment and CAC2S's ability to support continuous operations during DASC displacement. The primary objectives of LUE Phase 2 testing were to assess accuracy and timeliness of the Common Tactical Picture, Joint Range Extension Application Protocol A/B connectivity, Global Command and Control System integration, Advanced Field Artillery Data System integration, and maximum track processing capability. Data collected during both phases of the LUE were used to assess system reliability, availability, and maintainability.
- The LUE satisfactorily addressed key deficiencies previously identified, and there were no major limitations to testing. The minor limitations of not having the Service-level preventative maintenance plan established, as well as not having a logistics spares and delivery structure in place, did not hinder the overall assessment. The WTI exercise, during which the LUE was conducted, did allow sufficient data collection to resolve TAOC effectiveness operations. The combination of both IOT&E and LUE testing provided adequate data to assess the operational effectiveness and suitability of CAC2S.
- The CAC2S is operationally effective in its primary mission to support the DASC and TAOC. DASC operators were able to use the CAC2S to support direct air support missions during both the IOT&E and LUE. The CAC2S Common Tactical Picture provided DASC operators with timely, accurate, and relevant information. Early Warning and Control TAOC operators were able to use the CAC2S communications capabilities to support airspace surveillance, air direction and control, coordination of air assets, and weapons systems integration during the LUE.
- The CAC2S is operationally suitable. The combination of data from both the IOT&E and LUE are adequate to assess reliability, availability, and maintainability. DASC and TAOC operators were able to consistently employ the system in the operationally representative environment provided during WTI operations. The reliability of completing a 24-hour mission was 88 percent, and the estimated Mean Time Between Operational Mission Failure was 192 hours. The operational availability was calculated as 97.9 percent.

Recommendations
- Status of Previous Recommendations. The Marine Corps addressed all previous FY10 and FY11 recommendations.
- FY12 Recommendations. The Marine Corps should:
  1. Ensure that future test venues for Phase 2 IOT&E provide for a balanced use of air and ground combat forces along with a 24-hour operational window to ensure adequate system operating hours for assessment of system reliability. In order to reduce risk, an operational assessment should be conducted prior to IOT&E that assesses functionality, integration, and employment for all MACCS users.
  2. Develop and implement a data collection plan to aid in assessment of reliability, availability, and maintainability requirements of currently fielded systems and use the data to supplement the evaluations of Phase 2.
  3. Establish requirements for and develop a Service-level preventative maintenance plan.
  4. Conduct a supportability assessment to assess the availability of logistic support and spares for Phase 2.

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CV-22 Osprey

Executive Summary
- Air Force Special Operations Command (AFSOC) conducted recent operational testing of upgrades to the Directional Infrared Countermeasure (DIRCM) and Suite of Integrated Radio Frequency Countermeasures (SIRFC) systems that demonstrated improvements in countermeasure effectiveness.
- AFSOC completed operational assessments of ramp-mounted machine guns and flight control software in FY12.
- AFSOC plans to evaluate improvements to the icing protection and communications systems in FY13.

System
- There are two variants of the V-22: the Marine Corps MV-22 and the Air Force/U.S. Special Operations Command (USSOCOM) CV-22. The air vehicles for Air Force and Marine Corps missions are nearly identical, with common subsystems and military components sustainable by each Service's logistics system.
- The CV-22 is the replacement for aging Special Forces MH-53 helicopters. It is a tilt-rotor aircraft capable of conventional fixed-wing flight and vertical take-off and landing over the range of Special Operations missions.
- Its speed and range enable the ability to support Special Operations mission demands that were not possible with legacy rotary- or fixed-wing aircraft.
- The CV-22 can carry 18 combat-ready Special Operators 538 nautical miles (nm) and return. It can self-deploy up to 2,100 nm with one aerial refueling.
- The CV-22 will augment Air Force Special Operations MC-130 aircraft. It has terrain-following/terrain-avoidance radar, an advanced multi-frequency communication suite, and a more robust electronic defense suite.



- Future capabilities will include engine sub-assembly upgrades, strategic refueling capability, and various fixes to deficiencies identified during IOT&E.

Mission
Air Force squadrons equipped with the CV-22 will provide high speed, long-range insertion and extraction of Special Operations Forces to and from high-threat objectives.

Major Contractors
Bell-Boeing Joint Venture:
- Bell Helicopter – Amarillo, Texas
- The Boeing Company – Ridley Township, Pennsylvania

Activity
- To address deficiencies with electronic defense systems discovered during the 2008 CV-22 IOT&E, AFSOC tested upgraded hardware and software of the DIRCM (April through June 2010) and SIRFC (April through July 2012).
- The CV-22 program relocated communication antennas to address limited operating range and inadequate reliability with the CV-22 radios demonstrated during the 2008 IOT&E.
- AFSOC conducted operational assessments of the GAU-18 and GAU-21 .50 caliber Upgraded Ramp-Mounted Weapon System in March through June 2012. AFSOC had modified these machine guns to improve weapons reliability following brownout landings.
- AFSOC evaluated the Tactical Software Suite 10.3.01 in March through April 2012. The major feature of this software version was the addition of the capability to perform coupled or uncoupled tactical approaches (during a coupled approach, flight crew utilize autopilot to fly the aircraft; during an uncoupled approach, the flight crew fly the aircraft manually).

Assessment
- DOT&E evaluated the DIRCM system during the CV-22 IOT&E in 2009 and reported significant reliability and performance shortfalls. Since IOT&E, AFSOC upgraded the CV-22 DIRCM with a new system processor, updated software, and Guardian Laser Transmitter Assembly designed to reduce system weight and to improve system reliability. AFSOC tested the hardware and software upgrades to the CV-22 DIRCM and the upgrades meet performance

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requirements. IOT&E reliability failures have not resurfaced during testing or fielding.
- DOT&E evaluated the SIRFC system during the IOT&E and reported substantial significant shortfalls in providing threat situational awareness and limited countermeasure effectiveness. DOT&E also reported a high rate of reliability failures during IOT&E. Since IOT&E, AFSOC upgraded the CV-22 SIRFC with new high-power transmitters, cabling, radio-frequency switches, antennas, and Block 7 Operational Flight Software with over 140 changes to correct system deficiencies; nonetheless, some deficiencies remain outstanding. Analysis of the SIRFC test data from FY12 testing is ongoing and will be reported in 2013.
- The GAU-18 .50 caliber Upgraded Ramp-Mounted Weapon System is not effective or suitable for fielding. Dust covers proposed for the GAU-18 did not protect the weapon from dust intrusion and resulted in numerous broken extractor pins.
- In testing, the GAU-21 demonstrated potential for reliable performance following exposure to brownout conditions. Repeated brownout landings did not adversely affect the rate of fire.
- The Tactical Software Suite 10.3.01 enabled pilots to conduct coupled and uncoupled tactical approaches. This enhancement reduces pilot workload when coupled approaches are feasible.
- While the program has made progress in improving CV-22 radio effectiveness and reliability, further testing and assessment is needed. Additionally, deficiencies with the Icing Protection System remain. Improvement and further testing is needed in both areas.
- No development or testing has been accomplished to address aerial refueling from strategic tankers.
- No additional flight testing or engineering analysis have been performed, indicating a change would be appropriate to DOT&E's September 2005 assessment that the V-22 cannot perform autorotation to a survivable landing.

Recommendations
- Status of Previous Recommendations. The program addressed all but one of the previous recommendations. The recommendation regarding development of battle damage repair procedures and fire suppression systems for the aircraft dry bays remains valid.
- FY12 Recommendations.
  1. The program should address deficiencies with the multi-mission advanced tactical terminal and the strategic refueling capability as documented in IOT&E and then operationally test the fixes.
  2. AFSOC should proceed with plans to evaluate communications effectiveness and reliability in FY13.
  3. AFSOC should proceed with plans to evaluate reliability fixes to the Icing Protection System under operationally representative icing conditions in FY13.

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CVN-78 *Gerald R. Ford* Class Nuclear Aircraft Carrier

Executive Summary

- The current Test and Evaluation Master Plan (TEMP) does not adequately address integrated platform-level developmental testing, significantly raising the likelihood that platform-level test problems will be discovered during IOT&E. The Program Office has begun to address the problem and has refined the post-delivery schedule. However, the details as to the extent of any additional integrated platform-level CVN-78 developmental tests are unclear.
- The Navy began CVN-78 construction in 2008 and plans to deliver the ship in September 2015. Current progress supports this plan; however, the Electro-Magnetic Aircraft Launch System (EMALS), Advanced Arresting Gear (AAG), Dual Band Radar (DBR), and Integrated Warfare Systems will continue to drive the timeline for successful delivery of the ship.
- The Navy continues to work on integration deficiencies related to the F-35 Joint Strike Fighter (JSF) and its fleet of aircraft carriers, including CVN-78.
- Although CVN-78 will include a new heavy underway replenishment (UNREP) system that will allow transfer of 12,000-pound cargos, the Navy's plan to install heavy UNREP systems on resupply ships has slipped eight years.
- DOT&E rescinded approval of the alternative LFT&E Management Plan pertaining to the *Gerald R. Ford* (CVN-78) class carrier program because the Navy unilaterally decided to modify the previously approved LFT&E plan. The Navy wanted to limit the scope of the Total Ship Survivability Trial (TSST) on CVN-78 to conform to the Navy budget, and to defer the Full-Ship Shock Trial (FSST) to CVN-79, a change to the previously approved LFT&E Management Plan with which DOT&E does not concur.

System

- The CVN-78 *Gerald R. Ford* class nuclear aircraft carrier program is a new class of nuclear powered aircraft carriers that replaces the previous CVN-21 program designation. It has the same hull form as the CVN-68 *Nimitz* class, but many ship systems, including the nuclear plant and the flight deck, are new.
- The newly designed nuclear power plant is intended to reduce reactor department manning by 50 percent and produce significantly more electricity when compared to a current CVN-68 class ship.
- The CVN-78 will incorporate electromagnetic catapults (instead of steam-powered), and have a smaller island with a DBR (a phased-array radar which replaces/combines five legacy radars used on current aircraft carriers).
- The Navy intends for the Integrated Warfare System to be adaptable to technology upgrades and varied missions throughout the ship's projected operating life including increased self-defense capabilities when compared to current aircraft carriers.
- The Navy redesigned weapons stowage, handling spaces, and elevators to reduce manning, increase safety, and increase throughput of weapons.
- The Navy designed CVN-78 to increase the sortie generation capability of embarked aircraft to 160 sorties per day (12-hour fly day) and to surge to 270 sorties per day (24-hour fly day) as compared to the CVN-68 *Nimitz* class sortie generation rate demonstration of 120 sorties per day/240 sorties for 24-hour surge.
- The Consolidated Afloat Networks and Enterprise Services (CANES) program replaces five shipboard legacy network programs to provide a common computing environment for command, control, intelligence, and logistics.
- The Navy plans to declare CVN-78 Initial Operational Capability in FY17 with Full Operational Capability in FY18 after the Milestone C decision.



Mission

Carrier Strike Group Commanders will use the CVN-78 to:

- Conduct power projection and strike warfare missions using embarked aircraft
- Provide force protection of friendly units
- Provide a sea base as both a command and control platform and an air-capable unit

Major Contractor

Huntington Ingalls Industries, Newport News Shipbuilding – Newport News, Virginia

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Activity

Test Planning

- The Navy continues to develop the CVN-78 Sortie Generation Rate (SGR) (number of aircraft sorties per day) test concept. Discussions have focused on the specific details of live testing days (e.g., which test ranges to use, how many aircraft, which weapons). The ship's SGR requirement is based on a 30-plus-day wartime scenario. DOT&E concurs with the proposed 6 consecutive 12-hour fly days followed by 2 consecutive 24-hour fly days. This live testing will be supplemented with modeling and simulation from the Virtual Carrier model to extrapolate results to the 30-plus-day SGR requirement.
- DOT&E approved an operational assessment that began in September 2012, to assess the progress of the CVN-78 build and its ability to successfully undergo operational test and evaluation in the future. The assessment is being led by U.S. Navy's Commander, Operational Test and Evaluation Force and is a five-month series of site visits and evaluations by fleet experienced operators who will perform a detailed analysis of the carrier and all its major subcomponents. This review is expected to be completed in 2QFY13 and will be used to inform the Defense Acquisition Board decision regarding future procurement of CVN-79.
- The CVN-78 *Gerald R. Ford* class carrier program Office is revising the TEMP in an effort to align planned developmental tests with corresponding operational test phases and to identify needed platform-level developmental testing. As part of this process, the Program Office recently released a Post Delivery Test and Trials schedule.

EMALS

- The EMALS system functional design test site at Joint Base McGuire-Dix-Lakehurst, New Jersey, continues to test the new electromagnetic catapult system.
- The Navy completed Phase I of Aircraft Compatibility Testing and installed a re-designed armature. Additionally, the system was reconfigured to enable testing of simulated shared energy storage and simulated shared power conversion to provide an early examination of multiple catapults on a carrier.

AAG

- The Navy is testing the AAG on a jet car track at Joint Base McGuire-Dix-Lakehurst, New Jersey. Earlier testing prompted design changes for the system's Water Twisters, Cable Shock Absorbers, Inverters, and Purchase Cable Drum frames. In August 2012, the program completed two test milestones that validated system performance in the uppermost regions of the system performance envelope. AAG performance testing began in September 2012.
- As of October 2012, about one third of AAG hardware items have been delivered to the shipyard.

JSF

- The Navy completed land-based JSF testing associated with the Jet Blast Deflector (JBD). The JBD is designed to deflect engine exhaust during catapult launches.

CANES

- The Navy conducted developmental testing on the unit-level CANES configuration used on Aegis destroyers in the lab from July 11 – 24, 2012. The Navy has scheduled developmental and follow-on testing of the force-level CANES configuration used on the *Nimitz* and *Gerald R. Ford* classes for the 4QFY14.

DBR

- The Navy is reactivating the Engineering Development Model of the Volume Search Radar portion of the DBR at the surface Combat System Center at Wallops Island, Virginia. In addition, the Navy is installing a production Multi-Functional Radar component of DBR to establish capability by January 2013 to support CVN-78 combat system integration and test.
- The Navy plans to conduct DBR testing at Wallops Island, Virginia, to verify the radar will meet CVN-78's Air Traffic Control requirements in January 2013. The Navy will also begin CVN-78 combat system integration testing with DBR in April 2013.

LFT&E

- DOT&E rescinded approval of the alternative LFT&E Management Plan pertaining to the *Gerald R. Ford* class carrier program because the Navy unilaterally decided to modify the previously approved LFT&E plan. The Navy informed DOT&E of its intent to limit the scope of the TSST on CVN-78 to conform to the Navy budget. While progress has been made toward reaching consensus on the scope of the TSST, the budget has not been adjusted accordingly. The Navy also deferred the FSST to CVN-79, a change to the previously approved LFT&E Management Plan with which DOT&E does not concur. Though the change is motivated by the desire to reduce the gap in available carriers caused by the retirement of the USS *Enterprise,* the delay due to the FSST is minimal, and only a small portion of the already substantial delay caused by other factors. The benefit of having test data to affect the design of future carriers in the class outweighs the delay.

Assessment

Test Planning

- The current state of the Virtual Carrier model does not fully provide for an accurate accounting of SGR due to a lack of fidelity regarding manning and equipment/aircraft availability. Spiral development of the Virtual Carrier model continues in order to ensure that the required fidelity will be available to support the SGR assessment during IOT&E.
- The current TEMP does not adequately address whole platform-level developmental testing. The Program Office has begun to address the problem and has refined the Post Delivery Test and Trials schedule. The details are unclear on the extent of any additional integrated platform-level CVN-78 developmental tests. Lack of platform-level

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developmental testing significantly raises the likelihood of the discovery of platform-level problems during IOT&E.
- The Navy plans to deliver CVN-78 in September 2015. Current progress supports this plan; however, the EMALS, AAG, DBR, and Integrated Warfare Systems remain pacing items for successful delivery of the ship.

EMALS
- DOT&E holds moderate concern regarding the performance risk generated by the inability to test the full four-catapult electrical distribution system prior to initial trials aboard ship. This concern is partially mitigated by the current phase of test using a simulated shared electrical storage and shared power conversion at the EMALS system functional design test site in Joint Base McGuire-Dix-Lakehurst, New Jersey.

AAG
- Significant redesign of multiple components has slowed development of AAG development. The program will begin performance testing in FY13.

JSF
- JBD testing identified no deficiencies for catapult launch operations of JSF at military rated thrust. The tests did, however, determine that additional JBD side panel cooling (SPC) and other adjustments are required for operations at combat rated thrust, i.e., with afterburner. The existing JBD panels will need to be replaced with new panels with SPC to be fully JSF-compatible. JBD panels with SPC are form, fit, and function replacements and will be installed after CVN-78 delivers.
  - JSF data flow aboard ship via the Autonomic Logistics Information System (ALIS) is critical to proper F-35 maintenance. Currently, the ALIS system has provided all required parametric information to interface properly with CANES, but CANES is not fully developed yet, as the contract was awarded in August 2012. ALIS is expected to undergo Application Integration Process testing in FY13 to ensure proper interface with CANES. DOT&E will be able to better assess the impact on JSF operations aboard CVN-78 after the test. Currently, data are planned to be exchanged manually until ALIS and CANES properly interface.
  - In 2007, the Program Office identified discrepancies with the integration of the JSF's F135 engine onto aircraft carriers. The weight of the F135 power module, approximately 10,000 pounds, exceeds the limit of current underway replenishment (UNREP) systems. Although CVN-78 will include a heavy UNREP system that will allow transfer of 12,000 pounds, supply ships must include the new system for power module transfer to occur. The Navy's plan to install heavy UNREP systems on resupply ships has slipped eight years.
- Navy Fleet Force's JSF "day-in-the-life" analysis identified a significant number of aircraft-ship interface deficiencies that must be accomplished by the Navy in post-delivery ship modification. They include the following:
  - JSF battle damage assessment and non-traditional Intelligence, Surveillance, and Reconnaissance information captured on the Portable Memory Device or cockpit video recorder cannot be shared real-time with the Distributed Common Ground System-Navy (DCGS-N). This prevents assessment by shipboard intelligence analysts for inclusion in mission reports.
  - Ships are unable to receive and display Link 16 imagery; this problem is not unique to JSF. The Combatant Commanders have stated a need to display imagery to intelligence analysts and operations command and control nodes to enhance engagement decisions.
  - Limited shipboard capabilities exist with expeditionary Link 16. The Navy is considering a program of record to distribute imagery to analysts and maritime operations command and control nodes (e.g., carriers and amphibious ships). This would be a temporary workaround for the DCGS-N post-flight data gap.
  - The JSF Prognostic Health Maintenance (PHM) downlink design for ships is not mature. The uncertainty in the technical characteristics of the final design means that there are potential challenges to integrating PHM into current shipboard communications suites and networks. These challenges include unidentified Information Assurance considerations and unidentified waveform hosting and interfacing.
  - The JSF wheel supplier's recent rim inspection requirement may force a significant increase in shipboard tire and wheel storage requirements. The JSF Program Office is currently working to determine the effect of this deficiency and the need for inspection by the wheel supplier.

DBR
- Previous testing of Navy combat systems similar to CVN-78's revealed numerous integration problems that degrade the performance of the combat system. The previous results emphasize the necessity of maintaining a DBR/CVN-78 combat system asset at Wallops Island. The Navy is considering long-term plans (i.e., beyond FY15) for testing DBR at Wallops Island, Virginia, but it is not clear if a Multi-Functional Radar and funding will be available. Such plans are critical to delivering a fully capable combat system and ensuring lifecycle support after CVN-78 delivery in 2015.

LFT&E
- While the Navy has made substantial effort in component and surrogate testing, this work does not obviate the need to conduct the FSST to gain the critical empirical data that past testing has repeatedly demonstrated are required to rigorously evaluate the ship's ability to withstand shock and survive in combat. Shock Trials conducted on both the *Nimitz* class aircraft carrier and the *San Antonio* class Amphibious Transport Dock demonstrated the need for and substantial value of conducting the FSST. Postponing the FSST until CVN-79 would cause a five- to seven-year delay

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in obtaining the data critical to evaluating the survivability of the CVN-78 and would preclude timely modification of subsequent ships of this class to assure their survivability.

- The Navy proposes delaying the shock trial by five to seven years because of the approximately four- to six-month delay required to perform the FSST. The delay is not a sufficient reason to postpone the shock trial, since the shock trial could reveal valuable lessons, including previously unknown vulnerabilities.
- DOT&E has requested the Navy adequately fund and complete the actions necessary to conduct the TSST on the CVN-78. This includes updating the Damage Scenario Based Engineering Analyses (DSBEA) from prior Vulnerability Assessment Reports and enough new DSBEAs, including machinery spaces, to conduct an adequately scoped TSST. DOT&E expects this will require five or six TSST drills. While progress has been made toward reaching consensus on the scope of the TSST, there is still work to be done, mainly to include the machinery spaces, and the budget has not been adjusted to adequately support the TSST.

Recommendations

- Status of Previous Recommendations. The Navy addressed one of eight previous recommendations but the following seven remain valid:
  1. Adequately test and address integration challenges with JSF; specifically logistics (storage of spare parts and engines, transport of support equipment and spares to/from the carrier), changes required to JBDs, changes (due to heat and or noise) to flight deck procedures, and ALIS integration.
  2. Finalize plans that address CVN-78 integrated warfare system engineering and ship's self-defense system discrepancies prior to the start of IOT&E.
  3. Continue aggressive EMALS and AAG risk-reduction efforts to maximize opportunity for successful system design and test completion in time to meet required in-yard dates for shipboard installation of components.
  4. Continue development of a realistic model for determining CVN-78's SGR, while utilizing realistic assumptions regarding equipment availability, manning, and weather conditions for use in the IOT&E.
  5. Provide scheduling, funding, and execution plans to DOT&E for the live SGR test event during the IOT&E.
  6. Continue to work with the Navy's Bureau of Personnel to ensure adequate depth and breadth of required personnel to ensure that the 100 percent Navy Enlisted Classification fit/fill manning requirements of CVN-78 are met.
  7. Conduct system-of-systems developmental testing to preclude discovery of deficiencies during IOT&E.
- FY12 Recommendations. None.

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Direct Attack Moving Target Capability (DAMTC)

Executive Summary

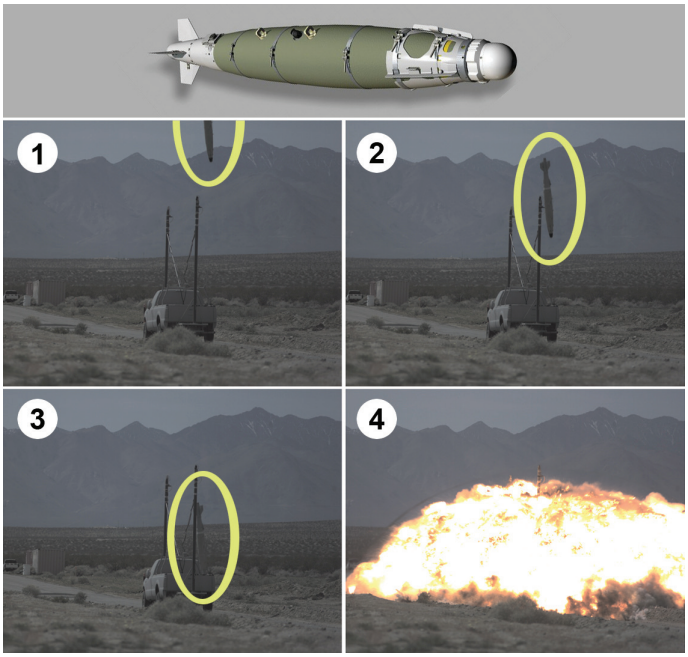
- The Direct Attack Moving Target Capability (DAMTC) is a non-developmental program that expands the employment envelope of the original Laser Joint Direct Attack Munition (LJDAM) that was fielded in response to an Urgent Operational Need (UON) requirement. DAMTC expands the UON LJDAM's capability from a simple moving target to a more challenging maneuvering target. A maneuvering target is a target that is moving but changes velocity, direction, or both during the time it is engaged.
- The Navy conducted operational testing between November 2011 and April 2012 resulting in a Full-Rate Production decision in June 2012.
- The Navy dropped 22 LJDAM weapons in FY12 during the DAMTC LJDAM operational testing.

System

- The JDAM is a low-cost, autonomously controlled, adverse weather, accurate guidance kit tailored for Air Force/Navy general purpose bombs to include:
  - 2,000-pound Mk 84 and BLU-109 bombs
  - 1,000-pound Mk 83 and BLU-110 bombs
  - 500-pound Mk 82, BLU-111, BLU-126, and BLU-129/B bombs
  - A GPS-aided inertial navigation system that provides primary guidance to the weapon. Augmenting the JDAM inertial navigation system with GPS signals enhances accuracy.
- Guidance and control designs enable accuracy of less than 5 meters when GPS is available and less than 20 meters when GPS is absent or jammed after release.
- The LJDAM provides the capability to attack moving targets by enabling such targets to be illuminated with laser energy that LJDAM's seeker detects and tracks. In addition to retaining the precision of JDAM when used against stationary targets, the LJDAM provides precise laser target designation to eliminate Target Location Error, ability to operate beneath a cloud layer, and the ability to select weapon impact angle in combination with laser-guided precision. LJDAM's laser guidance allows for self-lasing by the engaging aircraft or buddy-lasing by another aircraft or a ground-party.
- The Navy established DAMTC as a program of record in February 2010 and selected LJDAM as the non-developmental material solution.

Mission

- Combatant Commanders use JDAMs employed by fighter, attack, and bomber aircraft, to engage targets day or night, in all weather at the strategic, operational, and tactical levels of warfare.
- Combatant Commanders employ JDAM against fixed and relocatable soft and hard targets, to include command and control facilities, airfields, industrial complexes, logistical and air defense systems, lines of communication, and all manner of battlefield forces and equipment.
- Combatant Commanders employ the UON LJDAM to engage stationary targets using JDAM-type tactics, as well as to reactively engage stationary and moving targets.
- The Navy and Marine Corps intend to use the moving and maneuvering target capability of the DAMTC LJDAM for Close Air Support, Strike Coordination and Armed Reconnaissance, and Time Sensitive Target missions to strike armored and unarmored vehicles, both maneuvering and stationary, due to their potential to start maneuvering.



Major Contractor

The Boeing Company, Integrated Defense Systems – St. Charles, Missouri

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Activity

- The Navy's Commander, Operational Test and Evaluation Force (COTF) initiated operational testing in November 2011. Testing incorporated 22 DAMTC LJDAM weapon deliveries using F/A-18 and AV-8B aircraft from VX-9 against 18 moving and 4 stationary targets. The Navy completed IOT&E testing in April 2012.
- The Navy established DAMTC as a program of record in February 2010, selecting LJDAM as the non-developmental material solution. An updated laser sensor lens necessitated limited integrated and developmental testing prior to commencement of operational testing.
- The LJDAM employment history showed significant degradation of the lens when deployed in harsh environments (such as Afghanistan). The Navy initiated a search for a replacement material and Boeing developed a Sapphire lens to replace the existing glass lens.
- The Navy conducted a six-weapon developmental test phase, using side-by-side comparison testing between the two lens types, immediately prior to the operational test phase to ensure the Sapphire lens does not negatively affect system effectiveness.
- COTF conducted all testing in accordance with the DOT&E-approved Test and Evaluation Master Plan and test plan.

Assessment

- Preliminary developmental test results using the new Sapphire lens indicate highly comparable sensor detection ranges to the previous material.
- The Sapphire material is expected to provide improved reliability in harsh environments during its intended service life. Laboratory environmental testing and flight test results demonstrated Sapphire performance met system-level requirements. However, due to limited flight testing, data are currently insufficient to assess the reliability of the new lens material.
- Operational test results showed the DAMTC LJDAM to be operationally effective in the self-lasing mode against targets that both moved and maneuvered during weapon flight. The DAMTC LJDAM's demonstrated accuracy was 5.8 meters, meeting the 6-meter accuracy requirement. Accuracy using the buddy-lasing mode was poor; however, the range restrictions and target limitations that prevailed during the four buddy-lasing weapon deliveries (and not present during the self-lasing deliveries) are believed to have contributed to the poor results. Demonstrated accuracy is sufficient to assure lethal effects against a DAMTC LJDAM maneuvering vehicle or stationary targets.
- Operational test results showed the DAMTC LJDAM to be operationally suitable. Using both operational test and integrated test phase weapons to estimate reliability resulted in a material reliability of 98 percent (46 of 47), exceeding the 90 percent requirement. The only hardware failure was a live weapon that did not detonate upon impact. An overall system reliability of 77 percent is the result of three different operator error failures and a single large miss distance of unknown origin. It should be noted that there is not a requirement specified for system reliability.
- Operational testing highlighted two deficiencies related to human factors. The first is the dense wiring inside the tail-kit of the LJDAM weapons that makes verifying fuze arming and function settings extremely difficult, especially at night. The umbilical wire bundles result in a very crowded tail compartment making it difficult to read the settings. Workarounds were all deemed unacceptable because they either prevent the aircrew from positively confirming proper fuze settings or interfere with the configuration of the original assembly of a live weapon.
- The second human factors deficiency is the high cockpit workload associated with delivering a DAMTC LJDAM, though this is comparable with the high workloads found with other laser-guided weapons. Some reduction should be achievable through aircraft Operational Flight Program improvements but targeting pod limitations appear to drive most of the inherent workload.

Recommendations

- Status of Previous Recommendations. The Navy completed the FY11 recommendation.
- FY12 Recommendations. The Navy should:
  1. Conduct additional testing using buddy-lasing from rear aspect geometries to distinguish between the effects of the range restrictions and target limitations and the use of the buddy-lasing tactic on the DAMTC LJDAM's accuracy.
  2. Re-design the wiring bundle in the weapon's tail compartment to enable an accurate visual pre-flight check of the weapon's fuze settings.

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E-2D Advanced Hawkeye

Executive Summary

- E-2D IOT&E occurred from February to September 2012. The Navy plans to seek a Full-Rate Production decision from USD(AT&L) in January 2013.
- IOT&E included over 600 flight hours in overland, littoral, and over water environments. During testing, the E-2D tracked drone and traditional fighter-size aircraft targets. The test squadron embarked aircraft aboard a Navy aircraft carrier for at-sea testing, including carrier suitability, interoperability, and supportability.
- The Navy's Cooperative Engagement Capability (CEC) was supposed to complete follow-on testing in conjunction with the E-2D IOT&E; however, CEC developmental delays forced the de-coupling of these two events. As such, during IOT&E the Navy did not test the operationally representative software configuration of the CEC system in the E-2D.
- IOT&E was adequate to assess the E-2D Advanced Hawkeye's Air-to-Air and Strike Warfare mission performance.
- E-2D demonstrated improved surveillance capabilities relative to the E-2C. Test aircrews identified performance shortfalls with operator workload in dynamic, complex, high-target density environments.
- DOT&E was unable to assess during IOT&E the final E-2D CEC system configuration performance – a critical enabler for the Theater Air and Missile Defense (TAMD) mission.
- The E-2D Advanced Hawkeye demonstrated the ability to track cruise missile-sized targets during developmental and operational testing. While the system provided improved overland performance, the Navy needs to continue development efforts to provide a robust capability in all overland environments.
- Based on IOT&E reliability and availability data, DOT&E has identified shortfalls on some radar reliability and weapon system availability metrics, as well as immature training systems.

System

- The E-2D Advanced Hawkeye is a carrier-based Airborne Early Warning and Command and Control aircraft.
- Significant changes to this variant of the E-2 include upgraded engines to provide increased electrical power and cooling relative to current E-2C aircraft; a strengthened fuselage to support increased aircraft weight; replacement of the radar system, the communications suite, and the mission computer; and the incorporation of an all-glass cockpit, which permits the co-pilot to act as a tactical fourth operator in support of the system operators in the rear of the aircraft.
- The radar upgrade replaces the E-2C mechanically scanned radar with a phased-array radar that has combined mechanical and electronic scan capabilities.
- The upgraded radar is intended to provide significant improvement in Hawkeye littoral and overland detection performance and TAMD capabilities.
- The total E-2D Advanced Hawkeye system includes all simulators, interactive computer media, and documentation to conduct maintenance, as well as aircrew shore-based initial and follow-on training.



Mission

The Combatant Commander, whether operating from the aircraft carrier or from land, will use the E-2D Advanced Hawkeye to accomplish the following missions:

- Theater air and missile sensing and early warning
- Battlefield management, command, and control
- Acquisition, tracking, and targeting of surface warfare contacts
- Surveillance of littoral area objectives and targets
- Tracking of strike warfare assets

Major Contractor

Northrop Grumman Aerospace Systems – Bethpage, New York

Activity

- The Navy conducted the E-2D IOT&E from February to September 2012 in accordance with the DOT&E-approved Test and Evaluation Master Plan and test plan. The Navy plans to seek a Full-Rate Production decision from USD(AT&L) in 2QFY13.
- IOT&E testing included over 600 flight hours in overland, littoral, and over water environments. During testing, the E-2D tracked drone and traditional fighter-size aircraft targets. The test squadron conducted over 200 tracking events to assess Air-to-Air and Strike Warfare mission performance.
- The test squadron embarked aircraft aboard a Navy aircraft carrier for at-sea testing, including carrier suitability, interoperability, and supportability. This testing included operations from the aircraft carrier in support of a Joint Task

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Force-level exercise as well as additional interoperability testing during Carrier Strike Group certification training, which involved all current carrier air wing capable aircraft. The test squadron conducted E-2D operations while participating in joint Large Force Exercises at Nellis AFB, Nevada, and Fallon Naval Air Station, Nevada. Additionally, the test squadron conducted over-water TAMD tracking exercises operating with Navy ships off the California coast.

- The Navy's CEC program planned to complete follow-on testing in conjunction with the E-2D IOT&E; however, CEC developmental delays forced the de-coupling of these two events. As such, during IOT&E the Navy did not test the operationally representative software configuration of the CEC system in the E-2D. The Navy addressed the flaws in the CEC system during the summer of 2012 with new system software loads for both the E-2D mission system and the CEC system and entered follow-on test for the CEC system in October 2012.

Assessment

- IOT&E was adequate to assess the E-2D Advanced Hawkeye's legacy mission performance. DOT&E expects to publish a report assessing the E-2D IOT&E performance in January 2013.
- E-2D was found to have improved surveillance capabilities relative to the E-2C. Test aircrews identified performance shortfalls with operator workload in dynamic, high-target density environments where the E-2D mission system erroneously swapped identification labels for crossing/closely-spaced aircraft tracks. Subsequently, the tracks required manual aircrew re-labeling in the mission system, which can lead to operator overload and loss of situational awareness.
- DOT&E was unable to assess the final E-2D CEC system configuration performance – a critical enabler for the TAMD mission. The TAMD mission, which is the primary reason the E-2D is being procured, will not be fully accessible until the CEC system is successfully tested and end-to-end TAMD testing is completed in the 2015 timeframe, shortly before the E-2D Initial Operational Capability declaration.
- The E-2D Advanced Hawkeye demonstrated the ability to track cruise missile-sized targets during developmental and operational testing. While the system provided improved overland performance, the Navy needs to continue radar and mission system development efforts to provide a robust capability in all overland environments.
- With the exception of CEC testing still in progress, E-2D voice and datalink communications match those of E-2C. The E-2D has the same Passive Detection System found in the E-2C. DOT&E assesses this capability as matching that of the current E-2C.
- The E-2D mission planning system, the Joint Mission Planning System (JMPS), is not currently effective. Operators use the JMPS to provide a means of importing mission-planning data into the E-2D mission computer for use during flight. There are JMPS shortcomings in reliability and usability causing the mission-planning process to be cumbersome and time-consuming. Additionally, there is a deficiency with JMPS loading the proper network configuration data for some Link 16 networks.
- Based on IOT&E reliability and availability data, DOT&E has identified shortfalls on some radar reliability and weapon system availability metrics. E-2D maintainability had no significant shortfalls in on-aircraft maintenance procedures, documentation, or support equipment. However, the maintenance training system for the E-2D will not be available until July 2013 due to prior acquisition decisions. The lack of a maintenance training system precludes a full assessment of the maintainability of the E-2D system.
- DOT&E could not assess aircrew training due to the non-availability of the E-2D integrated simulator, which will be used for shore-based initial and follow-on training, as well as aircrew tactical and carrier operating procedures proficiency.
- The E-2D aircraft performed nominally during at-sea operations. The current E-2C system operates in a four aircraft-per-squadron configuration as opposed to the E-2D, which the Navy plans to operate in a five aircraft-per-squadron configuration. The E-2D at-sea testing did not demonstrate fully the ability to logistically support the proposed five-aircraft E-2D squadron in the aircraft carrier environment. The limited number of at-sea sorties and the current limited spare parts support for E-2D precluded a full at-sea logistics supportability assessment of the five-aircraft E-2D squadron concept.

Recommendations

- Status of Previous Recommendations. The Navy continues efforts to address CEC and radar performance improvements as recommended in FY11. These efforts are critical to achieving the 2015 E-2D Initial Operational Capability and full TAMD capability.
- FY12 Recommendations.
  1. The Navy should continue to improve E-2D CEC performance following completion of the E-2D CEC follow-on test in January 2013.
  2. The E-2D program should investigate potential radar and mission system performance upgrades to improve system performance in the challenging overland arena.
  3. The E-2D program should resolve the mission system track re-labeling deficiency.
  4. The E-2D program should work with the JMPS Program Office to provide for E-2D aircrews an effective mission planning system.
  5. The E-2D program should aggressively focus on implementing the full logistics posture to support the E-2D five-aircraft squadron concept in the aircraft carrier environment.
  6. The E-2D Program Office should continue to improve radar and overall weapon system reliability and availability.

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Enhanced Combat Helmet (ECH)

Executive Summary

- The Enhanced Combat Helmet (ECH) successfully met its ballistic and non-ballistic requirements during its First Article Test (FAT). However, while the ECH protects against perforation by the specified small arms threat, it does not provide a significant overall improvement in operational capability over currently fielded helmets against that threat. The ECH provides improved fragmentation protection compared to the fielded Advanced Combat Helmet and the Light Weight Helmet (LWH).
- Subsequent to FAT, during Engineering Change Proposal (ECP) testing of helmets manufactured using new machinery and tooling intended to provide increased helmet production capacity, the ECH experienced unexpected ballistic failures.
- Ceradyne (the manufacturer) indicated it had identified the reasons for these ballistic failures and implemented corrective actions. The ECH Program Office conducted additional testing to verify the effectiveness of Ceradyne's corrective actions. The ECH continued to experience unexpected ballistic failures during this testing.
- The ECH Program Office and Ceradyne continue to investigate the reasons for the ballistic failures.
- The ECH Program Office has delayed production and fielding of the ECH pending identification and correction of the reasons for the ballistic failures. The ECH Program Office projects testing to determine the effectiveness of corrective actions will begin in early 2013.

System

- The Marine Corps developed the ECH in response to a 2009 Urgent Statement of Need to produce a helmet that provides ballistic protection from energetic fragments and selected small arms ammunition, yet maintains all other characteristics of the Marine Corps' LWH and the Army's Advanced Combat Helmet (ACH).
- The ECH is compatible with and is typically worn in conjunction with other components of infantry combat equipment such as body armor systems, protective goggles, night vision equipment, and a camouflage fabric helmet cover. This new helmet is intended to provide Marines and Soldiers improved protection compared to the currently fielded LWH and ACH.



- The ECH consists of a ballistic protective shell, a pad suspension system, and a 4-point chin strap/nape strap retention system. Unlike the ACH and LWH helmets, which are constructed with aramid fibers, the ECH is constructed using ultra-high-molecular-weight polyethylene fibers.

Mission

Forces equipped with the ECH will rely on the helmet to provide ballistic protection from selected small arms ammunition and fragmentation when engaged with enemy combatants during tactical operations in accordance with applicable tactics, techniques, and procedures.

Major Contractor

Ceradyne, Inc. – Costa Mesa, California

Activity

- The Marine Corps conducted FAT II during November and December 2011 in accordance with the DOT&E-approved test plan. Following successful completion of this FAT, the Marine Corps conducted Full-Up System-Level live fire tests against both direct and indirect fire threats between December 2011 and February 2012.
- In April 2012, the ECH Program Office began testing ECPs to assess if helmets produced using new machinery, tooling,

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or hardware (necessary to expand ECH production capability) continued to meet performance requirements prior to incorporating these new items into the production process.
- Due to unexpected ballistic failures during ECP testing, Ceradyne began an analysis of the causes for the failures, as well as actions required to correct the reasons for the failures. Ceradyne implemented corrective actions it thought would be effective and submitted newly-manufactured helmets for testing that began in late June 2012. The ECH Program Office designed the testing to verify that the corrective actions addressed the reasons for the ballistic failures, and that the helmets met ballistic requirements. However, the helmet continued to experience ballistic failures during this verification testing.
- In July 2012, the ECH Program Office assembled a team to assist Ceradyne with the subsequent failure analysis. Both the ECH Program Office and Ceradyne continue to conduct root cause analysis to determine the reasons for the ballistic failures.
- The ECH Program Office currently projects testing will begin in early 2013 to verify Ceradyne has corrected the reasons for the ballistic failures and that the helmets continue to meet requirements.

Assessment
- Although the ECH protects against perforation by the specified small arms threat, it does not provide a significant overall improvement in operational capability over currently fielded helmets against that threat. It is unlikely to provide meaningful protection against this small arms threat over a significant portion of the threat's effective range. However, the ECH does provide improved penetration protection against fragments relative to currently fielded helmets. The ECH met all ballistic performance requirements.
- In stopping high-energy threats, the helmet absorbs the projectile energy by deforming inward toward the skull. It is unknown, definitively, whether the ECH provides protection against injury when the deforming helmet impacts the head. There is, however, reason to be concerned because the deformation induced by the impact of a non-perforating small arms threat exceeds accepted deformation standards across most of the threat's effective range.
- There are no definitive medical criteria or analytic methods to correlate the extent of helmet deformation to injury. However, according to the Armed Forces Medical Examiner's Office, even absent medical studies definitively correlating helmet deformation with specific injury, the deformation observed during testing represents significant blunt force and/or penetrating trauma to the head that could be lethal.
- While the ECH met the stated resistance to the perforation requirement against the specified small arms threat, one helmet shot location was more prone to small arms perforations than others. The ECH Program Office plans to implement an ECP to address this problem.
- Structural degradation as a result of prolonged temperature and humidity exposure may be a concern for the ECH. Published data document the degradation of ballistic performance in ultra-high-molecular-weight polyethylene materials, but the long-term performance of the ECH's specific ballistic material is unknown.
- The ECH Program Office has contracted to procure ECHs in production lots of mixed helmet sizes. There is no assurance that testing of these mixed lots will include sufficient numbers of the individual sizes produced within a lot to draw valid conclusions from the test results.

Recommendations
- Status of Previous Recommendations. There were no previous recommendations for this program.
- FY12 Recommendations. The ECH Program Office should:
  1. Conduct adequate testing to ensure the failures observed during ECP testing are identified and corrected. In addition, they should test and implement the planned ECP to address small arms perforation concerns at the one shot location. Until the ECP addressing the small arms perforation concern is implemented, the ECH Program Office should conduct adequate lot acceptance testing to ensure the helmet provides adequate protection from small arms perforation at all impact locations.
  2. Carefully monitor the results of lot acceptance testing when ECH production begins for indications of variations in the manufacturing process that could affect the ECH's ballistic protection.
  3. Improve ECH protection by reducing the amount of helmet deformation caused by non-perforating small arms impacts, as improvements in materials and manufacturing processes permit.
  4. Conduct testing to determine whether long-term exposure to elevated temperatures and humidity degrades ECH ballistic performance.
  5. Procure ECH in production lots of a single helmet size to ensure adequate lot acceptance testing.

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F/A-18E/F Super Hornet and EA-18G Growler

Executive Summary

- In FY11, the Navy conducted Software Qualification Testing (SQT) of System Configuration Set (SCS) H6E for F/A-18E/F Super Hornet and EA-18G Growler aircraft, SQT of SCS 23X for early-model F/A-18E/F aircraft, and a second FOT&E period for the APG-79 Active Electronically Scanned Array (AESA) radar. DOT&E issued individual classified reports on this testing for both F/A-18E/F and EA-18G in FY12.
- The APG-79 AESA radar provides improved performance relative to the legacy APG-73 radar; however, operational testing did not demonstrate a statistically significant difference in mission accomplishment between F/A-18E/F aircraft equipped with AESA and those equipped with the legacy radar.
- While SCSs H6E and 23X demonstrate acceptable suitability, the AESA radar's reliability continues to suffer from software instability. The radar's failure to meet reliability requirements and poor built-in test (BIT) performance remain as shortfalls from previous test and evaluation periods.
- Overall, the F/A-18E/F Super Hornet weapon system is operationally effective and suitable for most threat environments. However, the platform is not operationally effective for use in certain threat environments, the specifics of which are addressed in the DOT&E FY12 classified report.
- The EA-18G Growler weapon system is operationally effective and operationally suitable.
- The Navy is conducting F/A-18E/F and EA-18G SCS H8E SQT in two phases. Phase I operational testing commenced in 4QFY12 and is scheduled to complete in 1QFY13. The Navy expects to conduct Phase II testing during 2Q – 3QFY13. DOT&E will issue a single report covering both H8E phases after the completion of Phase II in 4QFY13.

System

F/A-18E/F Super Hornet

- The Super Hornet is the Navy's premier strike-fighter aircraft that replaces earlier F/A-18 variants in carrier air wings. The F/A-18E is a single-seat aircraft while the F model has two seats.
- F/A-18E/F Lot 26+ aircraft provide functionality essential for integrating all Super Hornet Block 2 hardware upgrades, which include:
  - Single pass multiple targeting for GPS-guided weapons
  - Use of off-board target designation
  - Improved datalink target coordination precision
  - Implementation of air-to-ground target points



- Additional systems include:
  - APG-73 or APG-79 radar
  - Advanced Targeting and Designation Forward-Looking Infrared System
  - AIM-9 infrared-guided missiles and AIM-120 and AIM-7 radar-guided missiles
  - Shared Reconnaissance Pod
  - Multi-functional Information Distribution System for Link 16 tactical datalink connectivity
  - Joint Helmet Mounted Cueing System
  - Integrated Defensive Electronic Countermeasures

EA-18G Growler

- The Growler is the Navy's land- and carrier-based, radar and communication jamming aircraft.
- The two-seat EA-18G replaces the four-seat EA-6B. The new ALQ-218 receiver, improved connectivity, and linked displays are the primary design features implemented to reduce the operator workload in support of the EA-18G's two-person crew.
- The Airborne Electronic Attack (AEA) system includes:
  - Modified EA-6B Improved Capability III ALQ-218 receiver system
  - Advanced crew station
  - Legacy ALQ-99 jamming pods
  - Communication Countermeasures Set System
  - Expanded digital Link 16 communications network
  - Electronic Attack Unit
  - Interference Cancellation System that supports communications while jamming

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  - Satellite receive capability via the Multi-mission Advanced Tactical Terminal
- Additional systems include:
  - APG-79 AESA radar
  - Joint Helmet Mounted Cueing System
  - High-speed Anti-Radiation Missile
  - AIM-120 radar-guided missiles

System Configuration Set (SCS) Software

- Growler and Super Hornet aircraft employ SCS operational software to enable major combat capabilities. All EA-18Gs and Block 2 F/A-18s (production Lot 26 and beyond) use high-order language or "H-series" software, while F/A-18E/F prior to Lot 26 and all legacy F/A-18 A/B/C/D aircraft use "X-series" software. The current fleet-release software are H6E and 23X, respectively.

Mission

- Combatant Commanders use the F/A-18E/F to:
  - Conduct offensive and defensive air combat missions
  - Attack ground targets with most of the U.S. inventory of precision and non-precision weapon stores
  - Provide in-flight refueling for other tactical aircraft
  - Provide the fleet with an organic tactical reconnaissance capability
- Combatant Commanders use the EA-18G to:
  - Support friendly air, ground, and sea operations by countering enemy radar and communications
  - Jam integrated air defense systems
  - Support non-integrated air defense missions and emerging non-lethal target sets
  - Enhance crew situational awareness and mission management
  - Enhance connectivity to national, theater, and tactical strike assets
  - Provide enhanced lethal suppression through accurate High-speed Anti-Radiation Missile targeting
  - Provide the EA-18G crew air-to-air self-protection with the AIM-120

Major Contractor

The Boeing Company, Integrated Defense Systems – St. Louis, Missouri

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Activity

- DOT&E reported on APG-79 radar IOT&E in FY07, assessing it as not operationally effective or suitable due to significant deficiencies in tactical performance, reliability, and BIT functionality.
- The Navy conducted APG-79 radar FOT&E in FY09 in conjunction with SCS H4E SQT. The Navy's Commander, Operational Test and Evaluation Force subsequently reported that significant deficiencies remained for both APG-79 AESA performance and suitability; DOT&E concurred with this assessment.
- Concurrent with SQT for SCSs H6E and 23X, the Navy conducted a second APG-79 radar FOT&E period in FY11. The Navy conducted the testing in accordance with the DOT&E-approved Test and Evaluation Master Plan (TEMP) and test plan. DOT&E issued a classified report on this testing in FY12; finding that the Super Hornet made incremental improvements, but still retained important deficiencies.
- The Navy is conducting F/A-18E/F and EA-18G SCS H8E SQT in two phases. Phase I operational testing was originally scheduled for 1QFY12, but due to multiple software anomalies during developmental testing, the Navy postponed the Operational Test Readiness Review until 3QFY12. H8E Phase I operational testing commenced in 4QFY12 and is scheduled to complete in 1QFY13. The Navy is conducting the testing in accordance with the DOT&E-approved TEMP and test plan.
- The Navy expects to conduct H8E Phase II operational testing during 2Q – 3QFY13.
- SCS H8E testing does not include an end-to-end multi-AIM-120 missile shot. This capability is a Navy operational requirement not previously demonstrated or successfully tested. The Navy tentatively plans to conduct a multi-missile shot in conjunction with SCS H12E testing.

Assessment

- The APG-79 AESA radar demonstrated marginal improvements since the previous FOT&E period and provides improved performance relative to the legacy APG-73 radar. However, operational testing does not demonstrate a statistically significant difference in mission accomplishment between F/A-18E/F aircraft equipped with AESA and those equipped with the legacy radar.
- Full development of AESA electronic warfare capability remains deferred to later software builds.
- While SCSs H6E and 23X demonstrate acceptable suitability, the AESA radar's reliability continues to suffer from software instability despite software upgrades. The radar's failure to meet reliability requirements and poor BIT performance remain as shortfalls from previous test and evaluation periods.
- Overall, the F/A-18E/F Super Hornet weapon system is operationally effective and suitable for most threat environments. However, the platform is not operationally effective for use in certain threat environments, the details of which are addressed in DOT&E's classified report.
- The EA-18G Growler weapons system is operationally effective and operationally suitable.
- DOT&E will report on Super Hornet and Growler SCS H8E capability improvements after both Phase I and II operational testing are complete in 4QFY13.

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Recommendations

- Status of Previous Recommendations.
  - The Navy made minimal progress addressing FY11 F/A-18E/F recommendations. Recommendations to continue to improve APG-79 AESA reliability and BIT functionality, to conduct an operationally representative end-to-end missile shot to demonstrate APG-79 radar and current SCS ability to support multi-AIM-120 engagement, and to develop and characterize the APG-79 AESA's full electronic warfare capability remain valid.
  - The Navy satisfactorily addressed three of seven FY11 EA-18G recommendations. Recommendations to improve aircraft maintainability and BIT software maturity, to improve ALQ-218 and ALQ-99 maintenance documentation and diagnostic tools, and to assess the need for a more capable threat range at Whidbey Island, Washington, remain valid.
- FY12 Recommendations. None.

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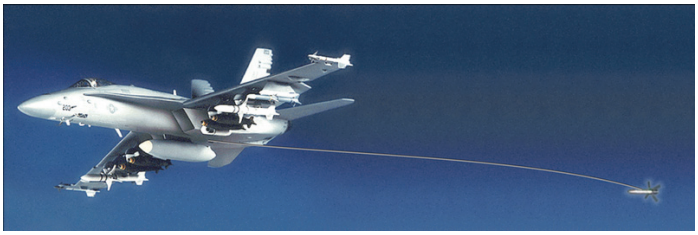
Integrated Defensive Electronic Countermeasures (IDECM)

Executive Summary

- DOT&E approved the classified Integrated Defensive Electronic Countermeasures (IDECM) Block IV (IB-4) Test and Evaluation Master Plan (TEMP) in January 2012.
- The Navy authorized the first lot buy of IB-4 systems in March 2012 following its In-Process Review (IPR) #3. At that time, DOT&E assessed that the system was nine months behind schedule and less mature than planned. No effectiveness or suitability results were available to support the lot production decision.
- Since IPR #3 in March 2012, the program has been delayed an additional three months and the operational assessment (OA) has been reduced in scope because of IB-4 software immaturity and unavailability of laboratory resources.
- The IB-4 OA began September 2012 and is expected to conclude by December 2012. It includes flight tests and a laboratory test. The Navy has made progress in hardware testing and software development, and is resolving deficiencies at an increasing rate since the IPR #3. However, the Navy continues to discover system deficiencies at a steady rate, and DOT&E anticipates that the program will need additional time to resolve system deficiencies, thus extending the test schedule.

System

- The IDECM system is a radio frequency, self-protection electronic countermeasure suite on F/A-18 aircraft. The system is comprised of onboard and off-board components. The onboard components receive and process radar signals and can employ onboard and/or off-board jamming components in response to identified threats.
- There are four IDECM variants: Block I (IB-1), Block II (IB-2), Block III (IB-3), and Block IV (IB-4). All four variants include an onboard radio frequency receiver and jammer.
  - IB-1 (fielded FY02) combined the legacy onboard receiver/jammer (ALQ-165) with the legacy (ALE-50) off-board towed decoy.
  - IB-2 (fielded FY04) combined the improved onboard receiver/jammer (ALQ-214) with the legacy (ALE-50) off-board towed decoy.
  - IB-3 (fielded FY11) combines the improved onboard receiver/jammer (ALQ-214) with the new (ALE-55) off-board fiber optic towed decoy that is more integrated with the ALQ-214.
  - IB-4 (currently in development) is intended to replace the onboard receiver/jammer (ALQ-214(V)3) with a lightweight, repackaged onboard jammer (ALQ-214(V)4 and ALQ-214(V)5).
- The F/A-18E/F installation includes off-board towed decoys. The F-18C/D installation includes only the onboard receiver/jammer components and not the towed decoy.



Mission

- Combatant Commanders will use IDECM to improve the survivability of Navy F/A-18 strike aircraft against radio frequency-guided threats while on air-to-air and air-to-ground missions.
- The Navy intends to use IB-3's and IB-4's complex jamming capabilities to increase survivability against modern radar guided threats.

Major Contractors

- ALE-55: BAE Systems – Nashua, New Hampshire
- ALQ-214: ITT Electronic Systems – Clifton, New Jersey
- ALE-50: Raytheon Electronic Warfare Systems – Goleta, California

Activity

IDECM Block III

- DOT&E completed its IDECM Block III IOT&E report in June 2011, assessing the system as operationally effective and operationally suitable for combat. The Navy authorized IDECM Block III full-rate production in July 2011.

IDECM Block IV

- Developmental laboratory testing began in September 2011 at the Navy's Advanced Weapons Laboratory system integration lab at China Lake, California, and the Navy's Electronic Combat System Evaluation Laboratory (ECSEL) at Point Mugu, California.

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- DOT&E approved the classified IB-4 TEMP in January 2012.
- The Navy's Commander, Operational Test and Evaluation Force (COTF) completed a Developmental Test Assist assessment in February 2012, which consisted primarily of observations of contractor and Navy laboratory testing. COTF noted significant hardware, software, and compatibility shortfalls based on its observations (details are classified).
- The Navy approved the first lot production of IB-4 systems in March 2012.
- The Navy conducted developmental ground-mount open-air range testing at the Navy's Slate Range at China Lake, California, and at the Nevada Test and Training Range. The Navy began developmental risk reduction flight testing in May 2012 at China Lake, California.
- The Navy began IB-4 OA testing in September 2012, consisting of flight testing at the Electronic Combat Range in China Lake and laboratory testing at the ECSEL in Point Mugu. The OA was reduced in scope from what was originally described in the January 2012 TEMP. The Navy requested a delay in one of the planned laboratory tests to further mature IB-4 software, and a national priority Air Force program took precedence over IB-4 at one of the laboratory test facilities. DOT&E approved this reduction in scope. The Navy will complete the two deferred tests as described in the DOT&E-approved test plan prior to the start of FOT&E and DOT&E will issue an FOT&E report.
- The Navy plans to complete a redesign of the IDECM receiver near the end of the FOT&E. The Program Office expects the redesigned receiver's effect on system performance to be minimal; DOT&E will work with the Program Office to determine the scope of any necessary additional testing.
- With each future IPR, beginning with IPR #3 (March 2012), the Navy is authorizing purchases of the ALQ-214(V)4 for the F/A-18 E/F and the ALQ-214(V)5 for the F/A-18 C/D.

Assessment

- At the IPR #3, IB-4 was 9 months behind the schedule the Navy presented at the hardware critical design review 30 months earlier. The Navy had not completed several key hardware tests and had not started system effectiveness and suitability testing, which led to a less informed IPR #3. Deficiency report submissions from developmental testing were continuing at a steady rate, with the number of unresolved deficiencies outpacing the number of resolved deficiencies, showing lack of system maturity.
- The Navy has made progress in hardware testing and software development, and is resolving deficiencies at an increasing rate since IPR #3. However, the Navy continues to discover system deficiencies at a steady rate, and DOT&E anticipates that the program will need additional time to resolve system deficiencies, thus extending the test schedule. This will require the Navy to either postpone conducting the next IPR and lot production decision (currently scheduled for March 2013) or again make a lot production decision with much less information than originally intended.
- DOT&E assessed system maturity at the start of the OA test as less than the program originally planned. No suitability data and limited effectiveness data were available to support the OA test readiness review, and therefore the program assumed increased risk of inadequate system performance during the OA.
- The Navy has significantly reduced the time period between the completion of all testing planned for the OA and FOT&E, thus leaving little time to correct deficiencies found as a result of testing.

Recommendations

- Status of Previous Recommendations. The Navy has adequately addressed three of the nine IDECM-specific recommendations from FY11. The Navy has partially addressed an additional three of the nine recommendations and further activity to resolve them is ongoing. The three recommendations that may require material solutions and/or further Research and Development Test and Evaluation have not yet been addressed and are repeated below. One electronic warfare recommendation that was not program-specific is also repeated below.

  IDECM System

  1. The Navy should restructure and reorganize the complex and poorly organized IDECM system software code. This will minimize potential software problems yet to be discovered and simplify future modifications.
  2. The Navy should develop hardware and/or software changes to provide pilots with correct indications of whether a decoy was completely severed. This recommendation does not apply to the F/A-18 C/D installation since that installation does not include a towed decoy.
  3. The Navy should investigate the effects of IDECM on threat missile fuses.

  Electronic Warfare Warfighting Improvements

  4. In coordination with the Defense Intelligence Agency, the Navy should update the threat lethal radii and/or the evaluation processes that are used to determine whether simulated shots are hits or misses.
- FY12 Recommendations. None.

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Joint Standoff Weapon (JSOW)

Executive Summary

- The Navy completed developmental testing and initiated integrated testing of the AGM-154C-1 Joint Standoff Weapon (JSOW) variant during FY12. The JSOW C-1 integrated testing completed in early FY13, with operational testing to begin in mid-FY13.
- Preliminary results to date indicate that weapon impact accuracy for moving maritime targets is well within the accuracy requirement value, and accuracy performance against stationary land targets has been maintained.
- Preliminary results to date indicate that the JSOW C-1 Mean Flight Hours Between Operational Mission Failure (MFHBOMF) is well below the requirement value, primarily the result of software-driven problems. Another concern is the excessively complicated pilot-vehicle interface (PVI), which could prevent successful mission execution.
- Planned updates to the software to address these problems may invalidate use of some integrated test data for DOT&E's operational evaluation of JSOW C-1.



System

- The AGM-154 JSOW family uses a common and modular weapon body capable of carrying various payloads. The JSOW is a 1,000-pound class, air-to-surface glide bomb intended to provide low observable, standoff precision engagement with launch and leave capability. All variants employ a tightly coupled GPS/Inertial Navigation System.
- AGM-154A (JSOW A) payload consists of 145 BLU-97/B combined effects submunitions.
- AGM-154C (JSOW C) utilizes an imaging infrared seeker and its payload consists of an augmenting charge and a follow-through bomb that can be set to detonate both warheads simultaneously or sequentially.
- AGM-154A and AGM-154C are fielded weapons, and are no longer under DOT&E oversight. AGM-154C-1 (JSOW C-1) adds moving maritime target capability and the two-way strike common weapon datalink to the baseline AGM-154C weapon.

Mission

- Combatant Commanders use JSOW A to conduct pre-planned attacks on soft point and area targets such as air defense sites, parked aircraft, airfield and port facilities, command and control antennas, stationary light vehicles, trucks, artillery, and refinery components.
- Combatant Commanders use JSOW C to conduct pre-planned attacks on point targets vulnerable to blast and fragmentation effects and point targets vulnerable to penetration such as industrial facilities, logistical systems, and hardened facilities.
- Units will use JSOW C-1 to conduct attacks against moving maritime targets and have the ability to retarget weapons post-launch. JSOW C-1 will retain the JSOW C legacy capability against stationary land targets.

Major Contractor

Raytheon Company, Missile Systems – Tucson, Arizona

Activity

- The Navy conducted developmental and integrated testing in accordance with a DOT&E-approved Test and Evaluation Master Plan for the JSOW C-1.
- The Navy completed the developmental test phase in FY12 with the release of the second of two planned free flight weapon drops against moving maritime targets.
- The Navy completed the four planned integrated test free flight weapon drops in 4QFY12 through 1QFY13. Two were against a moving maritime target and two regression tests of JSOW C legacy capability against a stationary land target.
- Results from the developmental and integrated testing will support an Operational Test Readiness Review (OTRR) in 2QFY13. The Navy has scheduled JSOW C-1 operational testing for FY13 following the OTRR.

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Assessment

- Navy testing of JSOW C-1 is ongoing. Preliminary results to date indicate:
  - Weapon impact accuracy for moving maritime targets is well within the accuracy requirement value and accuracy performance against stationary land targets has been maintained.
  - JSOW C-1 MFHBOMF is well below the requirement value. This is primarily the result of software-driven problems. Achieving adequate assessment of MFHBOMF during operational testing is an area of high risk.
  - Excessively complicated PVI that could prevent successful mission execution is an area of high risk during operational testing.
- Planned updates to the JSOW software to address these problems may invalidate use of some developmental and integrated test data for DOT&E's operational evaluation of JSOW C-1.

Recommendations

- Status of Previous Recommendations. The Navy has satisfactorily addressed previous recommendations for JSOW A and C. There are no previous recommendations for JSOW C-1 since it is a new variant of the AGM-154.
- FY12 Recommendation.
  1. Before proceeding to JSOW C-1 operational testing, the Navy should verify that newly incorporated software updates adequately reduce software-driven failures and that PVI complexity have been mitigated sufficiently to permit successful mission execution.

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Light Armored Vehicle (LAV) Upgrade

Executive Summary
- The Marine Corps has developed a special purpose kit to improve protection from under-vehicle attacks. This kit (known as the D-Kit) is designed to work with the Ballistic Protection Upgrade Package (BPUP) and is installed at the discretion of the operational commander.
- The Marine Corps completed eight system-level underbody blast tests in March 2012 at Aberdeen Test Center, Maryland; the data indicate that the D-kit increases crew protection.

System
- The Family of Light Armored Vehicles (LAV) shares a common base platform configuration (eight-wheels, armored hull, suspension, power plant, drive train, and auxiliary automotive subsystem) among eight Mission Role Variants (MRVs). The LAV-25 personnel carrier is the predominant MRV.
- The Marine Corps initiated a Service Life Extension Program in FY05 primarily to address obsolescence deficiencies. The Marine Corps undertook the Survivability Upgrade I program based on an Urgent Need Statement from the operating forces. This upgrade became the LAV A2 configuration standard, and involved developing and installing a BPUP, power pack enhancements, upgraded suspension, and other modifications.
- The BPUP system consists of three kits, two of which provide additional protection against threats, while the third provides an internal and external stowage system.
- In 2007, the Program Management LAV Office internally designed an underbody kit (known as a D-Kit) that can be incorporated to counteract under-vehicle strikes. The D-kit has been fielded since 2009.
- The LAV A2 D-Kit is designed to work with the previously installed BPUP system and is a special purpose mission kit used in theater at the discretion of the operational commander.



LAV-25 A2 Variant

The BPUP provides armor protection to the sides and front of the vehicle, whereas the D-Kit provides additional armor protection with a V-shaped hull attachment under the vehicle.

Mission

Marine Corps commanders will use LAVs to provide combined arms reconnaissance, security missions, and mobile electronic support.

Major Contractors
- General Dynamics Land Systems – Canada
- Conversion of a LAV A1 to a LAV A2 is conducted at Marine Corps Logistics Base – Albany, Georgia, and Marine Corps Logistics Base –Barstow, California

Activity
- Follow-on System-Level Underbody Testing completed in March 2012 at Aberdeen Test Center, Maryland, in accordance with the DOT&E-approved LFT&E Strategy and the Event Design Plan. The LAV Program Office provided two fully-armored LAV-25 A2 assets to test and characterize the force protection capabilities and vehicle vulnerability against underbody blast threats. The test also included Mine Resistant Ambush Protected All-Terrain Vehicle level threats, as well as threshold threats, and a single test without the D-Kit.
- DOT&E will provide a classified LFT&E report to Congress.

Assessment
- Analysis of data after completion of the Follow-on System Level Underbody Testing confirms DOT&E's assessment of emerging results from FY11.
- Testing and analysis confirm that the LAV-25 A2 D-Kit increases crew protection against some under-vehicle mine and IED strikes. The details are available in the December 2012 classified DOT&E LFT&E report.
- The location of the LAV-25 A2 fuel cell, which is centered under the rear of the vehicle, increases crew vulnerability to some under-vehicle threats.

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Recommendations

- Status of Previous Recommendations. The Marine Corps is addressing the previous two recommendations through funding efforts in the Program Objective Memorandum for FY14, and is pursuing additional LAV survivability upgrades (such as blast mitigation seats, 5-point harness seat belts, and advanced suspension designs) with development and procurement slated for the FY17-20 timeframe. Additionally, the Marine Corps is actively engaged in the recommendation to consider relocating the fuel cell of the LAV-25 A2, by utilizing the LAV MRV fuel cell relocation program as a pre-cursor to a LAV-25 A2 fuel cell relocation program. The results of the MRV fuel cell relocation program will aid the program manager with engineering analysis for the subsequent LAV-25 A2 fuel cell relocation.
- FY12 Recommendations. None.

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Littoral Combat Ship (LCS)

Executive Summary

- The draft revision of the Littoral Combat Ship (LCS) Test and Evaluation Master Plan (TEMP) currently being proposed by the Navy will require additional revisions to be approved by DOT&E. In particular, the TEMP must incorporate phased operational testing of all increments of mission module capability to be deployed for use in combat.
- The Navy commenced a Quick Reaction Assessment (QRA) of the gun systems on LCS 1 in June 2012. Results from the QRA revealed performance, reliability, and operator training deficiencies for both the 30 mm and 57 mm guns.
- The Navy conducted testing of the MH-60S Block 2 Airborne Mine Countermeasures (AMCM) System, which is intended to support LCS mine countermeasures. Testing indicated shortfalls in performance:
  - The Navy determined the MH-60S helicopter cannot safely tow the AN/AQS-20A Sonar Mine Detecting Set (AQS-20A) or the Organic Airborne Sweep and Influence System (OASIS) because the helicopter is underpowered for these operations. The MH-60S helicopter will no longer be assigned these missions operating from any ship, including LCS.
  - Preliminary evaluation of test data collected during operational assessment (OA) of the MH-60S Block 2 Airborne Laser Mine Detection System (ALMDS) indicates that the system does not meet Navy requirements for False Classification Density and has low reliability.
- DOT&E agreed to defer the Total Ship Survivability Trials (TSSTs) from LCS 1 and 2 to LCS 3 and 4, which affords the Navy time to complete pre-trial damage scenario analysis.
- DOT&E also agreed to defer the Shock Trials from LCS 3 and 4 to LCS 5 and 6, resulting in a one-year delay, due to significant seaframe and system design changes expected. LCS 5 and 6 will be most representative of the class for purposes of the Shock Trials.



LCS 1



LCS 2

System

- The LCS is designed to operate in the shallow waters of the littorals where larger ships cannot maneuver as well. It is intended to accommodate a variety of individual warfare systems (mission modules) assembled and integrated into interchangeable mission packages.
- The Navy currently plans to field Mine Countermeasure (MCM), Surface Warfare (SUW), and Anti-Submarine Warfare (ASW) mission packages.
- The Navy is procuring two ship (seaframe) variants:
  - USS *Freedom* (LCS 1, 3, 5, and follow-on ships) is a semi-planing monohull design constructed of steel (hull) and aluminum (deckhouse) with a combined diesel and gas turbine main propulsion system.
  - USS *Independence* (LCS 2, 4, 6, and follow-on ships) is an aluminum trimaran design driven by four independent steerable water jets.
- Common design specifications:
  - Sprint speed in excess of 40 knots, draft of less than 20 feet, and unrefueled range in excess of 3,500 nautical miles at 14 knots
  - Accommodations for up to 76 personnel (air detachment personnel, mission module personnel, and a core crew of no more than 40)
  - A Common Mission Package Computing Environment for mission package control
  - Hangars sized to embark MH-60R/S and Vertical Take-Off Unmanned Aerial Vehicles (VTUAVs)
  - 57 mm Bofors Mk 3 gun
- The designs have different core combat systems to provide command and control, situational awareness, and self defense against anti-ship cruise missiles and surface craft.
  - *Freedom* Variant: COMBATSS-21, an Aegis-based integrated combat weapons system with a TRS-3D air/surface search radar, Ship Self-Defense System Rolling Airframe Missile (RAM) system (one 21-cell launcher),

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and a DORNA Electro-Optical/Infrared system for Mk 110 57 mm gun fire control.
  - *Independence* Variant: Integrated combat management system (derived from Dutch TACTICOS system) with a Sea Giraffe air/surface search radar, one RAM (11-cell) launcher integrated with the Close-In Weapons System (Mk 15) search and fire control radars (called SeaRAM), and Sea Star SAFIRE Electro-Optical/Infrared systems for 57 mm gun fire control.
- Multiple individual programs of record involving sensor and weapon systems and off-board vehicles make up the individual mission modules. Mission modules provide offensive capability.
  - SUW Mission Package:
    - Gun Mission Module (two Mk 46 30 mm guns) (Increment 1)
    - Aviation Module (embarked MH-60R and VTUAV) (Increment 1)
    - Maritime Security Module (small boats) (Increment 2)
    - Surface-to-Surface Missile system intended to provide limited "interim" SUW capability in response to an urgent operational need (Increment 3)
    - Longer range Surface-to-Surface Missile (Increment 4)
  - MCM Mission Package:
    - Remote Minehunting System (RMS), consisting of the Remote Multi-Mission Vehicle (RMMV) and the AQS-20A sonar system (Increment 1)
    - MH-60S Block 2A/B AMCM System, consisting of an AMCM system operator workstation, a tether system, and the two MCM systems currently under development – ALMDS for detection and classification of near-surface mines, and the Airborne Mine Neutralization System (AMNS) for identification and neutralization of in-volume and bottom mines (the AQS-20A sonar system and OASIS are no longer being developed for use in the AMCM System) (Increment 1)
    - AMNS Pre-Planned Product Improvement (P3I) Program for neutralization of near-surface mines and Coastal Battlefield Reconnaissance and Analysis Block I (COBRA Blk I) system for unmanned aerial tactical reconnaissance to detect and localize minelines and obstacles in the daylight in the beach zone and partially in the surf zone (Increment 2)
    - Unmanned Influence Sweep System (UISS) to activate acoustic-, magnetic-, and combined acoustic/magnetic-initiated volume and bottom mines in shallow water so they self-destruct (Increment 3)
    - COBRA Block II system, which has Block I capability with the addition of night-time minefield and obstacle detection capability and full detection capability in surf zone; and Knifefish Unmanned Undersea Vehicle, a self-propelled, untethered, autonomous underwater vehicle, employing a low-frequency broadband sonar sensor to detect, classify, and identify volume and bottom mines in shallow water (Increment 4)
  - ASW Mission Package:
    - Torpedo Defense and Countermeasures Module (Light Weight Tow torpedo countermeasure) (Increment 2)
    - ASW Escort Module (Multi-Function Towed Array and Variable Depth Sonar) (Increment 2)
    - Aviation Module (embarked MH-60R and two VTUAVs) (Increment 2)
- The Navy plans to acquire a total of 55 LCSs. In early FY11, the USD(AT&L) authorized the procurement of hulls 3 through 22 (10 of each ship design), subject to Congressional appropriations.

Mission

- The Maritime Component Commander will employ LCS to conduct MCM, ASW, or SUW tasks depending on the mission package fitted into the seaframe. With the Maritime Security Module, installed as part of the SUW mission package, the ship can conduct Visit, Board, Search, and Seizure maritime interception operations. Commanders can employ LCS in a maritime presence role in any configuration because of capabilities inherent to the seaframe.
- The Navy can employ LCS alone or in company with other ships. The Navy is still developing the concept of employment and operations for these ships in each of the mission areas.

Major Contractors

- *Freedom* Variant (LCS 1, 3, 5, 7, and follow-on ships)
  - Prime: Lockheed Martin Maritime Systems and Sensors – Washington, District of Columbia
  - Shipbuilder: Marinette Marine – Marinette, Wisconsin
- *Independence* Variant (LCS 2, 4, 6, 8, and follow-on ships)
  - Prime for LCS 2 and LCS 4: General Dynamics Corporation Marine Systems, Bath Iron Works – Bath, Maine
  - Prime for LCS 6, LCS 8, and follow-on ships: Austal USA – Mobile, Alabama
  - Shipbuilder: Austal USA – Mobile, Alabama
- Mission Packages
  - Future Mission Package Integration contract awarded to Northrop Grumman – Los Angeles, California

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Activity

Seaframe

- *Freedom* Variant (LCS 1):
  - The Navy completed the first phase of the Post-Shakedown Availability (PSA), which commenced in 3QFY11, on LCS 1. During sea trials following this event, the ship developed a shaft seal leak and subsequently reentered dry-dock for six weeks to repair.
  - The Navy's Board of Inspection and Survey (INSURV) graded LCS 1 as fit for service during special trials in May 2012 following the emergent dry-docking.
  - The Navy continued developmental testing of the 57 mm gun system on LCS 1.
  - The Navy's Commander, Operational Test and Evaluation Force (COTF) commenced a QRA on LCS 1 in support of FY13 early deployment. Part I (57 mm gun assessment) of the QRA began in 3QFY12. Part II (Information Assurance and Maritime Interdiction Operations assessments) will take place on LCS 1 during 1QFY13.
  - The Navy started the second PSA in July 2012 on LCS 1 in San Diego, California.
- *Independence* Variant (LCS 2):
  - The Navy commissioned LCS 2 in January 2010 and began MCM mission module developmental testing in Mobile, Alabama, after commissioning.
  - LCS 2 departed the east coast and arrived in San Diego, California, in May 2012.
  - The Navy commenced the first phase of the nine-month PSA in September 2012 in San Diego, California.
- *Freedom* Variant (LCS 3):
  - INSURV evaluated LCS 3 as satisfactory during acceptance trials in April 2012.
  - The Navy commissioned LCS 3 in Galveston, Texas, in September 2012.

SUW Module

- COTF tested the 30 mm gun on LCS 1 during the QRA in June and July 2012 in accordance with the DOT&E-approved data collection plan. The Navy continued developmental testing of the 30 mm gun system on LCS 1.

MCM Module

- The Navy conducted testing of the MH-60S Block 2 AMCM System, which is intended to support LCS MCM.
  - COTF completed testing of the MH-60S Block 2A AMCM System with the AQS-20A sonar system in 4QFY11 in accordance with the DOT&E-approved test plan. DOT&E issued an OA report in June 2012.
  - COTF commenced Phase A (Shore-based and Training Phase) of the planned OA of the MH-60S Block 2 AMCM System with the ALMDS in 2QFY12; testing completed in 4QFY12, and was conducted in accordance with the DOT&E-approved test plan. DOT&E expects to issue a formal test report in 2QFY13. The Navy postponed conduct of Phase B (LCS Ship-based Phase) of the planned OA due to the unavailability of an LCS seaframe to facilitate conduct of MCM mission module testing. The Navy intends to conduct the LCS ship-based phase of the planned ALMDS and AMNS OAs in conjunction with the LCS Technical Evaluation scheduled to occur in FY14.
- The RMS program completed reliability growth testing (developmental testing) of RMMV version 4.1 in 1QFY12.
- The Navy commenced a ship-based phase of MCM mission module developmental testing (DT-B2) in 1QFY12; testing completed in 4QFY12.

LFT&E

- The Navy revised the survivability requirements for LCS 3 and beyond to describe the ships' survivability requirements in terms of class-specific LCS Vulnerability Levels:
  - LCS Vulnerability Level I – Operate emergency and damage control systems/equipment to provide for an orderly abandon ship.
  - LCS Vulnerability Level II – All of the capabilities of LCS Vulnerability Level I, plus the capability for mobility to exit the immediate area, electrical power and other required services to operate vital systems, exterior communications to support contact with the operational commander, and small-to-medium caliber weapons or equivalent capability to prevent boarding from small craft.
  - LCS Vulnerability Level III – All of the capabilities of LCS Vulnerability Level II, plus retain some critical mission capability as defined in Conditions for Total Ship Survivability Analyses, Test, and Evaluation for Susceptibility and Vulnerability/Recoverability.
- DOT&E agreed to defer the TSST from LCS 1 and 2 to LCS 3 and 4. This delay affords the Navy enough time to complete the needed pre-trial damage scenario analyses. The TSST is currently scheduled to be conducted on LCS 3 in December 2013 and on LCS 4 in August 2014.
- DOT&E also agreed to defer the Shock Trials from LCS 3 and 4 to LCS 5 and 6, resulting in a one-year delay. With significant seaframe and system design changes expected, LCS 5 and 6 will be most representative of the respective class for purposes of Shock Trials. LCS 5 and 6 will also be the first ships to include shock-qualified equipment.
- DOT&E reviewed drafts of the Navy's Detail Design Integrated Survivability Assessment Reports for LCS 1 and 2. The Navy is working to address DOT&E's comments and finalize these reports.
- The Navy is planning surrogate tests to address knowledge gaps related to the vulnerability of an aluminum ship structure to weapon-induced blast and fire damage. These tests will be conducted during FY13 and FY14.
- DOT&E approved the 57 mm ammunition LFT&E Management Plan, which details the test and evaluation necessary to evaluate the lethality of the 57 mm ammunition. The Navy is coordinating with the Finnish Navy to use their operational equipment to conduct an effectiveness test exercise in September 2013.

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- DOT&E approved the 30 mm ammunition LFT&E Management Plan, which details the test and evaluation necessary to evaluate the lethality of the 30 mm ammunition.
- The Navy will submit the Surface-to-Surface Missile LFT&E Management Plan, which details the test and evaluation necessary to evaluate the lethality of the missile, for approval in FY13.
- Fire insulation testing was successfully conducted on a flight deck section of LCS 2 (referred to as grillage test) on the Ex-USS *Shadwell* in March 2012. The test article exceeded performance requirements for a fully intact insulated flight deck. Weapon-induced blast and fire damage will be addressed in surrogate testing planned for FY13 and FY14.

Assessment

This assessment is based on information from DOT&E's observations of selected events and operations. The program offices have issued limited developmental test results and have not been able to provide developmental test data for independent analysis. No formal at-sea operational tests were conducted.

Program

- The draft revision of the LCS TEMP currently being proposed by the Navy will require additional revisions to be approved by DOT&E. In particular, the TEMP must incorporate phased operational testing of all increments of mission module capability to be deployed for use in combat.

Seaframe

- *Freedom* Variant (LCS 1 and 3):
  - As reported in the FY11 Annual Report, the Navy discovered cracks in the hull and superstructure of LCS 1 that required interim repairs as well as design changes. The Navy made production changes to reduce cracking on LCS 3; cracking has not been observed to date.
- *Independence* Variant (LCS 2):
  - As noted in the FY11 Annual Report, the Navy completed interim repairs on LCS 2 because of aggressive galvanic corrosion in the vicinity of water jets. The Navy is installing a system to prevent corrosion on LCS 2 during the current PSA. An Impressed Current Cathodic Protection system is planned for the water jet tunnels on LCS 4.
  - The Navy continued to work through problems associated with the Twin Boom Extensible Crane on LCS 2. Limited testing to date precludes further assessment of this variant.
- Both variants:
  - Crew size can limit the mission capabilities of the ship. Core crew size provides little flexibility to support more than one operation at a time; unplanned manning losses and corrective maintenance further exacerbate the problem. The Navy is reviewing manning levels and installing 20 additional bunks in LCS 1 for flexibility during its deployment, but is not changing the final manning levels.
  - Ship operations at high speeds cause vibrations that make accurate use of the 57 mm gun very difficult. Insufficient operator training and proficiency also appear to have contributed to the poor performance of the 57 mm gun.

SUW Module

- Both variants:
  - The Navy has not finalized how the ships will be utilized with the SUW mission module. Additionally, the Navy has not completed the revised capabilities document defining the incremental approach to fielding mission modules.
  - The 30 mm guns and associated combat system exhibit reliability problems. The Navy established a Failure Review Board to identify and correct deficiencies in 30 mm gun performance.
- *Freedom* Variant: Performance deficiencies with COMBATSS-21 and TRS-3D affect tracking and engagement of contacts.

MCM Module

- Testing of the MH-60S Block 2 AMCM System revealed significant shortfalls in performance.
  - The MH-60S helicopter with the AQS-20A sonar is not operationally effective or suitable because the helicopter is underpowered and cannot safely tow the sonar under the variety of conditions necessary. The Navy cancelled the MH-60S helicopter mission to tow the AQS-20A and OASIS. The cancellation of the OASIS mission creates a gap in LCS organic mine sweeping capability that the Navy intends to address with the implementation of UISS in Increment 3 of the MCM mission module.
  - As observed during the OA and developmental testing, the AQS-20A does not meet some Navy requirements. Contact depth localization errors exceeded Navy limits in all AQS-20A operating modes. False contacts also exceeded Navy limits in two of three search modes. The Navy has implemented modified tactics intended to mitigate these deficiencies; however, those tactics limit platform-level productivity (Area Coverage Rate Sustained). Additionally, the Navy is developing a P3I program to correct these deficiencies.
  - The analysis of test data collected during Phase A of the OA of the MH-60S and ALMDS is still in progress. Preliminary evaluation of data collected during the OA suggests that the ALMDS does not meet Navy requirements for False Classification Density or reliability. DOT&E expects to issue a formal test report in 2QFY13. The Navy has implemented modified tactics intended to mitigate this deficiency; however, those tactics limit platform-level productivity (Area Coverage Rate Sustained). Additionally, the Navy is developing a P3I program to correct this deficiency. Phase B testing was originally intended to provide early operational testing insight into the operational effectiveness and suitability of AMCM systems when operating from an

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LCS, and to identify risk to the successful completion of IOT&E. However, the Navy's postponement of Phase B testing will eliminate these intended benefits.

- As reported by the Navy, the reliability of RMMV version 4.1 grew as predicted by the program's reliability growth curve. However, the observed growth is predicated on limited test data collected in a minimally stressing operational environment. The limited scope of testing prevents any meaningful conclusions about operational availability of the RMS.
- As observed and reported by the Navy, during developmental testing (DT-B2), launch and recovery of the RMS was problematic due to material deficiencies with launch and recovery systems, manpower and training deficiencies, and compatibility with the operating environment.

LFT&E

- LCS is not expected to be survivable in that it is not expected to maintain mission capability after taking a significant hit in a hostile combat environment. This assessment is based on a review of LCS design requirements, which do not require the inclusion of the survivability features necessary to conduct sustained operations in its expected combat environment. DOT&E's review of the Navy's draft Detail Design Integrated Survivability Assessment Reports has not changed this assessment.

Recommendations

- Status of Previous Recommendations. The Navy has partially addressed one FY09 recommendation to develop an LFT&E program with the approval of the LFT&E Management Plan; however, the recommendation will not be fully addressed until the details of the surrogate testing and the lethality testing are developed. The Navy has partially addressed the FY10 recommendations to implement all recommendations from DOT&E's Combined Operational and Live Fire Early Fielding Report. Significant remaining recommendations from the Early Fielding Report include enhancing sensors and improving capability of gun systems. With respect to FY11 recommendations, the Navy is adjusting tactics and increasing funding to address deficiencies with the AQS-20A and ALMDS. The FY11 recommendation for the Navy to continue to report vulnerabilities during live fire tests remains valid.
- FY12 Recommendations. The Navy should:
  1. Complete the revised capabilities document defining the incremental approach to fielding mission modules.
  2. Publish the concept of operations for all the mission modules.
  3. Complete manning level studies and finalize manning prior to LCS IOT&E.
  4. Correct gun reliability issues identified during QRA. These problems need to be addressed prior to completion of the LCS SUW Mission Package IOT&E.
  5. Conduct LCS ship-based phases of the planned OA of the MH-60S Block 2 and ALMDS as well as an OA of the MH-60S Block 2 and AMNS MCM systems in FY13 to reduce risk to the LCS MCM Mission Package IOT&E.
  6. Investigate and correct material deficiencies with mission module launch and recovery systems, and manpower and training deficiencies that prevent safe and effective shipboard launch and recovery of the RMS.

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LPD-17 *San Antonio* Class Amphibious Transport Dock

Executive Summary

- The Navy demonstrated the efficacy of LPD-17's collective protection system, its countermeasure wash-down system, and the crew's ability to decontaminate the ship's equipment, personnel, and spaces, and to conduct amphibious operations in chemical protective suits during FOT&E in February 2012.
- The Navy conducted FOT&E in August 2012 to examine the reliability of systems during the first five hours of an amphibious assault. Testing was not sufficient to demonstrate that the ship class satisfies its requirements.
- The Navy is working to correct deficiencies identified during IOT&E that led DOT&E to assess the ship not operationally effective, not operationally suitable, and not survivable in a hostile environment. However, correction of a number of these deficiencies has not yet been verified by follow-on operational testing.
- The Navy's Board of Inspection and Survey (INSURV) assessed the material condition of LPD-17, LPD-22, and LPD-23 as satisfactory.

System

- LPD-17 is a diesel engine-powered ship designed to embark, transport, and deploy ground troops and equipment. Ship-to-shore movement is provided by Landing Craft Air Cushion (LCAC), Landing Craft Utility (LCU), Amphibious Assault Vehicles (AAVs), MV-22 tiltrotor aircraft, and/or helicopters. Key ship features and systems include the following:
  - A floodable well deck for LCAC, LCU, and AAV operations
  - A flight deck and hangar to support Navy and Marine Corps aircraft and helicopters
  - Command, Control, Communications, Computers, and Intelligence facilities and equipment to support Marine Corps Landing Force operations
  - Self defense against anti-ship cruise missile capability provided by the Ship Self-Defense System (SSDS) Mk 2-based combat system, which includes the Cooperative Engagement Capability radar tracking system and data distribution system, the Rolling Airframe Missile point defense system, the SLQ-32B (V)2 (with Mk 53 Decoy Launching System with Nulka electronic decoys) passive electronic warfare system, and radars (SPQ-9B horizon search radar and SPS-48E long-range air search radar)



  - Two Mk 46 30 mm gun systems and smaller caliber weapons (e.g., Mk 2 .50-caliber machine guns) to provide the ship's self-defense against small surface threats
  - A Shipboard Wide Area Network that serves as the data backbone for most of the ship's computer systems (LPD-17 is one of the first ships built with a fully integrated data network system).
  - Design features that reduce the ship's radar cross section and are intended to make the ship less susceptible to attack

Mission

- A Fleet Commander will employ LPD-17 class ships as part of a notional, three-ship Amphibious Ready Group or independently to conduct Amphibious Warfare.
- The Commanding Officer will use these ships to:
  - Transport combat and support elements of a Marine Expeditionary Unit or Brigade
  - Embark, launch, and recover LCACs, LCUs, and AAVs for amphibious assault missions
  - Support aerial assaults by embarking, launching, and recovering Marine Corps aircraft
  - Carry and discharge cargo to sustain the landing force
  - Conduct non-combatant evacuation operations and other crisis response missions

Major Contractor

Huntington Ingalls Industries – Pascagoula, Mississippi

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Activity

- The Navy completed FOT&E designed to demonstrate capability to conduct operations in a chemical warfare environment (onboard LPD-21) in February 2012.
- The Navy conducted limited reliability FOT&E on ship systems during the first five hours of an amphibious assault (onboard LPD-20) in August 2012.
- The Navy's INSURV assessed the material condition of LPD-17, LPD-22, and LPD-23 as satisfactory during Acceptance Trials.
- The Navy, using the Probability of Raid Annihilation Test Bed Modeling and Simulation tool, commenced a modeling and simulation study to determine if upgrades and corrections to the ship's combat system improve the ship's capability to defeat raids of anti-ship cruise missiles.
- The Navy provided its final survivability assessment identifying 99 deficiencies to DOT&E in FY12 and commenced corrective actions. However, the Navy has not submitted the shock deficiency correction plan nor demonstrated the effectiveness of corrective actions taken to date.

Assessment

- The Navy demonstrated the efficacy of LPD-17's collective protection system, its countermeasure wash-down system, and its crew's ability to decontaminate the ship's equipment, personnel, and spaces, and to conduct amphibious operations in chemical protective suits during FOT&E.
- The Navy has made progress in improving reliability and availability of critical ship systems affecting communications and propulsion based on results from INSURV and limited reliability testing onboard LPD-20. However, reliability and availability of the ship's critical systems require further improvements to assure the ship is both operationally effective and survivable.
- Since IOT&E, the Navy has not conducted any operational testing to demonstrate improvements to LPD-17's capability to defend itself against the threats it is likely to encounter to permit a reassessment of that capability. However, operational testing on other SSDS Mk 2 platforms has revealed similar combat system deficiencies to those found during LPD-17's IOT&E, confirming these issues are not LPD-17 specific. DOT&E's classified report to Congress in November 2012 titled "Ship Self-Defense Operational Mission Capability Assessment Report," provides details. The Navy is conducting a study of Probability of Raid Annihilation against anti-ship cruise missiles and expects to provide their report in the spring of 2013.
- Although improvements have been made, the Navy has not yet demonstrated the fully effective Command, Control, Communications, Computers, and Intelligence capabilities needed to support LPD-17 when performing amphibious assault operations. The Joint Staff issued the Joint Interoperability Certification (with conditions) on October 26, 2012, but the Navy still needs to successfully test the Advanced Field Artillery Tactical Data System onboard LPD-17.

Recommendations

- Status of Previous Recommendations. The Navy has satisfied recommendations relating to interoperability testing with AV-8B aircraft; completion of chemical, biological, and radiological defense testing; review of past INSURV inspections; initiation of the Probability of Raid Annihilation modeling and simulation effort; and improving the performance of the SPS-48E in the Advanced Enclosed Mast Structure. The Navy should act on the remaining 10 recommendations, which are listed below.

  FY08

  1. Test fixes to critical systems including the Shipboard Wide Area Network and review the effect of ship's manning, training, and logistics support on the reliability and maintainability of ship systems.

  FY09

  2. Address and test fixes to reliability problems with amphibious support equipment and propulsion equipment during FOT&E.
  3. Continue to pursue mitigations to address integration problems with self defense in multiple warfare areas.
  4. Conduct FOT&E in order to demonstrate improvements to performance problems related to the Advanced Enclosed Mast Structure (verify installation of the shroud on the SPS-48E radar corrects performance problems).

  FY10

  5. Improve reliability of critical systems including gun systems, Magnetic Signature Control System, and effectiveness of SSDS Mk 2-based combat system.
  6. Measure Total Ship Operational Availability over an extended period after completing reliability improvements.

  FY11

  7. Correct remaining deficiencies from Shock Trial Reports.
  8. Complete FOT&E to test Information Assurance.
  9. Conduct FOT&E using the Advanced Mine Simulation System to determine vulnerability of LPD-17 to enemy mines.
  10. Incorporate outstanding test events as FOT&E into the LPD-17 Test and Evaluation Master Plan.

- FY12 Recommendations. The Navy should:
  1. Develop an FOT&E test plan for adequate, rigorous testing of the critical ship systems that must perform reliably to assure LPD-17 is operationally effective and survivable.
  2. Complete and disseminate the Probability of Raid Annihilation study.

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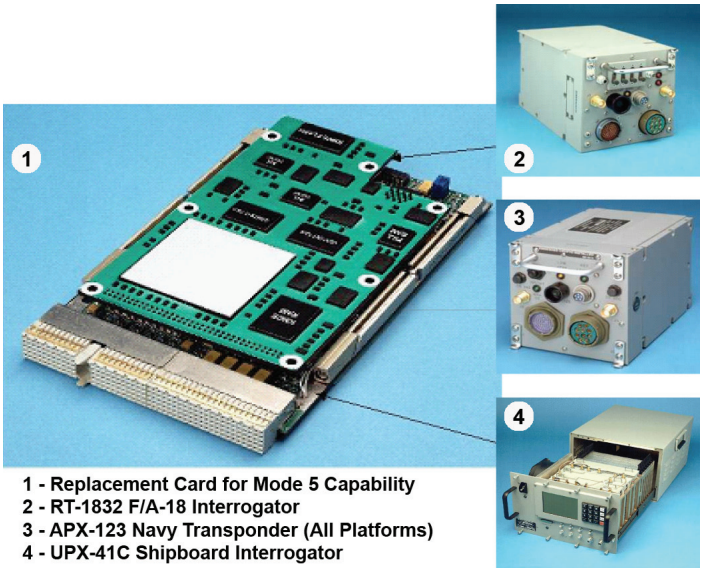
Mark XIIA Identification Friend or Foe (IFF) Mode 5

Executive Summary

- Independent Mark XIIA Mode 5 Identification Friend or Foe (IFF) (referred to as "Mode 5") programs exist in each U.S. Military Service as well as some NATO countries. Although not a joint program, the Services are developing equipment capable of employment on multiple Service platforms.
  - Of the four separate Service efforts, the Navy has the only established Acquisition Category II program, with incorporation of Service-specific Mode 5 capability through platform-specific Engineering Change Proposals (ECPs).
  - The Army and Marine Corps will leverage the Navy program and the Air Force will execute individual ECPs on their affected hardware.
- Although the Services are designing and building Mode 5 systems to comply with NATO and DoD IFF standards, DOT&E initiated oversight because of the concern that the multiple programs and vendors add risk to achieving joint interoperability.
- The Navy conducted an IOT&E of Mode 5 capability that included significant joint Service participation in FY12. However, the event was severely truncated due to adverse weather. Lack of adequate test data prevented DOT&E from fully assessing system effectiveness and suitability under realistic operational conditions. However, there were sufficient data to assess the performance of the individual components that comprise the Navy Mode 5 system. Those components met their performance thresholds and the Navy Acquisition Executive granted full-rate production authority to the program in July 2012.
- Following IOT&E, the Program Office released new software builds for both its transponder and interrogator systems to address those discrepancies highlighted during the operational test and subsequent reporting. Additional testing is required to assess the performance of these software fixes as well as the Mode 5 interoperating with both existing and planned IFF systems. The next opportunity to conduct that testing is now planned for the 3QFY13. Successful planning and execution of this event should resolve DOT&E concerns about joint interoperability and identification in a system-of-systems context.

System

- The Mark XIIA Mode 5 IFF is a cooperative identification system that uses interrogators and transponders located on host platforms to send, receive, and process friendly identification data.
- Mode 5 is a military-only identification mode, which modifies the existing Mark XII Mode 4 IFF (referred to as "Mode 4") system and addresses known shortcomings of the legacy Mode 4 identification mode. Mode 5 will eventually replace Mode 4 and allows National Security Agency-certified secure encryption of interrogations and replies. Primary system features include:
  - A lethal interrogation format, which is used by a "shooter" prior to weapons release as a final attempt to get a valid Mode 5 reply from the target, even with the target's interrogated Mode 5 transponder system in standby; this is intended to reduce fratricide
  - A random-reply-delay, which prevents overlapping replies and provides better display discrimination for closely spaced platforms
- Mode 5 offers more modern signal processing, compatibility with legacy Mode 4 systems and civilian air traffic control, and secure and encrypted data exchange through the use of the new waveform.
- Mode 5 serves as a component of the combat identification process used on ground-based systems such as the Army's Patriot missile system, sea-based systems such as Aegis-equipped ships, and military aircraft to include the E-3 Airborne Warning and Control System and E-2 Hawkeye command and control platforms.
- Independent Mode 5 programs exist in each U.S. Military Service as well as some NATO countries. Although not a joint program, the Services are developing equipment capable of employment on multiple Service platforms.
  - Of the four separate Service efforts, the Navy has the only established Acquisition Category II program, with incorporation of Service-specific Mode 5 capability through platform-specific ECPs.



1 - Replacement Card for Mode 5 Capability
2 - RT-1832 F/A-18 Interrogator
3 - APX-123 Navy Transponder (All Platforms)
4 - UPX-41C Shipboard Interrogator

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- The Army and Marine Corps will leverage the Navy program, and the Air Force will execute individual ECPs on its affected hardware.

Mission
The Combatant Commander employs the Mode 5 system to provide positive, secure, line-of-sight identification of friendly platforms equipped with an IFF transponder. In the future, this system's information will be combined with other cooperative and non-cooperative combat identification techniques in order to provide identification of all platforms – enemy, neutral, and friendly.

Major Contractor
BAE Systems – Arlington, Virginia

Activity
- Although the Services are designing and building Mode 5 systems to comply with NATO and DoD IFF standards, DOT&E initiated oversight because of the concern that the multiple programs and vendors add risk to achieving joint interoperability.
- The Navy executed IOT&E on their Mode 5 system for shipboard interrogators and transponders as well as aircraft transponders from October through November 2011. The Navy executed the test in accordance with the DOT&E-approved Test and Evaluation Master Plan (TEMP) and test plan; however, poor weather and technical test execution deficiencies truncated the amount of test data recorded. There were sufficient data to assess the performance of the Navy Mode 5 system-under-test; however there was insufficient data to provide a full assessment of the Mode 5 system-of-systems interoperability and suitability.
- DOT&E published its IOT&E report in July 2012, assessing the Navy's Mode 5 hardware/software as well as the overarching Mode 5 system-of-systems. The Navy Acquisition Executive approved full-rate production of the Navy Mode 5 system in July 2012 following the Navy Mode 5 IOT&E.
- The Army and Air Force are developing and testing Service-specific Mode 5 capabilities:
  - The Army developed a Mode 5 Air Defense Interrogator for the Patriot and Sentinel systems; it is currently in developmental testing.
  - The Air Force is developing a separate Mode 5 interrogator for the E-3 Airborne Warning and Control System.
  - The Air Force Operational Test and Evaluation Center tested the integration of an Air Force-developed Mode 5 interrogator and transponder on the F-15C/E aircraft in conjunction with the Navy IOT&E in November 2011.
- The Navy submitted, and DOT&E approved, a revised Test and Evaluation Master Plan that will ensure that Mode 5 is assessed in operationally realistic environments that include (in addition to Navy ship and aircraft platforms) a variety of Army, Air Force, and allied systems equipped with Mode 5 capability.
- USD(AT&L) and DOT&E worked with the Services to develop and approve a revised Joint Operational Test Approach (JOTA) (version 2.0) document to guide Mode 5 interoperability testing across the DoD.
  - Utilizing the approved JOTA guidance, the Navy is currently leading development of a test concept for the conduct of an operationally realistic test of Mode 5 capability in 2013.
  - This event will employ a variety of joint Service and allied aircraft equipped with interrogators and transponders using representative flight profiles. JOTA efforts are critical to informing the DoD-wide FY14 Mode 5 Initial Operational Capability and FY20 Full Operational Capability declarations.

Assessment
- During IOT&E, Mode 5 demonstrated significant improvement over the existing Mode 4. However, weather limited the scope of testing and prevented a complete operational assessment. Lack of adequate test data prevented DOT&E from fully assessing system effectiveness and suitability under operationally realistic conditions. However, there were sufficient data to assess the performance of the individual hardware components that comprise the Navy Mode 5 system. Those components met their individual performance requirements thresholds during the IOT&E.
- Although no hardware or software failures occurred during IOT&E, DOT&E observed substantial suitability deficiencies, including short battery life, easily triggered anti-tamper features, and difficulty loading cryptographic keys.
- The IOT&E highlighted interoperability concerns between Mode 5 and other systems onboard Navy ships. These include:
  - Shipboard integration problems of Navy Mode 5 equipment into the larger shipboard Aegis weapons system, which could cause incorrect engagement decisions with potentially severe consequences.
  - Problems with the accurate and timely flow of Mode 5-derived identification information between components of the Navy Cooperative Engagement Capability system.
- Following IOT&E, the Program Office released new software builds for both its transponder and interrogator systems to address those discrepancies highlighted during the operational test and subsequent reporting. Additional testing is required to assess the performance of these software fixes as well as the Mode 5 interoperating with both existing and planned IFF

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systems. The next opportunity to conduct that testing is now planned for the 3QFY13. Successful planning and execution of this event should resolve DOT&E concerns about joint interoperability and identification in a system-of-systems context.

Recommendations

- Status of Previous Recommendations. The Navy has adequately addressed all previous recommendations.
- FY12 Recommendations.
  1. In order to ensure interoperability between interrogators, transponders, and combined interrogator-transponders, the Service program managers must continue to integrate their test schedules. Additionally, all Services must fully participate in the JOTA evaluation process to ensure that Mode 5 capabilities are tested in a realistic joint Service environment.
  2. The Navy needs to address problems with the Mode 5 shipboard integration on the Aegis weapons system and the information flow between Mode 5 and the Cooperative Engagement Capability command and control infrastructure to ensure that the Mode 5 system capabilities are fully effective.

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MH-60R Multi-Mission Helicopter

Executive Summary

- DOT&E issued a combined FOT&E report (MH-60R and MH-60S) in April 2012 assessing the operational effectiveness and operational suitability of selected systems of the MH-60R Pre-Planned Product Improvement Program. The Ground Proximity Warning System (GPWS) and the Integrated Maintenance Diagnostic System (IMDS) are operationally effective and operationally suitable for all MH-60R missions. The overall assessment of the MH-60R airframe for all mission areas remains operationally effective, operationally suitable, and survivable.
- The Navy's Commander, Operational Test and Evaluation Force (COTF) commenced two tests in 4QFY12. Both tests are anticipated to complete in 1QFY13:
  - IOT&E of MH-60R equipped with the Automatic Radar Periscope Detection and Discrimination (ARPDD) Upgrade
  - Testing focused on previously identified Multi-spectral Targeting System (MTS) deficiencies
- The analyses of test data collected during IOT&E of MH-60R with ARPDD and testing of MH-60R with MTS are still in progress. DOT&E expects to issue formal test reports in 2QFY13.

System

- The MH-60R is a ship-based helicopter designed to operate from cruisers, destroyers, frigates, littoral combat ships, and aircraft carriers.
- It incorporates dipping sonar and sonobuoy acoustic sensors, multi-mode radar, electronic warfare sensors, a forward-looking infrared sensor with laser designator, and an advanced mission data processing system.



- It employs torpedoes, Hellfire air-to-surface missiles, and crew-served mounted machine guns.
- It has a three-man crew: two pilots and one sensor operator.

Mission

The Maritime Component Commander employs the MH-60R from ships or shore stations to accomplish the following:

- SUW, Under Sea Warfare, Area Surveillance, Combat Identification, and Naval Surface Fire Support missions previously provided by two different helicopters (SH-60B and SH-60F)
- Support missions such as Search and Rescue at-sea and, when outfitted with necessary armament, maritime force protection duties

Major Contractors

- Sikorsky Aircraft Corporation – Stratford, Connecticut
- Lockheed Martin Mission System and Sensors – Owego, New York

Activity

- DOT&E issued a combined FOT&E report (MH-60R and MH-60S) in April 2012 assessing the operational effectiveness and operational suitability of selected systems of the MH-60R Pre-Planned Product Improvement Program. The tested systems were the GPWS and the IMDS. COTF completed testing in 1QFY12. COTF conducted the testing in accordance with the DOT&E-approved test plan.
- COTF commenced IOT&E of MH-60R with the ARPDD Upgrade in 4QFY12. COTF conducted the testing in accordance with a DOT&E-approved test plan. Testing is anticipated to complete in 1QFY13.
- COTF commenced testing of previously identified deficiencies of the MH-60R with MTS in 4QFY12. Testing was conducted in accordance with a DOT&E-approved data management and analysis plan and is anticipated to complete in 1QFY13.
- All LFT&E activities have been completed and reported in the LFT&E report to Congress in 2008.

Assessment

- The GPWS and IMDS are assessed to be operationally effective and operationally suitable for all MH-60R missions. There were no significant operational effectiveness or operational suitability deficiencies identified during testing. The test results did not affect any prior findings on the overall operational effectiveness, operational suitability, or survivability of the MH-60R airframe in any mission area.

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- The analysis of test data collected during IOT&E of MH-60R with ARPDD is still in progress. DOT&E expects to issue a formal test report in 2QFY13.
- The analysis of test data collected during testing of MH-60R with MTS is still in progress. The scope of the testing was focused on previously identified MTS deficiencies. The testing was not designed to assess surface warfare mission capability of MH-60R when equipped with MTS and the Hellfire missile. DOT&E expects to issue a formal test report in 2QFY13.

Recommendations

- Status of Previous Recommendations. The Navy satisfactorily addressed the four previous recommendations.
- FY12 Recommendation.
  1. The Navy should plan to conduct FOT&E to assess MH-60R's surface warfare capability when equipped with MTS and the Hellfire missile.

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MH-60S Multi-Mission Combat Support Helicopter

Executive Summary

- The Navy's Commander, Operational Test and Evaluation Force (COTF) completed testing of selected systems of the MH-60S Pre-Planned Product Improvement (P3I) Program in 1QFY12. DOT&E issued a combined FOT&E report (MH-60R and MH-60S) in April 2012 assessing the operational effectiveness and operational suitability of these systems. The Active Vibration Control System (AVCS), Ground Proximity Warning System (GPWS), and Integrated Maintenance Diagnostic System (IMDS) are operationally effective and operationally suitable for all MH-60S missions. The overall assessment of the MH-60S airframe remains operationally effective, operationally suitable, and survivable for all mission areas.
- COTF completed testing of the MH-60S Block 2 Airborne Mine Countermeasures (AMCM) System in 4QFY11. DOT&E issued an operational assessment (OA) report in June 2012 assessing operational effectiveness and operational suitability of the minehunting capability meant to be provided by the AMCM System and the AN/AQS-20A Sonar Mine Detecting Set (AQS-20A).
  - The MH-60S helicopter with the AQS-20A sonar is not operationally effective or suitable because the helicopter is underpowered and cannot safely tow the sonar under the wide variety of conditions necessary.
  - As observed during the OA and developmental testing, the AQS-20A does not meet some Navy requirements.
- COTF completed two test events in 4QFY12. The analysis of test data collected during these events is still in progress.
  - Phase A (Shore-based and Training Phase) of the planned OA of the MH-60S Block 2 AMCM System and the Airborne Laser Mine Detection System (ALMDS), commenced in 2QFY12. Preliminary evaluation of data collected during the OA suggests that the ALMDS does not meet Navy requirements for False Classification Density (FCD) and has low reliability. DOT&E expects to issue a formal test report in 1QFY13.
  - The Quick Reaction Assessment (QRA) of MH-60S with the 20 mm Gun System (Forward Fixed Firing Weapon) commenced in 3QFY12. Preliminary evaluation of data collected during the QRA suggests that the 20 mm Gun System may provide enhanced Surface Warfare performance to the MH-60S helicopter. DOT&E expects to issue a formal test report in 1QFY13.
- COTF commenced testing focused on previously identified Multi-spectral Targeting System (MTS) deficiencies in 4QFY12; testing is anticipated to complete in late 1QFY13. The analysis of test data collected during testing of MH-60S with MTS is still in progress. DOT&E expects to issue a formal test report in 2QFY13.



System

- The MH-60S is a helicopter modified into three variants (Blocks) from the Army UH-60L Blackhawk. It is optimized for operation in the shipboard/maritime environment.
- The Blocks share common cockpit avionics and flight instrumentation with the MH-60R.
- Installed systems differ by Block based on mission:
  - Block 1, Fleet Logistics – precision navigation and communications, maximum cargo or passenger capacity
  - Block 2A/B, AMCM System – AMCM system operator workstation, a tether/towing system, and the two MCM systems currently under development; ALMDS for detection and classification of near-surface mines and the Airborne Mine Neutralization System (AMNS) for neutralization of in-volume and bottom mines. The AQS-20A sonar system and Organic Airborne and Surface Influence Sweep are no longer being developed for use in the AMCM System
  - Block 3A, Armed Helicopter – tactical moving map display, forward-looking infrared with laser designator, crew-served side machine guns, dual-sided Hellfire air-to-surface missiles, and defensive electronic countermeasures
  - Block 3B, Armed Helicopter – Block 3A with addition of tactical datalink (Link 16)
- P3I components add Link 16 and various communication, navigation, and command and control upgrades.

Mission

The Maritime Component Commander can employ variants of MH-60S from ships or shore stations to accomplish the following missions:

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- Block 1 – Vertical replenishment, internal cargo and personnel transport, medical evacuation, Search and Rescue, and Aircraft Carrier Plane Guard
- Block 2 – Detection, classification, identification and/or neutralization of sea mines depending on which AMCM systems are employed on the aircraft
- Block 3 – Combat Search and Rescue, Surface Warfare, Aircraft Carrier Plane Guard, Maritime Interdiction Operations, and Special Warfare Support

Major Contractors
- Sikorsky Aircraft Corporation – Stratford, Connecticut
- Lockheed Martin Mission System and Sensors – Owego, New York
- Raytheon Company, Integrated Defense Systems – Tewksbury, Massachusetts
- Northrop Grumman Corporation – Melbourne, Florida

Activity
- COTF completed testing of the AVCS, GPWS, and IMDS improvements in 1QFY12. DOT&E issued a combined FOT&E report (MH-60R and MH-60S) in April 2012 assessing the operational effectiveness and operational suitability of these systems.
- COTF completed testing of the MH-60S Block 2A AMCM System and the AQS-20A in 4QFY11. DOT&E issued an OA report in June 2012 assessing operational effectiveness and operational suitability of the minehunting capability.
- COTF commenced Phase A (Shore-based and Training Phase) of the planned OA of the MH-60S Block 2 AMCM System and the ALMDS in 2QFY12; testing completed in 4QFY12. The Navy postponed conduct of Phase B (Littoral Combat Ship (LCS) Ship-based Phase) of the planned OA due to the unavailability of an LCS seaframe to facilitate conduct of MCM mission module testing. The Navy intends to conduct the LCS ship-based phase of the planned ALMDS and AMNS OAs in conjunction with the LCS Technical Evaluation scheduled to occur in FY14.
- COTF conducted all testing in accordance with the DOT&E-approved test plan.
- COTF commenced a QRA of MH-60S with the 20 mm Gun System (Forward Fixed Firing Weapon) in 3QFY12; testing completed in 4QFY12. COTF conducted the assessment in accordance with the DOT&E-approved data management and analysis plan.
- COTF commenced testing of previously identified deficiencies of the MH-60S with MTS in 4QFY12. COTF conducted the testing in accordance with a DOT&E-approved data management and analysis plan. Testing is anticipated to complete in 1QFY13.
- All LFT&E activities have been completed and reported in the LFT&E report to Congress in 2008.

Assessment
- The AVCS, GPWS, and IMDS are assessed to be operationally effective and operationally suitable for all MH-60S missions. There were no significant operational effectiveness deficiencies identified during testing. The test results did not affect any prior findings on the overall operational effectiveness, operational suitability, or survivability of the MH-60S airframe in any mission area.
- The MH-60S helicopter and AQS-20A sonar are not operationally effective or suitable because the helicopter is underpowered and cannot safely tow the sonar under the variety of conditions necessary. The Chief of Naval Operations recently concluded that the MH-60S helicopter is significantly underpowered for the safe performance of the AMCM tow mission and provides limited tactical utility relative to the risk to aircrew, and cancelled that MH-60S mission. The decision to cancel the AMCM tow mission affects employment of both the AQS-20A sonar and Organic Airborne and Surface Influence Sweep.
- As observed during the OA and developmental testing, the AQS-20A does not meet all Navy requirements in all operating modes. Contact depth (vertical localization) errors exceeded Navy limits in all AQS-20A operating modes. FCD also exceeded Navy limits in two of three search modes.
- The analysis of test data collected during Phase A of the OA of the MH-60S and ALMDS is still in progress. Preliminary evaluation of data collected during the OA suggests that the ALMDS does not meet Navy requirements for FCD or reliability. DOT&E expects to issue a formal test report in 2QFY13. Phase B testing was originally intended to provide early operational testing insight into the operational effectiveness and suitability of AMCM systems when operating from an LCS, and to identify risk to the successful completion of IOT&E. However, the Navy's cancellation of Phase B testing will eliminate these intended benefits.
- The analysis of test data collected during the QRA of MH-60S with the 20 mm Gun System (Forward Fixed Firing Weapon) is still in progress. Preliminary evaluation of data collected during the QRA suggests that the 20 mm Gun System may provide enhanced Surface Warfare performance to the MH-60S helicopter. DOT&E expects to issue a formal test report in 1QFY13.
- The analysis of test data collected during testing of MH-60S with MTS is still in progress. The scope of the testing was focused on previously identified MTS deficiencies. The testing was not designed to assess Surface Warfare mission capability of MH-60S when equipped with MTS and the Hellfire missile. DOT&E expects to issue a formal test report in 2QFY13.

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Recommendations

- Status of Previous Recommendations. The Navy satisfactorily addressed 8 of the 11 previous recommendations. The Navy should still:
  1. Investigate solutions and correct AN/AQS-20A FCD and Vertical Localization deficiencies prior to IOT&E.
  2. Investigate solutions and correct the ALMDS FCD deficiency prior to IOT&E.
  3. Conduct LCS ship-based phases of the planned OA of the MH-60S Block 2 and ALMDS as well as an OA of the MH-60S Block 2 and AMNS MCM systems in FY13 to reduce risk to the LCS MCM Mission Package IOT&E.
- FY12 Recommendation.
  1. The Navy should plan to conduct FOT&E to assess MH-60S's surface warfare capability when equipped with MTS and the Hellfire missile.

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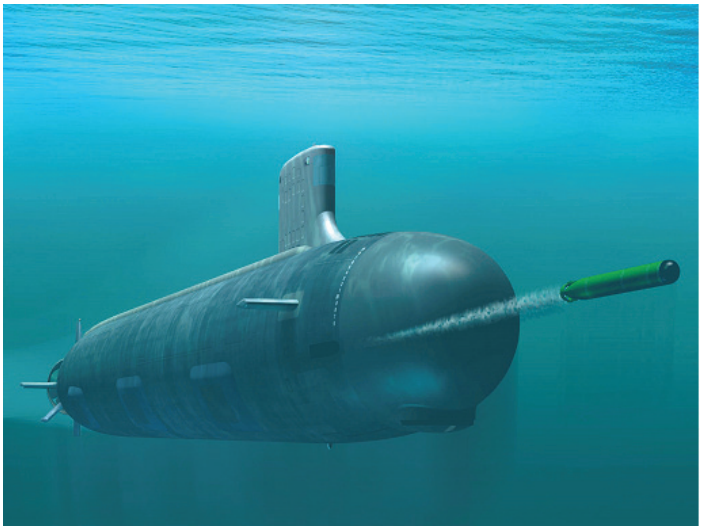
Mk 48 Advanced Capability (ADCAP) Torpedo Modifications

Executive Summary

- In FY12, the Navy continued operational testing of the Advanced Processor Build (APB) Spiral 4 operational software for the Mk 48 Advanced Capability (ADCAP) Modification (Mod) 7 Common Broadband Advanced Sonar System (CBASS) torpedo and Mk 48 ADCAP Mod 6 Advanced Common Torpedo (ACOT). OT&E, which began in FY11, is expected to continue into early FY13.
- Since the commencement of operational testing in FY11, the Navy has fired approximately 330 torpedoes equipped with Spiral 4 tactical software for training and testing at both surface and submerged targets in a variety of different environmental and tactical scenarios. These scenarios have included targets deploying multiple static countermeasures, targets deploying the mobile countermeasure, and targets designed to emulate the threat identified in the Navy's Urgent Operational Needs Statement (UONS) of March 19, 2010.
- Because the Navy did not complete developmental testing before early fielding and before commencing operational testing of the Mk 48 Spiral 4 torpedo, operational testers, the Navy's laboratories, and fleet users identified several performance deficiencies during operational testing. The Navy interrupted the operational testing and issued new Mk 48 Spiral 4 torpedo operational software with the intention of fixing identified deficiencies.

System

- The Mk 48 ADCAP torpedo is the only Anti-Submarine Warfare and Anti-Surface Ship Warfare weapon used by U.S. submarines. Mk 48 ADCAP torpedo modifications are a series of hardware and software upgrades to the weapon.
- Mk 48 Mod 6, Mod 6 Spiral 1, Mod 6 ACOT – Guidance and Control Box, and Mod 7 CBASS Phase I are fielded torpedoes.
- Mk 48 Mod 7 CBASS upgrades the Mk 48 ACOT with a new sonar designed to improve torpedo effectiveness through future software upgrades. Phase 1 torpedoes deliver the initial hardware and software; Phase 2 torpedoes are required to deliver full capability.



- The software developed for CBASS Phase 2 is designated APB Spiral 4. The Navy subsequently determined that Spiral 4 software can run on ACOT weapons as well. As a result, the Navy is testing Spiral 4 on both CBASS and ACOT weapons. The Navy has authorized the limited fielding of Mk 48 Spiral 4 torpedoes.
- CBASS is a co-development program with the Royal Australian Navy.

Mission

The Submarine Force employs the Mk 48 ADCAP torpedo as a long-range, heavy-weight weapon:

- For destroying surface ships or submarines
- In both deep-water open ocean and shallow-water littoral environments

Major Contractor

Lockheed Martin Sippican Inc. – Marion, Massachusetts

Activity

- In FY12, the Navy continued operational testing of the APB Spiral 4 operational software for the Mk 48 ADCAP Mod 7 (CBASS) torpedo and Mk 48 ADCAP Mod 6 (ACOT). OT&E, which began in FY11, is expected to continue into early FY13.
- Since the commencement of operational testing in FY11, the Navy has fired approximately 330 torpedoes equipped with Spiral 4 tactical software for training and testing at both surface and submerged targets in a variety of different environmental and tactical scenarios. These scenarios have included targets deploying multiple static countermeasures, targets deploying the mobile countermeasure, and targets designed to emulate the threat identified in the Navy's UONS of March 19, 2010.

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- Relevant prior activity includes:
  - The Navy's Commander, Operational Test and Evaluation Force (COTF) observed and analyzed the results of the in-water Mk 48 Spiral 4 exercises and developmental testing from January to February 2011. COTF also conducted modeling and simulation assessments using the Weapons Analysis Facility (WAF) located at the Naval Undersea Warfare Center, Newport, Rhode Island, to examine Mk 48 Spiral 4 performance in baseline warfare scenarios.
  - The Navy released the Mk 48 Spiral 4 torpedo for limited operational use in March 2011.
  - DOT&E delivered an Early Fielding report to Congressional defense committees in March 2011.
  - The Navy has shifted to a Technical Insertion (TI) and APB model for torpedo development. The Navy intends the hardware modernizations (TIs) to address component obsolescence and to enable future capability. The Navy intends the new operational software (APBs) to use the new TI hardware and to improve the torpedo's capability.
- The Navy updated the Joint Test and Evaluation Master Plan to cover the Spiral 4 with Mk 48 ADCAP CBASS and Mk 48 ADCAP ACOT, and to address the UONS threat. DOT&E approved the updated Test and Evaluation Master Plan on January 13, 2012.
- The Navy completed development of a Submarine-Launched Countermeasure Emulator (SLACE) to support Mk 48 Spiral 4 testing. The SLACE emulator enables the Navy to conduct more realistic torpedo operational testing against threat submarine surrogates that can employ mobile countermeasures. The Navy also developed a Steel Diesel Electric Submarine surrogate to evaluate torpedo performance against submarine threats in limited operational scenarios.
- DOT&E approved the OT&E initial test plan for Mk 48 Spiral 4 on July 14, 2011, to support the initial operational test events. Because the Navy was unable to identify future test locations and test resources, and provide the execution details of the operational scenarios, DOT&E required the Navy to update the test plan once the follow-on testing was planned and before conducting the remainder of the operational testing. DOT&E approved updated test plans on June 15, 2012, and August 24, 2012. DOT&E also required the Navy to submit a final update to the test plan once the details of the remainder of the Mk 48 Spiral 4 testing were known.
- The Navy conducted the first phase of Spiral 4 operational testing in conjunction with FOT&E on the *Virginia* class submarine in March 2011 off Maui and at the Pacific Missile Range Facility off Kauai, Hawaii. Submarines fired 17 Spiral 4 weapons with software versions 3x.4.3 and 3x.4.4.
- In June 2011, the Navy conducted 10 firings, with Spiral 4 software version 3x.4.4, off southern California.
- In September 2011, the Navy conducted 10 additional Mk 48 Spiral 4 torpedo developmental test events using the Steel Diesel Electric Submarine target surrogate at a shallow-water site off the Virginia coast. The purpose was to gain additional torpedo performance information against the UONS threat.
- In December 2011, the Navy issued Mk 48 Spiral 4 torpedo software version 3x.4.6 to correct problems identified in the completed testing and by fleet operators. In order to avoid the costly repetition of all completed operational testing, the Navy's testers evaluated the effects of these changes on the torpedo's performance. Test events where performance would likely be affected by the new software change were invalidated from the operational test database and retesting was incorporated into future test periods.
- The Navy conducted 13 firings with the new Spiral 4 software, version 3x.4.6, in June 2012 in the Narragansett Bay Operating Area. This test was held in conjunction with a Tactical Development Exercise that featured another 12 torpedo firings.
- In September 2012, the Navy conducted 11 Spiral 4 shots with software version 3x.4.6 at two sites off Maui, Hawaii. An Australian *Collins* class diesel submarine served as the target and four of the runs featured the SLACE mobile countermeasure emulator.
- During FY12, the Navy employed Spiral 4 weapons during four Submarine Command Course exercises at the Atlantic Undersea Test and Evaluation Center and the Pacific Missile Range Facility. To conserve test resources, DOT&E agreed to utilize these torpedo events as regression testing to evaluate the performance of the Mk 48 Spiral 4 in some deep-water scenarios.
- In October 2012, the Navy conducted an additional three Spiral 4 shots with software version 3x.4.6 off Cape Cod, Massachusetts.
- The Navy accredited the WAF, located at the Navy Undersea Warfare Center, in August 2012 to compare the performance of the two hardware versions of the Mk 48 torpedo that use the Spiral 4 software.
- The Navy conducted two Mk 48 Sink Exercise (SINKEX) events in FY12, using war-shot torpedoes. Both SINKEXs were executed by allied submarine forces. A Canadian submarine fired an Mk 48 Mod 4M (Mk 48 version sold to allies), while an Australian submarine fired a Mk 48 Mod 7. These test events confirmed the warhead performance of in-service and stored Mk 48 torpedoes.

Assessment

- The Navy's Quick Reaction Assessment and WAF testing of the Mk 48 Spiral 4 torpedo enabled a limited assessment of its performance. DOT&E's report on the early fielding assessed that testing indicated the Mk 48 Spiral 4 has a limited capability, under certain operational conditions, against the threat identified in the UONS; however, the Navy did not have adequate threat surrogates for the evaluation. DOT&E's assessment also reported that the Spiral 4 torpedo did not demonstrate expected improvements over the legacy torpedo, and may degrade current capability in certain warfare scenarios.
- Additional information on Mk 48 Spiral 4 performance can be found in DOT&E's classified Mk 48 ACOT and CBASS Spiral 4 Early Fielding Report dated March 18, 2011.

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- During operational testing, the Navy's testers and laboratories discovered several torpedo deficiencies not identified during developmental testing that resulted in the Navy developing software corrections intended to fix the identified deficiencies. The Navy used the WAF for assessing the software changes, issued a new software version, and continued with the operational testing. As the WAF consistently overestimates performance and was not accredited for evaluating torpedo effectiveness or for operational testing of the Mk 48 Spiral 4, DOT&E assesses this development approach as high risk for adequately predicting satisfactory torpedo in-water performance.
- The Navy and DOT&E are assessing the completed Mk 48 Spiral 4 test events for operational realism and validity incrementally as the fleet training and test events are completed. Most fleet training events have been too structured or lacked the necessary post firing operational conditions to meet required torpedo test conditions. Navy testers are working with fleet trainers to improve the post torpedo firing operational realism.
- Due to delays in completing the development of the SLACE mobile countermeasure surrogate and the Navy's focus on the UONS threat, the Navy did not conduct adequate developmental testing against SLACE-like countermeasures. DOT&E assessed that Mk 48 Spiral 4 performance against SLACE-like threats is high risk because the Program Office completed little in-water developmental testing. Assessment of the Mk 48 Spiral 4 operational testing with SLACE, conducted in September 2012, is in progress.
- Due to the shortage of available test submarine shooters and targets, the Navy continues to have difficulty scheduling and planning adequate torpedo operational test events. Thus, Navy testers have been unable to provide the execution details for completing operationally realistic events for all required Mk 48 Spiral 4 test events. As a result, DOT&E has required the Navy to submit updates to the test plan once the event details are known and approved the testing event by event.
- Initial regression and operational testing results indicate Mk 48 performance in deep-water and shallow-water areas has not substantially changed; however, insufficient testing has been completed to allow a statistically significant assessment.

Recommendations

- Status of Previous Recommendations. The Navy has addressed six of the nine previous Annual Report recommendations. The three outstanding recommendations are as follows:
  1. While some improvements have been made by conducting regression testing in conjunction with scheduled fleet training events and by using WAF simulations, the Navy should continue to address reducing in-water test delays and improve the WAF simulations.
  2. As the Navy continues to conduct only limited torpedo training and testing in shallow waters, they should develop shallow-water test and training areas and modernize the exercise torpedo locating and recovery systems.
  3. The Navy should complete development of threat representative target and countermeasure surrogates for torpedo testing. In addition to representing the physical and signature characteristics of the threat, the surrogate should be capable of emulating appropriate operational profiles of the threat.
- FY12 Recommendations. The Navy should:
  1. Plan and conduct adequate developmental testing before starting operational testing.
  2. Continue conducting the Mk 48 Spiral 4 torpedo testing in FY13. Testing should include the evaluation of torpedo performance against submarine surrogates for the small diesel-electric threat.

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Mk 54 Lightweight Torpedo

Executive Summary

- In August to September 2011, the Navy fired 22 Mk 54 Block Upgrade (BUG) torpedoes against a Steel Diesel Electric Submarine surrogate target and against U.S. attack submarine targets in order to address the March 2010 Navy Fifth Fleet Urgent Operational Need Statement (UONS). Based on the results of this test, the Navy revised the Mk 54 BUG tactical software, conducted an additional phase of in-water developmental testing in November 2011, and completed a limited release of the weapon to the fleet.
- DOT&E issued an Early Fielding report on January 12, 2012. DOT&E reported that based on completed testing, crews employing the Mk 54 have a limited capability against the UONS threat under favorable targeting and environmental conditions. DOT&E also reported that the Navy's testing was completed under best-case scenarios, and the Navy did not have an adequate threat surrogate for the UONS threat. For additional details, see DOT&E's classified report.
- The Navy did not complete adequate in-water or modeling and simulation developmental testing of the Mk 54 BUG as planned. As the Program Office shifted resources to demonstrate that the Mk 54 BUG has a capability against the UONS emerging submarine threat, testing focused on the UONS threat scenarios vice the operational scenarios for which the Mk 54 BUG was originally intended.
- The Navy began operational testing on the Mk 54 with BUG software in March 2012.

System

- The Mk 54 Lightweight Torpedo is the primary Anti-Submarine Warfare weapon used by U.S. surface ships, fixed-wing aircraft, and helicopters.
- The Mk 54 combines the advanced sonar transceiver of the Mk 50 torpedo with the legacy warhead and propulsion system of the older Mk 46. The Mk 46 and Mk 50 torpedoes can be converted to an Mk 54 via an upgrade kit.
- The Mk 54 sonar processing is an expandable, open-architecture system. It combines algorithms from the Mk 50 and Mk 48 torpedo programs with the latest commercial off-the-shelf technology.
- The Navy designed the Mk 54 sonar processing to operate in shallow-water environments and in the presence of sonar countermeasures.



- The Navy has designated the Mk 54 torpedo to replace the Mk 46 torpedo as the payload section for the Vertical Launched Anti-Submarine Rocket for rapid employment by surface ships.
- The High-Altitude Anti-Submarine Warfare Weapons Capability program will provide an adapter kit to permit long-range, high-altitude, GPS-guided deployment of the Mk 54 by a P-8A Maritime Patrol Aircraft.
- The Mk 54 BUG is a software upgrade to the Mk 54 baseline torpedo designed to correct deficiencies identified during the 2004 Mk 54 IOT&E.
- The Navy is planning a series of near-term improvements to the Mk 54, including an improved sonar array and block upgrades to the tactical software.

Mission

Navy surface ships and aircraft employ the Mk 54 torpedo as their primary anti-submarine weapon:

- For offensive purposes, when deployed by Anti-Submarine Warfare aircraft and helicopters
- For defensive purposes, when deployed by surface ships
- In both deep-water open ocean and shallow-water littoral environments
- Against fast, deep-diving nuclear submarines; and slow moving, quiet, diesel-electric submarines

Major Contractor

Raytheon Integrated Defense Systems – Tewksbury, Massachusetts

Activity

- The Navy started operational testing of the Mk 54 BUG torpedo in FY12. The operational testing is being conducted with the same version of the torpedo's tactical software that the Navy early fielded in January 2012 to address the Fifth Fleet UONS threat. Relevant prior activity includes:

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  - The Navy developed a Steel Diesel Electric Submarine surrogate to evaluate torpedo performance against stationary submarine threats in limited operational scenarios. The Navy also developed a Submarine-Launched Countermeasure Emulator to support torpedo testing. The emulator enables the Navy to conduct realistic torpedo operational testing against threat submarine surrogates that can employ mobile countermeasures.
  - In August to September 2011, the fleet fired 22 Mk 54 BUG torpedoes with software version 42.B.1 against a Steel Diesel Electric Submarine surrogate target and against U.S. attack submarine targets. Based on the results of this test, the Navy issued Mk 54 BUG software version 42.B.2 to correct some identified performance problems, conducted an additional phase of in-water testing in November 2011, and fielded the Mk 54 early for limited use in January 2012.
- DOT&E issued a classified Early Fielding report on January 12, 2012. DOT&E reported that based on completed testing, crews employing the Mk 54 have a limited capability against the UONS threat under favorable targeting and environmental conditions. DOT&E also reported that the Navy's testing was completed under best-case scenarios, and the Navy did not have an adequate threat surrogate for the UONS threat. For additional details, see DOT&E's classified report.
- During FY11 and FY12, the Navy updated the Mk 54 BUG Test and Evaluation Master Plan (TEMP) to address both the new testing required for the UONS threat and the planned correction of major deficiencies identified during the 2004 IOT&E. DOT&E approved the Mk 54 BUG TEMP in December 2012.
- DOT&E approved the Navy's Operational Test Plan on February 24, 2012, to cover the first phase of operational testing. Because Navy testers could not identify the test execution details of all planned future test events, DOT&E approved the test plan for the first event and required it to be updated when the execution details could be defined for the future test events. DOT&E approved an update to the test events on July 31, 2012, and expects a final test plan update to cover the remainder of the operational testing in early FY13. The Navy conducted the first phase of BUG operational testing, designated OT-B1A, off the coast of southern California in March 2012. Three weapons were fired by an *Arleigh Burke* class destroyer and five were dropped by MH-60R helicopters. Another five weapons were intended to be dropped by P-3C aircraft, but those events were cancelled due to aircraft material problems. After the testing, the Navy declared the MH-60R runs invalid due to testing irregularities.
- The Navy conducted the second phase of BUG operational testing off Cape Cod, Massachusetts, in August 2012. The P-8A aircraft delivered eight weapons; MH-60R helicopters dropped another six weapons. Three more planned torpedo runs were not completed.
- The Navy conducted the third scheduled phase of BUG operational testing off Maui, Hawaii, in September 2012. P-8A aircraft delivered eight weapons and SH-60B helicopters dropped four weapons. An additional two runs were not completed.
- The Navy is planning an additional test event to complete the remaining Mk 54 BUG testing in 3QFY13.
- As a result of concerns about warhead performance and changes to the warhead exploder, DOT&E placed the Mk 54 on live fire oversight in 2010. The Navy had completed the Mk 54 BUG exploder modification and testing; therefore, DOT&E agreed to the Navy's proposal to develop a LFT&E plan starting with the Mk 54 Mod 1 version of the torpedo. The Mk 54 Program Office met with DOT&E in July 2012, and held an LFT&E meeting in August 2012 to develop an adequate lethality program for the Mk 54 Mod 1 torpedo. DOT&E is working with the Navy to establish a strategy for LFT&E to support the FY13 Mk 54 Milestone B.
- The Navy plans to continue the Mk 54 program with the Mk 54 Mod 1 torpedo and plans to approve a new set of requirements documents in FY13.
- In September 2012, the Navy conducted the first Mk 54 Service Weapons Test in an attempt to assess the performance of the warhead. The result of the event is under evaluation.

Assessment

- The Navy originally planned the Mk 54 BUG software to improve Mk 54 classifier and tracker performance and to resolve IOT&E Mk 54 deficiencies. The UONS emerging threat provided the incentive for the Navy to accelerate the development and fielding of the Mk 54 BUG software.
- The operational profile of the UONS emerging threat and the resulting changes to the torpedo's final homing software and exploder requires further testing to confirm Mk 54 performance, to include additional target operational scenarios, additional submarine target types, and the assessment of the torpedo's final terminal homing and impact of the target (set-to-hit).
- Since safety concerns prevent using manned submarines for set-to-hit testing, the Navy developed an unmanned Steel Diesel Electric Submarine target. The Navy is using this surrogate for both set-to-hit and set-not-to-hit testing. The Steel Diesel Electric Submarine target has different signature characteristics than the UONS emerging threat, thus this surrogate is of limited utility in assessing torpedo operational performance for the UONS. However, completing set-to-hit terminal homing testing may address some unresolved test scenarios identified in the IOT&E. Mk 54 BUG performance in these previously unresolved test areas will affect the overall effectiveness and suitability of the torpedo against other submarine threats.
- The Navy did not complete adequate in-water developmental testing of the Mk 54 BUG. As the Program Office shifted resources to demonstrate that the Mk 54 BUG has a capability against the UONS emerging submarine threat, testing focused

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on the UONS threat scenarios vice the operational scenarios for which the Mk 54 BUG was originally intended.
- To date, the Navy's emerging threat test scenario execution was structured so that attacking crews had near perfect knowledge of the target's location. In addition, the Navy conducted UONS testing in a relatively benign area that minimized torpedo interactions with the bottom or false contacts. Testing in these structured scenarios indicates the Mk 54 BUG likely has a limited capability against the Steel Diesel Electric Submarine surrogate target. The Mk 54 BUG performance in other environmental areas and against some operationally realistic target scenarios is being tested in FY12/13.
- The Navy is using a 1995 Operational Requirements Document, supplemented with sponsor clarification letters, as the reference to develop improvements and to test the Mk 54 torpedo upgrades. These documents are out of date and do not reflect the current threats, the current threat capabilities, or the current or desired torpedo performance.
- The operational realism of the Mk 54 BUG testing from fleet platforms suffers from significant test and safety limitations intended to prevent the Mk 54 from hitting the manned submarine target when it is dropped from an aircraft and due to time constraints for completing the testing. The time constraints associated with Mk 54 exercise torpedo employment and recovery often do not allow sufficient time for fully operationally realistic events.

Recommendations
- Status of Previous Recommendations. Two previous recommendations remain outstanding.
  1. The unresolved IOT&E of the Mk 54 terminal homing is superseded by changes to the Mk 54 BUG software; however, the updated terminal homing software will require a set-to-hit testing evaluation to resolve torpedo effectiveness.
  2. The Navy should continue to develop a lethality strategy that includes the firing of the Mk 54 against appropriate targets.
- FY12 Recommendations. The Navy should:
  1. Complete Mk 54 BUG OT&E in 2013. The testing should include scenarios against representative surrogates employing current threats, tactics, and torpedo countermeasures.
  2. Obtain an operationally realistic mobile set-to-hit target and complete the terminal homing testing of the Mk 54 torpedo.
  3. Investigate alternatives, such as the use of a portable range, to minimize or eliminate the test and safety limitations that minimize operational realism in Mk 54 testing.

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Mobile User Objective System (MUOS)

Executive Summary
- The Navy successfully launched the first Mobile User Objective System (MUOS) satellite (MUOS-1) in February 2012, and conducted contractor and government developmental testing on the MUOS-1 legacy communications capability and primary and alternate control stations.
- The Navy's Commander, Operational Test and Evaluation Force (COTF) conducted a Multi-Service Operational Test and Evaluation (MOT&E) from August 15 – 29, 2012. Integrated developmental testing and preliminary analysis of operational testing indicate the MUOS-1 satellite is capable of providing legacy Ultra-High Frequency (UHF) communications to mobile users and the Navy is able to command and control the satellite over the MUOS primary and back-up telemetry, tracking, and commanding systems.
- Continuing challenges integrating the secure MUOS waveform onto the Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) terminals may cause cost increases and schedule delays.

System
- MUOS is a satellite-based communications network designed to provide worldwide, narrowband, beyond line-of-sight, point-to-point, and netted communication services to multi-Service organizations of fixed and mobile terminal users. The Navy designed MUOS to provide 10 times the throughput capacity of the current narrowband satellite communications. The Navy intends for MUOS to provide increased levels of system availability over the current constellation of UHF follow-on satellites, as well as improved availability for small, disadvantaged terminals.
- MUOS consists of six segments:
  - The space transport segment consists of four operational satellites and one on-orbit spare. Each satellite hosts two payloads: a legacy communications payload that mimics the capabilities of a single UHF follow-on satellite, and a MUOS communications payload.
  - The Ground Transport Segment is designed to manage MUOS communication services and allocation of radio resources.
  - The Network Management Segment is designed to manage MUOS ground resources and allow for government controlled precedence-based communication planning.



  - The Ground Infrastructure Segment is designed to provide transport of both communications and command and control traffic between MUOS facilities and other communication facilities.
  - The Satellite Control Segment consists of MUOS Telemetry, Tracking, and Commanding facilities at the Naval Satellite Operations Center Headquarters and Detachment Delta.
  - The User Entry Segment provides a MUOS waveform hosted on MUOS-compatible terminals. The JTRS is responsible for developing and fielding MUOS-compatible terminals.

Mission
Combatant Commanders and U.S. military forces deployed worldwide will use the integrated MUOS satellite communications system to accomplish globally assigned operational and joint force component missions with increased operational space-based narrowband, beyond line-of-sight throughput, point-to-point, and netted communications services.

Major Contractor
- Lockheed Martin Space Systems – Sunnyvale, California
- General Dynamics C4 Systems – Scottsdale, Arizona

Activity
- The Navy successfully launched the MUOS-1 satellite on February 24, 2012. The contractor conducted orbital operations and contractor testing and transferred the MUOS-1 satellite to the government Program Office on June 21, 2012.
- The Navy conducted a government Technical Evaluation on the MUOS-1 and the Satellite Control Segment July 2 through August 1, 2012, in preparation for operational testing.

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- COTF conducted MOT&E-1 on the satellite control capability and MUOS-1 legacy communications capability from August 15 – 29, 2012, in accordance with the DOT&E-approved Test and Evaluation Master Plan and test plan.
- The Navy completed MUOS- 2 satellite thermal vacuum testing and is preparing to ship the satellite in November 2012 for an anticipated launch in July 2013. The Navy plans to ship satellites #3, #4, and #5 in FY13, FY14, and FY15, respectively.
- The Navy operators have completed training and are commanding the MUOS-1 satellite at the Naval Satellite Operations Center in Point Mugu, California.
- The ground transport site preparation at Wahiawa, Hawaii; Geraldton, Australia; and Northwest, Virginia, is on schedule.
- The Navy's JTRS Network Enterprise Domain program is working to resolve integration problems associated with porting the secure MUOS waveform on the JTRS HMS Manpack radio.
- The MUOS program developed an end-to-end developmental test strategy incorporating additional testing prior to the MUOS MOT&E-2 and JTRS HMS FOT&E to discover and correct any integration problems prior to operational testing.
- The Navy plans to conduct the MUOS MOT&E-2 in the FY14 timeframe to operationally test the full MUOS capability.

Assessment

- Although analysis of the operational test data is ongoing, integrated developmental testing and preliminary analysis of operational testing suggest the MUOS-1 satellite is capable of providing legacy UHF communications to mobile users and the Navy is able to command and control the satellite over the MUOS primary and back-up systems.
- Challenges integrating the secure MUOS waveform onto the JTRS HMS terminals may cause cost increases and schedule delays to both programs. If the MUOS and JTRS program managers cannot resolve latency and reliability issues due to terminal processing constraints, the MUOS MOT&E-2 may be delayed.
- COTF cannot adequately test the MUOS capacity requirements in MOT&E-2 due to an insufficient number of JTRS-equipped mobile users. COTF will need to supplement MOT&E-2 data with validated modeling and simulation or other data to evaluate the system's ability to operate at its planned capacity and link availability levels.
- The MUOS Performance Model that will be used to model MUOS capacity is behind schedule and needs improvements to be accredited in time for MOT&E-2.

Recommendations

- Status of Previous Recommendations. The Navy adequately addressed two of the three previous recommendations. The remaining recommendation to operationally load the system for MOT&E-2 is no longer valid.
- FY12 Recommendation.
  1. The Navy should ensure adequate resources and expertise are applied to the MUOS Performance Model to make this a viable simulation to assess MUOS capacity requirements.

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MQ-4C Triton Broad Area Maritime Surveillance (BAMS)

Executive Summary

- DOT&E approved the MQ-4C Triton Broad Area Maritime Surveillance (BAMS) Test and Evaluation Master Plan (TEMP) in January 2012 to guide system development and operational testing through an initial operational assessment and Milestone C Low-Rate Initial Production (LRIP) decision.
- The Navy postponed MQ-4C first flight and the start of developmental flight testing from May 2012 until at least January 2013 due to aircraft flight control computer software stability problems. Resulting test schedule revisions compress developmental and operational test events and significantly increase schedule risk prior to the planned operational assessment in June 2013 and the Milestone C decision in October 2013. The reduction in planned developmental testing means that evaluating the planned operational assessment is particularly critical to an informed production decision.
- The Navy began the Multi-Function Active Sensor (MFAS) radar payload risk-reduction flight test program in December 2011 using a Northrop Grumman surrogate test bed aircraft to identify and resolve potential radar performance problems prior to integration on the MQ-4C air vehicle.
- In June 2012, a Navy BAMS-Demonstrator (BAMS-D) aircraft crashed during a training mission near Patuxent River Naval Air Station, Maryland. The aircraft was one of five Air Force RQ-4A Global Hawk Block 10 aircraft acquired by the Navy to provide interim support for U.S. Central Command operations and develop unmanned maritime surveillance tactics and doctrine. This mishap did not affect the MQ-4C Triton development and test program.

System

- The MQ-4C Triton BAMS unmanned aircraft system is an Intelligence, Surveillance, and Reconnaissance system-of-systems consisting of the high-altitude, long-endurance MQ-4C air vehicle, sensor payloads, and supporting ground control stations. The MQ-4C system is a part of the Navy Maritime Patrol and Reconnaissance family-of-systems, with capabilities designed to complement the P-8A Poseidon.
- The MQ-4C air vehicle design is based on the Air Force RQ-4B Global Hawk air vehicle with significant modifications that include strengthened wing structures, anti-ice and de-icing systems, and an air traffic de-confliction and collision avoidance radar system.



- The MQ-4C is equipped with the MFAS maritime surveillance radar to detect, identify, and track surface targets and produce high-resolution imagery. The BAMS Electro-Optical Infrared Sensor provides full motion video and still imagery of surface targets. An Electronic Support Measures system detects, identifies, and geo-locates radar threat signals. An Automatic Identification System (AIS) receiver permits the detection, identification, geo-location, and tracking of cooperative vessels equipped with AIS transponders.
- Onboard line-of-sight and beyond line-of-sight datalink systems transmit sensor data from the air vehicle to ground control stations for dissemination to fleet tactical operation centers and intelligence exploitation sites.

Mission

- Commanders use units equipped with MQ-4C to conduct maritime surveillance operations and provide high-altitude, long-endurance intelligence collection.
- MQ-4C operators detect, identify, track, and assess maritime and littoral targets of interest and collect imagery and signals intelligence information. Operators disseminate sensor data to fleet units to support a wide range of maritime missions to include surface warfare, intelligence operations, strike warfare, maritime interdiction, amphibious warfare, homeland defense, and search and rescue.

Major Contractor

Northrop Grumman Aerospace Systems, Battle Management and Engagement Systems Division – Bethpage, New York

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Activity

- DOT&E approved the MQ-4C TEMP in January 2012 to guide system development and operational testing through an initial operational assessment and Milestone C LRIP decision.
- The Navy postponed MQ-4C first flight and the start of developmental flight testing from May 2012 until at least December 2012 due to aircraft mission computer software stability problems.
- The program also deferred development and testing of some air vehicle and sensor capabilities until after Milestone C in order to reduce current test schedule pressures. The program is currently assessing the potential effect of these deferrals on post-Milestone C test schedules leading to the planned IOT&E in FY15.
- In June 2012, the first MQ-4C developmental test aircraft began initial ground test activities leading to first flight.
- The Navy began MFAS radar payload risk-reduction flight test program in December 2011 using a Northrop Grumman surrogate test bed aircraft to identify and resolve potential radar performance problems prior to integration on the MQ-4C air vehicle.

Assessment

- The MQ-4C program experienced a significant test schedule delay in 2012, primarily due to aircraft flight control computer software stability problems discovered during laboratory testing. These problems delayed first flight of the MQ-4C developmental test aircraft from May 2012 until at least January 2013. The revised program test schedule compresses developmental and operational test events and significantly increases schedule risk prior to the planned operational assessment in June 2013 and the Milestone C decision in October 2013. If developmental flight testing identifies any significant air vehicle, ground station, or mission system deficiencies, additional program schedule delays are possible.
- Following delivery of the first flight test air vehicle in June 2012, acceptance and ground testing proceeded more slowly than expected. Additional ground test delays encountered in early FY13 may result in further delays in the flight test program.
- The MFAS radar risk-reduction flight test program progressed more slowly than the Navy expected in FY12. The program is currently focusing MFAS flight test activities on improving identified sensor software stability, maritime target detection and tracking consistency, and radar image quality issues.
- In June 2012, a Navy BAMS-D aircraft crashed during a training mission near Patuxent River Naval Air Station, Maryland. The aircraft was one of five Air Force RQ-4A Global Hawk Block 10 aircraft acquired by the Navy to provide interim support for U.S. Central Command operations and develop unmanned maritime surveillance tactics and doctrine. BAMS-D airframe design, aircraft systems, and sensor payloads differ significantly from the more advanced MQ-4C Triton system that will begin flight test in FY13. This mishap did not affect the MQ-4C Triton development and test program.

Recommendations

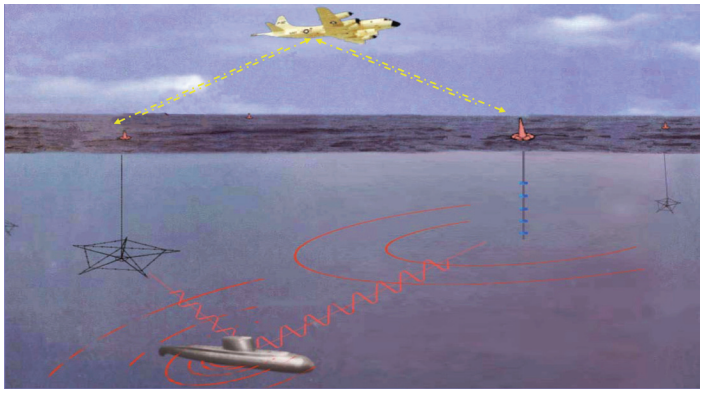
- Status of Previous Recommendations. This is the first annual report for this program.
- FY12 Recommendation.
  1. The Navy should fully implement the event-driven test and evaluation strategy outlined in the January 2012 TEMP to ensure that the program completes the previously approved system maturity demonstrations and operational assessments prior to a Milestone C LRIP decision. Given the reductions in developmental testing that are occurring, the operational assessment will be a key, critical source of information on the system's performance prior to the production decision.

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Multi-Static Active Coherent (MAC) System

Executive Summary
- DOT&E placed the Multi-Static Active Coherent (MAC) program on oversight in 2012. MAC will be the primary wide-area acoustic search system for the P-8A; without it, P-8A has limited large-area Anti-Submarine Warfare (ASW) search capability.
- The Navy conducted developmental testing in 2012; the Navy plans to begin operational testing in early FY13.

System
- The MAC system is an active sonar system composed of two types of buoys (source and receiver) and an acoustic processing software suite. It is employed by the Navy's maritime patrol aircraft (P-3Cs and eventually P-8As) to search for and locate threat submarines in a variety of ocean conditions.
- MAC is an upgrade to the Navy's current Improved Extended Echo Ranging (IEER) system, which employs non-coherent sources to produce loud sounds that reflect off submarine targets; these echoes are then detected by receiver buoys. MAC employs the same receiver buoys, but uses new coherent source buoys that enables multiple pings, optimized waveforms, and various ping durations, none of which the legacy IEER system provided.
- The Navy intends to initially employ MAC on P-3Cs in a limited set of acoustic environments. Future increments of MAC will be employed on P-8A and in a wider variety of acoustic ocean environments in order to span the operational envelope of threat submarine operations.



- MAC is expected to have fewer effects on marine mammals and the environment than the legacy IEER system.
- MAC will be the primary wide-area acoustic search system for the P-8A.

Mission
The Navy intends for P-3C and P-8A crews equipped with MAC to support the search, detect, and localization phases of the ASW mission. MAC is particularly focused on large-area active acoustic searches for threat submarines.

Major Contractors
- Lockheed Martin Corporation – Manassas, Virginia
- Sparton Electronics Florida, Inc. – De Leon Springs, Florida
- Ultra Electronics, Undersea Sensor Systems Incorporated (USSI) – Columbia City, Indiana

Activity
- DOT&E placed the MAC program on oversight in 2012. The Navy intends MAC to be a primary system for the successful ASW mission performance of the Maritime Patrol P-3 aircraft and the new P-8A aircraft. Because of technical difficulties integrating multi-static active wide-area ASW search systems, the Navy deferred the P-8A Maritime Patrol aircraft's wide-area search requirements and deferred this testing on P-8A.
- MAC achieved Milestone C in March 2012. DOT&E did not approve the program's Test and Evaluation Master Plan (TEMP) since it was written prior to DOT&E's oversight; however, DOT&E accepted the current Navy TEMP as adequate for MAC's IOT&E. An update to the TEMP is required to plan for future MAC upgrades and for the implementation of MAC on the P-8A.
- The program conducted developmental and integrated testing on P-3C aircraft in the summer of 2012; DOT&E is evaluating the data collected.
- The Navy reported the Active System Performance Estimate Computer Tool (ASPECT)/Multi-static Planning Acoustics Toolkit (MPACT) used for MAC mission planning inaccurately predicts MAC search probability of detection. The Navy also reported that the current aircraft system's tactical mission software for determining the position of the Air Deployable Active Receiver sonobuoys and aircraft Mark-on-Top tactical procedures were not sufficient to maintain geographically accurate sonobuoy locations throughout the MAC search field. The sonobuoy location inaccuracy is caused by the variable currents and resulting buoy drift rates encountered in the large ocean search field. In October 2012, the Navy waived these deficient conditions for the MAC IOT&E.
- The Navy will begin MAC operational testing on P-3C aircraft in early FY13. The Navy began test planning for the integration of MAC onto P-8A as well as planning for the testing of a future upgrade to the MAC system in late FY12.

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Assessment

- Based on the limited developmental testing data available to date, the reliability of the buoys and the software appear to be meeting developmental test requirements. The Navy and DOT&E will evaluate final configuration changes to the system during IOT&E.
- The IOT&E will not fully examine the capability of MAC across all operational conditions, operational environments, and target types; additional testing is necessary once MAC is integrated onto P-8A operational systems to examine performance under other conditions. Additional testing is also required to examine planned system upgrades.
- The inaccurate ASPECT/MPACT probability of detection prediction tool used for MAC and the inaccurate sonobuoy locating systems will likely affect the MAC system's mission performance and the ability of the system to accurately locate submarine targets. These inaccuracies could result in operators installing a MAC search field that is not optimized based on the environmental conditions for detecting the target in the required search area. The buoy location inaccuracies will affect the crew's ability to efficiently and accurately locate the target. Additional testing is required to assess the impact of these waived conditions.
- Based on the initial scope of the system's capabilities, the planned IOT&E will allow an assessment of MAC performance in some threat areas and against nuclear submarine targets. DOT&E requires future testing to determine performance against diesel electric submarine targets and in the variety of threat environmental conditions where the Navy intends to employ the MAC system.

Recommendations

- Status of Previous Recommendations. This is the first annual report for this program.
- FY12 Recommendation.
  1. Update the MAC TEMP to include sufficient testing in other operational conditions, operational environments, and against diesel-electric submarines. The TEMP should include planned testing on both P-3C and P-8A.

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MV-22 Osprey

Executive Summary
- The Navy conducted FOT&E in June 2012.
- The Navy's Commander, Operational Test and Evaluation Force evaluated capabilities of the latest Block C software and six other minor enhancements.
- Testing demonstrated the utility of all new enhancements with the exception of the Traffic Advisory System (TAS). Intended to warn pilots of impending collision with approaching aircraft, the TAS does not distinguish between approaching aircraft and aircraft in formation. Additional development is needed to address operational test findings and improve the utility of TAS for the MV-22 fleet.
- The Block C aircraft demonstrated improved reliability, availability, and maintainability compared to Block B aircraft performance in previous operational tests. The MV-22 has met all RAM requirements in the Capability Production Document.
- The Navy continues to execute a viable reliability growth program for the MV-22 fleet.

System
- There are two variants of the V-22: the Marine Corps MV-22 and the Air Force/U.S. Special Operations Command CV-22. The air vehicles for Air Force and Marine Corps missions are nearly identical, with common subsystems and military components sustainable by each Service's logistics system.
- The Marine Corps is replacing the aging CH-46 and CH-53D helicopters with MV-22s. The MV-22 is a tilt rotor aircraft capable of conventional wing-borne flight and vertical take-off and landing.
- The MV-22 can carry 24 combat-equipped Marines and operate from ship or shore. It can carry an external load up to 10,000 pounds over 40 nautical miles ship-to-shore and return, and can self-deploy 2,267 nautical miles with a single aerial refueling.
- Block C (software version C1.01) enhancements include:
  - Redesigned Environmental Control System (ECS), which enhances system reliability and improves cabin cooling using directional nozzles, larger heat exchangers, and a new ECS controller.
  - Electronic Standby Flight Instruments (ESFI), which replace the analog standby instrument cluster.
  - Color Weather Radar System, which provides weather detection, ground mapping, and sea search functions.



  - Day Heads-up Display (HUD), which provides basic flight and performance instrument information in a helmet-mounted monocle.
  - TAS, which is intended to warn MV-22 pilots of other aircraft in close proximity or with the potential for collision.
  - Cabin Situational Awareness Device, which displays essential mission information to troop commanders in the cabin and assists the troop commander to communicate with Marines independent of the aircrew.

Mission
- Squadrons equipped with MV-22s will provide medium-lift assault support in the following operations:
  - Ship-to-Objective Maneuver
  - Sustained operations ashore
  - Tactical recovery of aircraft and personnel
  - Self-deployment
  - Amphibious evacuation
- Currently deployed squadrons are providing high-tempo battlefield transportation in Iraq and Afghanistan.

Major Contractors

Bell-Boeing Joint Venture:
- Bell Helicopter – Amarillo, Texas
- The Boeing Company – Ridley Township, Pennsylvania

Activity
- The Navy conducted FOT&E in June 2012 in accordance with the DOT&E-approved plan. This dedicated operational test was preceded by about 8 months of integrated testing in which MV-22 aircraft accumulated 320 flight hours. During operational test, aircraft accumulated approximately 67 flight hours.

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- Commander, Operational Test and Evaluation Force evaluated capabilities of the latest Block C enhancements: software version C1.01, upgraded ECS, ESFI, Color Weather Radar System, Day HUD, TAS, and Cabin Situational Awareness Device upgrades.
- VMX-22 conducted all operational test missions at or near the Marine Corps Air Station New River, North Carolina, using four production-representative aircraft (two Block C aircraft and two Block B aircraft). DOT&E observed as passengers on all of the operational test missions.

Assessment

- Except for minor functionality upgrades, software version C1.01 is identical to the existing Block B software. DOT&E noted no degradation in existing capability during testing.
- The upgraded ECS proved effective at cooling troops in the cabin. The adjustable nozzles allow troops to direct cool/warm air onto their head/neck. In surveyed responses, 78 percent of Marines in a cabin with upgraded ECS described their general comfort during missions as good or excellent versus 45 percent of those in a cabin without the upgraded ECS.
- The ESFI was well mechanized and integrated into the cockpit with over 75 percent of survey responses indicating adequate visibility of ESFI, and about 65 percent noting the ESFI was effective for management of flight profile during basic instrument maneuvering. Pilots noted a lag in the Vertical Velocity Indicator of about 1 to 5 seconds, which makes altitude management difficult.
- The Color Weather Radar provided accurate weather information to include precipitation intensity and storm cell turbulence. The system clearly defined terrain features along coastlines out to 20 nautical miles, and easily detected ships in sea search mode. The location and integration of the Color Weather Radar was not ideal. The radar display and controls are accessible only to the right seat pilot, and the pilot must dedicate one of two multi-functional displays to view the weather radar.
- The Day HUD enhances the pilot's situational awareness during tactical situations and reduced visibility conditions.
- Troop commanders said the Cabin Situational Awareness Display enhances situational awareness. Access to GPS updates for handheld devices, way points, flight plans, location, and other mission information increased commanders' confidence in knowing their location on leaving the aircraft and their ability to navigate the terrain once disembarked.
- Testing demonstrated the lack of utility of the TAS. This system displays the top three traffic advisory priorities by calculating the bearing, range, and altitude of nearby aircraft. These top three priorities include other aircraft in formation, essentially rendering the advisory information useless in most MV-22 multi-aircraft missions.
- The Block C aircraft demonstrated improved reliability, availability, and maintainability relative to aircraft in previous operational tests and the MV-22 fleet, and met requirements for reliability, availability, and maintainability.
- An analysis of reliability data from 2008 to 2012 revealed that integrated wiring systems in engine nacelles have high failure rates from intrusion of sand and oil, causing internal chafing and deterioration of insulated coatings. PMA-275 has funded a program to redesign and replace 13 wiring bundles to improve wiring system reliability and repairability.
- No additional flight testing or engineering analysis have been done indicating a change would be appropriate to DOT&E's September 2005 assessment that the MV-22 cannot perform autorotation to a survivable landing.

Recommendations

- Status of Previous Recommendations. The Navy has made improvements and has plans to make other reliability improvements to the icing protection system, as recommended in FY11. The Navy should conduct operational testing in icing conditions when all icing protection system enhancements are completed.
- FY12 Recommendations. The Navy should:
  1. Continue development and testing to improve overall MV-22 reliability, availability, and maintainability with particular emphasis on the flight controls, integrated wiring, and drive train subsystems.
  2. Withhold fielding the TAS as implemented in FOT&E. Additional development is needed to address operational test findings and improve the utility of TAS for the MV-22 fleet.

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Navy Multiband Terminal (NMT)

Executive Summary

- The Navy's Commander, Operational Test and Evaluation Force (COTF) conducted the Navy Multiband Terminal (NMT) IOT&E from July 20 through August 19, 2011, on two surface ships, one submarine, a shore site, and various supporting sites.
- The NMT met requirements to provide legacy Extremely High Frequency (EHF) communications over Milstar and Ultra High Frequency Follow-On EHF Enhanced payloads; X-band over the legacy Defense Satellite Communication System and Wideband Global System (WGS); and Ka-Band over WGS.
- When the IOT&E showed that NMT is not operationally suitable, the NMT program manager performed root cause analyses and undertook corrective actions to correct deficiencies found during the IOT&E and improve suitability.
- COTF conducted further operational testing from June 1 through August 1, 2012, to verify that the deficiencies had been corrected. The testing included two surface ships and one shore site, operating under realistic conditions. The NMT is now operationally suitable.

System

- The NMT system is the next-generation maritime military satellite communications terminal for the Navy and its coalition partners; the Navy uses it for enhancing protected and survivable satellite communications.
- The NMT is interoperable with the legacy service satellite communications terminals, including the Follow-on Terminal and Navy EHF Satellite Program.
- The NMT has variants for surface ships, submarines, and shore sites. The NMT system variants have two major component groups: the Communications Group and the Antenna Group.
- The Communications Group includes the following:
  - Operator User Interface
  - Power Distribution Unit
  - Keyboard
  - EHF and Wideband drawers
  - Prime Power Interface
- The Antenna Group varies across different platforms and includes new, reused, and modified antennas to support the required Q- and Ka-Bands, as well as X-band with Global Broadcasting System.



- The key features of the NMT system are:
  - Open system architecture
  - Full compatibility with legacy terminal components
  - High commonality, reliability, and effective fault isolation
  - Mission Planning capability

Mission

The Navy Component Commander uses the NMT to provide secure, protected, and survivable connectivity across the spectrum of mission areas including land, air, and naval warfare; special operations; strategic nuclear operations; strategic defense; theater missile defense; and space operations and intelligence.

Major Contractor

Raytheon Net-Centric Systems – Marlboro, Massachusetts

Activity

- COTF conducted the NMT IOT&E from July 20 through August 19, 2011, on two surface ships, one submarine, a shore site, and various supporting sites. COTF executed the test in accordance with the DOT&E-approved Test and Evaluation Master Plan and test plan.
- The Assistant Secretary of the Navy (Research, Development, and Acquisition) authorized the NMT Program Office to procure FY12 quantities of 26 NMTs in support of the program and an additional 24 NMTs in support of other programs such as foreign military sales.

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- The NMT program manager performed root cause analyses and undertook corrective actions to correct deficiencies found during the IOT&E.
- COTF conducted further operational testing from June 1 through August 1, 2012, to verify that the deficiencies had been corrected. The testing included two surface ships and one shore site, operating under realistic conditions.
- The Navy plans to conduct a Full-Rate Production Decision Review for NMT in November 2012.
- COTF plans to conduct an FOT&E in 3QFY14 to test the NMT's ability to operate over Advanced EHF satellites using the extended data rate waveform.

Assessment

- NMT can meet requirements to provide legacy EHF communications over Milstar and Ultra High Frequency Follow-On EHF Enhanced payloads; X-band over the legacy Defense Satellite Communication System and WGS; and Ka-Band over WGS. NMT also demonstrated the capability to receive Global Broadcast System broadcasts over WGS.
- The FY11 IOT&E demonstrated that the NMT is not operationally suitable. Deployed ships' communications could be hampered by poor reliability and long repair times when compared to the Navy's requirements. The time needed to repair the NMT when spare parts were unavailable resulted in long periods of degraded operations or complete outages either for a specific communications band or for the entire NMT system during IOT&E.
- During the recent operational test to verify corrections of deficiencies observed during IOT&E, the NMT demonstrated a Mean Time Between Critical Failure of 1,461 hours for surface ship variants and 701 hours for shore variants against a requirement of 1,400 hours. The low reliability for shore variants is due to software problems with the operator interface that require system reboots to restore the NMT to operation. These reboots temporarily disrupted communications. The operational consequences were mitigated by the availability of redundant Q-band terminals and the ability to shift communications between terminals. The corrective actions taken by the program manager improved suitability. The NMT is now operationally suitable.
- The recent operational test demonstrated that improvements to NMT logistic support are still required for deployed ships. The NMT was capable of adequately supporting shore sites and ships in port. Off-board logistics delay time for a ship deployed in the Mediterranean was 287 hours against a requirement of 100 or less hours.
- The Navy may not identify additional risks, other than those observed during the IOT&E, until the FOT&E when Advanced EHF modes of operation, including the new extended data rate waveform and the new Mission Planning System, will be tested. These capabilities were not evaluated during the IOT&E because they depend on capabilities being delivered by the Advanced EHF program on a different timeline.

Recommendations

- Status of Previous Recommendations. The Navy has made satisfactory progress on all previous recommendations.
- FY12 Recommendations. The Navy should:
  1. Synchronize the NMT FOT&E with the Air Force's Advanced EHF Multi-Service Operational Test and Evaluation to efficiently use test resources.
  2. Continue to explore methods to improve logistic supportability for deployed ships prior to the FY14 FOT&E.
  3. Correct the operator interface errors that are reducing shore site reliability.

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P-8A Poseidon Multi-Mission Maritime Aircraft (MMA)

Executive Summary

- The Navy delayed the P-8A IOT&E from February 2012 to September 2012 to develop and test a series of mission system software improvements intended to correct significant radar, electro-optical/infrared (EO/IR) sensor, Electronic Support Measures (ESM), and communications system performance deficiencies identified during developmental testing.
- In August 2012, the Navy completed development of Operational Flight Program (OFP) Release 9.3 and approved it as the IOT&E software baseline. Developmental test results indicate that OFP Release 9.3 improved system performance, particularly for the ESM sensor. However, it did not resolve a number of other deficiencies that could degrade operational effectiveness for all P-8A missions. These deficiencies pose a high risk to operational effectiveness, particularly in the Intelligence, Surveillance, and Reconnaissance (ISR); Command, Control, and Communication; and Joint Interoperability mission areas. Unresolved sensor performance deficiencies also affect the primary Anti-Submarine Warfare (ASW) mission.
- P-8A ASW sonobuoy acoustic processing and torpedo carriage/release systems continued to mature during developmental test events, despite recurring system stability and reliability problems.
- The Navy's decision to waive P-8A wide-area acoustic search requirements for IOT&E and defer integration of a multi-static active acoustic capability until at least FY14 will limit ASW mission effectiveness in the near-term. In order to achieve full ASW mission capability on the P-8A aircraft, the Navy will have to complete future integration of the Multi-Static Active Coherent broad area acoustic system on the aircraft. P-8A airframe and aircraft subsystem maturity improved during developmental test events. Remaining weather, take-off, and flight envelope restrictions will not significantly affect mission operations. However, main tank fuel overheating during ground and low-level flight will limit ASW operations in hot weather environments.
- P-8A system reliability approached the minimum operational requirement of 11.7 Mean Flight Hours Between Operational Mission Failure during the OFP Release 9.3 developmental test phase just prior to IOT&E. While promising, this reliability assessment was inconclusive due to the small number of operating hours observed with OFP Release 9.3 installed. The IOT&E results will provide a more complete assessment of system reliability.
- The P-8A live fire test program completed an initial assessment of P-8A vulnerabilities for a range of ballistic projectiles. DOT&E requires completion of remaining vulnerability test events on the S-1 static test article to support completion of the P-8A IOT&E report in advance of the July 2013 Full-Rate Production decision.



- The Navy did not release the P-8A On-Board Inert Gas Generating System (OBIGGS) for operational testing due to serious system design deficiencies discovered during developmental testing. The program is currently evaluating design changes and will conduct further developmental testing in late FY12 and early FY13.

System

- The P-8A Poseidon Multi-mission Maritime Aircraft (MMA) design is based on the Boeing 737-800 aircraft with significant modifications to support Navy maritime patrol mission requirements. It will replace the P-3C Orion.
- The P-8A incorporates an integrated sensor suite that includes radar, electro-optical, and electronic signal detection sensors to detect, identify, locate, and track surface targets. An integrated acoustic sonobuoy launch and monitoring system detects, identifies, locates, and tracks submarine targets. The P-8A carries Mk 54 torpedoes and is currently integrating the AGM-84 Harpoon missile system to engage identified submarine and surface targets. Sensor systems also provide tactical situational awareness information for dissemination to the fleet and ISR information for exploitation by the joint intelligence community.
- The P-8A aircraft incorporates aircraft survivability enhancement and vulnerability reduction systems. An integrated infrared missile detection system, flare dispenser, and directed infrared countermeasure system is designed to improve survivability against infrared missile threats. On and off-board sensors and datalink systems are used to improve tactical situational awareness of radio frequency missile threat systems. Fuel tank inerting and fire protection systems reduce aircraft vulnerability.

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Mission

- Theater Commanders primarily use units equipped with the P-8A MMA to conduct Anti-Submarine Warfare. P-8A units detect, identify, track, and destroy submarine targets.
- Additional P-8A maritime patrol missions include:
  - Anti-Surface Warfare operations to detect, identify, track, and destroy enemy surface combatants or other shipping targets.
  - Maritime and littoral ISR operations to collect and disseminate imagery and signals information for exploitation by the joint intelligence community.
  - Collection and dissemination of tactical situation information to improve the fleet common operational picture.
  - Identification and precise geo-location of targets ashore to support fleet strike warfare missions.

Major Contractor

Boeing Defense, Space, and Security – St. Louis, Missouri

Activity

- The Navy delayed the P-8A IOT&E from February 2012 to September 2012 to develop and test a series of mission system software improvements intended to correct significant radar, EO/IR sensor, ESM, and communications system performance deficiencies identified during developmental testing.
- From May 2012 to September 2012, Navy operational testers conducted a series of pre-IOT&E integrated developmental and operational test events using production-representative test aircraft and interim OFP software releases to evaluate P-8A deployment capabilities and assess evolving aircraft and mission system maturity. These events also provided additional flight crew and maintenance training experience in preparation for IOT&E. Major integrated test events included:
  - Joint Warrior fleet exercise conducted with the United Kingdom and other NATO countries in April 2012. Test crews completed 6 missions totaling 36.3 flight hours during this exercise.
  - U.S.–Australian fleet exercise in Australia in June 2012. Operational test crews completed 6 missions totaling 24.8 flight hours during this exercise.
  - Rim of the Pacific fleet exercise in Hawaii in July 2012. Operational test crews completed 20 missions totaling 102.2 flight hours during this exercise.
  - Mk 54 torpedo tests at the Atlantic Underwater Test Center in May 2012, Cape Cod Atlantic test areas in August 2012, and Hawaii Pacific test ranges in September 2012.
- In August 2012, the Navy completed development of OFP Release 9.3 and approved it for use in IOT&E. This release addressed some of the most serious sensor performance and communications system deficiencies identified during earlier testing.
- The Navy entered IOT&E beginning with participation in the U.S. Pacific Command Valiant Shield exercise in early September 2012. The Navy plans to complete IOT&E in December 2012. The Navy is conducting testing in accordance with the DOT&E-approved test plan.
- The P-8A live fire test program completed ballistic testing of P-8A emergency oxygen bottles on a surrogate Boeing 737 test aircraft in March 2012. The program also completed an evaluation of wing fuel tank tolerance against threat-induced hydrodynamic ram damage in September 2012.
- The Navy completed an initial flight test of the missile warning system, flare dispenser, and directed infrared countermeasures system against simulated infrared threats. The program is planning to conduct additional hardware-in-the-loop testing of these systems in early FY13 to complete required live fire and operational test requirements.

Assessment

- Developmental test results indicate P-8A airframe and aircraft subsystem maturity continued to improve as the developmental test program progressed. Remaining aircraft weather, take-off, and flight envelope restrictions should not significantly affect mission operations and are on track for resolution prior to P-8A operational deployment. However, developmental testing identified main tank fuel overheating during ground and low-level flight operations as a serious deficiency that will limit ASW mission on-station time in hot weather environments.
- Developmental test results indicate that OFP Release 9.3 improved system performance, particularly for the ESM sensor. However, it did not resolve a number of other deficiencies that could seriously degrade operational effectiveness for all P-8A missions. These deficiencies pose a high risk to operational effectiveness, particularly in the ISR; Command, Control, and Communication; and Joint Interoperability mission areas:
  - Common Data Link and International Maritime Satellite data transfer deficiencies that prevent reliable transmission of synthetic aperture radar (SAR) and EO/IR imagery intelligence products to operational users
  - Ineffective voice satellite communications systems that prevent transmission and receipt of mission critical information
  - SAR high-resolution image quality problems that degrade imagery intelligence capabilities
  - Radar pointing errors that prevent effective SAR imagery collection for some littoral/land targets

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  - EO/IR sensor cross-cue errors and inoperative auto-track modes that significantly increase sensor operator workload
  - Non-standard imagery metadata formats that prevent joint intelligence exploitation of P-8A imagery intelligence products
  - Ineffective ESM Specific Emitter Identification subsystem that does not reliably collect and identify emitter signatures to enable identification of specific hostile targets
  - Radar track-while-scan deficiencies that degrade P-8A and fleet situational awareness
- P-8A ASW sonobuoy launch, positioning, and acoustic processing systems continued to mature during developmental test events, despite recurring system stability and reliability problems. Unresolved radar, EO/IR, and ESM sensor performance deficiencies also affect ASW mission operations. Excessive ESM system interference and bleed over onto ASW operator displays frequently preclude ESM operation during ASW operations. In addition, developmental test events included few ASW search and detect events against operationally realistic submarine targets, which increases the potential for discovery of additional deficiencies during IOT&E.
- The Navy decision to waive P-8A wide-area acoustic search requirements for IOT&E and defer integration of a multi-static active acoustic capability until at least FY14 will limit ASW mission effectiveness in the near-term. Future integration of the Multi-Static Active Coherent broad area acoustic system will be required to achieve full ASW mission capabilities.
- Developmental test results indicate that P-8A torpedo release and water impact point accuracies meet operational requirements. Complete end-to-end torpedo employment effectiveness will be assessed during IOT&E events. However, inadequate weapons bay heating systems currently restrict torpedo carriage altitudes and combat mission radius in cold weather environments. The program is planning to develop and test system design changes to improve weapons bay heating in FY13, prior to operational fielding.
- P-8A system reliability improved significantly during the final OFP Release 9.3 developmental test phase prior to IOT&E, approaching the minimum operational requirement of 11.7 Mean Flight Hours Between Operational Mission Failure. While promising, this pre-IOT&E reliability assessment was inconclusive due to the small number of operating hours observed with OFP Release 9.3 installed. Most P-8A mission reliability failures are directly attributable to system software deficiencies. Hardware reliability exceeded the 1.25 Mean Flight Hour Between Operational Mission Failure requirement throughout the developmental and integrated test phases.
- The P-8A live fire test program completed an initial assessment of P-8A vulnerabilities for a range of ballistic projectiles. DOT&E requires completion of remaining vulnerability test events on the S-1 static test article to support completion of the P-8A IOT&E report in advance of the July 2013 Full-Rate Production (FRP) decision. The current S-1 test schedule supports a live fire vulnerability assessment in 3QFY13, but with little margin for additional delay prior to the planned July 2013 FRP decision.
- The Navy did not release the P-8A OBIGGS for operational testing during IOT&E due to serious system design deficiencies discovered during developmental testing. The program is currently implementing design changes and has begun further developmental testing, which will continue into FY13. This system is a critical P-8A survivability feature that maintains inert fuel tank environments to improve ballistic projectile protection.

Recommendations

- Status of Previous Recommendations. The Navy made progress on all FY11 recommendations. Developmental testing cleared the P-8A operational flight envelope to support IOT&E operational flight profiles. The program realigned S-1 live fire test schedules to support completion of testing prior to the FRP decision. The Navy corrected many, but not all, mission critical software deficiencies during the FY12 extended developmental test period leading to IOT&E.
- FY12 Recommendations. The Navy should:
  1. Accelerate correction of the remaining unresolved radar, EO/IR, ESM, and communications/data transfer deficiencies and conduct operational testing to verify software fix effectiveness.
  2. Correct weapons bay heating and main tank fuel overheating hardware deficiencies and conduct testing to verify unrestricted flight envelopes in cold and hot weather environments.
  3. Closely monitor progress of live fire vulnerability and OBIGGS test events to ensure completion and data delivery in time to support DOT&E's P-8A IOT&E report and FRP Decision.
  4. Complete Test and Evaluation Master Plan development and test planning for P-8A Increment 1 FOT&E events and the series of P-8A Increment 2 developmental and operational tests scheduled to begin in FY14.

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Ship Self-Defense

Executive Summary

- The ship self-defense mission for aircraft carriers, destroyers, and amphibious warfare ships coordinates several legacy shipboard systems, as well as five major acquisition programs: Ship Self-Defense System (SSDS), Rolling Airframe Missile (RAM), Evolved SeaSparrow Missile (ESSM), Cooperative Engagement Capability (CEC), and the Air and Missile Defense Radar (AMDR). These comprise a self-defense capability for in-service ships, as well as the LPD-17, LHA-6, DDG-51 Flight III, and CVN-78 ship classes still in acquisition.
- DOT&E issued a classified report to Congress in November 2012 entitled "Ship Self-Defense Operational Mission Capability Assessment Report."
- While the integration of sensor and weapon systems with the command and decision system enhances the ships' self-defense capability over non-integrated combat systems, the Navy has not successfully demonstrated the ability to effectively complete the self-defense mission against the types of threats and threat scenarios for which the overall system was designed.
- The Navy must complete the currently planned operational test program and conduct additional testing to demonstrate the correction of significant deficiencies with SSDS Mk 2, RAM, ESSM, CEC, and legacy ship self-defense combat system elements.

System

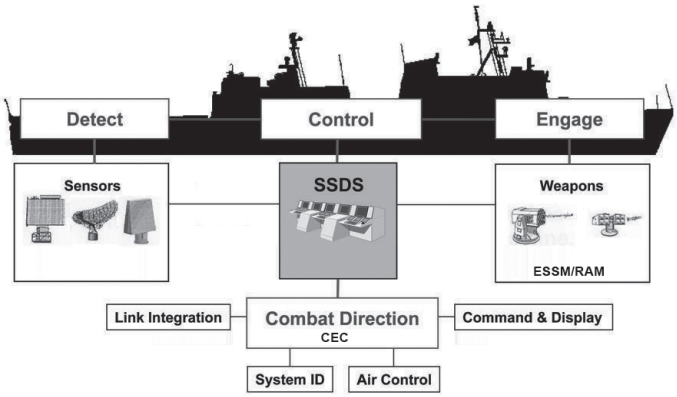
Surface ship self-defense is addressed by several legacy combat system elements (ship class-dependent) and five acquisition programs: SSDS, RAM, ESSM, CEC, and AMDR.

SSDS

- SSDS is a local area network that uses open computer architecture and standard Navy displays to integrate a surface ship's sensors and weapons systems to provide an automated detect-track-engage sequence for ship self-defense. SSDS Mk 1 is the command and control system for LSD-41/49 class ships.
- SSDS Mk 2 has six variants:
  - Mod 1, used in CVN-68 class aircraft carriers
  - Mod 2, used in LPD-17 class amphibious ships
  - Mod 3, used in LHD-7/8 class amphibious ships
  - Mod 4, in development for LHA-6 class amphibious ships
  - Mod 5, in development for LSD-41/49 class amphibious ships
  - Mod 6, in development for CVN-78 class aircraft carriers

RAM

- The RAM, jointly developed by the United States and the Federal Republic of Germany, provides a short-range, lightweight, self-defense system to defeat Anti-Ship Cruise Missiles (ASCMs). RAM is currently installed in all aircraft carriers and amphibious ships (except LPD-4 class).
- There are four RAM variants:
  - RAM Block 0 uses dual mode, passive radio frequency/infrared guidance.
  - RAM Block 1 adds infrared guidance improvements to extend defense against non-radio-frequency-radiating ASCMs.
  - RAM Block 1A extends the capability of RAM Block 1 against non-ASCM targets including helicopters, slow aircraft, and surface threats.
  - RAM Block 2 is in development and will extend the capability of RAM Block 1A against newer classes of ASCM threats.



ESSM

- The ESSM, cooperatively developed among 13 nations, is a medium-range, ship-launched self-defense guided missile designed to defeat ASCM, surface, and low velocity air threats. The ESSM is currently installed on DDG-51 Flight IIA destroyers, as well as CVN-68 class aircraft carriers equipped with the SSDS Mk 2 Mod 1 Combat System. The Navy is planning for future ESSM installations in CG-47 class cruisers, LHA-6 class amphibious assault ships, CVN-78 class aircraft carriers, DDG-1000 class destroyers, and DDG-51 Flight III class destroyers.
- There are two variants of ESSM.
  - ESSM Block 1 is a semi-active radar-guided missile that is currently in-service.
  - ESSM Block 2 is in development and will have semi-active radar-guidance as well as active radar-guidance.

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CEC

- CEC is a sensor network with integrated fire control capability that is intended to significantly improve battle force air and missile defense capabilities by combining data from multiple battle force air search sensors on CEC-equipped units into a single, real-time, composite track picture. The two major hardware pieces are the Cooperative Engagement Processor, which collects and fuses radar data, and the Data Distribution System, which exchanges the Cooperative Engagement Processor data. CEC is an integrated component of, and serves as the primary air tracker for, SSDS Mk 2-equipped ships.
- There are four major variants of CEC:
  - The CEC USG-2 is used in selected Aegis cruisers and destroyers, LPD-17/LHD amphibious ships, and CVN-68 class aircraft carriers.
  - The CEC USG-2A, an improved version of the USG-2, is used in selected Aegis cruisers and destroyers.
  - The CEC USG-3 is used in the E-2C Hawkeye 2000 aircraft.
  - The CEC USG-3B is in development for use in the E-2D Advanced Hawkeye aircraft.

AMDR

- The AMDR is the Navy's next generation radar system that is being developed to provide DDG-51 Flight III Destroyer combat systems with simultaneous sensor support of ballistic missile defense (BMD) and air defense (AD) (to include self-defense) missions.

Mission

Naval Component Commanders use SSDS, RAM, ESSM, and CEC, as well as many legacy systems, to provide faster, more effective accomplishment of ship self-defense missions.

- Naval surface forces use SSDS to provide automated and integrated detect-to-engage ship self-defense capability against ASCM, air, and surface threats.
- Naval surface forces use RAM to provide a short-range hard kill engagement capability against ASCM threats.
- Naval surface forces use ESSM to provide a medium-range hard kill engagement capability against ASCM, surface, and low velocity air threats.
- Naval surface forces use CEC to provide accurate air and surface threat tracking data to SSDS.
- Naval surface forces will use AMDR as a primary sensor for simultaneous BMD and AD (to include self-defense) missions.

Major Contractors

- SSDS: Raytheon – San Diego, California
- RAM and ESSM: Raytheon – Tucson, Arizona
- CEC: Raytheon – St. Petersburg, Florida

Activity

- DOT&E issued a classified report to Congress on the ship self-defense mission area in November 2012. The report covers ship self-defense related operational testing conducted from February 2008 through December 2011 aboard USS *Ronald Reagan* (CVN-76), USS *Carl Vinson* (CVN-70), and the Self-Defense Test Ship (SDTS).
- The Navy's Commander, Operational Test and Evaluation Force (COTF) completed FOT&E testing of ESSM, RAM, CEC, and SSDS on the SDTS in December 2011. Testing was conducted in accordance with a DOT&E-approved test plan.
- COTF continued planning for operational testing of the ship self defense mission area during IOT&E of the RAM Block 2 and FOT&E of the SSDS Mk 2 Mod 4 and ESSM on the SDTS. The Navy plans to continue testing in November 2012.
- COTF continued planning for IOT&E testing of the LHA-6 class ship self-defense combat system on the SDTS. The Navy plans to commence IOT&E testing in November 2012.

Assessment

- The November 2012 DOT&E ship self-defense mission area report includes the following assessments:
  - The CVN-68 ship class combat systems continue to have difficulty defeating certain ASCM raid types. In particular, the legacy combat system sensor elements have limited capability against the threat surrogates used in those raid types.
  - The CVN-68 ship class combat system continues to have several problems that hinder it from successfully completing the ship self-defense mission. Specific problems include deficiencies in weapon employment timelines, sensor coverage, system track management, and NATO ESSM performance, as well as deficiencies with the recommended engagement tactics for use against multiple ASCM threat classes.
- The test infrastructure is inadequate to support self-defense testing on the next flight of destroyers. There is no unmanned, at-sea test capability to safely demonstrate a self-defense capability for Aegis destroyers against anti-ship missile threats. The test capability must be in place by 2020 to support DDG-51 Flight III Destroyer Combat System, ESSM Block 2, and AMDR integration self-defense operational testing.
- The classified November 2012 DOT&E report to Congress contains further ship self-defense mission area assessments.

Recommendations

- Status of Previous Recommendations. The Navy has satisfactorily completed the majority of previous

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recommendations. The Navy has not resolved the following previous recommendations:

1. Optimize SSDS Mk 2 weapon employment timelines to maximize weapon probability of kill.
2. Acquire range-safe supersonic sea-skimming ASCM surrogate targets for ESSM FOT&E with the Aegis Combat System.
3. Ensure availability of a credible open-loop seeker subsonic ASCM surrogate target for ship self-defense combat system operational tests.
4. Correct the identified SSDS Mk 2 software reliability deficiencies.
5. Correct the identified SSDS Mk 2 training deficiencies.
6. Develop and field deferred SSDS Mk 2 interfaces to the Global Command and Control System–Maritime and the TPX-42A(V) command and control systems.
7. Continue to implement the Program Executive Office for Integrated Warfare Systems' plan for more robust, end-to-end systems engineering and associated developmental/operational testing of ship self-defense combat systems.
8. Provide a capability to launch a raid of four supersonic sea skimming targets at the Naval Air Warfare Center/Weapons Division, Point Mugu, California, test range to support Test and Evaluation Master Plan-approved Air Warfare/Ship Self-Defense Enterprise testing planned for FY16.
9. Improve the ability of legacy ship self-defense combat system sensor elements to detect threat surrogates used in specific ASCM raid types.
10. Ensure availability of adequate and credible target resources for ship self-defense and electronic warfare operational testing.
11. Take action on the classified recommendations contained in the March 2011 DOT&E report to Congress on the ship self-defense mission area.

- FY12 Recommendations. Based on the classified information contained in the November 2012 report to Congress, the Navy should:
  1. Improve the SSDS Mk 2 integration with the Mk 9 Track Illuminators to better support ESSM engagements, as well as preventing the Mk 9 Track Illuminators from contributing to the composite track during certain threat raid types.
  2. Develop combat system improvements to increase the likelihood that ESSM and RAM will home on their intended targets.
  3. Conduct additional operational testing on the CVN-68 class once the ship is equipped with additional self-defense weapons. This additional testing will determine whether the additional weapons are sufficient to meet the ship's self-defense requirements.
  4. Develop an unmanned, at-sea self-defense test capability that will allow safe demonstration of the self-defense mission of DDG-51 Flight III destroyers against anti-ship missile threats.
  5. Take action on the classified recommendations contained in the November 2012 DOT&E report to Congress on the ship self-defense mission area.

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SSN 774 *Virginia* Class Submarine

Executive Summary

- The Navy conducted two *Virginia* class FOT&E events that began in FY11 and extended into FY12. The first test event examined the *Virginia* class submarine's ability to operate under-ice and to conduct Anti-Submarine Warfare (ASW) in the Arctic. The second test event examined the modernized *Virginia* class submarine's performance with the Navy's latest combat system and sonar suite.
- DOT&E issued a classified report on the modernized *Virginia* FOT&E in November 2012, and concluded that the modernization of the combat system and sonar suite did not change the performance of the *Virginia* class for the missions tested.
- The Navy completed an update to the Test and Evaluation Master Plan (TEMP) and DOT&E approved the revision on July 24, 2012. The revision outlines plans to test deferred capabilities, electronic systems upgrades, and affordability changes included in the third increment of submarines (Block III).

System

- The *Virginia* class submarine is the replacement for the aging fleet of *Los Angeles* class submarines. The *Virginia* class:
  - Is capable of targeting, controlling, and launching Mk 48 Advanced Capability torpedoes, Tomahawk cruise missiles, and future mines
  - Has mission capability similar to the *Seawolf* submarine class with improvements to the electronic support suite, sonar, and combat control systems
  - Has a new-design propulsion plant incorporating components from previous submarine classes
  - Uses a modular design and significant commercial off-the-shelf computer technologies and hardware intended to allow for rapid and cost-effective technology refresh cycles
- The Navy is procuring and upgrading *Virginia* class submarines incrementally in a series of blocks.
  - Block I (hulls 1-4) and Block II (hulls 5-10) ships incorporated the initial design of the *Virginia* class.
  - Block III (hulls 11-18) ships will include the following affordability enhancements:
    - A Large Aperture Bow array will replace the spherical array in the front of the ship.



    - Two *Virginia* payload tubes will replace the 12 vertical launch tubes. Each payload tube is capable of storing and launching six Tomahawk land attack missiles used in strike warfare.
  - The Navy has not finalized the design for Block IV and beyond ships.

Mission

The Operational Commander will employ the *Virginia* class submarine to conduct open ocean and littoral covert operations in support of the following submarine mission areas:

- Strike Warfare (STW)
- Anti-Submarine Warfare (ASW)
- Intelligence, Surveillance, and Reconnaissance (ISR); Indications and Warnings (I&W); and Electronic Warfare (EW)
- Anti-Surface Ship Warfare (ASUW)
- Naval Special Warfare (NSW)
- Mine Warfare (MIW)
- Battle Group Operations (BGO)

Major Contractors

- General Dynamics Electric Boat – Groton, Connecticut
- Huntington Ingalls Industries, Newport News Shipbuilding – Newport News, Virginia

Activity

- In accordance with DOT&E-approved test plans, two *Virginia* class submarine FOT&E events started in FY11 and extended into FY12 due to data processing, data analysis, and reporting delays.
  - The Navy conducted the first FOT&E period in conjunction with a bi-annual Ice Exercise (ICEX-11). This event allowed testers to examine the *Virginia* class submarine's ability to transit to and operate under-ice and

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in the Arctic. This test period also assessed the *Virginia* class's ASW mission performance against a modern threat SSN surrogate under-ice in the Arctic. As part of the transit to northern latitudes, testers examined the *Virginia* class' susceptibility to fixed passive sonar arrays. DOT&E plans to issue a report on this testing in 2QFY13.
  - The second FOT&E period was a series of test events to examine the mission performance changes as a result of the modernization of the *Virginia* class submarines' sonar and combat control system. These tests were combined with the operational evaluations of the latest variants of the Acoustic Rapid Commercial Off-the-Shelf Insertion (A-RCI) Sonar System, the AN/BYG-1 Combat Control System, and the Mk 48 Advanced Capability torpedo. DOT&E issued a combined operational test report on this testing in November 2012.
- The *Virginia* TEMP also required FOT&E in order to complete testing of the Naval Special Warfare mission support capabilities for the Dry Deck Shelter (DDS) and for a diver emergency recompression capability in the *Virginia* class submarine's Lock-Out Trunk (LOT). The Navy completed LOT and DDS system design changes and began test planning for the LOT diver oxygen recompression system certification and for operations with a DDS in FY12. The Navy plans to complete these test events in early FY13.
- DOT&E approved Revision G to the TEMP on July 24, 2012. The revision outlines plans to test the mission performance of the *Virginia* class affordability changes (new bow array and vertical payload tubes) with the electronic systems upgrades planned for the third increment submarines (Block III) and to complete the testing of deferred mission capabilities.
- Because Navy security rules prevent collection of useful operational test data from *Virginia* when conducting exercises with foreign ASW capable platforms, the Navy finished IOT&E and recent FOT&E without testing the *Virginia* class submarine against one of its primary threats, the foreign diesel electric submarine (SSK). The Navy investigated alternative test strategies as part of the TEMP update process. The approved strategy asserts that the primary data for assessing this capability will come from three sources: related sonar system testing on *Los Angeles* class submarines, the use of an onboard training system that injects simulated acoustic targets into the combat system, and the possibility for future testing against real allied-nations' SSKs when security rules are relaxed.
- The Block III design will require shock testing of the Common Weapons Launcher and the *Virginia* Payload Tube (VPT) hatch. The Navy plans to complete VPT hatch shock qualification testing in April 2013 to support the first Block III delivery in August 2014.
- The Navy is performing verification and validation of the Transient Shock Analysis (TSA) modeling method used for the design of *Virginia* class Block III items. The Navy plans to accredit the TSA modeling method in March 2013.
- The Navy plans to update the Vulnerability Assessment Report to include the Block III modifications in July 2014.

Assessment

- The Navy achieved test efficiencies by combining the operational testing of several programs into a series of test events. Since submarine platform and mission systems testing are interdependent, the consolidation of the *Virginia* class testing with A-RCI sonar, acoustic arrays, Mk 48 torpedoes, and the AN/BYG-1 testing increased test efficiency and enabled a more complete end-to-end evaluation of the *Virginia* class submarine's mission performance. This testing also provided insights into the effectiveness and suitability of each individual system and weapon the Navy uses on other classes of submarines.
- The FOT&E event in the Arctic was adequate; however, the transfer and analysis of the data were significantly delayed and the Navy did not retain some test data. DOT&E's assessment of *Virginia's* effectiveness in the Arctic environment and *Virginia's* susceptibility to low-frequency fixed passive sonar arrays will be contained in an early FY13 classified report.
- DOT&E's classified report on *Virginia's* modernization FOT&E, issued in November 2012, concluded the following:
  - *Virginia's* operational effectiveness is dependent on the mission conducted. The modernization of the sonar and fire control systems (A-RCI and AN/BYG-1) with the Advanced Processor Build 09 software did not change (improve or degrade) the performance of the *Virginia* class for the missions tested. DOT&E's assessment of mission effectiveness remains the same for ASW, ISR, High Contact Management, Situational Awareness, and Mine Avoidance. DOT&E's overall assessment of Information Assurance remains unchanged from IOT&E, although the new software represents an improvement in Information Assurance over previous systems.
  - Although *Virginia* was not effective for some of the missions tested, it remains an effective replacement for the *Los Angeles* class submarine, providing similar mission performance and improved covertness.
  - Testing to examine ASW-Attack and situational awareness in a high-surface-ship density environment was adequate for the system software tested, but not adequate for the software version fielded. After completion of operational testing, the Navy issued software changes intended to address the severe performance problems observed with the Wide Aperture Array. The Navy has not completed operational testing on the new software, which is fielded on deployed submarines. DOT&E assesses that the late fix of the array's deficiencies is a result of the Navy's schedule-driven development processes, which fields new increments without completing adequate developmental testing.
  - The Navy collected adequate data to assess the suitability of the sonar and fire control systems. Insufficient data were collected to reassess the suitability of *Virginia's* hull, mechanical, electrical, or electronic systems; however, these data were not expected to demonstrate significantly different reliability compared to what was

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observed in IOT&E. Of note, the installation of the new Advanced Processor Build 09 of the A-RCI sonar system on *Virginia* class submarines will degrade the reliability of the sonar system on these submarines relative to what was demonstrated in the IOT&E.

Recommendations

- Status of Previous Recommendations. The Navy has made progress in addressing 22 of the 30 recommendations contained in the November 2009 classified BLRIP report and the October 2011 classified FOT&E report. Of the outstanding recommendations, the significant unclassified ones are:
  1. Test against an SSK threat surrogate in order to evaluate *Virginia's* capability, detectability, and survivability against modern diesel-electric submarines.
  2. Conduct FOT&E to examine *Virginia's* susceptibility to airborne ASW threats such as Maritime Patrol Aircraft and helicopters.
- FY12 Recommendations. The Navy should:
  1. Coordinate the *Virginia*, A-RCI, and AN/BYG-1 TEMPs and utilize Undersea Enterprise Capstone documents to facilitate testing efficiencies.
  2. Complete the verification, validation, and accreditation of the TSA method used for *Virginia* class Block III items.
  3. Repeat the FOT&E event to determine *Virginia's* susceptibility to low-frequency active sonar and *Virginia's* ability to conduct ASUW in a low-frequency active environment. This testing should include a *Los Angeles* class submarine operating in the same environment to enable comparison with the *Virginia* class.
  4. Address the 21 recommendations that are included in the November 2012 DOT&E-published FOT&E report on *Virginia's* modernization and the associated sonar and combat control systems. In particular, the Navy should re-evaluate operational effectiveness on a submarine with a repaired Wide Aperture Array.

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Standard Missile-6 (SM-6)

Executive Summary

- The Navy completed the Phase 2 modeling and simulation in support of IOT&E in July 2012. Phase 2 was an extensive modeling and simulation effort that examined Standard Missile-6 (SM-6) battlespace with the legacy Aegis Weapon System but not the Navy Integrated Fire Control-Counter Air (NIFC-CA) or Aegis Baseline 9 capability.
- The Navy will not demonstrate achievement of all of the SM-6 Capability Production Document performance requirements until the fielding of the NIFC-CA From the Sea capability in FY14/15. The Navy plans to demonstrate NIFC-CA From the Sea SM-6 capability during FOT&E as documented in the SM-6 Test and Evaluation Master Plan.
- In IOT&E Phase 1 flight tests, SM-6 demonstrated significant new capabilities against maneuvering targets, low-altitude targets, and targets with electronic countermeasures, successfully completing 7 of 12 intercept attempts. Within the constraints of the legacy Aegis combat system, SM-6 also demonstrated the longest downrange engagement range for a Standard Missile to date. IOT&E Phase 2 modeling and simulation confirmed SM-6 performance demonstrated in flight test.
- To demonstrate corrective actions to suitability anomalies discovered during IOT&E, the Navy conducted a series of high-temperature wind tunnel and flight tests. The results of that testing demonstrated the corrective actions were effective; however, the unexpected discovery of insulation inter-layer delamination on three of five wind tunnel test articles questions the finality of the Navy's corrective actions. Additional testing is ongoing.
- An unresolved performance anomaly from flight-testing affects SM-6 effectiveness. The Phase 2 modeling and simulation testing confirmed this. The Navy is working to develop corrective actions for this performance deficiency; however, testing of these actions has not been scheduled.

System

- SM-6 is the latest evolution of the Standard Missile family of fleet air defense missiles that incorporates components from two existing Raytheon product lines: the SM-2 Block IV and the Advanced Medium-Range Air-to-Air Missile (AMRAAM).
- SM-6 is employed from cruisers and destroyers equipped with Aegis combat systems.



- The SM-6 seeker and terminal guidance electronics derive from technology developed in the AMRAAM program. SM-6 retains the legacy Standard Missile semi-active radar homing capability.
- SM-6 receives midcourse flight control from the Aegis combat system via ship's radar; terminal flight control is autonomous via the missile's active seeker or supported by the Aegis combat system via the ship's illuminator.

Mission

- The Joint Force Commander/Strike Group Commander will use SM-6 for fleet air defense against fixed-/rotary-winged targets and anti-ship missiles operating at altitudes ranging from very high to sea-skimming.
- The Joint Force Commander will use SM-6 as part of the NIFC-CA concept to provide extended-range, over-the-horizon capability against at-sea and overland threats.

Major Contractor

Raytheon Missile Systems – Tucson, Arizona

Activity

- The Navy completed Phase 2 of the IOT&E in July 2012 in accordance with the DOT&E-approved operational test plan. Phase 2 was an extensive modeling and simulation effort that examined legacy Aegis Weapon System SM-6 battlespace but not the NIFC-CA or Aegis Baseline 9 capability.

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- The Navy conducted high-temperature wind tunnel tests to verify correction of the uplink/downlink antenna reliability deficiency. The Navy plans to continue this verification with the conduct of follow-on flight testing in FY13. The Navy conducted one SM-6 flight test in support of the Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS) integration testing. Data from this flight combined with the FY13 flight tests will provide some but not all of the data needed to verify the uplink/downlink antenna deficiencies have been corrected.

Assessment

- The Navy will not demonstrate all of the SM-6 Capability Production Document performance requirements until the fielding of the NIFC-CA From the Sea capability in FY14/15.
- In Phase 1 IOT&E, SM-6 demonstrated significant new capabilities against maneuvering targets, low-altitude targets, and targets with electronic countermeasures, successfully completing 7 of 12 intercept attempts. The current capabilities of the legacy Aegis SPY-1 B/D and associated combat system are unable to demonstrate the full operational capability of the SM-6. Within those constraints, SM-6 demonstrated the longest downrange engagement range for a Standard Missile to-date. Phase 2 modeling and simulation confirmed SM-6 performance demonstrated in flight test with the legacy Aegis combat system.
- As an excursion during the Phase 2 modeling and simulation activity, the Navy conducted a number of trials using third party sensors similar to the NIFC-CA capability. The trials indicated that the SM-6 battlespace will be significantly expanded once these capabilities are fielded.
- A performance deficiency discovered during IOT&E remains unresolved. The Phase 2 modeling and simulation trials confirmed this. The Navy is exploring corrective actions; however, implementation and testing of these corrective actions are not scheduled.
- The high-temperature wind tunnel tests of the uplink/downlink antenna reliability deficiency examined the antenna sealant material fixes and the insulation bonding manufacturing process improvements. The trials recorded no anomalies against these fixes; however, the unexpected discovery of insulation inter-layer delamination on three of five wind tunnel test articles questions the finality of the Navy's corrective actions. Coupled with the data collected on the JLENS integration flight test, the data are insufficient to assess corrective action efficacy on the overall uplink/downlink antenna reliability deficiency. DOT&E will continue to collect data on upcoming SM-6 FOT&E flight tests and will re-assess effectiveness and suitability when sufficient data are available.
- Based upon combined data from the IOT&E and developmental/operational flight tests, the SM-6 does not meet the flight reliability criteria established by USD(AT&L) for full-rate production. DOT&E will continue to collect reliability data during upcoming SM-6 FOT&E firings and will re-assess suitability at the conclusion of these tests.
- First seen in developmental testing, the Mk 54 Safe-Arm Device anomaly carried forward into IOT&E with additional occurrences. The Phase 2 modeling and simulation trials confirmed that the sensitivity of missile lethality is dependant on the fuze mode, target, and engagement conditions.

Recommendations

- Status of Previous Recommendations. The Navy is addressing the previous recommendations.
- FY12 Recommendation.
  1. Until reliability deficiencies are resolved, the Navy should consider issuing tactics that employ multiple missiles for certain targets.

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Surveillance Towed Array Sensor System (SURTASS) and Compact Low Frequency Active (CLFA) System

Executive Summary

- The Navy has installed one engineering developmental model and two production Compact Low Frequency Active (CLFA) systems on three of the five Western Pacific-based tactical auxiliary general ocean surveillance (T-AGOS) ships. Installation of the CLFA system on remaining T-AGOS ships is not planned.
- The Navy's Commander, Operational Test and Evaluation Force (COTF) commenced IOT&E on the Surveillance Towed Array Sensor System (SURTASS)/CLFA during fleet exercise Valiant Shield 12 in September 2012. IOT&E will complete in FY13. The analysis of test data collected is still in progress. No preliminary evaluation is available.

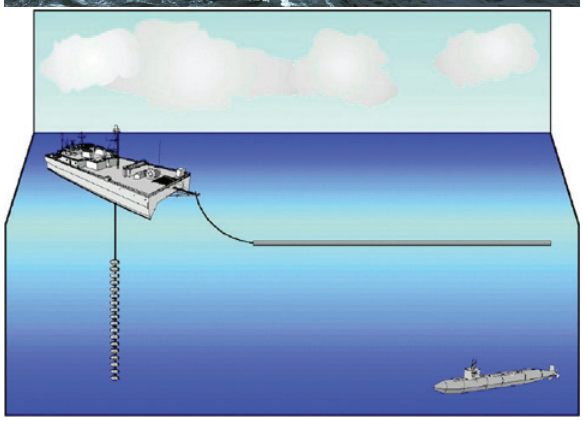
System

- SURTASS/CLFA is a low frequency, passive and active, acoustic surveillance system installed on T-AGOS ships as a component of the Integrated Undersea Surveillance System (IUSS).
- SURTASS provides passive detection of quiet nuclear and diesel submarines and enables real-time reporting of surveillance information to Anti-Submarine Warfare (ASW) commanders.
- CLFA is a low frequency, active sonar system developed to provide an active detection capability of quiet submarines operating in environments that support active sonar propagation.
- The system consists of:
  - A T-AGOS host ship with array-handling equipment
  - A towed vertical string of active acoustic projectors
  - A towed horizontal twin line (TL-29A) acoustic array
  - An integrated common processor (ICP) for processing active and passive acoustic data
  - A communications segment to provide connectivity to shore-based IUSS processing facilities and to fleet ASW commanders

Mission

- Maritime Component Commanders employ T-AGOS ships equipped with SURTASS/CLFA systems to provide active and passive acoustic sensors for long-range ASW detection, classification, and tracking of submarines in support of theater naval operations.
- Maritime Component Commanders use SURTASS/CLFA to protect naval ships from threat submarines and to provide accurate targeting information to theater ASW forces to prosecute the threat submarines.





Major Contractors

- Overall Integrator: Maritime Surveillance Systems Program Office (PMS 485)
- ICP: Lockheed Martin – Manassas, Virginia
- CLFA Projectors: BAE – Nashua, New Hampshire
- CLFA Handling System: Naval Facilities Engineering Service Center (NAVFAC ESC) (Government Lab) – Port Hueneme, California
- High Frequency Marine Mammal Monitoring Sonar: Scientific Solutions Incorporated (SSI) – Nashua, New Hampshire
- TL-29A Towed Arrays: Lockheed Martin – Syracuse, New York

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Activity

- After the August 2010 DOT&E Operational Assessment of SURTASS/CLFA installed on USNS *Able*, the Navy determined that additional system development was required to address system reliability, automated detection, and active tracking concerns before the system could proceed to IOT&E.
  - In January 2011, the Navy conducted at-sea test (AST) 11-2 to assess developmental changes to improve reliability.
  - In October 2011, the Navy conducted AST 11-4 to assess developmental changes to improve automated detection and active tracking performance.
  - In May 2012, the Navy conducted AST 12-1A as an advanced engineering analysis and system validation to inform a system certification decision.
  - On August 29, 2012, the Program Executive Office, Submarines certified the CLFA system ready to proceed to IOT&E.
- DOT&E approved the IOT&E test plan for SURTASS/CLFA on September 4, 2012, and agreed to use operationally realistic test and exercise data collected during a scheduled fleet exercise, Valiant Shield 12, which commenced on September 10, 2012, in the Western Pacific, as well as a dedicated test phase not associated with Valiant Shield 12.
- In September 2012, COTF and DOT&E commenced IOT&E on the SURTASS/CLFA system installed on USNS *Effective* (T-AGOS-21). Testing focused on SURTASS/CLFA contribution to coordinated ASW against threat diesel and nuclear submarines and included both passive and active sonar from multiple air and sea platforms. IOT&E will complete in FY13.
- The Navy acquired and installed one engineering developmental model and two production CLFA systems on three of the five Western Pacific-based T-AGOS ships. Installation of the CLFA system on remaining T-AGOS ships is not planned.

Assessment

- The conduct of IOT&E during an operationally relevant fleet exercise, Valiant Shield 12, allowed data collection that will provide insight into the effectiveness of SURTASS/CLFA as a primary contributor to theater ASW. The data will allow assessment of the ASW commander's ability to utilize SURTASS/CLFA contact reports with other ASW assets to protect surface ships and prosecute threat submarines.
- Due to a limitation in submarine support availability, substantially less data were obtained to support evaluation of the long-range active detection capability against threat-representative submarines than was planned. Additional testing is required to allow an adequate assessment.
- The analysis of test data collected during the combined SURTASS/CLFA IOT&E and Valiant Shield 12 fleet exercise is still in progress. No preliminary evaluation is available. DOT&E expects to issue a formal test report in FY13 after completion of IOT&E. The Navy has executed testing completed thus far in accordance with the DOT&E-approved test plan.

Recommendations

- Status of Previous Recommendations. The Navy and Program Office are satisfactorily addressing previous recommendations. The Navy implemented the FY11 recommendation to conduct IOT&E during a fleet exercise. The Program Office continued system development consistent with FY11 recommendations. Correction of deficiencies identified in COTF's and DOT&E's operational assessment reports will be validated during IOT&E.
- FY12 Recommendation.
  1. The Navy should complete remaining IOT&E to include a follow-on test event that allows an adequate determination of long-range active detection capability against threat-representative submarines.

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T-AKE *Lewis & Clark* Class of Auxiliary Dry Cargo Ships

Executive Summary
- The second FOT&E test series (OT-IIIB) for the T-AKE *Lewis & Clark* program specifically addressed the ship's Chemical, Biological, and Radiological (CBR) defenses; Information Assurance (IA); and mine susceptibility including magnetic silencing (degaussing).
- While the majority of deficiencies were verified as corrected, a major deficiency involving corrosion in the Countermeasure Water Wash Down (CMWWD) piping system still remains.

System
- T-AKE *Lewis & Clark* is a class of non-combatant ships operated by the Military Sealift Command (MSC) designed to carry dry cargo, ammunition, and fuel (in limited amounts) for naval combat forces at sea. There are 14 ships in the class; 11 ships are under contract for the Combat Logistics Force and 3 additional ships for the Maritime Prepositioning Force (Future).
- The T-AKE is:
  - Constructed to commercial standards (American Bureau of Shipping) with some additional features to increase its survivability in hostile environments such as the Advanced Degaussing System to reduce the ship's magnetic signature against mines, shock resistance in selected equipment, and increased damage control measures in firefighting and stability
  - Operated by civilian mariners from the MSC and a small Navy military detachment
  - Propelled with a single shaft and propeller; driven by electric motors powered by diesel generators

Mission
The Maritime Component Commander can employ the T-AKE *Lewis & Clark* class of ships to:



- Re-supply other ships while connected underway using Standard Tensioned Replenishment Alongside Method rigs and embarked helicopters
- Move cargo and ammunition between a port and a larger consolidating replenishment ship, which stays with the Carrier/Expeditionary Strike Group
- Be part of the hybrid combination of ships of the Maritime Prepositioning Force (Future)

Major Contractor
General Dynamics National Steel and Shipbuilding Company – San Diego, California

Activity
- The Navy conducted OT-IIIB February through May 2012 in accordance with the DOT&E-approved test plan. It focused on final resolution of IA and survivability vulnerabilities. The tests were intended to continue evaluation of T-AKE operational effectiveness and suitability, verify deficiencies identified in IOT&E and an earlier FOT&E were corrected, and complete deferred OT&E.
- The Navy installed a new intruder detection system on T-AKE 12 and integrated the navigation and engineering control system with the ship's network.
- The Navy's Commander, Operational Test and Evaluation Force's (COTF) Blue Team completed an Operational Information Assurance Vulnerability Evaluation on T-AKE 12 while in-port in February 2012. COTF's Red Team completed a penetration test while underway during April and May 2012.
- During the May at-sea period, COTF completed CBR and magnetic mine survivability tests. The Navy installed a new Improved Point Detection System-Lifecycle Replacement (IPDS-LR) on T-AKE 12, which was evaluated during the CBR test.
- The Surface Warfare Center Panama City Division conducted the Advanced Mine Simulation System test series during May 2012.

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Assessment

- During the Operational Information Assurance Vulnerability Evaluation, COTF's Blue Team found a number of potential Category I vulnerabilities within the various components of T-AKE 12. During the penetration test, however, none of the exploits the Red Team ran against T-AKE 12 were able to penetrate the ship's premise (outer most) router. However, the Red Team did achieve unauthorized access to the ship's computing system during the penetration test, which ultimately allowed the team to escalate user privileges and gain system access.
- During the CBR test, the ship's crew was able to don the necessary personal and collective equipment to defend themselves against the effects of CBR attacks and hazards. The newly installed IPDS-LR functioned properly and watch officers were able to respond to audible and visual alarms on the bridge. Unlike U.S. Navy ships, however, on MSC ships the IPDS-LR does not automatically activate the ship's general or chemical alarm. The crew must manually activate this alarm, followed by a general announcement that there is a CBR emergency.
- The CMWWD system was adequate. However, COTF conducted an additional test on T-AKE 1 (5 years old) that revealed that the system was severely degraded due to corrosion of the mild carbon steel piping.
- The analysis of test data collected while T-AKE operated near the Advanced Mine Simulation System (AMISS) is ongoing and no preliminary evaluation is available. DOT&E expects to issue a formal test report in 2QFY13.

Recommendations

- Status of Previous Recommendations. The Navy satisfactorily addressed all previous recommendations.
- FY12 Recommendations. The Navy should:
  1. Resolve IA Category I vulnerabilities.
  2. Resolve the CMWWD system's corrosion problem.

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Tomahawk Missile and Weapon System

Executive Summary
- As demonstrated during FY12 test flights, the Tomahawk Weapon System continues to meet Navy standards for reliability and performance.
- As assessed in the February 2012 FOT&E report to Congress, the Tomahawk Weapon System continues to be effective and suitable.
- DOT&E considers the planned Operational Test Launch program to be adequate for continued verification of system reliability and accuracy. DOT&E places high value on continuing flight data collection to evaluate end-to-end system performance and reliability for all deployed and deployable Tomahawk missile variants. However, in FY12, the Navy discontinued flight testing of the fielded Block III missiles, which are to remain in operational use until FY20.



System
- The Tomahawk Land Attack Missile is a long-range, land attack cruise missile designed for launch from submarines and surface ships.
- Production of Tomahawk Block II and III missiles is complete. There are four fielded variants: a Block II with a nuclear warhead (not deployed), a Block III with a unitary conventional warhead, a Block III with a conventional submunitions warhead, and a Block IV with a conventional unitary warhead.
- Block IV Tomahawk is in production as the follow-on to the Block III conventional unitary warhead variant. These missiles are produced at lower cost and provide added capability, including the ability to communicate with command and control and be redirected to an alternate target during flight.
- The Tomahawk Weapon System also includes the Tomahawk Command and Control System (TC2S) and the shipboard Tactical Tomahawk Weapon Control Systems (TTWCS). The TC2S and TTWCS provide for command and control, targeting, mission planning, distribution of Tomahawk tactical and strike data, and post-launch control of Block IV missiles.

Mission
The Joint Force Commander employs the Tomahawk Weapon System for long-range, precision strikes against land targets.

Major Contractor
- Missile element: Raytheon Missile Systems – Tucson, Arizona
- Weapon Control System element: Lockheed Martin – Valley Forge, Pennsylvania
- Command and Control element: QinetiQ North America LLC – San Jose, California, and Boeing Inc. – St. Louis, Missouri

Activity
- DOT&E submitted the FOT&E operational test report to Congress in February 2012.
- In accordance with the DOT&E-approved Test and Evaluation Master Plan and operational test plan, the Navy continued to conduct FOT&E Operational Test Launches to verify reliability and performance of fielded Block III and IV Tomahawk missiles, their associated weapon control systems, and the TC2S. The Navy conducted a total of eight Tomahawk missile test launches in FY12.
- In FY12, DOT&E conducted a comparative flight reliability analysis of over 200 operational Tomahawk firings conducted by the fleet during FY11 to the reliability demonstrated during all Operational Test Launches conducted to date.

Assessment
- As demonstrated during FY12 test flights, the Tomahawk Weapon System continues to meet Navy standards for reliability and performance. As reported to Congress in the FY12 FOT&E report, the Tomahawk Weapon System continues to be effective and suitable.
- DOT&E considers the current Operational Test Launch program for all Tomahawk missile variants to be adequate

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for continued verification of system reliability and accuracy. However, while Block IV testing is funded through FY13, the Navy is not funding further Block III test launches. The Block III missiles are to remain in operational use until FY20. DOT&E places high value on continuing flight test data to evaluate end-to-end system performance and reliability for all deployed and deployable Tomahawk missile variants.

- The DOT&E analysis of FY11 operational Tomahawk firings concluded that Tomahawk fleet firing reliability is consistent with observed FOT&E Operational Test Launch results.

Recommendations

- Status of Previous Recommendations. The Navy has addressed all previous recommendations.
- FY12 Recommendation.
  1. The Navy should resource the FOT&E Operational Test Launch series to include testing of all fielded missile variants.

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Vertical Take-Off and Landing Unmanned Aerial Vehicle (VTUAV)

Executive Summary

- The Navy stopped production of the MQ-8B air vehicle after procuring 23 MQ-8Bs. They have not conducted IOT&E on the MQ-8B air vehicles. The Navy is considering replacement of the Schweizer 333 (MQ-8B) airframe with the Bell 407 (MQ-8C). MQ-8C development is in response to a U.S. Special Operations Command Joint Universal Operational Needs Statement.
- The Test and Evaluation Master Plan (TEMP) approved in 2007 is outdated and does not contain a clear path to successful development, integration, and testing of the Vertical Take-Off and Landing Unmanned Aerial Vehicle (VTUAV).
- The Navy deployed MQ-8B Fire Scout systems aboard Navy frigates USS *Simpson* and USS *Klakring* during 2012. The USS *Simpson* supported forward presence and training operations off the west coast of Africa while the USS *Klakring* conducted operations off the Horn of Africa. The *Simpson* and *Klakring* deployments aboard Navy frigates demonstrated that the VTUAV has potential to provide the commander with valuable Intelligence, Surveillance, and Reconnaissance (ISR) once the program addresses shortcomings identified during developmental testing. Demonstrated component lifecycle reliability is well below program planning levels.
- Past and present MQ-8B deployments aboard frigates and operations in support of the ISR Task Force resulted in a critical shortage of spare parts.
- Operational deployments and developmental testing confirmed that system reliability, availability, communications relay, and documentation remain unsatisfactory.
- Moving from the MQ-8B to the MQ-8C airframe may or may not improve VTUAV reliability.

System

- The VTUAV is a helicopter-based tactical Unmanned Aerial System comprised of up to three Fire Scout air vehicles with payloads, a shipboard integrated Ground Control Station with associated Tactical Common Data Link (TCDL), and the Unmanned Aerial Vehicle Common Automatic Recovery System (UCARS).



- The Navy intends the VTUAV with the MQ-8B to have the following capabilities:
  - Combat radius – 110 nautical miles
  - Endurance at combat radius – 3 hours on station
  - Target Identification – Small fast attack boats at 6 kilometer range
  - Initial payload consists of the AN/AAQ-22D Bright Star II electro-optical and infrared imaging system with laser designator
- The Navy is considering replacement of the Schweizer 333 (MQ-8B) airframe with the Bell 407 (MQ-8C).

Mission

Aviation detachments equipped with VTUAVs perform reconnaissance, surveillance, target acquisition, and communications relay missions in support of littoral Anti Submarine Warfare, Anti-Surface Warfare, and Mine Warfare operations. System deployments during 2012 provided reconnaissance and surveillance to units conducting combat operations ashore.

Major Contractor

Northrop Grumman-Ryan Aeronautical – San Diego, California

Activity

- The Navy has stopped production of the MQ-8B air vehicle after procuring 23 MQ-8Bs. Instead, the Navy has focused on development of the MQ-8C air vehicle (also known as the "Endurance Upgrade") as a Rapid Deployment Capability. The Navy is considering replacement of the Schweizer 333 (MQ-8B) airframe with the Bell 407 (MQ-8C).
- MQ-8C development is in response to a U.S. Special Operations Command Joint Universal Operational Needs

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Statement. The Program Office issued a sole source contract to Northrop Grumman for MQ-8C development.
- Northrop Grumman is conducting MQ-8C risk reduction flight testing using internal research and development funds.
- The Navy is considering procurement of 31 MQ-8C air vehicles (28 production air vehicles plus 3 research, development, and engineering air vehicles).
- The Navy has not conducted IOT&E on the 23 MQ-8B air vehicles already procured.
- The Navy is working on the integration of weapons and a search radar capability to the MQ-8B air vehicle in response to a Navy Urgent Operational Need.
- The Navy deployed MQ-8B Fire Scout systems aboard Navy frigates USS *Simpson* and USS *Klakring* during 2012. The USS *Simpson* supported forward presence and training operations off the west coast of Africa while the USS *Klakring* conducted operations off the Horn of Africa. The Navy's Commander, Operational Test and Evaluation Force published a Quick Reaction Assessment in September 2012.
- One Fire Scout system continues to support ISR Task Force operations in Afghanistan.
- The Navy lost two MQ-8B aircraft in April 2012. Operators aboard USS *Simpson* intentionally ditched one air vehicle after encountering problems with the recovery system. The Navy recovered this air vehicle. The second air vehicle was destroyed after crashing while operating in support of the ISR Task Force in Afghanistan.
- In May 2012, Naval Air Systems Command published an Interim Summary Report addressing the status of MQ-8B developmental testing.
- The Navy plans to update the TEMP by April 2013; this update is expected to expand the scope of IOT&E.

Assessment
- The TEMP approved in 2007 is outdated and does not contain a clear path to successful completion of IOT&E. The TEMP does not clearly define the objectives of near-term testing, nor does it prioritize future upgrades such as search radar and weapons integration.
- Developmental testing during 2012 verified the correction of several deficiencies that adversely affected system performance. Software updates corrected the target location error and payload automatic caging deficiencies. The software now allows skilled operators to conduct dual air vehicle operations.
- The *Simpson* and *Klakring* deployments demonstrated that the VTUAV has the potential to provide the commander with valuable ISR once the program addresses shortcomings identified during developmental testing.
- Data collected during operational deployments and developmental testing show that the VTUAV system has performed to a satisfactory level in the areas of air vehicle operations, maintainability, compatibility, interoperability, human factors, and safety.
- Demonstrated component lifecycle reliability is well below program planning levels. This resulted in unacceptable values for Availability, Mean Flight Hours Between Operational Mission Failures, and Mean Flight Hours Between Unscheduled Maintenance Actions, preventing the program from entering into IOT&E. This poor reliability adversely affects performance of the forward-deployed systems and increases the workload of the aviation detachments.
- The Navy based Fire Scout spare parts budgeting on design reliability and operating tempo in support of the Littoral Combat Ship. Past and present deployments aboard frigates and operations in support of the ISR Task Force combined with significantly lower lifecycle reliability have caused a critical shortage of spare parts.
- Data collected during operational deployments and developmental testing confirmed that system performance in the areas of reliability, availability, communications relay, and documentation remain unsatisfactory.
- The Navy has yet to assess several critical areas related to VTUAV performance. These include tactics, logistics supportability, training, and manning. Each of these areas, in and of themselves, could render the system not effective or not suitable during IOT&E.
- Moving from the MQ-8B to the MQ-8C airframe may or may not improve VTUAV reliability. While the Navy will not see some failure modes specific to the MQ-8B on the MQ-8C, the MQ-8C includes systems not found on the MQ-8B.

Recommendations
- Status of Previous Recommendations. The Navy has made satisfactory progress on three of the four FY11 recommendations. It has developed overland ISR standard operating procedures and an operator training syllabus for aviation detachments operating VTUAV. The Navy has also established an office to review and coordinate all Navy UAS development and fielding, which addresses the recommendation to conduct an end-to-end review of its command and control network to facilitate the dissemination of near-real-time video. Given the delay in IOT&E, the one remaining recommendation to expand the scope of IOT&E will be addressed as the Navy updates the TEMP.
- FY12 Recommendations. The Navy should:
  1. Conduct in-depth shipboard testing to fully characterize TCDL performance to include air vehicle orientation in relation to the ship and ship orientation in relation to the air vehicle.
  2. Use available data to conduct a formal assessment of VTUAV tactics, logistics supportability, training, and manning to identify areas of risk to successful IOT&E.
  3. Conduct a failure mode analysis between the MQ-8C and the MQ-8B to determine which failure modes are common, which failures modes do not transfer from the MQ-8B to the MQ-8C, and which failure modes are unique to the MQ-8C.

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AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM)

Executive Summary

- In 2009, key stakeholders, including the Program Office and DOT&E, suspended progression of the AIM-120D to operational testing due to four performance and reliability deficiencies. Raytheon addressed the four deficiencies, and DOT&E signed the revised AIM-120D Test and Evaluation Master Plan (TEMP) and separate, detailed operational test plan on May 25, 2012.
- The Air Force completed an Operational Test Readiness Review on May 31, 2012, and certified the AIM-120D Advanced Medium-Range Air-to-Air Missile (AMRAAM) to begin operational testing in June 2012. AIM-120D operational testing will consist of seven live missile shots and multiple captive-carry events. The Services are projected to complete operational testing in FY14.
- During operational testing to date, the Air Force has accomplished three AIM-120D shots, the first of which was unsuccessful. The unsuccessful shot was due to a reliability failure of a legacy Shortened Control Actuation System. The Air Force has re-executed this shot and is awaiting data analysis to determine its success.
- The AMRAAM Electronic Protection Improvement Program (EPIP) is a software upgrade to AIM-120C3-C7 variants currently in integrated testing, under the separate EPIP TEMP that DOT&E approved in April 2012.

System

- The AIM-120 AMRAAM is an all-weather, radar-guided air to-air missile with capability in both the beyond-visual-range and within-visual-range arenas. A single launch aircraft can engage multiple targets with multiple missiles simultaneously when using AMRAAM.
- The AMRAAM program develops and incorporates phased upgrades periodically. AMRAAM EPIP is a software upgrade to AIM-120C3-C7.



- The latest version, the AIM-120C7, incorporated an upgraded antenna, receiver, signal processor, and new software algorithms to counter new threats. The use of smaller system components created room for future growth.
- The AIM-120D is currently in development, and the Air Force intends for it to deliver performance improvements beyond the AIM-120C7 through the use of an internal GPS, an enhanced datalink, and new software.

Mission

- The Air Force and Navy, as well as several foreign military forces, use various versions of the AIM-120 AMRAAM to shoot down enemy aircraft.
- All U.S. fighter aircraft use the AMRAAM as the primary beyond-visual-range air-to-air weapon.

Major Contractor

- Raytheon Missile Systems – Tucson, Arizona
- Rocket Motor Subcontractors:
  - Alliant Techsystems (ATK) – Arlington, Virginia
  - Nammo – Raufoss, Norway

Activity

AIM-120D

- Production of the AIM-120D began in 2006, and developmental testing, which included three integrated developmental/operational test missile shots, began in 2007.
- In 2009, key stakeholders, including the Program Office and DOT&E, suspended progression of the AIM-120D to operational testing due to four performance and reliability deficiencies, including missile lockup, built-in test failures, aircraft integration problems, and poor GPS satellite acquisition.
- The Air Force accomplished the final developmental/operational test shot in August 2011. Raytheon addressed the four deficiencies, and DOT&E signed the TEMP and separate operational test plan on May 25, 2012. The Air Force conducted an Operational Test Readiness Review in May 2012, and certified the program to begin operational testing in June 2012. Testing

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is progressing in accordance with the DOT&E-approved TEMP and test plan.
- AIM-120D operational testing will consist of seven live missile shots and multiple captive-carry events. The Services are projected to complete operational testing in FY14.

AMRAAM EPIP
- DOT&E approved the AMRAAM EPIP TEMP on April 13, 2012, after which integrated testing began.

Lot Acceptance Test/Rocket Motors
- Beginning in December 2011, propellant hot spots, burn through, and failures at low temperatures (-65 degrees Fahrenheit) caused unpredictable Lot Acceptance Test (LAT) failures. ATK, the subcontractor who produces the rocket motors, continues to investigate these failures.
- The Program Office, Raytheon, and AMRAAM safety communities coordinated to certify Nammo to become an approved alternative rocket motor supplier.
- The Program Office has suspended performance-based payments until resolution of the shortage of rocket motors due to unacceptable LAT performance.

Assessment
- The Air Force originally planned for AIM-120D to begin operational testing in 2008; it is now approximately four years behind schedule.
- The Air Force adequately addressed fixes to the four performance and reliability deficiencies that precluded AIM-120D from proceeding to operational testing:
  - Raytheon fixed the built-in test false alarm with a software modification.
  - Raytheon fixed the GPS failure problem with a GPS filter, which was verified with multiple laboratory events and a successful live missile shot.
  - The Air Force and Navy requirements sponsors clarified software requirements, and subsequent software changes reduced the frequency of missile lockups.
  - Software changes mitigated some aircraft integration problems, but more problems will need resolution in a System Improvement Program following operational testing.
- Since the start of operational testing, the Air Force has executed three live missile shots. The first was a reliability failure most likely due to a grounding wire common to all AMRAAM variants going back to the AIM-120C5. The second live missile shot was the first AIM-120D launch from an F-22 and resulted in a direct hit on the drone. The third was a re-execution of the first live missile shot and the Air Force is awaiting data analysis to determine its success. Additionally, captive-carry performance has been nominal and the Air Force has yet to quantify system reliability.
- The shortage in rocket motors due to unacceptable LAT performance should not significantly affect AIM-120D testing, but it has created a backlog in production. After Insensitive Munitions certification in October 2012, Nammo will be the only AIM-120D and AIM-120C7 rocket motor producer for the foreseeable future. The government and Raytheon are still reviewing a path forward for ATK production.

Recommendations
- Status of Previous Recommendations. The FY07 recommendation for the Program Office to seek changes to the Air Force's full-scale and sub-scale target programs to ensure proper target presentation, target reliability, and availability remains valid. The Air Force has adequately addressed all other previous recommendations.
- FY12 Recommendations.
  1. The Air Force should complete a System Improvement Program within one year of the completion of operational testing to address any remaining aircraft integration problems, as well as any problems discovered during operational testing.
  2. The Program Office should continue root cause analysis of rocket motor LAT failures and keep the Air Force, Navy, and OSD updated on potential impacts to cost, schedule, and performance.

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Air Operations Center – Weapon System (AOC-WS)

Executive Summary

- The Air Operations Center – Weapon System (AOC-WS) 10.1 is a system-of-systems that contains numerous third-party software applications, including the Global Command and Control System – Joint (GCCS-J), Theater Battle Management Core Systems – Force Level (TBMCS-FL), Master Air Attack Plan Toolkit (MAAPTK), and Joint Automated Deep Operations Coordination System (JADOCS).
- The Air Force tests AOC-WS 10.1 software upgrades during Recurring Events (REs) and refers to each software upgrade by the event during which it was tested. For example, AOC-WS 10.1 RE11 is the software upgrade that was tested during RE11.
- The Air Force conducted operational testing of RE11 in March 2012 using older servers due to a short timeline to integrate newer servers for test.
- The 605th Test and Evaluation Squadron (TES) conducted a regression test in May 2012 on newer, more powerful servers. This test included additional software fixes to GCCS-J provided by the Defense Information Systems Agency (DISA).
- From July through September 2012, the Air Force conducted a third phase of RE11 operational testing at the 613th AOC, Hickam AFB, Hawaii.
- Using RE11, operators can successfully execute all critical missions and produce threshold or larger-sized target lists and Air Tasking Orders on schedule. The Common Operational Picture exceeded the AOC requirement for updating and displaying the threshold number of tracks in near real-time.
- RE11 demonstrated interoperability with other mission-critical systems. Operational testing showed that RE11 addresses the significant legacy RE10 and GCCS-J deficiencies identified from previous testing. RE11 provides a significant improvement to AOCs both in internal functionality, as well as in interoperability with Combatant Commands.
- The 605th TES is still evaluating RE11's operational suitability; however, data collected to date indicate the need for some improvement. RE11 requires significant manpower to maintain the security posture of the system. Each operational AOC has site-unique requirements that each unit must incorporate into RE11. The AOC-WS Help Desk is working to adapt their enabling concept to include the enhanced capabilities in RE11.
- Users find training acceptable, and the overall system availability is acceptable. Information Assurance risk is acceptable, and the system has obtained an Authority to Operate.

System

- The AOC-WS is the senior command and control element of the U.S. Air Force's Theater Air Control System and



provides operational-level command and control of air, space, and cyberspace operations, as well as joint and combined air, space, and cyberspace operations. Capabilities include command and control of joint theater air and missile defense; time-sensitive targeting; and intelligence, surveillance, and reconnaissance management.
- The AOC-WS 10.1 (AN/USQ-163 Falconer) is a system-of-systems that contains numerous third-party-developed software applications and commercial off-the-shelf products. Each third-party system integrated into the AOC-WS provides its own programmatic documentation.
- The AOC-WS consists of:
  - Commercial off-the-shelf hardware
  - Separate third-party software applications (GCCS-J, TBMCS-FL, MAAPTK, and JADOCS), from which the AOC-WS draws its capabilities
  - Additional third-party systems that accept, process, correlate, and fuse command and control data from multiple sources and share them through multiple communications systems
- AOC-WS 10.1 operates on several different local area networks (LANs), including Secret Internet Protocol Router Network, Joint Worldwide Intelligence Communications System, and a coalition LAN, when required. The LANs connect the core operating system and primary applications to joint and coalition partners supporting the applicable area of operation. Users can assess web-based applications through the Defense Information Systems Network.
- The Air Force tests AOC-WS 10.1 software upgrades during REs. The Air Force refers to each software upgrade by the event during which it was tested. For example, AOC-WS 10.1 RE11 is the software upgrade that was tested during RE11.
- The future AOC-WS 10.2 will be the first increment for modernization.

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Mission

The Commander, Air Force Forces, or the Joint/Combined Forces Air Component Commander use the AOC-WS to exercise control of joint (or combined) air forces including planning, directing, and assessing air, space, and cyberspace operations to meet operational objectives and guidance.

Major Contractors

- AOC-WS 10.1 Production Center: Jacobs Technology Inc., Engineering and Technology Acquisition Support Services – Hampton, Virginia
- AOC-WS 10.2 Modernization: Northrop Grumman Corporation – Hampton, Virginia

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Activity

- The Air Force has developed an RE test cycle for major AOC-WS 10.1 upgrades, along with lower-level testing events to sustain interoperability and Information Assurance, and to provide low-risk upgrades to third-party systems as required. DOT&E approved an update to the program's Test and Evaluation Master Plan in December 2011, and approved an overarching operational test plan for all AOC-WS 10.1 testing in February 2012.
- The Air Force conducted developmental testing of RE11 in January 2012 and made several fixes to mission-critical problems. The Air Force conducted a subsequent regression test in February 2012.
- RE11 introduced GCCS-J Integrated Imagery and Intelligence as the intelligence and targeting capability provider for AOC-WS and upgraded TBMCS-FL with Maintenance Release 2 to migrate to current Modernized Integrated DataBase (MIDB) 2.1. Without the TBMCS-FL and GCCS-J upgrades, the AOC-WS is restricted to using a less-capable MIDB 2.0.
- Air Combat Command (ACC) conducted a risk analysis of the 11 open Category I test problem reports following the developmental and regression test. ACC determined the best course of action to meet current operational need was to proceed to operational testing and fielding of RE11.
- ACC developed a plan of action and milestones to address the 11 open Category I deficiencies at the time of operational test initiation. This decision was to be revisited if any additional Category I problems were discovered during operational test.
- The Air Force conducted operational testing of RE11 in March 2012. The AOC-WS Program Office had addressed 4 of the 11 open Category I problem reports by the start of the operational test. The GCCS-J portion of this testing was conducted on older servers; previous testing has shown that these servers have insufficient computing power. The newer, more powerful servers were not available in time to meet the initial integration and test schedule.
- The 605th Test and Evaluation Squadron conducted regression testing of RE11 in May 2012 using newer, more powerful servers to host the GCCS-J software. DISA had also provided several fixes to GCCS-J in the form of an Update 1 software release.
- The Air Force conducted a third phase of operational testing of RE11 at the 613th AOC, Hickam AFB, Hawaii, July through September 2012. This testing focused on the ability of the install team to correctly upgrade and configure the AOC from legacy RE10 to RE11, and perform backup and recovery actions on RE11.
- DISA provided additional fixes to GCCS-J to the Air Force for incorporation into the next upgrade (RE12), currently scheduled for developmental and operational testing in December 2012.
- The Air Force conducted all RE11 testing in accordance with the DOT&E-approved test plan.

Assessment

- The Air Force adequately tested RE11 through a combination of developmental and operational testing.
- RE11 can successfully execute all critical missions and produce threshold or larger-sized target lists and Air Tasking Orders on schedule. The Common Operational Picture was able to exceed the AOC requirement for updating and displaying the threshold number of tracks in near real-time.
- RE11 demonstrated interoperability with other mission-critical systems. Operational testing showed that RE11 could address the significant AOC-WS and GCCS-J deficiencies identified from previous testing.
- Users successfully demonstrated the ability to transfer Joint Forces Air Component Command responsibilities. Users encountered three Category I critical deficiencies with third-party software systems that are used within RE11, but these problems did not prevent mission accomplishment. ACC accepted these limitations while encouraging prompt resolution of these problems. RE11 provides a significant improvement to AOCs, in both internal functionality as well as their ability to interoperate with their respective Combatant Commands.
- The 605th TES is still evaluating RE11's operational suitability; however, data collected to date indicate the need for some improvement. RE11 requires significant manpower to maintain the security posture of the system on a recurring basis and the AOC-WS password change procedures are complex and inordinately lengthy. The GCCS-J backup and recovery, and server password change procedures for the newer servers are deficient. System administrators require extensive training in order to competently manage the system. Each operational AOC has site-unique requirements that must be incorporated into RE11. The AOC-WS Help Desk is working to adapt their enabling concept to include the enhanced capabilities in RE11. Users find training acceptable and the overall system availability meets requirements. Information Assurance risk

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is acceptable, and the system has obtained an Authority to Operate.
- The key to successful testing and fielding of RE11 has been closer collaboration between the AOC-WS Program Office and DISA to ensure GCCS-J meets the operational needs of the AOCs. As a result of AOC-WS tester involvement in GCCS-J testing, the AOC-WS testers identified critical problems early for corrective action.
- The high-priority fixes DISA provided to GCCS-J in Update 1 improved data exchange between GCCS-J and RE11.

Recommendations
- Status of Previous Recommendations. The Air Force is adequately addressing previous recommendations. Two of the FY11 recommendations are long-term improvements that are currently being worked and still need continued effort.
  1. Coordinate with third-party programs to ensure that critical AOC-WS third-party systems (such as GCCS-J) have testable requirements that meet AOC-WS requirements. Requirements should be properly vetted within the appropriate user and program communities for schedule and funding priority.
  2. Ensure the AOC-WS users and test community continue to actively participate in GCCS-J developmental and operational testing and collaborate to develop a capability to adequately test GCCS-J to AOC-WS threshold stress levels.
- FY12 Recommendations.
  1. The Air Force should address suitability concerns with RE11, especially enabling system managers to more easily maintain the security posture of the RE11.
  2. Per the recommendation from DOT&E's Information Assurance/Interoperability assessment memorandum to the Director of Operations (J3), Joint Staff, the Joint Staff should establish or identify a systems integration group for command and control systems. These command and control systems will be responsible for providing comprehensive oversight/management of joint command and control systems and mission-critical interfaces, with particular emphasis on joint data fusion and operations centers, such as the AOC. Systems that should be addressed include, but are not limited to, GCCS-J, MIDB, TBMCS-FL, JADOCS, Joint Targeting Toolbox, and AOC-WS.

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ALR-69A Radar Warning Receiver (RWR)

Executive Summary

- The Air Force Operational Test and Evaluation Center (AFOTEC) accomplished IOT&E from May 18 through July 16, 2012. The flight tests were flown at the Fallon Range Training Complex, Nevada, and the Multi-Spectral Test and Training Environment at Eglin AFB, Florida, resulting in a total threat exposure time of 12 hours. The system logged a total of 204 hours of operating time during IOT&E.
- DOT&E assessed the system as not operationally effective but operationally suitable. The system was not operationally effective because it did not consistently provide the aircrew timely and accurate threat information and the system demonstrated a random threat symbol splitting deficiency. Threat symbol splitting occurs when one threat signal received by the system produces multiple threat symbols at different azimuths on the cockpit display. This degrades the aircrew's situational awareness as to which displayed threats are "real" and where those real threats are located and inhibits the aircrew's ability to appropriately react to the threat(s) in a timely manner. The details of the DOT&E assessment are presented in DOT&E's classified IOT&E report, dated October 2012.
- Although the Air Force System Program Office (SPO) and Raytheon conducted hardware-in-the-loop (HWIL) tests to demonstrate the threat signal splitting deficiency has been resolved, DOT&E does not think HWIL testing by itself is adequate to verify the deficiency has been resolved and that the software update did not induce any other adverse system performance.

System

- The ALR-69A is a Radar Warning Receiver (RWR) that detects, identifies, and locates threat electronic signals.
- The Core ALR-69A RWR is designed to improve performance over the Air Force's primary RWR system, the ALR-69, by enhancing:
  - Detection range and time
  - Accuracy of threat identification
  - Location of threat emitter systems
  - Performance in a dense signal environment
  - Reliability and maintainability



1 - Legacy ALR-69 Components
2 - Primary ALR-69 Components
3 - Radar Receiver
4 - Countermeasure Signal Processor

- The system integrates with transport and fighter aircraft. The lead platform is the C-130H, with other platforms possibly to be added at a later date.
- Core ALR-69A RWR components include:
  - Radar receivers (previously the digital quadrant receivers)
  - Modular Countermeasures Signal Processor (previously the countermeasures computer)
  - Control indicator
  - Azimuth indicator

Mission

- Combatant Commanders will use ALR-69A to enhance the survivability of transport, fighter, and Special Operations aircraft on missions that penetrate hostile areas.
- Aircrews use the ALR-69A to provide indication of ground and airborne radar threats in order to support threat avoidance maneuvers and/or timely use of defensive countermeasures.

Major Contractor

Raytheon, Space and Airborne Systems – Goleta, California

Activity

- The Air Combat Command 413th Flight Test Squadron issued a Developmental Test and Evaluation (DT&E) report in February 2012 to the SPO at Warner Robins Air Force Base, Georgia. The report covered testing accomplished between February 2010 and May 2011. The SPO briefed DT&E results to the Milestone Decision Authority in November 2011.
- DOT&E approved the AFOTEC IOT&E Test Concept on February 12, 2012, and approved the IOT&E test plan

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and revised Test and Evaluation Master Plan (TEMP) on February 16, 2012.
- AFOTEC began suitability flights in April 2012, and held IOT&E test crew training in early May 2012, with several suitability flight tests occurring shortly afterwards.
- AFOTEC began operational flight testing on May 18, 2012, at the Fallon Range Training Complex, Nevada. As a result of weather and competing range priorities, the system was only exposed to range threats for approximately 4 hours. In response, AFOTEC flew three additional missions on June 12, 13, and 15 at the Multi-Spectral Test and Training Environment at Eglin AFB, Florida. The combination resulted in a total threat exposure time of 12 hours. The system logged a total of 204 hours of operating time during IOT&E.
- AFOTEC conducted the final test of IOT&E on July 16, 2012. It was a ground-based test designed to evaluate the system's reprogramming capability.
- On August 1, 2012, the Air Force SPO and Raytheon conducted a HWIL test comparing the performance of the ALR-69A software that was used during IOT&E to updated software generated to correct a threat symbol splitting deficiency observed throughout IOT&E.
- AFOTEC did not execute testing in accordance with the DOT&E-approved test plan. AFOTEC deviated from the test plan in the following areas: AFOTEC pre-briefed aircrews about the type and location of threats, which reduced DOT&E's ability to determine the contribution the ALR-69A made to the aircrew's situational awareness; several missions lacked operational realism; and aircrew questionnaires did not incorporate inputs from DOT&E to improve the quality of the data generated from the questionnaires.

Assessment
- DOT&E assessed the ALR-69A system as not operationally effective but operationally suitable. The system was not operationally effective because it did not consistently provide the aircrew timely and accurate threat information and the system demonstrated a random threat symbol splitting deficiency. Threat symbol splitting occurs when one threat signal received by the system produces multiple threat symbols at different azimuths on the cockpit display. This degrades the aircrew's situational awareness as to which displayed threats are "real" and where those real threats are located and inhibits the aircrew's ability to appropriately react to the threat(s) in a timely manner. The details of the DOT&E assessment are presented in DOT&E's classified IOT&E report, dated October 2012.
- Although the SPO and Raytheon conducted HWIL tests to demonstrate the threat signal splitting deficiency has been resolved, HWIL testing by itself is not adequate to verify the deficiency has been resolved and that the software update did not induce any other adverse system performance.

Recommendations
- Status of Previous Recommendations. DOT&E last reported on this program in FY09. The Air Force has satisfactorily addressed previous recommendations.
- FY12 Recommendations. The Air Force should:
  1. Correct aircrew threat audio warnings so that the appropriate tone is associated with the correct status of the threat.
  2. Improve the timeliness and accuracy of threat information provided to the aircrew to improve the aircrew's situational awareness.
  3. Conduct flight testing to verify the system is operationally effective and that the software upgrade implemented by the SPO and Raytheon corrects the threat symbol splitting deficiency and did not degrade system performance in any other area.

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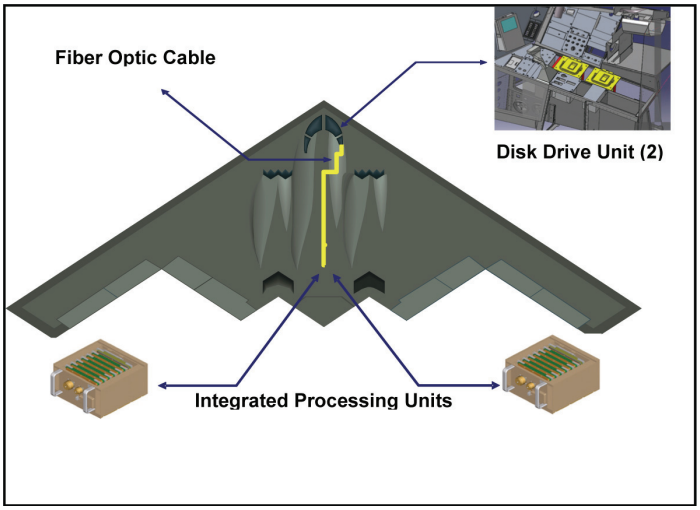
B-2 Extremely High Frequency (EHF) Satellite Communications (SATCOM) and Computer Upgrade Program

Executive Summary

- Developmental flight testing that began in September 2010 completed in April 2012.
- The Air Force Operational Test and Evaluation Center (AFOTEC) conducted IOT&E from June through August 2012 to assess the program's operational effectiveness, suitability, and mission capability. The IOT&E included 6 sorties and 56 hours of dedicated flight testing including navigation, long duration missions, and both conventional and nuclear weapons delivery events. IOT&E further assessed effectiveness and suitability data across 283 hours of developmental/integrated flight test missions conducted during formal developmental testing.
- IOT&E results indicate the system is operationally effective. However, the limited flight test hours accumulated preclude DOT&E from making a definitive assessment of the system's ability to meet the legacy system demonstrated Mean Time Between Critical Failure (MTBCF) of 671 hours. Therefore, continued monitoring of installed system performance in operational aircraft is necessary to confirm reliability.
- The Air Force plans to conduct the Full-Rate Production Decision in December 2012.

System

- The B-2 is a multi-role, low-observable bomber, capable of delivering conventional and nuclear munitions. It has four turbofan engines and twin side-by-side weapons bays.
- B-2 system avionics include a multi-mode radar, GPS-aided navigation, and a Defensive Management System for radar warning functions.
- The B-2 Extremely High Frequency (EHF) Satellite Communications (SATCOM) and Computer Upgrade program is designed to deliver capability across distinct increments. Increment 1 upgrades the core flight management processing capability of the B-2 and lays the foundation for subsequent avionics upgrades. Increment 1 replaces the existing aircraft flight management computers with two new Integrated Processing Units and two new Data Drive Units to increase data storage. Increment 1 also re-hosts the aircraft Flight Management Operational Flight Program from its legacy flight management software programming language, JOVIAL, to C.



- Follow-on B-2 EHF SATCOM Increments will remove the legacy B-2 MILSTAR AN/ASC-36 Ultra High Frequency (UHF)/Air Force SATCOM System, and add the Family of Advanced Beyond Line-of-Sight Terminals and a low observable antenna to support EHF and Advanced EHF communications connectivity. The final Increment is planned to be software-centric and provide full software integration of the B-2 EHF SATCOM upgrade, including Global Information Grid connectivity.

Mission

- Combatant Commanders use the B-2 aircraft to attack global targets during the day or at night, in all weather, in highly defended threat areas at the strategic, operational, and tactical levels of warfare.
- Commanders use the B-2 to engage high-value, heavily defended target sets including: command and control facilities, airfields, industrial complexes, logistical and air defense systems, lines of communication, and battlefield forces and equipment.

Major Contractor

Northrop Grumman – Falls Church, Virginia

Activity

- The Air Force conducted B-2 EHF SATCOM Increment 1 testing in accordance with the DOT&E-approved Test and Evaluation Master Plan and IOT&E plan.
- Developmental flight testing that began in September 2010 completed in April 2012. AFOTEC conducted IOT&E from

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June through August 2012 to assess the program's operational effectiveness, suitability, and mission capability. IOT&E included 6 sorties and 56 hours of dedicated flight testing including navigation, long-duration missions, and both conventional and nuclear weapons delivery events. IOT&E further assessed effectiveness and suitability data across 283 hours of developmental/integrated flight test missions conducted during formal developmental testing.
- The Air Force plans to conduct the Full-Rate Production Decision in December 2012.

Assessment
- Results from the IOT&E indicate B-2 met legacy SATCOM, nuclear and conventional weapons accuracy, and navigational system accuracy.
- Accumulated system flight test hours were sufficient to evaluate overall system maintainability consistent with the B-2 Global Strike Concept of Operations. However, the limited flight test hours accumulated preclude DOT&E from making a definitive assessment of the system's ability to meet the legacy system demonstrated operational MTBCF of 671 hours. Therefore, continued monitoring of installed system performance in operational aircraft is necessary to confirm reliability.
- Operational availability of 96.6 percent did not meet the legacy system performance, but the difference is not operationally significant.

Recommendations
- Status of Previous Recommendations. The Air Force has addressed all previous recommendations.
- FY12 Recommendation.
  1. The Air Force should monitor fielded performance to ensure that system MTBCF and operational availability meet user requirements within a narrower set of confidence bounds as fleet flying hours accumulate.

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Battle Control System – Fixed (BCS-F)

Executive Summary
- Air Combat Command completed a Force Development Evaluation (FDE) on the Battle Control System – Fixed (BCS-F) Increment 3, Release 3.1.3 (R3.1.3) and fielded it at all U.S. air defense sites in December 2011.
- Results from testing found R3.1.3 supports North American Aerospace Defense Command (NORAD) air defense operations with shortfalls in training and technical system documentation, system security management, and system combat identification operations. R3.1.3 testing also revealed significant deficiencies in Information Assurance (IA).
- The Air Force completed IOT&E and FDE on the BCS-F R3.2 at all U.S. air defense sites in September 2012. R3.2 presented some IA improvements and achieved an interim Authority to Operate.

System
- The BCS-F is a tactical air battle management command and control system that provides the two continental U.S. NORAD air defense sectors, as well as the Hawaii and Alaska Regional Air Operation Centers, with commercial off-the-shelf hardware using an open-architecture software configuration. The system operates within the NORAD air defense architecture and is employed by the U.S. and Canada.
- The R3.2 upgrade includes the following system enhancements:
  - Improved tactical datalinks with additional Link 16 and Link 11 message types that enable the operators to better digitally control fighters, send amplifying intelligence information, and create a more comprehensive air picture
  - Air Tasking Order (ATO) and Airspace Control Order (ACO) integration with theater battle management core system data sources that enables the operators to view the most current ATO/ACO and correlate the information with military aircraft
  - Adaptation data modification tools to enable system administrators easier field changes to system adaptation files and to perform error checks with greater fidelity
  - System control manager interface improvements that enable the system administrator improved system performance monitoring and diagnostics
  - Global Area Reference System coordinate conversion tool that facilitates NORAD interface with global search and rescue efforts ensuring a common set of coordinates



  - Remote Gateway Manager control through the virtual network computing interface that provides the operators a complete picture of the available datalinks and the flexibility to access link information from an operator workstation
  - Auxiliary server for offline training and support capabilities at the U.S. air defense sectors
  - Improved system capacities from 10,300 to 15,000 system tracks to support single sector continental United States operations

Mission
- NORAD and U.S. Pacific Command Commanders use BCS-F to execute command and control and air battle management in support of air sovereignty and air defense missions for North American Homeland Defense.
- Air defense operators employ BCS-F to conduct surveillance, identification, and control of U.S. sovereign airspace and control air defense assets, including fighters, to intercept and identify potential air threats to U.S. airspace.

Major Contractor
Thales-Raytheon Systems – Brea, California

Activity
- Air Combat Command completed an FDE of R3.1.3 at the System Support Facility at Tyndall AFB, Western Air Defense Sector, Eastern Air Defense Sector, Alaska Regional Air Operations Center, and the Hawaii Regional Air Operations Center in December 2011.

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- The Air Force fielded R3.1.3 to all U.S. air defense sectors and Canada in December 2011.
- In September 2011, the Air Force's 92nd Information Operations Squadron (IOS) completed an insider threat assessment on R3.1.3.
- The Air Force conducted developmental testing on R3.2 at the System Support Facility at Tyndall AFB from July through October 2011 and January 2012. Additionally, the Air Force accomplished an IA certification test at this time. The Air Force also conducted developmental testing at the U.S. operational sectors from February through July 2012.
- The Air Force conducted system interoperability tests in November and December 2011 to evaluate datalink compliance with military standards.
- The Joint Interoperability Test Command is evaluating critical information exchanges in R3.2; testing started in April and will end in November 2012.
- In April 2012, the Air Force's 92nd IOS conducted penetration and vulnerability testing on R3.2 at the System Support Facility.
- The Air Force's 92nd IOS conducted an insider threat assessment on R3.2 at the Eastern Air Defense Sector in August 2012.
- From April through August 2012, the Air Force Operational Test and Evaluation Center (AFOTEC) conducted IOT&E on R3.2 at the System Support Facility and two U.S. operational sectors. Air Combat Command conducted FDE at the other two operational sectors.
- Air Combat Command began integrated developmental and operational testing of R3.2.1 at the System Support Facility in September 2012. The Air Force intends for R3.2.1 to provide a fix for a critical deficiency discovered during R3.2 operational testing. This deficiency causes a loss of situational awareness for the operators conducting surveillance of the National Capital Region and results in an inaccurate air picture. The Air Force designed R3.2.1 to provide the ability to operate with mandatory International Civil Aviation Organization flight plan changes scheduled for November 2012, and provide an update to local radar site information.
- AFOTEC and Air Combat Command conducted operational testing in accordance with a DOT&E-approved Test and Evaluation Master Plan.

Assessment

- DOT&E analyses of R3.1.3 concluded:
  - R3.1.3 is operationally effective and supports NORAD air defense operations, providing the ability to adequately perform core competencies and tasks required to accomplish the air defense mission.
  - R3.1.3 is operationally suitable with major shortfalls in logistics supportability, system documentation, and training. While training on datalink operations and combat identification have improved, system security training and training for differences in each new build still have major deficiencies.
  - Shortfalls in system security management and deficiencies in all IA assessment areas jeopardize secure system operations. Test results from the September 2011 insider threat assessment indicate R3.1.3 is deficient in the IA areas of protect, detect, react, and restore. The large number of outstanding deficiencies indicates the system's continued vulnerability to detect, withstand, or recover from attacks by cyber threats.
  - R3.1.3 demonstrated adequate reliability, maintainability, and availability. R3.1.3 has an average system availability of 99.98 percent, with over 1,118 hours of system operation during operational test.
  - Deficiencies still exist in R3.1 training for the intrusion detection system, the firewall, the local area network, the gateway manager, system doctrine, and combat identification. Additionally, R3.1 lacked adequate vulnerability management plans.
- A final assessment of R3.2 performance will not be available until all testing is completed in FY13 and DOT&E and the Air Force have analyzed the data. However, DOT&E preliminary analyses indicate:
  - A critical deficiency was discovered during operational testing at the Eastern Air Defense Sector. The BCS-F system did not reliably pass tracks to the Joint Air Defense Operations Center at Bolling AFB, Washington, D.C. This deficiency causes a loss of situational awareness for the operators conducting surveillance of the National Capital Region and results in an inaccurate air picture. The Eastern Air Defense Sector will not accept R3.2 until this deficiency is corrected. The Air Force planned to resolve this deficiency in R3.2.1, which underwent testing from September through October 2012.
  - R3.2.1 did not resolve the critical deficiency, and DOT&E assessed it as not effective and not suitable. The Air Force subsequently developed a new software release (R3.2.0.1), which completed testing at the end of November; preliminary data shows it fixed the critical deficiency. R3.2.0.1 also successfully demonstrated a temporary solution to operate with mandatory International Civil Aviation Organization flight plan changes. The permanent solution will be incorporated into R3.2.2. DOT&E will update the assessment of R3.2 once all test data has been received and analyzed.
  - Operational testing of R3.2 also uncovered the potential for BCS-F to provide inaccurate bearing and range information on an air track of interest. The effect of this deficiency is that commanders could make incorrect tactical decisions based on erroneous data. The operational sectors assessed this deficiency as critical, but Air Combat Command downgraded the severity and plans to implement a fix in R3.2.2, which the Air Force plans to start testing in January 2013.
  - Test personnel discovered six other critical deficiencies during R3.2 testing, but the Air Force paused testing,

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developed a fix for each critical deficiency, and demonstrated each fix during subsequent test events.

- The BCS-F is required to demonstrate a Mean Time Between Critical Failure of 10,000 hours with an operational availability of 99.98 percent. Six critical failures occurred during 699 hours of operational testing at the System Support Facility and the Eastern and Western Air Defense Sectors. Total system downtime at the System Support Facility and Eastern and Western Air Defense Sectors was approximately 44 hours for an operational availability of 90.5 percent during operational testing, which users consider inadequate given the mission of BCS-F. However, the Air Force has subsequently demonstrated fixes for the failures causing the downtime.

Recommendations

- Status of Previous Recommendations. The Air Force satisfactorily addressed all but three of the previous recommendations. The Air Force still needs to:
  1. Correct and formalize all BCS-F Increment 3 system documentation and training deficiencies.
  2. Develop a plan for remote workstation management to include sustainment, training, documentation, and IA compliance.
  3. Upgrade the System Support Facility to support a more robust BCS-F developmental and operational testing capability in order to minimize the impact of overall testing at the operational sites.
- FY12 Recommendations. The Air Force should:
  1. Improve R3.2 reliability and operational availability until these suitability requirements are demonstrated with statistical confidence.
  2. Continue to track and correct IA deficiencies.
  3. Demonstrate the permanent solution for R3.2 to successfully incorporate and process International Civil Aviation Organization flight plans.
  4. Update the R3.2 Test and Evaluation Master Plan to reflect planning and FY13 funding for R3.2 follow-on testing.

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C-5M

Executive Summary

- In February 2012, the Air Force completed a Force Development Evaluation of Operational Flight Program (OFP) 3.5 software combined with modifications to the engine thrust reversers. The C-5M with these upgrades is operationally effective, but it is still not operationally suitable.
- The C-5 Program Office is addressing deficiencies identified during previous operational tests, including problems with training systems and devices, Information Assurance, additional nuisance faults, the mission computers, the automatic throttles, and various maintenance Technical Orders through an extensive correction action plan. The Air Force plans to begin operational testing of OFP 3.5.2 in August 2013.
- The Air Force intends to award a contract for Core Mission Computer and Weather Radar upgrades in FY13.

System

- The C-5 is the largest four-engine military transport aircraft in the United States. The C-5 has 36 standard 463L pallet positions and airline seats for 81 passengers. It can carry a maximum payload of 270,000 pounds. The typical C-5 crew size is seven (two pilots, two flight engineers, and three loadmasters).
- The C-5M designation is the result of two separate but related modernization efforts:
  - The Avionics Modernization Program incorporates a mission computer, a glass cockpit with digital avionics (including autopilot and automatic throttles), and state-of-the-art communications, navigation, and surveillance components for air traffic management.
  - The Reliability Enhancement and Re-Engining Program provides over 50 reliability enhancements, plus commercial engines with new nacelles, thrust reversers, and pylons.



Mission

- Units equipped with the C-5 perform strategic airlift, emergency aeromedical evacuation, transport of brigade-size forces and equipment in conjunction with other aircraft, and delivery of outsize or oversize cargo (cargo that does not fit on a standard pallet).
- Units equipped with the C-5 execute missions at night, in adverse weather conditions, and in civil-controlled air traffic environments around the world. The units are capable of completing extended-range missions because the C-5 can receive in-flight aerial refueling.

Major Contractor

Lockheed Martin Aeronautics Company – Marietta, Georgia

Activity

- In February 2012, the Air Force completed a Force Development Evaluation of OFP 3.5 software combined with modifications to the engine thrust reversers in accordance with the DOT&E-approved test plan. OFP 3.5 is the second major modification to C-5M software.
- The Air Force made hardware modifications to the thrust reversers to address known deficiencies with deployment and retraction of the reversers.
- The Air Force began developmental testing of the next C-5M software version, Block 3.5.2, in May 2012 and plans to conduct operational testing in August 2013.
- The C-5 Program Office continues to address deficiencies identified during the C-5M initial operational tests in 2010, including training systems and devices, Information Assurance, additional nuisance faults, the mission computers, the automatic throttles, and various maintenance Technical Orders through a long-term corrective action plan.
- The Air Force intends to award supplier contracts for a new Core Mission Computer and a new Weather Radar in early FY13.

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Assessment

- The C-5M is operationally effective with limitations. OFP 3.5 mitigates Environmental Control System Deficiency Reports, reduces nuisance faults related to the Engine Electronic Control, and marginally improves performance of the automatic throttles.
  - Operational problems remain that constrain throttle usage and increase pilot workload, including the automatic throttle's inability to "capture" a pre-set airspeed and the extent of airspeed deviations during critical flight conditions, such as final approach. OFP 3.5 modifications to the Environmental Control System and automatic throttles mitigated cabin pressure and cabin temperature fluctuations and reduced the very large throttle movements associated with the use of automatic throttles. However, failure to maintain a commanded airspeed during critical phases of flight remains a problem. The automatic throttle response improved with OFP 3.5 but still deviated outside specified criteria. During gusty or turbulent wind conditions, the automatic throttle had difficulty maintaining the set speed.
  - Prior to the recent modifications, the thrust reversers did not deploy reliably in flight due to the freezing of condensed water within the Center Drive Units of the thrust reversers. This condition limited the aircraft's capability for procedures such as rapid descent from high altitude and tactical descent in a combat zone. The Air Force installed a computer-controlled heater blanket on the Center Drive Units, which prevented ice formation and significantly increased the reliability of thrust reverser deployment in flight.
  - During developmental tests of the heater blanket, the thrust reversers exhibited retraction problems. If the reversers do not fully retract, the likelihood of a subsequent unintended deployment increases. Therefore, the engineers increased the retraction force and added mechanical snubbers (devices used to absorb excess force) to the thrust reversers. Now, the reversers deploy and retract reliably in flight, but require additional inspections.
- The C-5M is still not operationally suitable. The aircraft's ability to conduct the strategic airlift mission is hindered by deficiencies in the Automatic Flight Control System, by problems with the Embedded Diagnostics System (EDS) and built-in test (BIT) functionality, by inadequate support equipment, and by a lack of dedicated training systems.

  Deficiencies in several aspects of C-5M support functions, identified before the 2010 OT&E began, had a significant effect on suitability, specifically the maintainability of the aircraft. Planned fixes for the deficiencies described below remain in development:
  - BIT – a very high false alarm rate combined with a low fault isolation rate increased the time needed to troubleshoot and complete maintenance actions. BIT detections of critical faults did not meet the requirement of 99 percent during operational testing. Incremental improvements are underway.
  - Training Systems and Devices – aircrew and maintainer training devices specific to the C-5M are just becoming available two years after the Full-Rate Production decision. The Air Force uses one simulator and on-aircraft training to mitigate the shortage of aircrew simulators. Maintainers still have insufficient simulators and must conduct training on the aircraft, which is restricted by the aircraft availability. The Air Force intends to accredit simulators for both aircrews and maintainers in FY13.
  - Information Assurance – the C-5M is susceptible to Information Assurance problems. The additional risk from information operations on the EDS is low. Air Mobility Command is addressing the Information Assurance deficiencies in the interface of the EDS. Improvements are anticipated in the Block 3.5.2 and the Core Mission Computer upgrades.

Recommendations

- Status of Previous Recommendations. The Air Force is addressing all previous recommendations.
- FY12 Recommendations. The Air Force should:
  1. Continue to pursue comprehensive remediation programs for known capability deferrals/deficiencies in the C-5 modernization programs.
  2. Aggressively seek timely and technically accurate aircrew and maintenance training systems and documents for the C-5M.
  3. Regularly report on suitability improvements and shortfalls in both new and legacy C-5M subsystems.
  4. Correct the remaining BIT, EDS, and engine support equipment deficiencies.

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C-130J

Executive Summary

- The C-130J is in production with periodic Block Upgrades to correct deficiencies and to provide capability enhancements.
- Improvements to the Station Keeping Equipment (SKE), verified in a second FOT&E, now enable the C-130J to perform formation airdrop missions in instrument meteorological conditions (IMC), correcting an effectiveness shortfall from the C-130J IOT&E in 2005.
- The Air Force conducted FOT&E of the Data Transfer and Diagnostics System (DTADS), which will replace the legacy computerized maintenance system, in order to correct suitability shortfalls from the IOT&E.
- The Air Force is correcting some deficiencies and adding new capabilities in the Block Upgrade 7.0. Delivery of the upgrade has continued to experience delays, now estimated to occur by 2QFY13. The Air Force has not funded subsequent deployment of Block Upgrade 7.0 to the fleet, and operational testing of the upgrade in FY13 remains undefined. This deferment affects several mission design series of the C-130J operated by the Air Force, Navy, and Coast Guard.

System

- The C-130J is a medium-sized four-engine turboprop tactical transport aircraft.
- Compared to previous models, the cockpit crew requirement is reduced from four to two on the J model; loadmaster requirements vary (one or two), depending on mission need.
- Compared to legacy models, the C-130J has approximately 70 percent new development. Enhancements unique to the C-130J include a glass cockpit and digital avionics, advanced integrated diagnostics, a new propulsion system, improved defensive systems, and an enhanced cargo handling system.
- The C-130J has two different lengths denoted as a long and a short body. The long body carries eight standard pallets; the short carries six.



Mission

- Combatant Commanders use the C-130J within a theater of operations for combat delivery missions which include:
  - Airdrop of paratroopers and cargo (palletized, containerized, bulk, and heavy equipment)
  - Airland delivery of passengers, troops, and cargo
  - Emergency aeromedical evacuations
- Combat Delivery units operate in all weather conditions, use night-vision lighting systems, and may be required to operate globally in civil-controlled airspace.

Major Contractor

Lockheed Martin Aeronautics Corporation – Fort Worth, Texas

Activity

- The Air Force is correcting deficiencies found in both developmental and operational testing and adding new capabilities in the Block Upgrade 7.0. Block Upgrade 7.0 continues to experience delays, with government developmental test and evaluation now expected to be complete by 2QFY13. The Air Force is deferring some deficiencies originally planned for correction in Block Upgrade 7.0 to Block Upgrade 8.1. The Air Force has not funded the deployment of Block Upgrade 7.0, which will likely become the technical baseline for the development of Block Upgrade 8.1. The Air Force has not fully defined plans for operational testing of Block Upgrade 7.0 and may limit operational testing to an operational assessment of limited capability enhancements in 3QFY13.
- The Air Force conducted FOT&E of the DTADS in October and November 2011 in accordance with the DOT&E-approved test plan. DTADS will replace the current computerized maintenance system (the integrated diagnostics system interface and Portable Maintenance Aid) that had suitability shortfalls during the C-130J IOT&E. DOT&E released a report on the DTADS FOT&E in October 2012.

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- The Air Force conducted a second FOT&E of the SKE software enhancement from January to March 2012 in accordance with the DOT&E-approved test plan. DOT&E released reports on the first FOT&E in February 2012 and the second FOT&E in October 2012.

Assessment

- The Air Force decision not to deploy Block Upgrade 7.0 will affect all mission design series C-130J aircraft, including Air Force EC-, HC-, MC-, and WC-130J; Navy KC-130J; and Coast Guard HC-130J. Some future aircraft acquisitions that planned to incorporate Block Upgrade 7.0 modifications in the production line will have to be re-planned as kit installations at an increased cost and decreased aircraft availability.
- DTADS represents a significant improvement over the legacy maintenance support system in terms of usability, portability, diagnostic capability, and organic maintainability. Information Assurance shortfalls remain, particularly concerning the Windows XP® operating system used by DTADS and the procedures for handling potentially classified digital flight data recorder information. The Air Force cannot connect DTADS to government computer networks without a required Windows 7® update.
- The SKE has demonstrated significant improvement in successfully enabling formation flight in IMC, and some improvement in reliability. However, shortfalls remain in the troubleshooting and repair of SKE faults. The Air Force restricts formation flight in IMC to formations of only C-130J aircraft, limiting interoperability with legacy C-130 models.

Recommendations

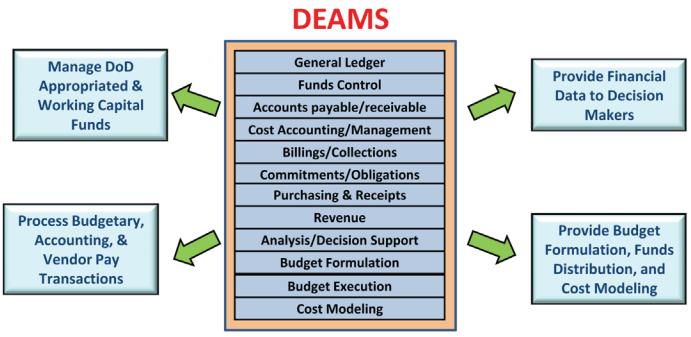
- Status of Previous Recommendations. The Air Force has made sufficient progress in addressing the FY11 recommendation to correct deficiencies in formation flying that will enable the SKE capability release. However, maintainability shortfalls remain in the troubleshooting and repair of SKE faults.
- FY12 Recommendations. The Air Force should:
  1. Correct remaining deficiencies in the technical data concerning the operation, fault isolation, and repair of the SKE system.
  2. Finalize plans for FY13 operational testing of Block Upgrade 7.0 and communicate them to DOT&E.
  3. Ensure adequate training and protocols are established for managing classified media associated with DTADS and digital flight data recorder downloads.

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Defense Enterprise Accounting and Management System (DEAMS)

Executive Summary

- The Air Force Operational Test and Evaluation Center (AFOTEC) conducted an Operational Assessment (OA) of the Defense Enterprise Accounting and Management System (DEAMS) Increment 1 Release 1 from May through June 2012. The test locations included Headquarters U.S. Transportation Command (HQ USTRANSCOM) and Headquarters Air Mobility Command (HQ AMC), both located at Scott AFB, Illinois; and the Defense Finance and Accounting Service in Limestone, Maine. An Air Force team from the 688th Information Operations Wing conducted a limited Information Assurance (IA) vulnerability assessment at Maxwell-Gunter Annex, Alabama, on June 26, 2012.
- DEAMS is neither operationally effective nor operationally suitable. Many key features do not work, while other features often require intervention by subject matter experts to make them work.
- DEAMS successfully performs some decision support functions such as budget management within authority and funds distribution and loading. However, it does not adequately perform budget analysis and planning, decision analysis, balancing the General Ledger, not exceeding budget control targets, and generating accurate reports. Many users rely on legacy systems to create reports.
- DEAMS is neither making sufficient progress towards achieving audit readiness of the Statement of Budgetary Resources by the end of 2014, nor towards achieving full financial auditability by the statutory deadline of September 30, 2017.
- DEAMS could already be the target of fraud or theft due to inconsistent telecommuting policies, IA vulnerabilities, inadequate control of budget targets, and large account imbalances.
- DEAMS is unable to match Accounts Payable or Accounts Receivable, reconcile subsidiary accounts to the General Ledger (none reconciled), perform end-of-year accounting closeouts, or balance appropriation accounts accurately with Treasury appropriation accounts. However, DEAMS successfully ages and liquidates Accounts Receivable, capitalizes and depreciates assets when full information is available, and processes only valid data.
- DEAMS does not provide timely information to close out financial accounts at the designated end-of-period times; however, it records transactions quickly and pays vendors promptly.
- The presence of over 200 high-severity operational deficiencies indicates that the software is unstable. Many of the deficiencies are related to interfaces, indicating that DEAMS is not satisfying the end-to-end information exchange requirements of the Net-Ready Key Performance Parameter (KPP). However, DEAMS hardware is reliable and response times are acceptable.
- Three of seven previously-identified major IA vulnerabilities still require correction.
- DEAMS users are highly critical of user training and user documentation.



System

- DEAMS is a Major Automated Information System that uses commercial off-the-shelf Enterprise Resource Planning software to provide accounting and management services.
- The Program Management Office (PMO) is following an evolutionary acquisition strategy that adds additional capabilities incrementally. DEAMS Increment 1 consists of six releases. Release 1, which provides approximately 75 percent of the system's capability, is designed to meet the accounting and financial management needs of HQ USTRANSCOM and HQ AMC. Releases 2 through 6 intend to provide enhanced capabilities to support other USTRANSCOM locations.
- DEAMS operates on the Global Combat Support System – Air Force Integration Framework. It interfaces with approximately 40 other systems that provide travel, payroll, disbursing, transportation, logistics, acquisition, and accounting support.

Mission

- USTRANSCOM and Air Force financial managers will use DEAMS to compile and share accurate, up-to-the-minute financial management data and information across USTRANSCOM and the Air Force.
- USTRANSCOM, Air Force, and DoD leadership will use DEAMS to access vital, standardized, real-time financial data and information to make strategic business decisions.

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- USTRANSCOM and the Air Force will use DEAMS to satisfy congressional and DoD requirements for auditing funds, standardizing financial ledgers, timely reporting, and reduction of costly rework.

Major Contractor
Accenture Federal Services – Fairborn, Ohio

Activity
- AFOTEC began, but did not complete, an Early Operational Assessment (EOA) of DEAMS from August through December 2010 in accordance with a DOT&E-approved test plan. AFOTEC cut the EOA short when it became apparent that major system deficiencies were present and that the planned Milestone B was significantly delayed.
- After the program manager declared that DEAMS had been stabilized, AFOTEC conducted a second OA of DEAMS Increment 1 Release 1 from May through June 2012 in accordance with a DOT&E-approved test plan. As with the EOA, the test locations included HQ USTRANSCOM and HQ AMC, both located at Scott AFB, Illinois; and the Defense Finance and Accounting Service in Limestone, Maine. DEAMS Increment 1 Release 1 contained approximately 75 percent of its final capabilities and had been in operational use for two years.
- An Air Force team from the 688th Information Operations Wing conducted a limited IA vulnerability assessment at Maxwell-Gunter Annex, Alabama, in June 2012.
- In July 2012, the DoD Inspector General reported (DoDIG-2012-111) that DEAMS's original life-cycle cost estimate had more than quintupled to over $2 Billion and that the program is 7.5 years behind schedule. In September 2012, another DoD Inspector General report (DoDIG-2012-140) found that DEAMS lacked critical functional capabilities needed to generate accurate and reliable financial management information and might not meet its 2014 and 2017 audit readiness requirements.
- DOT&E issued an OA report on DEAMS in September 2012. A Milestone Decision Authority decision followed immediately after, allowing the Air Force to deploy DEAMS to an additional 150 AMC users at McConnell AFB, Kansas.

Assessment
- AFOTEC conducted the FY12 OA of DEAMS Increment 1 Release 1 with the rigor of an IOT&E.
- DEAMS is neither operationally effective nor operationally suitable. Many key features do not work, while other features often require intervention by subject matter experts to make them work.
- Operational testers documented deficiencies in the areas of information quality, timeliness, and usability, along with many undocumented workarounds. DEAMS hardware is reliable and response times are acceptable, but the presence of more than 200 unresolved, high-severity deficiencies indicates that the software is still unstable, despite program attempts to resolve 245 prior high priority defects. According to the PMO, the fast tempo of delivery of software patches has not left any time for regression testing.
- Many of the software deficiencies are related to interfaces, indicating that DEAMS is not satisfying the end-to-end information exchange requirements of the Net Ready KPP.
- DEAMS is neither making sufficient progress towards achieving audit readiness of the Statement of Budgetary Resources by the end of 2014, nor towards achieving full financial auditability by the statutory deadline of September 30, 2017.
- DEAMS is unlikely to support financial operations because it does not meet the KPP for appropriations balance with the U.S. Treasury. Of 723 appropriation accounts examined, 109 had amounts out of balance for a total of $449 Million. DEAMS also does not meet the 95 percent KPP for General Ledger to subsidiary ledger reconciliation (none of the 49 samples reviewed were reconciled).
- DEAMS is unable to accurately match any Accounts Payable or Accounts Receivable documents and does not always prevent the posting of transactions that exceed Congressional appropriation funds control targets. AFOTEC identified two transactions that exceeded strict funds control by a total of $3 Million. However, DEAMS successfully ages and liquidates Accounts Receivable, capitalizes and depreciates assets when full information is available, and processes only valid data.
- DEAMS does not meet the KPP for timely reporting of period-end data to the official reporting system. DEAMS has not properly performed the end-of-year accounting closeouts for FY10 or FY11; however, it records transactions quickly and pays vendors promptly.
- DEAMS does not sustain financial decision support because it does not meet the KPP for fully accurate status of funds. While DEAMS successfully performs some decision support functions such as budget management within authority and funds distribution and loading, several important reports were inaccurate or incomplete. Many operators continue to use legacy systems, rather than DEAMS, to perform their daily tasks.
- DEAMS does not meet the KPP for budget control targets and is susceptible to fraud or theft. The additional in-test discovery of inconsistent telecommuting policies, IA vulnerabilities, and large account imbalances raise a concern that fraud or theft may be taking place.

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- Three of seven previously-noted major IA vulnerabilities still require correction. Furthermore, some DEAMS users are telecommuting without using a Virtual Private Network.
- DEAMS users are highly critical of user training and user documentation.

Recommendations

- Status of FY11 Recommendations. The PMO and AFOTEC addressed all FY11 recommendations.
- FY12 Recommendations.
  1. The Air Force should conduct immediate "Financial Red Team" penetration testing to assess DEAMS's fraud and theft vulnerabilities. The test should address both prevention and detection of potential thefts or frauds.
  2. The Air Force should conduct immediate tests of the IA risks associated with telecommuting. The tests should determine whether perpetrators have attacked the system and extracted data. The PMO and the Defense Information Systems Agency should rectify all remaining IA deficiencies in order to reduce vulnerability.
  3. In order to prevent the accrual of new deficiencies, the Air Force should recreate a realistic developmental test environment that incorporates automated testing and allows the conduct of thorough, systematic, repeatable regression testing.
  4. The PMO and Functional Management Office should document any required workarounds authorized by the users. Similarly, the PMO should develop training to better meet individual user group requirements and improve user documentation to include workarounds and the legacy systems that are still needed for mission accomplishment.
  5. AFOTEC and the Joint Interoperability Test Command should collaborate to assess interoperability that covers full Net-Ready KPP requirements, including the end-to-end functional exchange of required information.
  6. The Air Force should not permit further deployments of DEAMS until substantial progress is made addressing the system's deficiencies.

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E-3 Airborne Warning and Control System (AWACS)

Executive Summary

- The E-3 Airborne Warning and Control System (AWACS) provides airborne early warning, air surveillance, air battle management, and command and control without the beyond line-of-sight limitations inherent in ground-based air battle management systems.
- The Block 40/45 upgrade replaces the mission computing system on the E-3 with open-architecture, commercial off-the-shelf hardware including servers, and 15 mission crew interactive displays.
- The primary combat capability provided by the increased processing power of the Block 40/45 mission computing upgrade is to automatically fuse all onboard and off-board sensor inputs to provide a single track with a fused identification for each air, sea, and land entity using a multi-sensor integration algorithm.
- Block 40/45 is operationally effective. The modification provides many improvements for the operators, including automated tracking and identification. However, it did not provide the operators adequate control of the automated tracking capability. Additionally, it does not provide required enhancements to battle management capabilities, specifically the ability to automatically import data from the Air Operations Center to update the onboard database. It also does not provide Block 30/35 equivalent Link 16 datalink capabilities.
- Block 40/45 is not operationally suitable. During the IOT&E, the E-3 arrived on-station, on-time with both the radar and the Identification Friend or Foe (IFF) interrogation system functioning only one-third of the time. Operator and maintainer training were deficient and repair times exceeded requirements. Although Block 40/45 does not currently meet several key suitability requirements, Block 40/45 hardware is more reliable than the aging Block 30/35 equipment it replaces. Even when software failures are included, Block 40/45 is still more reliable than Block 30/35.

System

- AWACS is built on a Boeing 707 airframe. A surveillance radar and IFF system are located in the rotodome above the airframe. An Electronic Support Measures system has antennas on the cheeks of the airframe, under the nose, and in the tail. The E-3 has 13 Ultra High Frequency radios, 4 Very High Frequency radios, and 3 High Frequency radios.
- The Block 40/45 upgrade replaces the mission computing system on the E-3 with open-architecture, commercial off-the-shelf hardware including servers, and 15 mission crew interactive displays. The mission computing software program is replaced with a set of local area networked, open-architecture programs. The human-computer interface is built on the Windows® operating system and licenses the Raytheon Solipsys© Tactical Display Framework.



- The Block 40/45 mission computing upgrade provides the capability to automatically fuse all onboard and off-board sensor inputs to provide a single track for each air, sea, and land entity using a multi-sensor integration algorithm. The upgrade is also intended to provide:
  - An update to the E-3 AWACS Link 16 and satellite communications capabilities
  - Software to automatically refresh the onboard database
  - An updated mission system health monitoring tool
  - Improved interfaces and controls of the onboard passive Electronic Support Measure system
  - Improved mission planning and post mission processing capabilities
- The first six Block 40/45 E-3s are planned to have three different mission computing configurations. The Air Force plans to use the configuration of the seventh Block 40/45 E-3 to upgrade the next 11 jets.
- Block 40/45 requires several new ground support systems including the mission planning system, which the contractor delivered with the first upgraded aircraft. The contractor will deliver a deployable mission planning system before Initial Operational Capability in December 2013, in addition to trainers for maintenance personnel and mission crew.

Mission

The Air Component Commanders use AWACS-equipped units to:

- Provide early warning, air surveillance, air battle management, and beyond line-of-sight capabilities
- Provide command and control of offensive and defensive counterair and countersea operations, and strike missions

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including dynamic targeting, close-air support, suppression of enemy air defenses, and strategic attacks
- Manage air refueling operations, combat search and rescue missions, and special operations missions

Major Contractor
The Boeing Company – Seattle, Washington

Activity
- During FY11, Boeing conducted developmental test and evaluation (DT&E) using the first production Block 40/45 E-3. Air Force Joint Task Force personnel were present at all qualification test events and had signature authority for pass/fail determination. This contractor-conducted DT&E consisted of seven flights from Boeing Field, Seattle, Washington. The focus of the final phase of DT&E was to verify changes made to the production system after the Air Force Operational Test and Evaluation Center (AFOTEC) published the 2007 Operational Assessment in support of the Low-Rate Initial Production decision.
- AFOTEC conducted a 24-flight IOT&E operating from the E-3 main operating base, Tinker AFB, Oklahoma City, Oklahoma, between March and June 2012. The IOT&E was conducted in accordance with the DOT&E-approved test plan. While there were no overnight deployments, the two operational Block 40/45 E-3s participated in several large force exercises. The Block 40/45 IOT&E included flights working with assets from all four Services in training areas on both coasts as well as over land.

Assessment
- Block 40/45 testing was adequate to support an evaluation of operational effectiveness and suitability.
- Block 40/45 was not ready to enter IOT&E. Contractor-conducted DT&E focused on specification compliance verification in lieu of a government-conducted DT&E, which could have assessed risks to a successful IOT&E outcome.
- Training was not representative of the syllabus intended for maintainers and aircrews. Operator and maintainer training simulators were not ready for IOT&E. The deployable mission planning system was also not available for the IOT&E. Additionally, documentation for both operators and maintainers was incomplete.
- Several Block 40/45 capabilities, including the mission planning system and start-up checklist, were never tested in DT&E. The Program Office never documented workarounds for use by aircrews during contractor DT&E, nor did they modify the system design to reflect changes in interoperability standards during Block 40/45 development.
- Block 40/45 is operationally effective. It provides some improvements for the operators, but not all the required enhancements. Block 40/45 provided automated tracking and combat identification, but did not provide the operators adequate control of the automated tracking capability. The crews were able to accomplish their battle management command and control missions throughout the IOT&E; however, Block 40/45 did not adequately provide the required capability to receive free-text data from the Air Operations Center and automatically import the data into onboard databases.
- Block 40/45 does not provide equivalent Link 16 capabilities to Block 30/35, which it replaces. AFOTEC discovered several interoperability deficiencies during the IOT&E. Many of the tactical datalink deficiencies were caused by the Air Force not modifying the system design to reflect changes in interoperability standards during Block 40/45 development. The satellite communications terminal did not provide an operationally useful capability to receive digital information.
- Block 40/45 is not operationally suitable. During the IOT&E, the Block 40/45 E-3 arrived on-station, on-time, with both the radar and IFF interrogation system functioning only one-third of the time. Block 40/45 system deficiencies caused half the missed on-station times, while legacy system deficiencies caused the other half.
- Block 40/45 demonstrated poor reliability. The Mean Time Between Critical Failure was 9 hours, which is significantly less than the threshold of 2,500 hours. Two-thirds of all critical failures occurred while starting the mission computing system. However, the Block 40/45 hardware is already more reliable than the Block 30/35 hardware it replaces (72-hour vice 4.6-hour Mean Time Between Unscheduled Maintenance (MTBUM)).
- When considering the addition of software failures and the reduction of Block 40/45 MTBUM, Block 40/45 is still more reliable than Block 30/35.
- Two ground repair actions were incomplete at the end of the IOT&E. One open repair action was for a legacy Block 30/35 part. The second open repair action was for a Block 40/45 part that was either not ordered or not provided for 14 days.

Recommendations
- Status of Previous Recommendations. This is the first annual report for this program.
- FY12 Recommendations. The Air Force should:
  1. Incorporate the most current datalink message standards into Block 40/45. This will allow Block 40/45 to have a datalink capability equivalent to the fielded legacy Block 30/35 AWACS fleet.
  2. Complete and update aircrew and maintenance checklists and technical orders to address the new failure modes discovered during IOT&E.

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3. Modify the mission computing software and refine technician training to reduce the incidence of induced critical failures during Block 40/45 mission computing startup.
4. Develop software modifications to improve aircrew ability to control the automated tracking capability.
5. Review and update the planned training syllabus for both aircrew and maintenance personnel with information learned during the IOT&E.
6. Conduct FOT&E of Block 40/45 using the first Block 40/45 configuration that will be installed on more than two aircraft. The FOT&E should include an operationally representative deployment in a stressful tracking and combat identification environment.

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F-15E Radar Modernization Program (RMP)

Executive Summary
- F-15E Radar Modernization Program (RMP) developmental flight testing began in January 2011 and IOT&E was expected to begin in late FY12. Although the RMP continued to make progress towards operational effectiveness, suitability, and mission capability during FY12, unanticipated software performance challenges in air-to-ground mapping, precision velocity update, and air-to-air target detection and tracking led to developmental test delays. As a result, the program will not begin IOT&E until mid-FY13.
- The Air Force resolved electromagnetic interference between the APG-82(V)1 Active Electronically Scanned Array (AESA) transmitter/receiver and the radios through the incorporation of software changes.
- The Air Force made progress in overcoming aircraft Environmental Control System (ECS) component failures and in-flight cautions noted in FY11 flight testing. RMP hardware performed nominally throughout FY12 developmental testing.

System
- The F-15E is a twin engine, tandem seat, fixed wing, all weather, multi-role fighter aircraft. The F-15E has a fully missionized cockpit and a multimode air intercept and air-to-ground radar, giving the aircrew the capability to employ air-to-air and air-to-ground munitions, a 20-millimeter cannon, and countermeasures for evading enemy fire.
- The RMP replaces the F-15E legacy APG-70 mechanically scanned radar with an AESA system designated the APG-82(V)1. The RMP is designed to retain functionality of the legacy radar system while providing expanded mission employment capabilities to include:
  - Near-simultaneous interleaving of selected air-to-air and air-to-ground functions
  - Enhanced air-to-air and air-to-ground combat identification capabilities
  - Longer range air-to-air target detection and enhanced track capabilities
  - Longer range and higher resolution air-to-ground radar mapping
  - Improved ground moving target track capability
- The RMP upgrade is also intended to address legacy F-15E radar system suitability shortfalls including: poor reliability, parts obsolescence, and high sustainment costs. The Air Force intends to retrofit the RMP across the existing F-15E fleet.
- The RMP APG-82(V)1 design leverages capabilities from currently fielded AESA radar systems. The APG-82(V)1 antenna and power supply are currently in use on the F-15C APG-63(V)3 program, and the radar receiver/exciter and Common Integrated Sensor Processor are based on the F/A-18E/F APG-79 AESA system.
- Other hardware and software modifications comprising the RMP effort include a more powerful ECS, updates to the aircraft Operational Flight Program and Electronic Warfare software, a new radio frequency tunable filter, and aircraft modifications to include a new wideband radome and wiring changes.



Mission
A unit equipped with the F-15E conducts all weather, day and night missions to include:
- Offensive and Defensive Counterair
- Conventional Air Interdiction and Nuclear Strike
- Close Air Support and Strike Coordination and Reconnaissance
- Suppression of Enemy Air Defenses
- Combat Search and Rescue

Major Contractors
- The Boeing Company – Saint Louis, Missouri
- Raytheon – El Segundo, California

Activity
- The Air Force conducted F-15E RMP testing in accordance with the DOT&E-approved Test and Evaluation Master Plan.
- Developmental flight testing begun in January 2011 extended throughout FY12. The planned FY12 IOT&E start did not occur due to challenges in maturing system software to meet the user's functional requirements.
- The Air Force resolved electromagnetic interference between the APG-82(V)1 AESA transmitter/receiver and the radios

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through the incorporation of software changes. The Air Force verified the effectiveness of the corrective actions in subsequent FY12 developmental flight testing.
- The program experienced developmental challenges in maturing the integrated air-to-air and air-to-ground capabilities throughout FY12. Unanticipated software performance challenges in air-to-ground mapping, precision velocity update, and air-to-air target detection and tracking led to development delays. The Air Force has rescheduled IOT&E for March through July 2013.

Assessment
- The RMP continued to demonstrate incremental progress towards achieving the system's operational performance and suitability goals during FY12 developmental testing. However, the program experienced software maturation challenges and was unable to complete developmental testing in FY12. Unanticipated software performance shortfalls led to multiple radar OFP releases and associated regression testing to mature radar mode functionality. At the end of FY12, RMP performance had not yet met the user's requirements.
- Progress was made in overcoming aircraft ECS component failures and in-flight cautions noted in FY11 flight testing. Additionally, RMP hardware performed nominally throughout FY12.
- As noted in the DOT&E FY11 Annual Report, achieving the Air Force RMP software stability requirement by IOT&E may not be feasible. Multiple radar OFP version releases to correct system functionality shortfalls throughout FY12 precluded focus on stability requirements. As highlighted in the FY11 Annual Report, DOT&E continues to assess that the Air Force is not likely to meet the 30-hour Mean Time Between Software Anomaly requirement.

Recommendations
- Status of Previous Recommendations. The Air Force continues to address all previous recommendations.
- FY12 Recommendation.
  1. The Air Force should consider either amending the RMP 30-hour Mean Time Between Software Anomaly requirement or structuring the program (in particular, adding time and resources for additional development) such that it is able to achieve the desired performance measure.

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F-22A Advanced Tactical Fighter

Executive Summary

- The Air Force Operational Test and Evaluation Center (AFOTEC) completed FOT&E of F-22A Increment 3.1 Enhanced Global Strike capabilities in November 2011. FOT&E results demonstrated that the enhanced air-to-ground hardware and software enable the F-22A to perform its intended offensive counter-air suppression of selected, but not all relevant enemy air defenses in Global Strike scenarios.
- Overall Increment 3.1 operational suitability was substantially improved compared with the performance in previous evaluation periods.
- The Air Force completed a formal investigation of the aircraft life support system and associated onboard oxygen generation system, and ruled out contamination as the root cause of hypoxia-like incidents that resulted in the fleet-wide F-22A grounding in FY11. The Air Force concluded that impedance/restriction caused by life support system elements were significant contributors to the physiological incidents and is pursuing actions to resolve the problem including: removal of the aircrew C21A filter pack, and testing of a modified aircrew upper pressure garment. Additionally, the Air Force is installing a back-up emergency oxygen system to provide emergency oxygen in the event of an environmental control system shut down, rapid decompression, or failure of the onboard oxygen generator.
- In conjunction with the completion of Increment 3.1 FOT&E and the F-22A fleet achieving its "at maturity" 100,000 fleet flight hours milestone, DOT&E conducted an analysis of F-22A progress in satisfying the original weapon system operational suitability requirements. Based on performance from IOT&E through Increment 3.1 FOT&E, DOT&E assesses the mature F-22A weapon system is operationally effective and suitable.

System

- The F-22A is an air superiority fighter that combines low observability to threat radars, sustained high speed, and integrated avionics sensors.
- F-22A low observability reduces threat capability to engage with current weapons.
- The aircraft maintains supersonic speeds without the use of an afterburner.
- Avionics that fuse information from the Active Electronically Scanned Array radar, other sensors, and datalinked information for the pilot enable employment of medium- and short-range air-to-air missiles, guns, and air-to-ground munitions.
- The Air Force designed the F-22A to be more reliable and easier to maintain than legacy fighter aircraft.
- F-22A air-to-air weapons are the AIM-120C radar-guided missile, the AIM-9M infrared-guided missile, and the M61A1 20 mm gun.



- F-22A air-to-ground precision strike capability consists of the 1,000-pound Joint Direct Attack Munition (JDAM) and the 250-pound Small Diameter Bomb (SDB) Increment One.
- The F-22A program delivers capability in increments. Incremental Enhanced Global Strike modernization efforts include the following current and projected increments:
  - Increment 3.1 provides enhanced air-to-ground mission capability, to include geo-location of selected emitters, electronic attack, air-to-ground synthetic aperture radar mapping and designation of surface targets, and SDB integration. Increment 3.1 is currently fielded in operational F-22A units.
  - Increment 3.2A is a software-only upgrade intended to provide improved Electronic Protection, Link 16, and Combat Identification capabilities in FY14. Increment 3.2A is a modernization effort within the scope of the F-22A Advanced Tactical Fighter baseline acquisition program of record.
  - Increment 3.2B is a hardware and software upgrade intended to integrate AIM-120D and AIM-9X missile systems, and provide additional Electronic Protection enhancements and improved emitter geo-location capability in FY17. Increment 3.2B will be a separate Major Defense Acquisition Program with Milestone B projected for December 2012.

Mission

A unit equipped with the F-22A:

- Provides air superiority over friendly or enemy territory
- Defends friendly forces against fighter, bomber, or cruise missile attack

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- Escorts friendly air forces into enemy territory
- Provides air-to-ground capability for counter-air, strategic attack, counter-land, and enemy air defense suppression missions

Major Contractor
Lockheed Martin Aeronautics Company – Fort Worth, Texas

Activity

- The Air Force conducted F-22A testing in accordance with the DOT&E-approved Test and Evaluation Master Plan (TEMP) and FOT&E plans.
- The Air Force completed F-22A Increment 3.1 FOT&E in November 2011. Fleet-wide Increment 3.1 retrofits of Block 30 F-22As were ongoing throughout FY12.
- The Air Force completed a formal investigation of the aircraft life support system and associated onboard oxygen generation system due to several unexplained hypoxia-like incidents that occurred throughout FY11. Fleet-wide F-22A grounding from April through September 2011 delayed the planned completion of Increment 3.1 FOT&E until November 2011. The Air Force investigation ruled out contamination as the root cause of the incidents. As of August 2012, the Air Force concluded that impedance/restriction caused by life support system elements were significant contributors to the physiological incidents. Accordingly, the Air Force is pursuing the following actions in the interest of resolving the problem: removing the aircrew C21A filter pack, and testing a modified aircrew upper pressure garment. Additionally, the Air Force is installing a back-up emergency oxygen system to provide emergency oxygen in the event of an environmental control system shut down, rapid decompression, or failure of the onboard oxygen generator.
- The Air Force conducted planning activities in support of Increment 3.2A and 3.2B modernization efforts. Increment 3.2A developmental testing will begin in FY13. In conjunction with the completion of Increment 3.1 FOT&E and the F-22A fleet achieving its "at maturity" 100,000 fleet flight hours milestone, DOT&E conducted an analysis of F-22A progress in satisfying the original weapon system operational suitability requirements.

Assessment

Increment 3.1 FOT&E

- Results of Increment 3.1 FOT&E testing completed in November 2011 demonstrated that the enhanced air-to-ground capabilities enable the F-22A to perform its intended offensive counter-air suppression of enemy air defenses mission in Global Strike scenarios.
  - The F-22A remains capable of effectively employing legacy JDAM, AIM-9M, and AIM-120C weapons as well as the newly incorporated SDB.
  - Aircrews are capable of using the F-22A radar and onboard sensors to reliably locate and designate surface targets with sufficient accuracy to effectively employ both legacy JDAM and newly incorporated SDB munitions to suppress selected, but not all relevant enemy air defenses.
  - Overall Increment 3.1 operational suitability was substantially improved compared with the performance in previous evaluation periods. FOT&E demonstrated a significant improvement in Mean Time Between Critical Failure (MTBCF) compared to previous OT&E periods. Increment 3.1 FOT&E MTBCF was 4.68 hours (4.01 hours 80 percent lower confidence bound; 5.26 hours 80 percent upper confidence bound) compared to the reported MTBCF in the FY07 FOT&E of 1.73 hours.
  - The Increment 3.1 F-22A weapons system exceeded the operational deployability threshold requirement of seven C-17 airlift equivalents by one additional C-17.
  - The Increment 3.1 F-22A weapons system met both combat sortie generation requirements and material availability threshold requirements.

F-22A System At Maturity Assessment

- In conjunction with the completion of Increment 3.1 FOT&E, DOT&E assessed F-22A progress since the completion of IOT&E in satisfying the original weapon system's operational effectiveness and suitability requirements. Findings include the following:
  - Based on performance from IOT&E through Increment 3.1 FOT&E, DOT&E assesses the mature F-22A weapon system as operationally effective in both air-to-air and air-to-ground mission roles.
  - DOT&E compared Increment 3.1 FOT&E suitability results with operational F-22A unit performance through an independent model that simulated the combat sortie generation operations of an operational F-22A squadron. Based on suitability results achieved during Increment 3.1 FOT&E and results of the DOT&E model, DOT&E assesses that the mature F-22A weapons system is operationally suitable.
  - The Air Force has matured maintenance practices, improved subsystem suitability, adjusted manpower requirements, and modified the F-22A deployment concept of operations in order to meet F-22A combat air power needs. The F-22A weapons system is capable of achieving material availability and combat sortie generation Key Performance Parameter thresholds. However, based on increased maintenance manpower, equipment, and supplies necessary to sustain combat operations, the Air Force is likely to continue to require eight C-17 airlift equivalents to deploy an F-22A squadron in support of global operations.

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Recommendations

- Status of Previous Recommendations. The Air Force continues to address all previous recommendations.
- FY12 Recommendation.
  1. Commensurate with the maturation of the F-22A weapons system and ongoing F-22A modernization efforts, the Air Force should apply past lessons learned for forthcoming F-22A upgrades, and the development and fielding of future manned fighter aircraft programs. Particular attention should be given to the challenges of maintaining low observable systems.

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HC/MC-130J

Executive Summary

- DOT&E analysis of the IOT&E data was ongoing at the end of FY12. DOT&E expects to issue a Beyond Low-Rate Initial Production (BLRIP) report in 2QFY13 to inform the April 2013 Full-Rate Production decision.
- Preliminary IOT&E results indicate that the HC/MC-130J provides the capability to perform the combat search and rescue (CSAR) and Special Operations Forces (SOF) missions as well as or better than legacy aircraft in many aspects.
- Preliminary IOT&E results indicate that the HC/MC-130J met the required availability and mission capable rates, met the maintenance man-hour per flight hour requirement, and demonstrated a Mean Time Between Corrective Maintenance significantly better than the combat delivery C-130J fleet.
- Preliminary IOT&E results indicate that one aspect of aircraft survivability may be degraded relative to the legacy aircraft for the intended concept of employment.

System

- The HC/MC-130J is a medium-sized, four-engine turboprop tactical transport aircraft with hose and drogue aerial refueling, airdrop, and command and control capabilities. The core configuration is based on the Marine Corps KC-130J refueling tanker design with modifications including the ability to receive fuel in flight, a nose-mounted electro-optical/infrared sensor, and a combat systems operator flight deck station.
- The HC/MC-130J program delivers capability in increments. Increment 1 modifications include additional countermeasure dispensers, high-altitude ramp and door hydraulics, an additional (fourth) flight deck crew member station, an additional cargo compartment intercom panel, and cargo compartment 60-Hertz electrical outlets.
- The HC-130J will replace legacy HC-130P/N and MC-130P (rescue) aircraft; the MC-130J will replace legacy MC-130E/P aircraft. The Air Force intends to procure 37 HC-130Js and 94 MC-130Js.



Mission

- Air Combat Command (ACC) uses the HC-130J to support the personnel recovery mission through:
  - Aerial and ground refueling of vertical lift assets used during personnel recovery missions
  - Para-rescue jumper deployment with rescue-related equipment
  - Infiltration/exfiltration and resupply by airdrop or air land operations
- Air Force Special Operations Command (AFSOC) uses the MC-130J to support special operations missions requirements, including:
  - Aerial refueling and forward arming and refueling point operations of SOF rotary and tilt-rotor aircraft
  - Infiltration/exfiltration, resupply, or delivery of SOF personnel and equipment via airdrop or landing on austere, short runways in hostile or denied territory

Major Contractor

Lockheed Martin Aeronautics Company – Bethesda, Maryland

Activity

- Lockheed delivered 2 core configuration aircraft and 10 Increment 1 aircraft to the Air Force.
- The 46th Operations Group completed developmental test and evaluation (DT&E) of the core configuration aircraft in September 2011 and of the Increment 1 configuration, which was the production-representative test article for the IOT&E, in February 2012. The Increment 1 DT&E included regression testing of updated Operational Flight Program software on the new Sanders Technology and Advanced Risk Instruction Set Computer (STAR) IX mission computer hardware that is replacing STAR VII hardware throughout the C-130J fleet due to diminishing manufacturing sources.
- The Air Force Operational Test and Evaluation Center conducted IOT&E from March 1 through May 30, 2012, in accordance with the DOT&E-approved test plan. At least two full crews each from ACC and AFSOC flew two Increment 1 aircraft based at Cannon AFB, New Mexico. IOT&E included approximately 253 flight hours over 60 test missions, including a simulated deployment and arctic testing at Eielson AFB, Alaska; maritime testing at Hurlburt Field, Florida; and CSAR

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exercises at Nellis AFB, New Mexico. Test scenarios included air land and airdrop delivery of personnel and cargo, aerial refueling as a receiver and as a tanker to helicopters and tilt-rotors, forward arming and refueling point operations, and defensive reactions to simulated threat engagements.
- The IOT&E also included scenarios for defensive engagements with prepositioned and mobile threat simulators to assess aircraft survivability equipment.

Assessment
- DOT&E analysis of the IOT&E data was ongoing at the end of FY12. DOT&E expects to issue a BLRIP report in 2QFY13 to inform the April 2013 Full-Rate Production decision.
- Preliminary IOT&E results indicate that the HC/MC-130J provides the capability to perform the CSAR and SOF missions as well as or better than legacy aircraft in many aspects. The improved propulsion system enables better tactical take-off performance from short, unimproved runways and expands the flight envelope for aerial refueling. The C-130J enhanced cargo handling system greatly improved loading, unloading, and airdrop operations relative to legacy aircraft. There were deficiencies in the following areas:
  - Current airdrop procedures result in very high workload and head-down time for the pilot monitoring airdrop and should be revised.
  - Crews commented that the lack of a tactical datalink, such as Link 16, limited their situational awareness. The C-130J Block Upgrade 7.0 was planned to provide Link 16, but the C-130J program has deferred fielding of Block Upgrade 7.0 until Block Upgrade 8.1 has been developed and tested.
  - Loadmasters have insufficient control over cargo compartment lighting, and the night-vision compatible lighting does not adequately support covert operations.
  - The location of some litter support strap hangers above the centerline overhead avionics equipment rack hinders configuration of the cargo compartment for medevac operations.
  - Lack of several specialized features for search and rescue missions relative to legacy aircraft (flare launcher tubes, large forward scanner windows, additional oxygen regulators and intercom panels) may require ACC or the Air National Guard to make modifications to the aircraft after delivery.
  - The intercom system does not transmit system tones (diagnostic or defensive system alerts) to all intercom panels in the cargo compartment, limiting loadmasters' situational awareness.
- Preliminary IOT&E results indicate that the HC/MC-130J met the required availability and mission-capable rates, met the maintenance man-hour per flight hour requirement, and demonstrated a Mean Time Between Corrective Maintenance significantly better than the combat delivery C-130J fleet.
- Preliminary IOT&E results indicate that one aspect of aircraft survivability may be degraded relative to the legacy aircraft for the intended concept of employment. Although the aircraft survivability equipment installed on the HC/MC-130J has been tested and employed on other C-130J aircraft, it may exhibit shortfalls under the new mission-specific concepts of employment.

Recommendations
- Status of Previous Recommendations. This is the first annual report for this program.
- FY12 Recommendations. The Air Force should:
  1. Address cargo compartment lighting control by loadmasters, including AFSOC's need for blacked-out cargo compartment lighting in covert operations.
  2. Develop mitigation plans for the deferred release of Block Upgrade 7.0, including the need for a tactical datalink.
  3. Develop plan to integrate improvements of aircraft survivability equipment in future increments.

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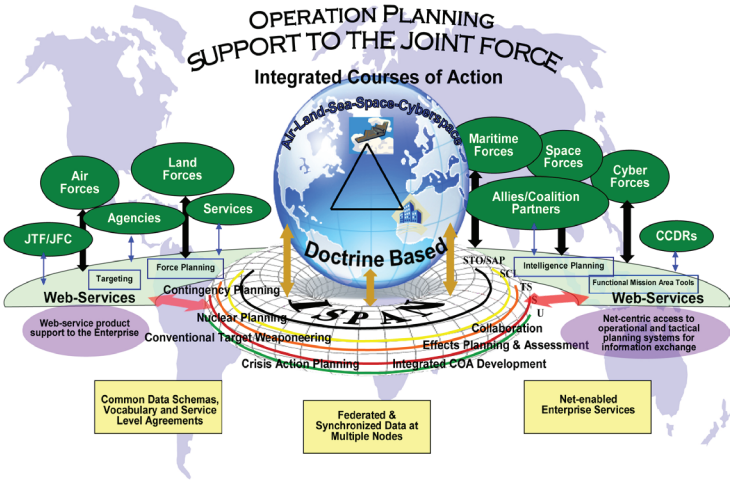
Integrated Strategic Planning and Analysis Network (ISPAN)

Executive Summary

- The overall Integrated Strategic Planning and Analysis Network (ISPAN) program consists of a system-of-systems approach that spans multiple security enclaves for strategic and operational-level planning and leadership decision making. ISPAN Increment 2 employed an agile acquisition approach that used two spirals to deliver this capability.
- U.S. Strategic Command (USSTRATCOM) and the Air Force Operational Test and Evaluation Center (AFOTEC) conducted an ISPAN Increment 2, Spiral 2, IOT&E in accordance with the DOT&E-approved test plan in July 2012.
- The IOT&E confirmed that the problems discovered during ISPAN Increment 2, Spiral 1, Integrated Test and Evaluation (IT&E), which USSTRATCOM and AFOTEC conducted in December 2011, were resolved.
- DOT&E assessed ISPAN Increment 2 as effective but not suitable due to system limitations involving software deficiencies, problematic configuration management processes, potential scalability deficiencies, and shortfalls in usability, timeliness, training, documentation, and maintenance of system interoperability.
- Web services provide interoperability functionality that can be unavailable when data structures are changed, interfaces are upgraded, or other events occur that affect how these services are implemented. The Program Office should negotiate service-level agreements between web interface partners to ensure that web services remain available and facilitate critical net-centric data exchanges.
- AFOTEC discovered a number of Information Assurance (IA) vulnerabilities during the IOT&E. The Program Office must promptly mitigate the two Category I IA vulnerabilities found during IOT&E and develop a plan of action and milestones to address the Category II and III findings.
- The Designated Accrediting Authority (DAA) reviewed the program manager-provided mitigation plan and issued an Authority to Operate on December 14, 2011. The Secretary of the Air Force granted a Full-Deployment decision in October 2012.

System

- The overall ISPAN program consists of a system-of-systems approach that spans multiple security enclaves for strategic and operational-level planning and leadership decision making.
- The ISPAN system is composed of two elements, which are developed in increments:
  - The Global Adaptive Planning Collaborative Information Environment (GAP CIE) that manages strategy-to-execution planning across all USSTRATCOM mission areas, which is being developed as part of Increments 2 and 3.
  - The Mission Planning and Analysis System (MPAS) that develops Joint Staff Level I through Level IV nuclear and conventional force application plans that support national and theater requirements, which will be modernized as part of Increment 4. Increment 4 is scheduled to begin development in FY14.
- Prior to Increment 2, the initial capabilities of GAP CIE and MPAS were fielded in ISPAN Block 1. After the fielding of ISPAN Block 1, the acquisition nomenclature was changed from a Block to Increment designation.
- ISPAN is employing an agile acquisition methodology, which delivers system capabilities in increments depending on user requirements. Increment 2 IOT&E consisted of approximately 40 percent of the planned system capabilities. The developers intend to deliver the remaining 60 percent in Increment 3, which is presently unfunded. USSTRATCOM intends to begin developing ISPAN MPAS capabilities in Increment 4.
- GAP CIE provides a web-enabled, net-centric collaborative environment for a contingency and crisis action planning (CAP) system at the Combatant Command (CCMD) and strategic level. The capability allows users from multiple CCMD staffs, subordinate commands, as well as other agencies, to collaborate online while providing planning and analyses to senior decision-makers.
- MPAS is intended to provide dedicated planning and analysis for all U.S. strategic nuclear forces, in addition to planning and analysis to create plans for specified theater and strategic conventional forces.



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- The ISPAN Increment 2 provides an Adaptive Planning capability to CCMDs and subordinate planning partners, while decreasing contingency and CAP timelines to meet the DoD-approved Adaptive Planning and execution process, as well as time sensitive Global Strike and Prompt Global Strike planning requirements. The ISPAN Increment 2 is intended to improve information access through net-centric means for time critical event management support to senior decision-makers, and deliver the ISPAN GAP CIE capability as a service to the Enterprise, by exposing critical ISPAN information as Net-Centric Enterprise Services registered web services.

Mission
- USSTRATCOM uses ISPAN to perform deliberate and adaptive, strategic, nuclear, and non-nuclear planning and analysis. This includes developing the national deterrence war plans offering both nuclear and non-nuclear weapon options using the MPAS.
- The CCMDs, subordinate staffs, and other national agencies use GAP CIE for collaborative mission planning and analysis, course of action development, and commander's decision briefing preparation in support of CAP scenarios and time critical decisions regarding force employment.

Major Contractors
- Lockheed Martin – Papillion, Nebraska
- BAE Systems – Bellevue, Nebraska
- Northrop Grumman –Bellevue, Nebraska
- SAIC – San Diego, California

Activity
- USSTRATCOM and AFOTEC conducted an ISPAN Increment 2, Spiral 1 IT&E at USSTRATCOM, Offutt AFB, Nebraska, and the Combined Air Operations Center, Barksdale AFB, Louisiana, in December 2011. AFOTEC did not conduct the IT&E in accordance with a DOT&E-approved test plan and collected most data from a single Integrated Mission Area Training exercise, rather than the three CAP events planned. In addition, IA testing was not conducted.
- In July 2012, USSTRATCOM and AFOTEC conducted an ISPAN Increment 2, Spiral 2 IOT&E at USSTRATCOM, Offutt AFB, Nebraska; the Combined Air Operations Center, Barksdale AFB, Louisiana; and Headquarters, U.S. Southern Command, Miami, Florida. AFOTEC conducted the IOT&E in accordance with the DOT&E-approved test plan.
- The Secretary of the Air Force granted a Full-Deployment decision in October 2012.

Assessment
- CCMD staffs can effectively use ISPAN Increment 2 to provide improvements to the planning process to achieve operational outcomes. Users were able to accomplish all necessary planning functions in a collaborative manner, including users at two different locations.
- During IOT&E, the operational test team was able to complete the principal functions of the ISPAN Increment 2 system: the development of Courses of Action (COAs) and the integration of multiple COAs for the commander's approval.
- ISPAN Increment 2 was not suitable. The system limitations involved software deficiencies, problematic configuration management processes, potential scalability deficiencies, and shortfalls in usability, timeliness, training, documentation, and maintenance of system interoperability. During operational testing, ISPAN Increment 2 satisfied the requirements for reliability, availability, and maintainability (RAM). DOT&E assessed the areas of supportability, interoperability, transfer of operations, and RAM as operationally suitable. DOT&E noted that some of these limitations are requirements for Increment 3; however, since Increment 3 is presently unfunded, the system was assessed to the Capability Development Document requirement.
- In DOT&E's October 2012 IOT&E report on ISPAN, DOT&E assessed configuration management as not suitable due to AFOTEC's discovery of several configuration management shortcomings during developmental testing and IOT&E that affected the ISPAN mission. The most critical incident was when a 48-minute outage occurred during IOT&E because a maintenance contractor working on a switch within the system accidentally disconnected the system, which resulted in a critical failure of the system. Since the completion of IOT&E, the Program Office has put in place updated procedures to tighten configuration control of the system to prohibit these issues from reoccurring.
- ISPAN demonstrated the capability to support 370 concurrent users including simulated users performing ISPAN representative tasks with a server response time of 5 seconds or less. The concurrent user capacity is acceptable in view of the near term user levels of about 140 concurrent users during CCMD events. However, when the simulation was extended to a larger number of users, the server response time increased significantly. These results indicate a scalability problem, but it is unclear how many concurrent users would degrade the user experience below an acceptable level of responsiveness.
- Web services provide interoperability functionality that can be unavailable when data structures are changed, interfaces are upgraded, or other events occur that affect how these services are implemented.
- User feedback indicates that the test schedule did not provide adequate training time/exposure and documentation to all IOT&E participants; therefore, user training is not suitable. Some U.S. Southern Command users were unable to attend the training but those who did attend found it inadequate.

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- AFOTEC discovered a number of IA vulnerabilities during the IOT&E. DOT&E recommended that the Program Office correct or mitigate the IA vulnerabilities to the satisfaction of the DAA prior to fielding. The Program Office continues to mitigate IA vulnerabilities.

Recommendations

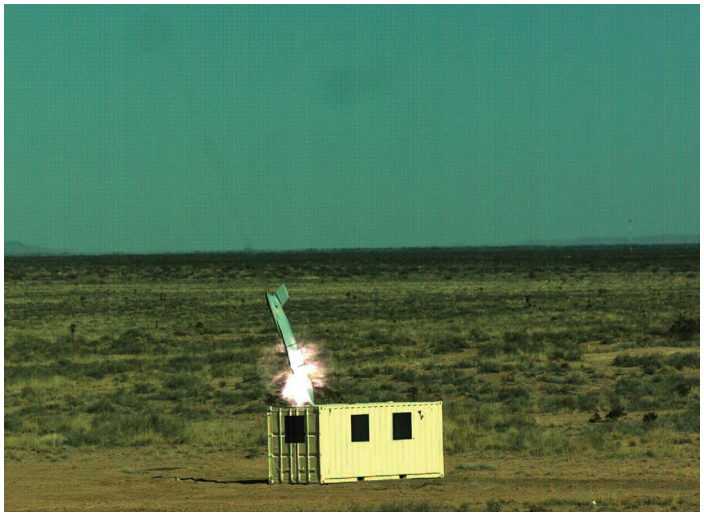
- Status of Previous Recommendations. USSTRATCOM and the ISPAN Program Office have effectively addressed all previous recommendations.
- FY12 Recommendations. The following recommendations are from DOT&E's October 2012 IOT&E report.
  1. The Program Office must tightly control configuration management of the ISPAN baseline to prevent incidents and outages of the system.
  2. The Program Office needs to continue to diagnose and address system latency problems during operations and sustainment. As the ISPAN user community increases above the Increment 2 threshold, poor response times will affect the acceptance of this system.
  3. The Program Office must implement a robust training program to include classroom tutorial instruction and on-the-job training that is tailored to the need of each CCMD. Training should be provided to users with regards to what documentation is available and how to access it.
  4. The Program Office should negotiate service-level agreements between web interface partners to ensure that web services remain available and facilitate critical net-centric data exchanges. Web services can be unavailable when data structures are changed, interfaces are upgraded, or other events occur that affect how these services are implemented.
  5. The Program Office should support the service-level agreements with automated tests of availability of the web services.
  6. The Program Office must promptly mitigate the two Category I IA vulnerabilities found during IOT&E and develop a plan of action and milestones to address the Category II and III findings.
  7. The DAA should conduct an IA assessment for ISPAN in the Joint Worldwide Intelligence Communications System environment to ensure that no Category I vulnerabilities exist, all other vulnerabilities are identified, and plans for correction of deficiencies are created.

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Joint Air-to-Surface Standoff Missile (JASSM)

Executive Summary
- The Air Force executed 16 AGM-158B Joint Air-to-Surface Standoff Missile – Extended Range (JASSM-ER) live fire shots in FY11 and 12, completing the IOT&E effort. All 16 prosecuted their targets successfully.
- The Air Force, in conjunction with the major contractor Lockheed Martin, is in the process of engineering development of the FMU-162/B Electronic Safe and Arm Fuze (ESAF) as a replacement for the mechanical fuzes currently used in JASSM.
- The Air Force completed AGM-158A Lot 6 Reliability Assessment Program (RAP) testing with three shots in FY12, two of which were successful, while one was terminated early to maintain range safety. There were three successful Lot 6 RAP shots in FY11 and one failed shot in FY10.
- The Air Force should continue to conduct RAP on Lot 8 and later via the Weapons System Evaluation Program (WSEP).



System
- The baseline AGM-158A JASSM is a stealthy cruise missile that flies a preplanned route from launch to a target, using GPS guidance and an internal navigation system. JASSM:
  - Has a 1,000-pound penetrating warhead
  - Has an imaging infrared seeker that can be used for greater accuracy and precision; the seeker uses image templates prepared by a rear echelon intelligence unit
  - Can be launched by B-1, B-2, B-52, F-15E, and F-16 aircraft
  - Includes a container that protects the weapon in storage and aids ground crews in moving, loading, and checking the missile
  - Uses the same Air Force mission planning systems used for aircraft and other weapons
- AGM-158B JASSM-ER is intended to fly longer ranges using a more efficient engine, larger capacity fuel tanks, and other modified components, all within the existing fuselage. JASSM-ER is currently integrated on the B-1.
- FMU-162/B ESAF takes advantage of advances in fuze technology and is intended to be a more reliable fuze with the same capabilities as the baseline mechanical fuze. The FMU-162/B ESAF would be used in JASSM baseline and ER variants.

Mission
- Operational units equipped with JASSM will employ the weapon from multiple aircraft platforms against high-value or highly-defended targets from outside the lethal range of many threats. Units equipped with JASSM will:
  - Destroy targets with minimal risk to flight crews and support air dominance in the theater
  - Strike a variety of targets greater than 200 miles away
  - Execute missions using automated preplanning or manual pre-launch retargeting planning
  - Attack a wide range of targets including soft, medium, and very hard (not deeply buried) targets
- Units with JASSM-ER will support the same missions as JASSM using a missile with a range more than twice as long.

Major Contractor
Lockheed Martin, Missile and Fire Control – Orlando, Florida

Activity

AGM-158A JASSM
- The Air Force certified JASSM for carriage and employment on the F-15E Strike Eagle. F-15E is the first JASSM-capable aircraft incorporating the Universal Armament Interface, a plug-and-play software that shortens the time required to integrate new weapons onto aircraft.
- There were three Lot 6 RAP test flight shots in FY12, two of which were successful, while one was terminated early to maintain range safety. Combined with the three successful FY11 shots and the single failed Lot 6 RAP test shot conducted early in FY10, this constitutes the completion of the Lot 6 RAP testing. The Lot 6 RAP tests used an

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equal mix of re-worked early production Lot 6 missiles and current configuration Lot 6 missiles, ensuring adequate and equal testing of both variants.

AGM-158B JASSM-ER

- The Air Force executed 16 JASSM-ER live fire shots in FY11 and 12. All 16 JASSM-ER missiles engaged and destroyed their targets at both nominal and maximum JASSM-ER ranges.

FMU-162/B JASSM ESAF

- The FMU-162/B ESAF currently is funded by the major JASSM contractor. The Air Force, in conjunction with the major contractor, is in the process of re-design and engineering development of the FMU-162/B ESAF as an option to replace the existing mechanical fuze and thereby increase JASSM and JASSM-ER reliability.
- The Air Force conducted all testing in accordance with the DOT&E-approved Test and Evaluation Master Plan and test plan.

Assessment

AGM-158A JASSM

- An April 2011 DOT&E memorandum stated that the Air Force needed to execute a minimum of 6 RAP flights to demonstrate an 80 percent confidence level that Lot 6 is more reliable than Lot 5. Currently, the RAP shots following the first failure have been successful. Omitting the one flight that range-safety terminated due to crew error, RAP testing has demonstrated improved reliability over Lot 5.
- Despite improvements in workmanship and production processes, there is still a need to evaluate the inherent reliability of production lot missiles (through Lot 8, at a minimum) to ensure that the reliability growth plan is successful. The Air Force should accomplish Lot 8 and later RAP testing via the WSEP.

AGM-158B JASSM-ER

- The 16 JASSM-ER shots indicate that the JASSM-ER meets requirements. These 16 tests, in combination with 5 approved production-representative integrated test shots, successfully conclude the IOT&E. There was a single failure (IT-8) in 21 test events.

FMU-162/B JASSM ESAF

- The FMU-162/B ESAF program has the potential to increase the overall reliability of all JASSM variants. The FMU-162/B ESAF program would replace the current electro-mechanical fuze, which relies on moving parts prone to reliability failures. In addition, the FMU-162/B ESAF has more built-in test capability than the current electro-mechanical FMU-156/B ESAF.

Recommendations

- Status of Previous Recommendations. The Air Force continued to characterize the reliability of baseline missile production lots with the completion of the Lot 6 RAP.
- FY12 Recommendations. The Air Force should:
  1. In conjunction with the contractor, continue the development and evaluation of the FMU-162/B ESAF.
  2. Continue RAP for Lot 8 and later via the WSEP.

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KC-46A

Executive Summary

- The KC-46A contract is firm-fixed-price with incentives for Engineering and Manufacturing Development. The Air Force awarded the contract to the Boeing Company in February 2011.
- The most recent DOT&E review of the post-Milestone B draft Test and Evaluation Master Plan (TEMP) indicates that the Air Force has made progress addressing test execution problems but further work is needed.
- The ALR-69A Radar Warning Receiver (RWR) has effectiveness shortfalls that require resolution prior to integration on the KC-46A.



System

- The KC-46A aerial refueling aircraft is the first increment (179) of replacement tankers for the Air Force's fleet of KC-135 tankers (more than 400). The KC-46A design uses a modified Boeing 767-200ER commercial airframe with numerous military and technological upgrades, such as the fly-by-wire refueling boom, the remote air refueling operator's station, additional fuel tanks in the body, and defensive systems. The KC-46A is intended to provide boom (pictured) and probe-drogue refueling capabilities. The Air Force intends to equip the KC-46A with an air-refueling receptacle so that it can also receive fuel from other tankers, including legacy aircraft.
- The KC-46A is designed to have significant palletized cargo and aeromedical capacities, chemical/biological/radiological/nuclear survivability, and the ability to host communications gateway payloads.
- Survivability enhancement features are incorporated into the KC-46 design. Susceptibility is reduced with an Aircraft Survivability Equipment suite consisting of Large Aircraft Infrared Countermeasures (LAIRCM), the ALR-69A RWR, and a Tactical Situational Awareness System. The suite is intended to compile threat information from the RWR and other on and off-board sources and prompt the crew with an automatic re-routing suggestion in the event of a threat. Vulnerability is reduced through the addition of fuel tank inerting and integral armor to provide some protection to the crew and critical systems.

Mission

Commanders will use units equipped with the KC-46A to:

- Perform air refueling to accomplish six primary missions: nuclear operations support, global strike, air bridge support, aircraft deployment, theater support, and special operations support. Secondary missions will include airlift, aeromedical evacuation, emergency aerial refueling, air sampling, and support of combat search and rescue.
- Operate in day/night and adverse weather conditions over vast distances to support U.S., joint, allied, and coalition forces.

Major Contractor

The Boeing Company, Commercial Aircraft in conjunction with Defense, Space & Security – Seattle, Washington

Activity

- The KC-46A Integrated Test Team has met quarterly since April 2011.
- Developmental, operational, and Federal Aviation Administration test planning are ongoing, with the most recent emphasis on developing an integrated test plan and a post-Milestone B TEMP.
- The Air Force submitted an operational assessment 1 plan. This assessment does not include flying since delivery of the first aircraft is not until June 2014.
- Survivability assessment planning is ongoing, integrating developmental, operational, and live fire testing and analysis. Susceptibility and vulnerability stakeholders are coordinating hardware-in-the-loop LAIRCM test planning to confirm system effectiveness using a modified 767 airframe model and to develop hit point distributions for the vulnerability assessment.
- The Air Force acquired two Boeing 767-200 assets for live fire testing at the Weapons Survivability Lab at China Lake,

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California. The Air Force developed a comprehensive live fire test plan and began the ballistic test program in FY12 with two test series:
- A replica wing dry bay fire test series, completed in FY12 at Wright-Patterson AFB, Ohio, as part of a risk reduction effort to characterize various threats against KC-46 production materials
- Wing dry bay fire testing on a 767-200 production asset, which began on schedule in 3QFY12.

Assessment
- The most recent DOT&E review of the post-Milestone B draft TEMP indicates that the Air Force has made progress addressing test execution problems but further work is needed.
- The draft TEMP now allocates 5.5 months and 750 hours for operational testing, which is adequate for an effectiveness evaluation. To assess suitability, a statistically significant evaluation (at a 76 percent confidence) requires 1,250 flight hours; IOT&E may have to be extended to generate the required 1,250 flight hours if operationally representative field flight data are not available from other sources.
- The planned test program includes the following shortfalls that have been partially addressed but require complete resolution to gain DOT&E approval:
  - Concurrent activities and planned flying hours for the Engineering, Manufacturing, and Development program place a high demand on limited aircraft and simulator resources.
  - The planned effectiveness for military flight testing substantially exceeds the relevant historical experience. The planned 75 percent test effectiveness rate for military test points is not consistent with experience for flight testing of military aircraft. An average historical test effectiveness rate of 55 percent combined with 30 flight-hours-per-aircraft-per-month would extend the current 16-month schedule for military testing by approximately 4 – 7 months, a best-case estimate.
  - The Test Program Schedule in the draft TEMP has insufficient calendar time allotted for correction of discrepancies and/or deficiencies discovered during developmental testing prior to the planned start of operational testing.
  - The draft TEMP allocates insufficient resources (time and aircraft) for the initial training of aircrews and maintainers and technical order verification. Additional training time between the end of developmental test and the start of IOT&E is required.
- The susceptibility assessment will focus on LAIRCM effectiveness and situational awareness provided by the RWR and Tactical Situational Awareness System. Since the majority of data for the evaluation of susceptibility will come from contractor and developmental testing, and this testing is governed by the firm-fixed-price contract, increases in the scope of testing identified by DOT&E may require additional funding. The building block design of experiments approach taken for dry bay fire testing will provide a method for wing leading and trailing edge damage prediction that should be useful for reducing uncertainty in the model-based vulnerability assessment.
- The ALR-69A RWR was selected as Contractor Furnished Equipment by Boeing; however, integration and performance on the KC-46A are high risk. DOT&E recently completed an assessment of the ALR-69A RWR on the C-130H1 and assessed it as not effective, but suitable, in a separate classified report dated October 22, 2012. Not only do these effectiveness problems require correction, but the system is required to improve its geo-location capabilities as compared to the demonstrated C-130J capability.

Recommendations
- Status of Previous Recommendations. The Air Force has addressed some of the FY11 recommendations to submit a TEMP incorporating realistic assumptions; however, additional work is needed.
- FY12 Recommendations. The Air Force should:
  1. Submit a TEMP with a realistic schedule mitigating the above mentioned shortfalls.
  2. Correct ALR-69A shortfalls prior to integration on the KC-46A.
  3. Plan to begin IOT&E at least six months later than the current draft TEMP indicates to allow for completion of developmental test and initial training.

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Massive Ordnance Penetrator (MOP)

Executive Summary
- DOT&E published a classified Massive Ordnance Penetrator (MOP) Early Fielding report in April 2012 that summarized testing during FY08 through FY11, including five B-2 Quick Reaction Capability flight tests.
- The Air Force executed two MOP sled tests at the Holloman AFB High-Speed Test Track during June and August 2012 to confirm the successful re-design of certain aspects of the weapon system.
- The Air Force, between June and October 2012, successfully completed five additional weapon drops from the B-2 aircraft on threat-representative targets. The tests, conducted at the White Sands Missile Range, New Mexico, further defined weapon behavior against the target sets.



System
- The MOP, GBU-57A/B, is a large penetrating weapon with the ability to attack deeply buried and hardened bunkers and tunnels. The warhead case is made from a special high performance steel alloy and its design allows for a large explosive payload while maintaining the integrity of the penetrator case during impact.
- The B-2 Spirit is the only aircraft in the Air Force programmed to employ the MOP.
- The MOP is a GPS-guided weapon designed to reach and destroy targets located in well protected facilities. The MOP is more powerful than its predecessors, the BLU-109 and GBU-28.

Mission
Combatant Commanders use MOP to conduct pre-planned, day or night attacks against defended point targets vulnerable to blast and fragmentation effects and requiring significant penetration, such as hardened and deeply-buried facilities.

Major Contractor
The Boeing Company, Defense, Space & Security – St. Louis, Missouri

Activity
- The Air Force, using the Holloman AFB High Speed Test Track in New Mexico, conducted two sled tests during the June to August 2012 period, to confirm the successful re-design of a critical part of the weapon system.
- The Air Force executed five weapon drops at White Sands Missile Range, New Mexico, between June and October 2012, on threat-representative targets to further evaluate weapon system performance and to provide additional confirmation of the weapon re-design. During the tests, a B-2 conducted five drops: three with live warheads, and two with inert warheads. Telemetry data and visual observations indicate that all five weapon drops effectively prosecuted the targets.

Assessment
- In the April 2012 Early Fielding report, DOT&E concluded that the MOP is capable of effectively prosecuting selected hardened, deeply buried targets. All recommendations in the Early Fielding report have been addressed by the Air Force.
- The sled test results and the additional weapon drops indicate that the weapon re-design is adequate for the successful prosecution of all of the elements of the currently defined target set.

Recommendations
- Status of Previous Recommendations. This is the first annual report for this program.
- FY12 Recommendations. None.

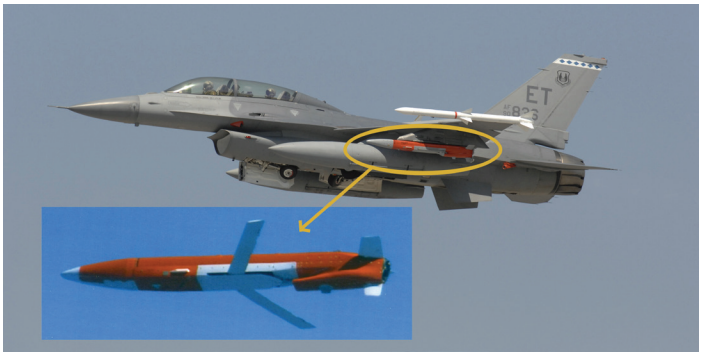
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Miniature Air-Launched Decoy (MALD) and MALD-Jammer (MALD-J)

Executive Summary

- DOT&E's April 2011 IOT&E report assessed the Miniature Air-Launched Decoy (MALD) as operationally effective for combat, but not operationally suitable due to poor materiel reliability. In July 2011, the Air Force identified a fault with the missile's radio frequency connector that caused it to separate from the missile during long-endurance carriage flights. The Air Force has repaired the fault and conducted further reliability testing; however, MALD operational reliability of 78 percent remains below the 93 percent threshold requirement.
- The Air Force will no longer procure any MALDs, as the Program Office converted the MALD procurement line to MALD-Jammer (MALD-J).
- The Air Force demonstrated corrective actions for long-endurance carriage time failures with an additional MALD-J Engineering, Manufacturing, and Development (EMD) test mission in March 2012.
- The Air Force launched 14 MALD/MALD-J shots during FY12 without failure.
- Limited accessibility to test ranges, unavailability of threat systems, and delays in processing and evaluating data have hampered MALD and MALD-J testing. The Air Force needs to allocate sufficient range time for testing and reduce data processing turnaround times.



System

- MALD is a small, low-cost, expendable, air-launched vehicle that replicates how fighter, attack, and bomber aircraft appear to enemy radar operators. The Air Force will no longer procure any MALDs, as the MALD procurement line was converted to MALD-J.
- The Air Force designed the MALD-J as an expendable, close-in jammer to degrade and deny an early warning or acquisition radar's ability to establish a track on strike aircraft while maintaining the ability to fulfill the MALD decoy mission.
- The F-16 C/D and B-52 are the lead aircraft to employ MALD and MALD-J.

Mission

Combatant Commanders will use units equipped with:

- MALD and MALD-J to improve battlespace access for airborne strike forces by deceiving, distracting, or saturating enemy radar operators and Integrated Air Defense Systems.
- MALD to allow an airborne strike force to accomplish its mission by forcing enemy radars and air defense systems to treat MALD as a viable target.
- MALD-J to allow an airborne strike force to accomplish its mission by jamming enemy radars and air defense systems to degrade or deny detection of friendly aircraft or munitions.

Major Contractor

Raytheon Missile Systems – Tucson, Arizona

Activity

MALD

- In August 2011, the Air Force identified a fault with the missile's radio frequency connector that caused it to separate from the missile during long-endurance carriage flights. After improving the connector system, the Air Force tested MALD with six additional shots under a Reliability Assessment Program throughout FY12.
- The Air Force will no longer procure any MALDs, as the Program Office converted the MALD procurement line to MALD-J.

MALD-J

- In March 2012, the Air Force completed the MALD-J EMD with one additional test mission to ensure Operational Flight Software (OFS) Build-7a operated successfully and corrected all software anomalies found with the EMD.
- DOT&E approved the MALD-J IOT&E plan in May 2012.
- AFOTEC launched four MALD-Js during IOT&E in August 2012.

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- The Air Force has conducted MALD-J testing to date in accordance with the DOT&E-approved Test and Evaluation Master Plan and test plan.
- The Air Force is currently working on modeling and simulation utilizing the Digital Integrated Air Defense System to evaluate MALD's ability to degrade an Integrated Air Defense System. Completion and final verification is scheduled for January 2013.

Assessment

- Limited accessibility to test ranges, unavailability of threat systems, and delays in processing and evaluating data have hampered MALD and MALD-J testing.

MALD

- The DOT&E assessment of MALD performance in the April 2011 MALD IOT&E Report remains unchanged. MALD performance is operationally effective for combat, but not operationally suitable due to poor materiel reliability in the intended operational environment.
- The six additional shots under the Reliability Assessment Program demonstrated no additional critical failures. However, the MALD reliability point estimate that combines free-flight and aircraft long-endurance carriage was 78 percent, which falls short of the threshold requirement of 93 percent. This reliability shortfall will increase the number of MALDs necessary to accomplish the mission.

MALD-J

- DOT&E conclusions regarding MALD-J suitability, particularly for reliability, depend in part upon data from MALD testing. DOT&E will use a combination of MALD and MALD-J data to evaluate whether the Air Force has resolved reliability problems. After completing MALD-J EMD, the Air Force launched 14 MALD and MALD-Js during FY12 without additional failures.
- Developing a full mission-level simulation (i.e., multiple MALD-Js versus multiple threat radars) is a technical challenge. However, the oversight of stakeholders and key leadership has helped the Air Force to continue development of the simulation capability in support of the AFOTEC MALD-J IOT&E.

Recommendations

- Status of Previous Recommendations. The Air Force is satisfactorily addressing four of the five FY11 recommendations. However, the remaining FY11 recommendation for the Air Force to provide sufficient resources to the Nevada Test and Training Range to enable personnel to process and distribute test data in a timely manner requires continued emphasis.
- FY12 Recommendation.
  1. Future strike aviation programs should consider utilizing the Air Force Digital Integrated Air Defense System modeling and simulation capability to accurately model the operational effect of MALD/MALD-J and other future weapons systems in robust scenarios.

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Mission Planning Systems (MPS) / Joint Mission Planning Systems – Air Force (JMPS-AF)

Executive Summary

- The Air Force paused IOT&E of the E-8 Mission Planning Environment (MPE), the representative test platform for the Joint Mission Planning System – Air Force (JMPS-AF) Increment IV mission planning functionality, in September 2011 to allow the Program Office to develop and integrate corrective actions to deficiencies identified during operational testing.
- In January 2012, the DOT&E Major Automated Information System (MAIS) report documented deficiencies in the E-8 MPE version 1.0 realized during the suspended FY11 IOT&E. These deficiencies included incomplete printed flight plans, errors in flight calculations for station magnetic variation, problems with exporting mission flight plans, inadequate training for intelligence specialists, unreliable and time-consuming system setup and installation, and excessive time needed for routine maintenance.
- Following additional development and regression testing, the Air Force certified E-8 MPE version 1.3 ready for resumed operational testing. Air Force Operational Test and Evaluation Center (AFOTEC) will re-execute the entire IOT&E in early FY13 in accordance with the DOT&E-approved test plan.

System

- A Mission Planning System (MPS) is a Standard Desktop Configuration (SDC)-based common solution for Air Force aircraft mission planning (the current SDC is Windows XP® or Vista® PC-based). It is a package of common and platform-unique mission planning applications.
- An MPE is a set of developed applications built from a Framework, common components, and Unique Planning Components for a particular aircraft. The Framework is the basis of the MPE. Software developers add common components (e.g., Weather, Electronic Warfare Planner, etc.) and federated applications that support multiple users to the framework. Developers then add a Unique Planning Component for the specific aircraft type (e.g., E-8) to complete the MPE.



- The MPE can operate as an unclassified system or a classified system.
- Although the Framework software is being co-developed among DoD components, MPS is not a joint program. Each Service tests and fields its own aircraft-specific MPEs.
- The representative test platform for JMPS-AF Increment IV mission planning functionality is the E-8 MPE.

Mission

Aircrews use MPS to conduct detailed mission planning to support the full spectrum of missions, ranging from simple training to complex combat scenarios. Aircrews save the required aircraft, navigation, threat, and weapons data on a data transfer device that they load into their aircraft before flight.

Major Contractors

- Northrop Grumman – Carson City, California
- Boeing – St. Louis, Missouri
- TYBRIN Corporation – Fort Walton Beach, Florida

Activity

- The Air Force conducted all MPE operational testing in accordance with a DOT&E-approved Test and Evaluation Master Plan.
- AFOTEC did not complete IOT&E of the E-8 MPE version 1.0 due to deficiencies in: navigation functionality; magnetic variation computation; mission loading; take-off and landing computations; inadequate intelligence specialist training; unreliable system set up/installation; and excessive time needed for routine maintenance. AFOTEC returned the system to development for corrective action.
- The 46th Test Squadron at Eglin AFB, Florida, conducted developmental regression testing of E-8 MPE version 1.3 from

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June through August 2012. The purpose of this test was to verify deficiency fixes, identify changes from the E-8 JMPS Version 1.0 MPE Report, and determine E-8 JMPS version 1.3 MPE readiness to resume IOT&E.

- Based on results from the E-8 MPE regression testing, the Air Force certified E-8 MPE version 1.3 ready for IOT&E in September 2012. AFOTEC will re-execute the IOT&E beginning in early FY13 in accordance with the DOT&E-approved test plan.

Assessment

- In February 2012, DOT&E published a MAIS report concluding that E-8 MPE version 1.0 was operationally suitable with limitations but not operationally effective. Significant findings included:
  - The time needed for E-8 MPE software installation was lengthy, due in large part to anomalies in the software functionality and installation process.
  - Threat database information was not easily accessible or usable. E-8 MPE training for intelligence specialists was inadequate.
  - While mission planners could use E-8 MPE version 1.0 to generate timely mission plans, they were unable to transfer some of these mission plans to the aircraft.
  - The MPE generated magnetic variation errors for user-specified waypoints. Developers identified critical calculation errors of the magnetic variation errors and incorporated fixes during 2012 developmental testing. AFOTEC will verify these corrections during the E-8 MPE version 1.3 IOT&E.
  - Mission planners could not plan missions with in-flight delays. Developers incorporated fixes during 2012 developmental testing and AFOTEC will verify these corrections during the E-8 MPE version 1.3 IOT&E.
  - The Take-Off and Landing Data (TOLD) module in E-8 MPE version 1.0, as well as in other platform MPEs tested and evaluated, does not generate accurate data and is not certified for flight use. The Automated TOLD capability is not integrated into version 1.3, and the Air Force has deferred incorporation of this objective capability to a future MPE release.

Recommendations

- Status of Previous Recommendations. The Air Force is addressing previous recommendations. However, the Air Force has yet to incorporate automated TOLD capabilities into the MPE.
- FY12 Recommendations. The Air Force should:
  1. Incorporate automated TOLD capabilities into the E-8 MPE.
  2. Re-execute the entire E-8 MPE IOT&E in accordance with the DOT&E-approved test plan in order to verify corrective actions and determine the system's operational effectiveness, suitability, and mission capability.

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MQ-9 Reaper Armed Unmanned Aircraft System (UAS)

Executive Summary

- The MQ-9 Unmanned Aircraft System (UAS) continues to support ongoing global combat operations. The MQ-9 UAS has met urgent combat operational needs through accelerated production and the rapid incorporation of emergent sensor and systems technologies outside of the MQ-9 baseline program of record.
- The Air Force accelerated the planned FY13 Milestone C Decision for the Block 5 remotely-piloted aircraft (RPA) to September 2012. USD(AT&L) approved Block 5 RPA Milestone C and Low-Rate Initial Production in September 2012 and the MQ-9 UAS Increment One designation as an Acquisition Category 1C program in conjunction with the Milestone C decision.
- The Air Force Operational Test and Evaluation Center (AFOTEC) conducted an operational assessment (OA) of the Increment One UAS to inform the Block 5 RPA Milestone C decision. A limited flight demonstration comprising 5 functional capabilities sorties and 18 flight test hours demonstrated basic integration and functionality of the Block 5 RPA configuration to inform the Milestone C decision.
- Ongoing developmental challenges precluded operational testing and subsequent fielding of baseline program enhanced capabilities to operational MQ-9 units in FY12 (Operational Flight Programs (OFP) 904.2, 904.4, and Joint Direct Attack Munition (JDAM)).

System

- The UAS includes both the MQ-9 RPA and a Ground Control Station (GCS).
  - The MQ-9 RPA is a remotely-piloted, armed air vehicle that uses optical, infrared, and radar sensors to locate, identify, target, and attack ground targets. The RPA is a medium-sized aircraft that has an operating ceiling up to 50,000 feet, an internal sensor payload of 800 pounds, an external payload of 3,000 pounds, and an endurance of approximately 14 hours.
  - The GCS provides aircraft launch/recovery and mission control of sensors and weapons. C-band line-of-sight datalinks are used for RPA launch and recovery operations, and Ku-band satellite links are used for RPA mission control.



- The MQ-9 RPA carries AGM-114, Hellfire II anti-armor precision laser-guided missiles and GBU-12, 500 pound laser-guided bombs.
- The Air Force is using an evolutionary acquisition approach for meeting Increment One Capability Production Document (CPD) requirements, with Block 1 and Block 5 RPAs and Block 15 and Block 30 GCSs.
- The Air Force is currently fielding the Block 1 RPA.
- The Air Force designed the Block 5 RPA to incorporate improved main landing gear, an upgraded electrical system with more power, an additional ARC-210 radio, encrypted datalinks, a redesigned avionics bay and digital electronic engine control system, the BRU-71 bomb rack, high-definition video, and upgraded software to allow the two-person aircrew to operate all onboard systems.

Mission

- The Combatant Commander uses the MQ-9 onboard sensors and weapons to conduct armed reconnaissance and pre-planned strikes. Units equipped with MQ-9s can find, fix, track, target, engage, and assess critical emerging targets (both moving and stationary).
- MQ-9 units can also conduct aerial intelligence gathering, reconnaissance, surveillance, and target acquisition for other airborne platforms.

Major Contractor

General Atomics Aeronautical Systems Inc. – San Diego, California

Activity

- The Air Force conducted MQ-9 testing in accordance with the DOT&E-approved Test and Evaluation Master Plan.
- In July 2012, the Air Force Requirements Oversight Council approved changes to the MQ-9 reliability requirements. The Air Force changed the Mean Time Between Critical Failure threshold requirement from 500 hours to 19 hours for the MQ-9 RPA and from 500 hours to 224 hours for the GCS.

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- MQ-9 Block 1 RPA software, Block 5 RPA hardware and software, and Block 30 GCS developmental testing were ongoing throughout FY12. The final MQ-9 Increment One UAS configuration will include the Block 5 RPA, Block 30 GCS, and OFP 904.6.
- Planned FY12 Air Force Air Combat Command (ACC) Force Development Evaluation (FDE) testing of MQ-9 Block 1 OFPs 904.2 and 904.4 did not occur. Software immaturity coupled with the implementation of new Air Force airworthiness requirements resulted in developmental delays.
- The 2009 GBU-38, 500-pound JDAM FDE to support limited MQ-9 fielding remains in a pause status pending resolution of MQ-9 OFP fuzing and weapons envelope discrepancies identified in 2010.
- The new Block 5 RPA completed five early developmental demonstration flights in FY12. These functional capabilities sorties demonstrated basic integration and functionality of the Block 5 RPA configuration.
- AFOTEC began an OA of MQ-9 in May 2012 in support of the September 2012 Block 5 Milestone C decision. AFOTEC conducted the testing in accordance with a DOT&E-approved OA plan.
- USD(AT&L) approved MQ-9 Block 5 RPA Milestone C and low-rate initial production in September 2012.

Assessment

- The Air Force intends to fulfill the MQ-9 Increment One CPD requirements with a final UAS configuration consisting of the Block 5 RPA, Block 30 GCS, and OFP 904.6. AFOTEC will conduct formal operational testing of the final MQ-9 Increment One UAS in 2014. This operational testing will assess Increment One UAS effectiveness, suitability, mission capabilities, and satisfaction of CPD key performance parameters.
- The MQ-9 program continues to face systemic challenges in prioritizing and maturing software OFPs to meet development and fielding timelines for the Increment One program of record. During FY12, such delays precluded the completion of developmental testing of OFPs 904.2 and 904.4 to support planned FY12 operational testing. Development, operational testing, and fielding of Increment One program of record capabilities will likely experience continued delays unless the program is able to better prioritize and control maturation of these capabilities.
- The program made incremental progress towards resolving deficiencies discovered during the 2009 MQ-9 JDAM FDE testing; however, the OFP has yet to demonstrate readiness for resumed JDAM operational testing.
- Findings from the AFOTEC OA of the Increment 1 Block 5 RPA indicated progress in conducting limited flight testing of the integrated hardware suite and early revisions of OFP 904.6 software in a prototype Block 5 RPA controlled with a Block 15 GCS. Across 5 sorties and 18 flight test hours these missions demonstrated:
  - Functional operation of aircraft handling, flight control systems, and payload systems
  - Successful operation of the heavyweight landing gear system
  - All power modes of the high capacity power system
  - Dual ARC-210 radio and wingtip antenna functionality in both clear and secure modes
  - Encrypted Ku-band satellite datalink control
  - Multi-spectral Targeting System B functionality in standard definition video format
  - Synthetic aperture radar legacy modes, including ground moving target indicator mode operation
- As was the case in FY11, Information Assurance (IA) vulnerabilities and deficiencies are not well characterized because the Air Force has only completed limited IA testing on the MQ-9 system. As of the end of FY12, the system is operating under an Interim Authority to Test, pending full system IA testing.

Recommendations

- Status of Previous Recommendations. In FY12, the Air Force satisfied several of the DOT&E FY11 recommendations. However, two FY11 recommendations remain outstanding:
  1. The Air Force should complete the JDAM FDE.
  2. The Air Force should conduct IA testing to include adversary system penetration testing.
- FY12 Recommendation

1. The Air Force should complete the development of the Increment One UAS hardware and software to support FOT&E of the Increment One system to assess operational effectiveness, suitability, and mission capability of the final Increment One UAS configuration.

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RQ-4B Global Hawk High-Altitude Long-Endurance Unmanned Aerial System (UAS)

Executive Summary

Block 20

- The Air Force successfully completed conversion of two additional RQ-4B Block 20 air vehicles to the EQ-4B configuration equipped with the Battlefield Airborne Communications Node (BACN) payload. This increased the total number of BACN-equipped air vehicles supporting U.S. Central Command (USCENTCOM) operations to three. Developmental and operational testing of RQ-4B and EQ-4B Block 20 Global Hawk variants are complete.

Block 30

- The Air Force continued developmental testing of RQ-4B Block 30 capability upgrades and deficiency corrections at a reduced pace due to the FY13 budget proposal to terminate the program. The Air Force continued to improve RQ-4B Block availability by correcting air vehicle and sensor reliability problems and increasing the availability of spare parts.
- The Air Force has not conducted an RQ-4B Block 30 operational test to field deficiency corrections or previously planned new system capabilities to operational units since IOT&E in December 2010. Future plans for system development and testing depend upon final FY13 budget decisions.

Block 40

- The Air Force completed the initial phase of RQ-4B Block 40/Multi-Platform Radar Technology Insertion Program (MP-RTIP) radar system-level performance verification testing in July 2012, which demonstrated basic integration of the MP-RTIP radar with the Global Hawk air vehicle. This phase also focused on improving radar software stability, image quality, and moving target false alarm rates.
- In response to a USCENTCOM early operational need request, the Air Force is planning a limited operational utility evaluation in March 2013 to support early fielding of two developmental RQ-4B Block 40 systems to support USCENTCOM operations.

System

- The RQ-4 Global Hawk is a remotely-piloted, high-altitude, long-endurance airborne intelligence, surveillance, and reconnaissance system that includes the Global Hawk unmanned air vehicle, various intelligence and communications relay mission payloads, and supporting command and control ground stations.
- The RQ-4B Global Hawk Block 20 system is equipped with the Enhanced Integrated Sensor Suite (EISS) imagery intelligence payload. The EQ-4B Block 20 variant is equipped with the BACN theater communications relay payload. The EISS sensor includes infrared, optical, and synthetic aperture radar sensors for collecting still imagery intelligence on ground targets. The BACN payload provides communications connectivity between geographically separated operational units.
- The RQ-4B Global Hawk Block 30 system is equipped with a multi-intelligence payload that includes both the EISS imagery intelligence payload and the Airborne Signals Intelligence Payload (ASIP) electronic signal collection sensor.
- The RQ-4B Global Hawk Block 40 system is equipped with the MP-RTIP synthetic aperture radar payload designed to simultaneously collect imagery intelligence on stationary ground targets and track ground moving targets.



Mission

Commanders use RQ-4 Global Hawk reconnaissance units to provide high-altitude, long-endurance intelligence collection capabilities or theater communications relay capabilities to supported commanders.

- Operators collect imagery and signals data in order to support ground units and to identify intelligence essential elements of information for theater commanders. Units equipped with RQ-4B Global Hawk use line-of-sight and beyond line-of-sight satellite datalinks to control the Global Hawk system and transmit collected intelligence data.
- Distributed intelligence processing, exploitation, and dissemination systems receive intelligence data directly from the air vehicle or from the Global Hawk ground station via intelligence data transmission systems.

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- Ground-based intelligence analysts exploit collected imagery and signals information to provide intelligence products in support of theater operations.
- Global Hawk can also provide imagery intelligence directly to forward-based personnel through direct line-of-sight datalink systems.

Major Contractor
Northrop Grumman Aerospace Systems, Strike and Surveillance Systems Division – San Diego, California

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Activity

Block 20
- In response to a USCENTCOM request, the Air Force successfully completed conversion of two additional RQ-4B Block 20 air vehicles to the EQ-4B configuration equipped with the BACN payload to support USCENTCOM operations. The Air Force completed testing, and deployed these modified systems to USCENTCOM in FY12.
- Three of the four operational EQ-4B Block 20 air vehicles are now supporting USCENTCOM operations with the BACN payload. The fourth aircraft is a RQ-4B test asset. Developmental and operational testing of this Global Hawk variant is complete.

Block 30
- Due to the FY13 budget proposal to terminate RQ-4B Block 30 production and retire all existing aircraft, USD(AT&L) deferred the planned RQ-4B Block 30 Full-Rate Production Decision from August 2011 until at least November 2012.
- The Air Force continued developmental testing of software improvements to correct operational deficiencies identified during the FY11 IOT&E. However, the Air Force did not complete planned RQ-4B Block 30 Force Development Evaluation follow-on operational testing in FY11 or FY12 to evaluate and field these improvements due to uncertainty resulting from the FY13 budget proposal to terminate the program. The Air Force continued to implement corrective actions to improve system reliability, availability, and maintainability for the RQ-4B Block 30 systems currently employed in USCENTCOM, U.S. Pacific Command, and U.S. European Command operational theaters.
- The Air Force continued planning for an RQ-4B Block 30 Force Development Evaluation operational test in FY13 to evaluate specific post-IOT&E air vehicle and sensor software upgrades and a new satellite communications link. Planning for a more comprehensive FY14 RQ-4B Block 30/ASIP FOT&E event to evaluate correction of all major system deficiencies identified during IOT&E remains on hold pending a final decision on the future of the RQ-4B Block 30 program.

Block 40
- Due to FY13 budget uncertainties, USD(AT&L) deferred the RQ-4B Global Hawk Block 40 Milestone C Decision from August 2011 until FY13.
- In preparation for a Milestone C decision, the Air Force is developing a revised RQ-4B Block 40 Capability Production Document for Joint Staff approval, which removes Battle Management Command and Control mission capabilities as a threshold requirement and lowers overall system reliability and availability requirements. The Air Force also initiated development of an RQ-4B Block 40 Milestone C Test and Evaluation Master Plan to guide system developmental and operational test activities leading to a combined RQ-4B Block 40/MP-RTIP IOT&E in FY14 and FOT&E of future capabilities and system improvements.
- The Air Force continued execution of the current RQ-4B Block 40/MP-RTIP development and test program. The Air Force completed the first phase of RQ-4B Block 40/MP-RTIP radar system-level performance verification testing in July 2012 to verify basic integration of the MP-RTIP radar with the air vehicle platform. Additional radar control, performance, and interoperability testing is in progress and will continue until IOT&E in FY14.
- In response to a USCENTCOM early operational need request, the Air Force is planning a limited operational utility evaluation in March 2013 to support early fielding of two developmental RQ-4B Block 40 systems to support USCENTCOM operations.
- Accelerated delivery of RQ-4B Block 40 air vehicles and MP-RTIP sensor systems continued in FY12. The Air Force will accept delivery of at least 9 of the 11 procured RQ-4B Block 40 systems at Grand Forks AFB, North Dakota, prior to IOT&E and initial operational capability in FY14.

Assessment

Block 20
- Correction of previously identified EQ-4B air vehicle reliability problems and procurement of additional spare parts increased the system reliability and availability.

Block 30
- Due to FY13 budget uncertainties and lack of planned follow-on operational testing, the Air Force has not fielded software deficiency corrections or previously planned additional capabilities to operational units. Future plans for system development and testing depend upon final FY13 budget decisions.

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- The Air Force continued to improve RQ-4B Block 30 reliability and availability by correcting air vehicle and sensor reliability problems and increasing the availability of spare parts. Maintenance training and technical order improvements also improved system maintainability. As a result, RQ-4B Block 30 mission capable rates increased from approximately 52 percent during the FY11 IOT&E to over 80 percent in FY12. At these rates, RQ-4B Block 30 effective-time-on-station performance at near continuous operational tempos should be sufficient to meet the minimum 55 percent effective-time-on-station operational requirement for single vehicle operations, if sufficient spare parts remain available.

Block 40

- The RQ-4B Block 40 and MP-RTIP development program made significant progress in FY12. The initial phase of radar system-level performance verification test in July 2012 demonstrated basic integration of the MP-RTIP radar with the air vehicle. This phase also focused on improving radar software stability, image quality, and moving target false alarm rates
- The RQ-4B Block 40/MP-RTIP test schedule to support early fielding of two systems to USCENTCOM in May 2013 and the FY14 IOT&E is aggressive with little room for recovery if ongoing developmental tests discover any significant system performance problems. Ongoing sensor data transfer and interoperability challenges and potential winter weather delays at the Grand Forks, North Dakota, test site further increase schedule risks.

Recommendations

- Status of Previous Recommendations. The Air Force made progress in addressing previous DOT&E recommendations to implement RQ-4B Block 30 system reliability, interoperability, and Information Assurance improvements. The Air Force delayed full implementation of the ASIP sensor performance improvement plans and other post-IOT&E RQ-4B Block 30 improvements due to the FY13 budget proposal to terminate the program. The Air Force successfully addressed DOT&E recommendations to revise RQ-4B Block 40 operational capability requirements and define related end-to-end operational architectures and interoperability requirements.
- FY12 Recommendations. The Air Force should:
  1. Develop an RQ-4B Block 30 test strategy to complete post-IOT&E corrective actions and conduct a comprehensive FOT&E if the decision is made to continue the program. If terminated, the Air Force should conduct FOT&E of the ASIP sensor on the U-2 aircraft to verify correction of serious performance deficiencies identified during IOT&E.
  2. Conduct an operational test to support early fielding of RQ-4B Block 40 developmental systems to meet the FY13 USCENTCOM operational need request.
  3. Complete an RQ-4B Block 40 Test and Evaluation Master Plan to guide system test activities leading to a combined RQ-4B Block 40/MP-RTIP IOT&E in FY14 and the required follow-on developmental and operational testing of planned future Global Hawk capabilities and system improvements.

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Space-Based Infrared System (SBIRS) Effectivity 5

Executive Summary

- The Air Force Operational Test and Evaluation Center (AFOTEC) conducted an Operational Utility Evaluation (OUE) of the Space-Based Infrared System (SBIRS) from September 27 to October 11, 2012. The capability tested was Effectivity 5, which includes the SBIRS ground architecture, the first SBIRS satellite in geosynchronous orbit (GEO-1), two hosted infrared payloads in Highly Elliptical Orbit (HEO), and legacy Defense Support Program (DSP) assets. DOT&E published a classified test report in December 2012.
- The OUE will inform Air Force operational acceptance of Effectivity 5. U.S. Strategic Command will use operational test results for its Integrated Tactical Warning/Attack Assessment system certification. The National Geospatial-Intelligence Agency (NGA) will utilize operational test results for its certification of GEO-1 data for technical intelligence.
- SBIRS Effectivity 5 is operationally effective and will be operationally suitable upon resolution of an open deficiency identified in the classified DOT&E report.



System

The SBIRS program provides infrared sensing from space to support Department of Defense and other user organizations. The SBIRS program is being developed in two system increments to replace the DSP satellites:

- Increment 1 uses the SBIRS Control Segment and User Segment, operating with DSP satellites, to provide current military capability. Initial Operational Capability for Increment 1 was attained in December 2001, consolidating the operations of the DSP and Attack and Launch Early Reporting to Theater missions.
- Increment 2 includes a space segment consisting of two hosted payloads in HEO and four satellites in geosynchronous orbit. Increment 2 also provides new software and hardware to process data from both the DSP and the SBIRS space segment.
- Increment 2 capabilities are being delivered in phases, both with ground system software and on-orbit assets, and therefore require several dedicated test and evaluation activities. The current phase tested, Effectivity 5, adds capabilities into the operational SBIRS system to support GEO-1, which was launched on May 7, 2011. New capabilities include GEO-1 command and control functions and use of GEO-1 scanner sensor data in mission processing and reporting functions.

Mission

Combatant Commanders, deployed U.S. military forces, and allies intend to use SBIRS to conduct missions that require improved space sensors and operational launch detection capabilities. Commanders will use SBIRS to enhance support to joint combat forces in four key areas:

- Timely and responsive space-based missile warning and detection
- Launch detection and characterization for missile defense operations
- Technical intelligence
- Battlespace awareness

Major Contractor

Lockheed Martin Space Systems – Sunnyvale, California

Activity

- AFOTEC conducted a dedicated OUE from September 27 through October 11, 2012. AFOTEC conducted the testing in accordance with the DOT&E-approved Test and Evaluation Master Plan (TEMP) and test plan. The OUE was executed in conjunction with Air Force Space Command's operational trial period. An initial period occurred from September 27 through November 27, 2012. An additional trial period is projected to occur following resolution of a deficiency affecting suitability, which is discussed in the classified report.
  - The capability tested was Effectivity 5, which includes the SBIRS ground architecture, GEO-1, two hosted infrared payloads in HEO, and legacy DSP assets.
  - DOT&E published a final test report in December 2012. The report will inform Air Force operational acceptance

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of Effectivity 5. U.S. Strategic Command will also use operational test results for its Integrated Tactical Warning/Attack Assessment system certification. NGA will utilize operational test results for its certification of GEO-1 data for technical intelligence.

- The Air Force successfully launched SBIRS GEO-1 on May 7, 2011, and conducted planned checkout and sensor tuning activities through May 2012 for the strategic and theater missile warning missions. Additional checkout activities are planned to continue throughout FY13, including testing and calibration of the staring sensor.
- DOT&E approved an updated Enterprise TEMP on March 7, 2012. Another update to the TEMP is in coordination for future testing of Increment 2. Finalizing this document is contingent upon a ground architecture definition, a concept of operations, and operational requirements for each key SBIRS Increment 2 delivery.
- AFOTEC and the SBIRS Program Office led an Integrated Test and Evaluation period between June and August 2012. The Air Force made modeling and simulation requirements a priority, working with the Program Office and contractor to ensure required capabilities were sustained and available for Integrated Test.

Assessment

- SBIRS Effectivity 5 is operationally effective. Integration of GEO-1 into the operational constellation improved accuracy of both strategic and theater missile warning mission data and did not degrade overall mission performance. SBIRS also demonstrated improved performance against the missile defense mission. SBIRS support to the technical intelligence and battlespace awareness missions was functional and effective. There were no major problems observed during the integrated and operational test periods. The SBIRS enterprise system accomplished its strategic and theater missile warning missions, successfully detecting and reporting all missile events during both real-world and simulation scenarios during these test periods.
- The SBIRS GEO-1 scanning sensor payload is meeting accuracy and sensitivity requirements, based on developmental and integrated test activities. It is at least as capable as legacy DSP sensors, while providing detection over a given location twice as frequently. This increased revisit rate is operationally significant as it enables the ability to determine target missile type with higher confidence by providing more data points for analysis during the target missile's powered flight.
- SBIRS Effectivity 5 will be operationally suitable upon resolution of an open deficiency identified in the classified DOT&E OUE report. The Air Force is addressing problems identified during the OUE with the overall system, technical intelligence missions, and specific Information Assurance postures.
- The classified test report includes more information on additional observations, detailed findings, and recommendations

Recommendations

- Status of Previous Recommendations. The Air Force satisfactorily addressed previous recommendations from FY05, FY07, FY08, and FY09.
- FY12 Recommendations. The Air Force should
  1. Specify the ground architecture, concept of operations, and operational requirements for each key SBIRS Increment 2 delivery due to recent SBIRS restructuring to support a timely update of the TEMP.
  2. Address the eight recommendations identified in the December 2012 classified DOT&E OUE report.

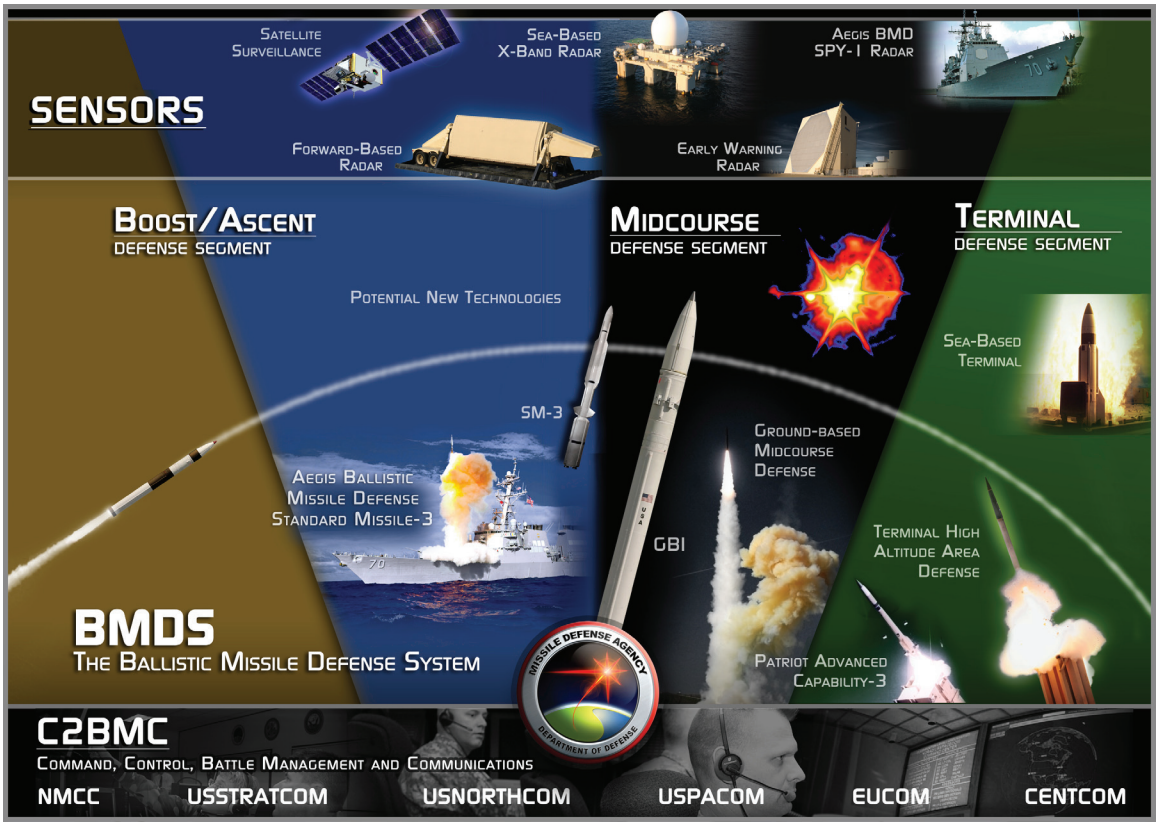
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Ballistic Missile Defense Systems

Ballistic Missile Defense Systems

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Ballistic Missile Defense System (BMDS)



Executive Summary

- In October 2012, the Missile Defense Agency (MDA) conducted the most complex ballistic missile defense flight test, combined developmental/operational Flight Test Integrated-01 (FTI-01), ever attempted in the history of the DoD. FTI-01 was the first flight test of a regional Ballistic Missile Defense System (BMDS) that included soldiers, sailors, and airmen from multiple Combatant Commands operating multiple sensors and missile defense systems to engage three ballistic and two cruise missile targets near simultaneously. Four of the five targets were successfully intercepted. Analysis is ongoing, but DOT&E will include the results in the 2012 BMDS report to Congress to be published in February 2013.
- Except for FTI-01, testing of the BMDS during the past fiscal year was limited to three ground tests, two Aegis BMD flight tests, one Terminal High-Altitude Area Defense (THAAD) flight test, and exercise Fast Eagle Increment 1 testing. The Ground-based Midcourse Defense (GMD) program did not accomplish any element flight testing.
- BMDS regional defensive capability was enhanced by completion of FTI-01, deployment of Phase 1 of the European Phased Adaptive Approach (EPAA), and the lessons learned during exercise Fast Eagle Increment 1.
- The MDA, in collaboration with the Operational Test community, continued to refine the content and quality of the BMDS Integrated Master Test Plan (IMTP) with emphasis on the verification, validation, and accreditation of the models and simulations supporting performance assessments.

System

- The current BMDS architecture integrates ballistic missile defense capabilities against all ranges of threats.
- BMDS is a distributed system currently comprised of five elements (four shooter elements and one command and control element) and five sensor systems (four radar systems and one space-based system).

Elements

- Aegis BMD (shooter)
- Command, Control, Battle Management, and Communications (C2BMC) (command and control)
- GMD (shooter)
- Patriot (shooter)
- THAAD (shooter)

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Sensors

- Aegis BMD AN/SPY-1 Radar
- Cobra Dane Radar
- Upgraded Early Warning Radars
- AN/TPY-2 (Forward-Based Mode [FBM]) Radar
- Space Based Infrared System/Defense Support Program (SBIRS/DSP)
- These two sensor systems will support the BMDS when available:
  - Sea-Based X-Band Radar (primarily a test asset that can be operationally deployed as needed)
  - Precision Tracking Space System (a projected addition to the BMDS sensor systems)

Mission

- The U.S. Strategic Command (USSTRATCOM) synchronizes operational-level global missile defense planning, operations support, and the development of missile defense effects for the DoD. When directed, it provides alternate missile defense execution.
- U.S. Northern Command (USNORTHCOM), U.S. Pacific Command (USPACOM), U.S. Central Command (USCENTCOM), and U.S. European Command (USEUCOM) will employ the assets of the BMDS to defend U.S. territory, deployed forces, friends, and allies against ballistic missile threats of all ranges and in all phases of flight. Initial capability permits defending U.S. territory against simple ballistic missile threats and defending deployed forces, friends, and allies from theater-level ballistic missile threats.
- USSTRATCOM, USNORTHCOM, USEUCOM, USCENTCOM, and USPACOM will use the C2BMC element of the BMDS to maintain situational awareness. USEUCOM, USCENTCOM, and USPACOM will also use the C2BMC to provide sensor management of theater AN/TPY-2 radars across the full mission engagement space.
- The Army employs Patriot to provide theater defense for deployed forces against short- and medium-range threats.

Major Contractors

- The Boeing Company, Integrated Defense Systems, Missile Defense Systems – Huntsville, Alabama
- Lockheed Martin:
  - Missile and Fire Control – Dallas, Texas
  - Mission Systems and Sensors – Moorestown, New Jersey
  - Information Systems and Global Solutions – Gaithersburg, Maryland
- Raytheon Missile Systems – Tucson, Arizona

Activity

- The MDA conducted FTI-01 in October 2012, which included near-simultaneous Aegis BMD and Patriot engagements of short-range ballistic missiles while defending against cruise missile attacks, and a THAAD first time engagement of a medium-range ballistic missile. SBIRS/DSP provided early warning and an AN/TPY-2 (FBM) radar provided acquisition cues via C2BMC. Soldiers performed command and control functions from the Air and Space Operations Center at Hickam AFB, Hawaii.
- In FY12, the MDA completed the Ground Test-04d (GT-04d) campaign, which consisted of Ground Test Integrated–04d Part 2 in October 2011 and Ground Test Distributed-04d (GTD-04d) Parts 2 and 3 in December 2011. These ground tests provided support to the MDA's European Phased Adaptive Approach (EPAA)-Phase 1 declaration against medium-range ballistic missiles and NATO's May 2012 declaration of an interim southern European missile defense capability.
- The MDA completed GTI-04 (Israel) in November 2011, which tested the interoperability of Israel's joint BMDS. It integrated the following U.S. and Israeli systems: C2BMC, Aegis BMD, AN/TPY-2 (FBM), SBIRS/DSP, THAAD, and a representation of the Israeli Arrow Weapons System.
- The MDA completed Ground Test Focused-04e (GTX-04e) in April 2012. This developmental ground test provided data to assess new functionality for Aegis BMD, GMD, and THAAD.
- The MDA completed the Fast Eagle Increment 1 hardware-in-the-loop testing in June 2012, a distributed test in August 2012, and follow-on hardware-in-the-loop testing in September 2012. These tests were designed to evaluate the capability of the AN/TPY-2 (FBM) and USCENTCOM C2BMC to augment the existing USCENTCOM BMDS capability.
- The MDA, in collaboration with the Operational Test community, made one update to the FY12 version of the BMDS IMTP that uses a critical factors analysis (referred to as Critical Engagement Conditions) and other important data needs (referred to as Empirical Measurement Events) to drive test design, planning, and execution. In July 2012, the MDA began a process of re-baselining the IMTP to better align it with BMDS modeling and simulation verification, validation, and accreditation data needs. The MDA conducted testing during FY12 in accordance with the DOT&E-approved IMTP.
- In FY11, the MDA established a Lethality Focus Group (LFG) in which the MDA, DOT&E, and the Operational Test community collaborate to identify lethality data gaps for all BMDS weapon elements. In FY12, the LFG generated a prioritized list of threat models needed to support lethality evaluations for planned flight and ground testing for Aegis BMD, GMD, Patriot, and THAAD, and has started developing a plan of action to address these data voids.
- During FY12, the MDA conducted numerous wargames and exercises that enhanced Combatant Command BMD readiness and increased confidence in the deployed elements of the BMDS. These events included: Air and Missile Defense Exercise (AMDEX), Joint Air and Missile Defense

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Exercise, Austere Challenge, Terminal Fury/Global Lightning, EUCOM AMDEX, Keen Edge, Ulchi Freedom Guardian, Vigilant Shield/Global Thunder, BMDS Wargame, Planning Exercise, Joint Tactical Air Picture, National Missile Defense Conference, Nimble Titan, Joint Deployable Integrated Air and Missile Defense, Integrated Air and Missile Defense Center Senior Level Seminar, Huntsville Wargame, and the Missile Defense Advisory Committee Wargame.

- To support operational testing beginning in FY13, the MDA completed major infrastructure improvement and modernization efforts at the Reagan Test Site (RTS) and on Wake Island. At RTS these include: development of Mission Operations Centers; upgrade of power, water, and fuel infrastructure to support THAAD, Patriot, and AN/TPY-2 radar sites in various locations on the Kwajalein Atoll; development of housing and dining facilities for Soldiers who will man the THAAD and Patriot batteries; a climate-controlled storage facility; improvement and modernization of housing for flight test personnel; and installation of communications infrastructure to support mission data and voice communications. On Wake Island these include: refurbishment of the 50k Rail Launcher; improvement and upgrade of the backup power systems; and repair and improvement of the existing communications infrastructure.

Assessment

- Many of the models and simulations used in the ground tests are still not accredited for performance assessment, thereby limiting quantitative assessments based on their results. Re-baselining the IMTP to better align it with BMDS modeling and simulation will support required verification, validation, and accreditation.
- The BMDS defensive capability against theater threats increased during the last fiscal year. The deployment of an AN/TPY-2 (FBM) radar to Turkey and an Aegis BMD ship to the Mediterranean Sea provided an interim defensive capability in the southeastern Europe theater, which was demonstrated through ground testing (although these ground tests have not been accredited for performance assessment). Similar ground testing provided evidence for an initial defensive capability for the Israeli and Middle Eastern theaters as well. During FTI-01, sensors and weapon systems worked together successfully to engage four of the five targets launched during the test scenario contributing to this assessment. Only Aegis BMD was unsuccessful while engaging a short-range ballistic missile. DOT&E anticipates continued increases in this capability over time.
- BMDS interoperability increased during the last fiscal year to support the additional defensive capabilities in the European, Israeli, and Middle Eastern theaters. Ground testing (GT-04 campaign and Fast Eagle Increment 1) uncovered some interoperability and command and control deficiencies that affected track processing, situational awareness, and battle management. The MDA is currently investigating these deficiencies.
- The BMDS capability against strategic threats has not increased because the GMD program continues to resolve deficiencies with its Capability Enhancement II (CE-II) Exo-atmospheric Kill Vehicle (EKV). As a result, the GMD program did not conduct a flight test in FY12.
- The designated Service members actively participated in system-level BMDS testing, as well as element-level testing. They perform operational roles at individual element levels through major Combatant Command levels using operational tactics, techniques, and procedures.
- Although the LFG has developed a plan of action to address BMDS lethality data voids, the MDA has made little progress in retiring lethality data needs.

Recommendations

- Status of Previous Recommendations. Although the MDA has made progress on previous recommendations, the FY08 recommendation regarding the BMDS lethality program and the FY09 recommendation regarding IMTP execution are still valid. The FY11 recommendation regarding flight testing to verify root causes and Failure Review Board results for Aegis BMD and GMD flight tests failures has been partially met for the Aegis BMD program, and is still being addressed for the GMD program.
- FY12 Recommendation.
  1. The MDA should continue addressing the interoperability and command and control deficiencies uncovered during the GT-04 test campaign and FTI-01. Resolution of these deficiencies should be demonstrated through ground and/or flight testing.

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Aegis Ballistic Missile Defense (Aegis BMD)

Executive Summary

- The Aegis Ballistic Missile Defense (BMD) program completed the initial phase of developmental flight testing of the Aegis BMD 4.0.1 and 4.0.2 defense capabilities with Standard Missile-3 (SM-3) Block IB interceptors, and it commenced a phase of combined developmental and operational testing (DT/OT) for the 4.0.1 and 4.0.2 system and interceptor.
- The Aegis BMD program conducted four intercept missions in FY12; three were successful and one failed.
- Although the program completed the FOT&E phase for the Aegis BMD 3.6.1 system in FY11, the system continued to take part in BMDS-level tests related to Phase 1 of the European Phased Adaptive Approach (EPAA) and other system-level deployments.
- Aegis BMD continued to improve interoperability with other Ballistic Missile Defense System (BMDS) elements and sensors during flight and ground testing in FY12.
- Hardware-in-the-loop (HWIL) ground testing demonstrated potential Aegis BMD capability to contribute to theater-level defense missions spanning a range of ballistic missile defense scenarios.

System

- Aegis BMD is a sea-based missile defense system that employs the multi-mission shipboard Aegis Weapon System, with new radar and missile capabilities to engage ballistic missile threats. Capabilities of Aegis BMD include:
  - Computer program modifications to the AN/SPY-1 radar, which allow long-range surveillance and track (LRS&T) of ballistic missiles of all ranges.
  - A modified Aegis Vertical Launch System, which stores and fires SM-3 Block IA and Block IB interceptors (on select ships), and modified SM-2 Block IV interceptors (on select ships).
  - SM-3 Block IA and Block IB interceptors, which use a maneuverable kinetic warhead to accomplish midcourse engagements of short-, medium-, and intermediate-range ballistic missiles.
  - Modified SM-2 Block IV interceptors, which provide terminal engagement capability against short-range ballistic missiles.



- Aegis BMD is capable of performing autonomous missile defense operations, operations that exploit networked sensor information, and can send or receive cues to or from other BMDS sensors through tactical datalinks.

Mission

The Navy can accomplish three missile defense-related missions using Aegis BMD:

- Defend deployed forces and allies from short- to intermediate-range theater ballistic missile threats
- Provide forward-deployed radar capabilities to enhance defense against ballistic missile threats of all ranges by sending cues or target track data to other elements of the BMDS
- Provide all short- to long-range ballistic missile threat data to the Command, Control, Battle Management, and Communications (C2BMC) system for dissemination to Combatant Commanders' headquarters to ensure situational awareness

Major Contractors

- Lockheed Martin Maritime Systems and Sensors – Moorestown, New Jersey
- Raytheon Missile Systems – Tucson, Arizona

Activity

- In accordance with the DOT&E-approved Integrated Master Test Plan, the Aegis BMD program completed the initial phase of developmental flight testing of the Aegis BMD 4.0.1 and 4.0.2 defense capabilities with SM-3 Block IB interceptors, and it commenced a phase of combined DT/OT for the 4.0.1 and 4.0.2 system and interceptor.
- Although the program completed FOT&E for the Aegis BMD 3.6.1 system in FY11, the program continued to use

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the 3.6.1 system in BMDS-level tests related to Phase 1 of the EPAA and other system-level deployments.

- The Aegis BMD program conducted four intercept missions in FY12; three were successful and one failed:
  - During Flight Test SM-16 (FTM-16) Event 2A in May 2012, an Aegis BMD 4.0.1 cruiser intercepted a short-range non-separating ballistic missile target with an SM-3 Block IB interceptor. The FTM-16 Event 2A engagement was the first intercept of a ballistic missile with the SM-3 Block IB interceptor and Aegis BMD 4.0.1 system.
  - During FTM-18 in June 2012, an Aegis BMD cruiser with 4.0.1 software intercepted a simple separating ballistic missile target with an SM-3 Block IB interceptor. FTM-18 was the second successful intercept mission conducted with the new Aegis BMD 4.0.1 system with an SM-3 Block IB interceptor, and the first combined DT/OT flight test for that system.
  - During Flight Test Integrated-01 (FTI-01) in October 2012, an Aegis BMD 3.6.1 ship performed a near-simultaneous engagement of a short-range simple separating ballistic missile target with an SM-3 Block IA interceptor and an anti-air warfare target with an SM-2 interceptor. FTI-01 was the first integrated flight test with multiple firing elements (Aegis BMD, Terminal High-Altitude Area Defense [THAAD], and Patriot) engaging multiple ballistic missile and air-breathing targets in a realistic BMDS-level architecture. While the SM-3 Block IA interceptor missed its target, the SM-2 interceptor achieved a successful intercept.
- In FY12, Aegis BMD participated in several flight and ground tests to assess Aegis BMD 3.6.1 and 4.0.1 system functionality and interoperability with the BMDS:
  - Ground Test Integrated-04d (GTI-04d) Part 2 in October 2011 tested the engagement capabilities of existing missile defense systems against short- and medium-range ballistic missiles and tested system-level sensor resource management and tasking in an HWIL environment in support of an EPAA Phase 1 assessment. Participants included Space-Based Infrared System/Defense Support Program (SBIRS/DSP), Aegis BMD (laboratory sites with 3.6.1 software), AN/TPY-2 (Forward-Based Mode [FBM]), and C2BMC.
  - The MDA completed GTI-04 (Israel) in November 2011, which tested the interoperability of Israel's joint BMDS. It integrated the following U.S. and Israeli systems: Aegis BMD 3.6.1, C2BMC AN/TPY-2 (FBM), SBIRS/DSP, THAAD, and a representation of the Israeli Arrow Weapons System.
  - During Flight Test THAAD (FTT)-12 in October 2011, an Aegis BMD laboratory representation was utilized to assess the capability of Aegis BMD 3.6.1 to conduct simulated engagements against separating and non-separating short-range ballistic missiles using track data from the Space Tracking and Surveillance System (STSS).
  - Ground Test Distributed-04d (GTD-04d) Part 2 in December 2011 tested the communication architecture that was deployed as part of EPAA Phase 1. Participants included a laboratory representation of Aegis BMD 3.6.1, and AN/TPY-2 (FBM) and C2BMC assets in a distributed environment using operational communication systems and operationally representative crews.
  - GTD-04d Part 3 in December 2011 tested interoperability and engagement capability of the EPAA Phase 1 system in support of deployment. Participants included Aegis BMD (3.6.1 laboratory representation), AN/TPY-2 (FBM), and C2BMC in a distributed environment using operational communication systems and operationally representative crews.
  - Aegis BMD 3.6.1 participated in the FTM-15 System-level Post-Flight Reconstruction (SPFR) in December 2011, which was a BMDS HWIL-based event designed to provide data in support of modeling and simulation anchoring efforts.
  - Aegis BMD 4.0.1 laboratory representations participated in Ground Test Other-04e (GTX-04e) in March and April 2012. GTX-04e provided the necessary HWIL architecture for testing new engagement and LRS&T capabilities of Aegis BMD 4.0.1. The test integrated C2BMC, Ground-based Midcourse Defense, AN/TPY-2 (FBM), Patriot, Sea-Based X-Band, THAAD, and Aegis BMD to support developmental test data collection.
  - Aegis BMD participated in the Fast Eagle Increment 1 HWIL exercise in June 2012, during which ballistic missile defense capabilities were explored using laboratory assets for Aegis BMD (3.6.1), AN/TPY-2 (FBM), C2BMC, SBIRS/DSP, and Patriot, with U.S. military operators manning the systems. These tests were designed to evaluate the capability of the AN/TPY-2 (FBM) and U.S. Central Command (USCENTCOM) C2BMC to augment the existing USCENTCOM BMDS capability.
  - The FTI-01 System Pre-Mission Test (SPMT) in July 2012 explored integrated engagement capability for Aegis BMD, THAAD, and Patriot in an operationally relevant architecture using HWIL assets. Aegis BMD 3.6.1 demonstrated simultaneous ship self-defense and ballistic missile defense as part of the test.
  - Fast Eagle Increment 1 Distributed in August 2012 assessed the capability of AN/TPY-2 (FBM) and C2BMC to augment a theater-regional defense architecture with Aegis BMD (3.6.1), THAAD, and Patriot fire units. U.S. military operators manned deployed tactical BMDS assets in the test.
  - Aegis BMD 3.6.1 participated in the Fast Eagle Increment 1+ HWIL exercise in September 2012. Laboratory representations of Aegis BMD, AN/TPY-2 (FBM), C2BMC, SBIRS/DSP, and Patriot explored ballistic missile defense capabilities in a theater regional environment. U.S. military operators manned the systems.

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Assessment

- In FY12, Aegis BMD demonstrated the capability to perform end-to-end engagements against non-separating and simple separating short-range ballistic missiles with the Aegis BMD 4.0 system and SM-3 Block IB interceptors.
- In response to the anomalous behavior observed during the SM-3 Block IA flyout in FTM-15 (April 2011), the program redesigned a component in the third stage rocket motor, which is common to both the Block IA and Block IB interceptors. The newly redesigned component was flown in FTM-18 and performed successfully.
- The failed intercept in FTM-16 Event 2 (September 2011) is currently being addressed by the program. The program conducted three initial ground firing tests of the SM-3 third stage rocket motor to further understand the FTM-16 anomaly. Subsequently, the program conducted three ground firings of the third stage rocket motor to further verify that it functions properly using newly-adjusted firing parameters. Two more ground firings are planned before the end of the calendar year to close-out actions from the FTM-16 failure review board.
- GT-04 series ground tests in early FY12, which addressed EPAA Phase 1, showed that improvements in interoperability are needed between the various elements and sensors that are part of the EPAA Phase 1 defense architecture, including the Aegis BMD 3.6.1 system that continues to take part in these tests after completion of its FOT&E.
- The near-simultaneous engagement of an anti-air warfare target during FTI-01 verified ship self-defense capability while conducting a ballistic missile engagement even though the SM-3 Block IA interceptor missed its target. The MDA is investigating the cause of the missed intercept; however, their efforts will be hindered because Kill Weapon telemetry was lost during key portions of the engagement flyout.
- No LRS&T events are planned for Aegis BMD 4.0 until FTG-08. Aegis BMD has tested that capability only once during a flight test (FTG-06a in December 2010) and in ground testing to date. Further live-target testing of this capability is needed to allow for an assessment.

Recommendations

- Status of Previous Recommendations. The program partially addressed the single recommendation from FY11 when it conducted FTM-18 testing with the redesigned component in the SM-3 third stage rocket motor (to address the FTM-15 anomaly). Flight testing to demonstrate the correction for the FTM-16 Event 2 failure has not yet taken place.
- FY12 Recommendations. The program should:
  1. Conduct further live-target testing of the Aegis BMD 4.0.2 LRS&T capability using long-range targets to provide additional data on that capability for the Aegis BMD 4.0.2 system.
  2. Engage a medium-range target before the Full-Rate Production Decision for the SM-3 Block IB interceptor to support an assessment of midcourse defense capability.

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Command, Control, Battle Management, and Communications (C2BMC) System

Executive Summary

- During FY12, Command, Control, Battle Management, and Communications (C2BMC) participated in three ground tests, three flight tests, exercise Fast Eagle Increment 1, and the Israeli Arrow Weapon System (AWS) Block 4 System Verification Flight Test.
- C2BMC Spiral 6.4 (S6.4) software demonstrated simultaneous live control of two AN/TPY-2 radars operating in Forward-Based Mode (FBM) in Turkey and Israel in support of the European Phased Adaptive Approach (EPAA) Phase 1 deployment.
- C2BMC demonstrated interoperability with Aegis Ballistic Missile Defense (BMD), Patriot, Terminal High-Altitude Area Defense (THAAD), the Space-Based Infrared System/Defense Support Program (SBIRS/DSP), and the AWS.
- The Missile Defense Agency (MDA) included the Global Engagement Manager (GEM) in the deployment of C2BMC S6.4 to the Combatant Commands. GEM provides greater automation of sensor management functions and improved track processing and reporting.
- Even with the deployment of GEM, C2BMC still has battle management capabilities limited primarily to situational awareness, radar track forwarding, and control of AN/TPY-2 (FBM) radars until at least FY17 when the MDA tentatively plans to field S8.2.

System

- C2BMC is a Combatant Command's interface to the fully integrated Ballistic Missile Defense System (BMDS).
- More than 70 C2BMC workstations are fielded at U.S. Strategic, Northern, European, Pacific, and Central Commands (USSTRATCOM, USNORTHCOM, USEUCOM, USPACOM, and USCENTCOM); numerous Army Air and Missile Defense Commands; Air and Space Operations Centers; and other supporting warfighter organizations. The current C2BMC system provides situational awareness to Combatant Commands and the National Command Authority with information on missile events, BMDS status, and system coverage. C2BMC also provides upper echelon deliberate planning at the Combatant Command and component level, permitting a federation of planners across the BMDS. BMDS elements (Aegis BMD, Ground-based Midcourse Defense [GMD], Patriot, and THAAD) use their own command, control, battle management systems and mission planning tools for stand alone engagements.
- C2BMC S6.4 provides command and control for multiple AN/TPY-2 (FBM) radars in the same area of responsibility.



S6.4 includes the deployment of GEM, which includes updated sensor management, track processing, and reporting.
- C2BMC provides track forwarding of AN/TPY-2 (FBM) and AN/SPY-1 tracks to GMD. Additionally, it provides track forwarding of AN/TPY-2 (FBM) tracks for THAAD and Patriot cueing and Aegis BMD engagement support.
- C2BMC S8.2, although not fully defined by the MDA, is intended to improve and expand the initial S6.4 capabilities as the next step toward integrated sensor management. The MDA plans to field S8.2 not earlier than FY17.

Mission

U.S. Strategic, Northern, European, Central, and Pacific Commands currently use C2BMC to support ballistic missile defense engagements. Commanders use C2BMC specifically for:

- Deliberate and dynamic planning
- Situational awareness
- Track management
- AN/TPY-2 (FBM) sensor management and control
- Engagement monitoring
- Data exchange between C2BMC and BMDS elements
- Network management

Major Contractor

Lockheed Martin Information Systems and Global Solutions – Gaithersburg, Maryland

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Activity

- The MDA conducted testing during FY12 in accordance with the DOT&E-approved Integrated Master Test Plan.
- The USEUCOM C2BMC upgrade to S6.4 was completed at the end of 2011 as part of the EPAA Phase 1 deployment. The USCENTCOM C2BMC upgrade to S6.4 will complete with the MDA publication of a Technical Capability Declaration in 4QFY12. Apart from already existing C2BMC roles in providing situational awareness, sensor management for acquisition, basic track forwarding, and some planning capability, S6.4 introduced the GEM suite at USPACOM (with a backup at Missile Defense Integration and Operations Center), USEUCOM, and USCENTCOM. C2BMC participated in the Flight Test THAAD-12 (FTT-12) IOT&E in October 2011, demonstrating interoperability with THAAD over Tactical Datalink 16. C2BMC provided situational awareness and status of the BMDS under test.
- The MDA conducted Ground Test Integrated-04d (GTI-04d) Part 2 in October 2011. The USEUCOM warfighters used C2BMC to control two AN/TPY-2 (FBM) radars. C2BMC also provided situational awareness and demonstrated interoperability with Aegis BMD, Patriot, Israeli AWS, and SBIRS/DSP.
- The MDA completed GTI-04 (Israel) in November 2011. C2BMC controlled one AN/TPY-2 (FBM) radar and demonstrated interoperability with Aegis BMD, Patriot, THAAD, SBIRS/DSP, and the Israeli AWS.
- In December 2011, C2BMC participated in Ground Test Distributed-04d (GTD-04d) Part 2. An AN/TPY-2 (FBM) radar was represented in the test architecture and controlled by C2BMC. Aegis BMD and SBIRS/DSP also participated.
- In December 2011, the MDA conducted GTD-04d Part 3 in support of the EPAA Phase 1 assessment. The USEUCOM sensor managers used C2BMC to command and control two AN/TPY-2 (FBM) radars for the first time in a distributed ground test. C2BMC demonstrated interoperability with Aegis BMD and SBIRS/DSP.
- In April 2012, the MDA conducted a developmental ground test, Ground Test Focused-04e (GTX-04e), and collected data for several C2BMC critical factors (referred to as Critical Engagement Conditions). C2BMC demonstrated interoperability with the full BMDS architecture, provided situational awareness, and controlled AN/TPY-2 (FBM) radars in USPACOM and USEUCOM areas of responsibility (one and two radars, respectively).
- C2BMC participated in the Fast Eagle Increment 1 hardware-in-the-loop test in June 2012 and distributed test in August 2012. It demonstrated the ability to provide situational awareness and command and control of one AN/TPY-2 (FBM) radar, and interoperability with other USCENTCOM BMD assets.
- In October 2012, C2BMC managed a deployed AN/TPY-2 (FBM) radar from which it forwarded acquisition cues to Aegis BMD and THAAD during the MDA's combined developmental/operational Flight Test Integrated – 01 (FTI-01).

Assessment

- GEM allows for automated management of multiple AN/TPY-2 (FBM) sensors located in one area of responsibility. It also provides greater automation of sensor management functions and improved track processing and reporting while requiring less operator involvement as compared to S6.2 software.
- C2BMC has limited battle management capabilities allowing Combatant Command sensor managers to direct AN/TPY-2 (FBM) radars to execute focused search plans or respond to a precision cue. S6.4 demonstrated command and control of a single AN/TPY-2 (FBM) radar in ground and flight tests. S6.4 demonstrated command and control of two AN/TPY-2 (FBM) radars in both a hardware-in-a-loop and distributed test environment, but not in a flight test using deployed assets.
- During the GTX-04e event, in which the MDA tested S6.4 interactions with strategic elements, C2BMC S6.4 demonstrated interoperability with strategic BMDS elements and the ability to provide situational awareness.
- The MDA tested C2BMC S6.4 interactions with theater elements throughout the GT-04 and Fast Eagle Increment 1 ground test campaigns in FY11 and FY12. In addition to providing situational awareness, C2BMC S6.4 demonstrated interoperability with theater BMDS elements and command and control of one and two AN/TPY-2 (FBM) radars contributing to the defensive capability for the southeastern European, Israeli, and Middle Eastern theaters.
- During the GT-04 and Fast Eagle Increment 1 campaigns, the MDA identified S6.4 interoperability and command and control deficiencies that affected track processing, situational awareness, and battle management. The MDA is currently testing solutions to these deficiencies. Some interoperability issues are outside of the C2BMC program's authority to resolve, and will require MDA and Service action.
- C2BMC appeared to successfully manage and forward cues from the deployed AN/TPY-2 (FBM) supporting FTI-01. Analysis is ongoing. DOT&E will report results in the 2012 BMDS report to Congress, scheduled for publication in February 2013.

Recommendations

- Status of Previous Recommendations. The MDA addressed eight of the previous nine recommendations. The MDA continues to make progress on the one outstanding FY06 recommendation to include assessments of Information Assurance during BMDS-centric C2BMC testing.
- FY12 Recommendation.
  1. The MDA should continue to address the C2BMC interoperability and command and control deficiencies uncovered during the GT-04 campaign. Resolution of these deficiencies should be demonstrated through ground and/or flight testing.

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Ground-Based Midcourse Defense (GMD)

Executive Summary

- Capability Enhancement II (CE-II) kill vehicle problems limited advancement of the Ground-based Midcourse Defense (GMD) flight test program. No flight tests were conducted during FY12.
- The Missile Defense Agency (MDA) did make progress on GMD return-to-intercept by conducting a ground test campaign consisting of 11 electrical and mechanical tests designed to further characterize CE-II kill vehicle component capability and performance. The MDA has scheduled a two-flight test series in FY13 designed to confirm fixes to the CE-II kill vehicle.

System

GMD is a Ballistic Missile Defense System (BMDS) element that counters intermediate-range and intercontinental ballistic missile threats to the U.S. Homeland. The GMD BMDS includes:

- Cobra Dane Upgrade Radar at Eareckson Air Station (Shemya Island), Alaska
- Upgraded Early Warning Radars (UEWR) at Beale AFB, California; Royal Air Force (RAF) Fylingdales, United Kingdom; and Thule Air Base, Greenland
- Ground-based Interceptor (GBI) missiles at Fort Greely, Alaska, and Vandenberg AFB, California
- GMD ground system including GMD Fire Control (GFC) nodes at Schriever AFB, Colorado, and Fort Greely, Alaska; Command Launch Equipment (CLE) at Vandenberg AFB, California, and Fort Greely, Alaska; and In-Flight Interceptor Communication System Data Terminals (IDTs) at Vandenberg AFB, California, Fort Greely, Alaska, and Shemya Island, Alaska
- GMD secure data and voice communication system including long-haul communications using the Defense Satellite Communication System (DSCS), commercial satellite communications, and fiber optic cable (both terrestrial and submarine)
- External interfaces that connect to Aegis Ballistic Missile Defense (BMD); North American Aerospace Defense – U.S. Northern Command (NORAD-NORTHCOM) Command Center (N2C2) and Command, Control, Battle Management, and Communications (C2BMC) at Peterson AFB, Colorado; Space Based Infrared System/Defense Support Program (SBIRS/DSP) at Buckley AFB, Colorado; and AN/TPY-2 (Forward-Based Mode [FBM]) radar at Shariki Air Base, Japan



- Sea-Based X-Band (SBX) radar, which is a sea-based mobile sensor platform primarily for use as a test asset, but can be operationally deployed as needed

Mission

Military operators for the U.S. Army Space and Missile Defense Command/Army Forces Strategic Command (the Army service component to U.S. Strategic Command) will use the GMD system to defend the U.S. Homeland against intermediate-range and intercontinental ballistic missile attacks using its weapon, the GBI, to defeat threat missiles during the midcourse segment of flight.

Major Contractors

- The Boeing Company, Integrated Defense Systems, Missile Defense Systems – Huntsville, Alabama
- Orbital Sciences Corporation – Chandler, Arizona
- Raytheon Missile Systems – Tucson, Arizona
- Northrop Grumman Information Systems – Huntsville, Alabama

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Activity

- The MDA conducted a GMD return-to-intercept ground test campaign (G-52-L) during 2QFY12. It consisted of 11 individual electrical and mechanical tests designed to further characterize CE-II kill vehicle component capability and performance.
- The MDA used hardware and software representations of the GFC IDTs and GBIs in the Ground Test Focused-04e (GTX-04e) in May 2012. The MDA conducted the GMD portion of the test to demonstrate functionality, interoperability, and performance of the GFC software version 6B2.1.

Assessment

- The MDA made progress on GMD return-to-intercept. It redesigned and tested Exo-atmospheric Kill Vehicle (EKV) components and established more stringent component and manufacturing process requirements. Analysis and ground test results indicate the previous mission failure root causes have been identified and fixed, but a demonstration flight test is required to validate that conclusion.
  - The MDA has scheduled a two-flight test series designed to validate these fixes. The GMD Control Test Vehicle-01 (GM CTV-01) has been scheduled for 2QFY13 as an interceptor-only diagnostic flight test to further characterize kill vehicle behavior in a representative flight environment. The Flight Test GMD-06b (FTG-06b) has been scheduled for 3QFY13 as a repeat of the FTG-06a flight test.
  - These current test windows represent the latest in a series of incremental slips over FY12. At the beginning of FY12, GM CTV-01 was scheduled to be flown in the middle of 3QFY12 and FTG-06b was scheduled for the middle of 4QFY12. Major causes of the slips were additional analysis time needed by the Failure Review Board, developmental issues with new inertial measurement unit firmware and isolation cradle hardware, and component manufacturing and quality concerns.
- GTX-04e demonstrated the capability to provide dynamic positioning updates to the GMD IDT onboard the SBX radar platform; the MDA had previously demonstrated this capability for the IDT at Fort Greely, Alaska, and Vandenberg AFB, California. Further, the MDA confirmed the transmission and data flow of a new message set from the AN/TPY-2 (FBM) radar to the new GFC software via the C2BMC.

Recommendations

- Status of Previous Recommendations. The MDA has started but not completed the FY11 recommendation to repeat the FTG-06a mission to verify root causes, Failure Review Board results, and permanent fixes for the deficiencies found during the flight test. They have identified root cause issues, implemented solutions, and scheduled a two-flight test series in FY13 designed to demonstrate GMD return-to-intercept. The FY07 recommendation to re-examine the GMD-specific lethality simulation needs has been transferred to the BMDS system-level assessment since it applies to all elements.
- FY12 Recommendations. None.

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Terminal High-Altitude Area Defense (THAAD)

Executive Summary

- The Terminal High-Altitude Area Defense (THAAD) system intercepted two short-range targets nearly simultaneously in October 2011. The program completed this multiple simultaneous intercept as part of an IOT&E, which included a full battle sequence from planning through intercept under operationally realistic conditions. DOT&E concluded that the IOT&E demonstrated THAAD is operationally effective, operationally suitable, and survivable against the threats and in the environments tested.
- The THAAD system successfully intercepted a medium-range ballistic missile target for the first time in October 2012.
- All planned THAAD Build 1.0 capabilities have not yet been demonstrated. The most significant example is that the performance of the system using the radar advanced algorithm against a complex target has not been scheduled for test until FY14. The algorithm has been implemented in the operational software, but THAAD flight test profiles prior to FY14 are not expected to trigger demonstration of it.
- Redesign and retesting of a number of components are required to address all of the Army materiel release conditions imposed before full materiel release can be granted. In particular, many reliability improvements are required to meet Army requirements with confidence.

System

- The THAAD ballistic missile defense system consists of five major components:
  - Missiles
  - Launchers
  - Radars (designated AN/TPY-2 (TM) for Terminal Mode)
  - THAAD Fire Control and Communications (TFCC)
  - Unique THAAD support equipment
- THAAD can accept target cues for acquisition from the Aegis Ballistic Missile Defense (BMD), satellites, and other external theater sensors and command and control systems.
- THAAD is intended to complement the lower-tier Patriot system and the upper-tier Aegis BMD system.



Mission

U.S. Strategic Command intends to deploy and employ THAAD, a rapid response weapon system, to protect critical assets worldwide. Commanders will use the THAAD kill vehicle to intercept an incoming threat ballistic missile in the endo-atmosphere or exo-atmosphere, limiting the effects of weapons of mass destruction on battlefield troops and civilian populations.

Major Contractors

- Lockheed Martin Missile and Fire Control – Dallas, Texas
- Lockheed Martin Space Systems Company – Sunnyvale, California
- Raytheon Integrated Defense Systems – Tewksbury, Massachusetts

Activity

- Flight Test THAAD Interceptor-12 (FTT-12) IOT&E occurred in October 2011. The test was a multiple simultaneous engagement of two short-range targets. This test supported materiel release of the first two THAAD batteries and future Beyond Low-Rate Initial Production decisions. The THAAD battery performed battle planning, overseas deployment, emplacement, and mission operations under operationally realistic conditions within the constraints of test range safety. The THAAD battery also conducted additional simulated intercept events against a raid, defeating threats generated by the Simulation Over Live Driver (SOLD).
- The combined developmental/operational Flight Test Integrated-01 (FTI-01) in October 2012 included a THAAD engagement against a medium-range target for the first time. The test evaluated interoperability between THAAD; Aegis BMD; Patriot; Command, Control, Battle Management, and

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Communications (C2BMC); and AN/TPY-2 Forward-Based Mode (FBM) elements with multiple live targets.
- Ground Test Integrated-04 Israel (GTI-04 ISR) in November 2011, Ground Test Other-04e (GTX-04e) in April 2012, Fast Eagle Increment 1 Hardware-In-The-Loop (HWIL) in June 2012, and GTI-04e in November 2012 included laboratory HWIL representations of THAAD. Interoperability, engagement coordination between the theater elements, and engagement capabilities against short- and medium-range ballistic missiles were tested using BMDS configurations that are deployed or nearing deployment.
- The MDA conducted testing during FY12 in accordance with the DOT&E-approved Integrated Master Test Plan.

Assessment
- The THAAD and AN/TPY-2 Radar systems performed a successful engagement of two targets during the FTT-12 test. The classified DOT&E February 2012 THAAD and AN/TPY-2 Radar Operational and Live Fire Test and Evaluation Report concluded the following:
  - THAAD is operationally effective against short-range ballistic missile threats of the types tested to date. It has not been demonstrated against medium-range threats. However, empirical data from short-range flight testing, ground testing, and analyses indicate THAAD likely has capability against medium-range threat missiles.
  - THAAD is operationally suitable. Nevertheless, examination of reliability data, ground test results, challenges encountered during testing, and Soldier feedback indicate that THAAD has suitability-related limitations. Adequate availability and maintainability were demonstrated, but testing identified maintenance shortfalls. Different failure modes were seen in two tests creating uncertainty in the Mean Time Between System Abort. Improvements are also needed in deployability, manpower and training, human factors engineering, and interoperability.
  - THAAD is survivable in chemical, biological, radiological, and external electromagnetic environments. It has not been tested in electronic warfare environments.
- Conditional Materiel Release of the first two THAAD batteries in February 2012 included 39 conditions that need to be resolved before a full materiel release could be granted. The THAAD Project Office and the Army have begun to address these conditions including verification testing of the thermally initiated venting system on the interceptor, electrical stress testing of the optical block in the interceptor flight sequencing assembly, and validation and verification demonstrations of changes and updates to the technical manuals. Four conditions (equipment grounding, air load certification, spares transport shelter, and the Surface Deployment and Distribution Command-Transportation Engineering Agency transportability certification) have been closed. Analyses of data collected during the FTI-01 test are ongoing, which potentially will close eight additional conditions. Fixes and testing of remaining conditions are scheduled through 2017.
- Initial assessment from the FTI-01 test mission data indicated that the THAAD system successfully intercepted a medium-range ballistic missile target. The interoperability assessment between THAAD and other elements based on FTI-01 test data is ongoing.
- Ground tests utilizing HWIL representations of THAAD demonstrated interoperability and engagement coordination between THAAD and other theater elements revealing problems that need to be addressed for multi-element coordination.

Recommendations
- Status of Previous Recommendations. The MDA has satisfactorily addressed all previous THAAD recommendations.
- FY12 Recommendations. The MDA and the Army have begun to address the 22 THAAD recommendations contained in the classified DOT&E February 2012 THAAD and AN/TPY-2 Radar Operational and Live Fire Test and Evaluation Report. Fifteen of the recommendations align directly with the Army materiel release conditions, which are being addressed through a corrective action plan agreed to by the THAAD Project Office and the Army. Of the remaining seven recommendations, three are classified (Effectiveness #2, Effectiveness #5, and Survivability #4). The four remaining unclassified recommendations are:
  1. The MDA and the Army should reassess the required spares and tools (including their quantities) that should be on site with the battery based on all available reliability and maintainability data (Suitability #5).
  2. The MDA and the Army should define duties related to THAAD at the brigade level. Until a battalion is established for THAAD, it should also define duties and training for THAAD battery personnel on any required battalion-level duties (Suitability #10).
  3. The MDA and the Army should implement equipment redesigns and modifications identified during natural environment testing to prevent problems seen in testing (Suitability #11).
  4. The MDA and the Army should conduct electronic warfare testing and analysis (Survivability #3).

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Sensors

Executive Summary

- Ballistic Missile Defense System (BMDS) sensors participated in five ground tests, three flight tests, and exercise Fast Eagle Increment 1 testing during the reporting period.
- Although the Missile Defense Agency (MDA) placed the Sea-Based X-band (SBX) radar into a limited test support and standby operational status, the MDA continued to include it in ground tests when appropriate.
- Accreditation of each of the sensor models for use in performance assessments continues to progress but is incomplete.
- The BMDS Operational Test Agency Team will be unable to accredit the Cobra Dane radar model until after the MDA completes a 3QFY15 flight test involving the radar.

System

The BMDS sensors are systems that provide real-time ballistic missile threat data to the BMDS. The data are used to counter ballistic missile attacks. These sensor systems are operated by the Army, Navy, Air Force, and the MDA, and include a satellite-based, infrared sensor system and five phased array radar system types. The sensor systems are:

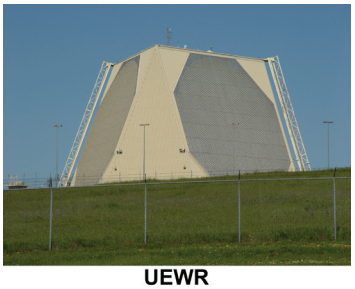
- Space Based Infrared System/Defense Support Program (SBIRS/DSP), a satellite constellation of infrared sensors operated by the Air Force with an external interface to the BMDS located at Buckley AFB, Colorado


SBIRS/DSP

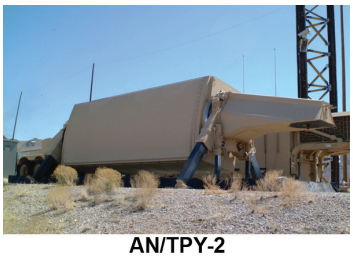
- Fixed site, fixed orientation, phased array radars
  - Cobra Dane Upgrade (CDU) Radar, an L-band radar (one radar face that provides 120-degree azimuth field of view) operated by the Air Force and located at Eareckson Air Station (Shemya Island), Alaska


Cobra Dane

  - Upgraded Early Warning Radars (UEWRs), ultra high frequency radars operated by the Air Force and located at Beale AFB, California (two radar faces that provide 240-degree azimuth field of view); Fylingdales, United Kingdom (three radar faces that provide 360-degree azimuth field of view); and Thule, Greenland (two radar faces that provide 240-degree azimuth field of view). [The MDA and Air Force Space Command awarded a contract in July 2012 for the upgrade of the Early Warning Radar (EWR) at Clear Air Force Station, Alaska. The contract also included an option for the upgrade of the EWR at Cape Cod Air Force Station, Massachusetts.]


UEWR

- Mobile platform, variable orientation, phased array radars
  - AN/TPY-2 (Forward-Based Mode [FBM]) Radars, X-band radars (one radar face that provides 120-degree azimuth field of view) operated by the Army and located at Shariki Air Base, Japan, and sites in Israel and Turkey


AN/TPY-2

  - Aegis Ballistic Missile Defense (Aegis BMD) AN/SPY-1 Long-Range Search and Track (LRS&T) Radars, S-band radars (four radar faces that provide 360-degree azimuth field of view) operated by the Navy and located aboard Aegis BMD-capable cruisers and destroyers


Aegis BMD

  - Sea-Based X-Band (SBX) Radar, an X-band radar operated by BMDS and located aboard a twin hulled, semi-submersible, self propelled, ocean going platform (primarily a test asset that can be operationally deployed as needed)


SBX

Mission

Military operators for the U.S. Strategic Command, U.S. Northern Command, U.S. European Command, U.S. Pacific Command, and U.S. Central Command will use the BMDS sensors to:

- Detect, track, and classify ballistic missile threats that target the United States, U.S. allies, and U.S. friends
- Provide data for situational awareness and battle management to the BMDS Command, Control, Battle Management, and Communications (C2BMC)
- Provide data that support engagement of ballistic missile threats by ballistic missile defense systems

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Major Contractors

Aegis AN/SPY-1
- Lockheed Martin – Moorestown, New Jersey

AN/TPY-2
- Raytheon Company, Integrated Defense Systems – Woburn, Massachusetts

CDU
- Raytheon Company, Integrated Defense Systems – Woburn, Massachusetts

SBIRS
- Lockheed Martin Space Systems Company – Sunnyvale, California

SBX
- Raytheon Company, Integrated Defense Systems – Woburn, Massachusetts

UEWRs/EWRs
- Thule, Beale, and Fylingdales
  - Exelis – Colorado Springs, Colorado
- Clear and Cape Cod
  - Raytheon Company, Integrated Defense Systems – Woburn, Massachusetts

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Activity
- The MDA conducted testing during FY12 in accordance with the DOT&E-approved Integrated Master Test Plan.
- The MDA used an AN/TPY-2 (FBM) radar, SBX radar, Cobra Dane radar, and the UEWRs at Beale, Fylingdales, and Thule in a BMDS-level satellite test campaign. Using these radars, the MDA tracked selected satellites to collect data that the MDA and the BMDS Operational Test Agency Team use to verify, validate, and accredit the radar models and simulations used to assess BMDS performance.

Aegis BMD Radar
- The MDA used a hardware-in-the-loop (HWIL) representation of the Aegis BMD radar in its long-range surveillance and track mode in Ground Test Focused-04e (GTX-04e) in April 2012.

AN/TPY-2 (FBM) Radar
- The AN/TPY-2 (FBM) radar participated in Flight Test Integrated-01 (FTI-01) in October 2012. In FTI-01, the AN/TPY-2 (FBM) radar provided up-range track data to C2BMC for processing, down-select, and forwarding of tracks to Aegis BMD, Patriot, and Terminal High-Altitude Area Defense (THAAD).
- In 1QFY12, deployed AN/TPY-2 (FBM) radars participated in Ground Tests Distributed (GTDs) to demonstrate Phase 1 European Phased Adaptive Approach (EPAA) capability:
  - GTD-04d (Part 2) provided the data required for a Technical Capability Declaration of the EPAA Phase 1 radar.
  - GTD-04d (Part 3) completed the EPAA Phase 1 Capability demonstration including C2BMC control of multiple deployed AN/TPY-2 radars.
- The AN/TPY-2 (FBM) radar participated in the BMDS-level distributed ground test Fast Eagle Increment 1 in August 2012. The MDA used this testing to evaluate the capability of the AN/TPY-2 (FBM) radar and the associated C2BMC to augment existing Combatant Command BMDS capability.
- The MDA used an HWIL representation of the AN/TPY-2 (FBM) radar in these BMDS-level ground tests: Ground Test Integrated-04d (GTI-04d) Part 2 (October 2011), GTI-04 (Israel [ISR]) (November 2011), GTX-04e (April 2012), and Fast Eagle Increment 1 (June 2012 and September 2012).
- AN/TPY-2 (FBM) radars participated in BMDS Integrated Sensor Demonstration – Space Situational Awareness (BISD-SSA), a Joint Chiefs of Staff sponsored test with C2BMC and Air Force Space Command. This test demonstrated the ability of AN/TPY-2 (FBM) radars to acquire and track space objects. The Joint Space Operations Center (JSPOC) sent tasking messages to C2BMC, which converted the messages into radar task commands that the radars executed. Data were collected and sent to JSPOC in real time, which then published the data for authorized user access.

Cobra Dane Radar
- HWIL representations of the Cobra Dane radar participated in the BMDS-level ground test GTX-04e in April 2012.
- In FY12, the Air Force used the Cobra Dane radar to observe targets of opportunity. The U.S. Space Command also used the Cobra Dane radar as a contributory sensor to the Space Surveillance Network to track orbital debris and active satellites.

SBIRS/DSP System
- During FY12, the Air Force used the SBIRS/DSP system to observe domestic and foreign launch events, provide launch event data to the operational BMDS, and participate in the intercept flight tests: Flight Test Standard Missile-3-16 (FTM-16) Event 2a, FTM-18, and FTI-01.
- A digital representation of the SBIRS/DSP system participated in the BMDS-level ground tests: GTI-04d Part 2 (October 2011), GTI-04 (ISR) (November 2011), GTX-04e (April 2012), and Fast Eagle Increment 1 (August 2012).

SBX Radar
- An HWIL representation of the SBX radar participated in the BMDS-level ground test GTX-04e in April 2012.
- Both an HWIL and digital representations (simulations) of the SBX radar participated in pre-mission testing for the upcoming Ground-based Midcourse Defense (GMD)

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intercept Flight Test Ground-based Interceptor-06B (FTG-06b).
- The MDA utilized Glory Trip-203, a Minuteman III intercontinental ballistic missile test, to demonstrate the ability of SBX to exercise software build 2.2.1.2.5 in a live track mission, collecting advanced discrimination algorithm data for future use, verifying algorithms, and supporting analysis/risk reduction for upcoming tests, such as FTG-06b.
- The MDA placed SBX in a limited test support status. The SBX can be reactivated based on warning of a threat presented to the United States, and for BMDS flight testing.

UEWR/EWR – Beale, Thule, Fylingdales, Clear, and Cape Cod
- HWIL representations of the UEWRs at Beale, Fylingdales, and Thule participated in the BMDS-level ground test GTX-04e in April 2012.
- In FY12, the U.S. Air Force used the Beale, Fylingdales, and Thule UEWRs, and Clear and Cape Cod EWRs, to observe targets of opportunity. U.S. Space Command also used these radars as collateral sensors to the Space Surveillance Network to track orbital debris and active satellites.

Assessment
- The MDA has gained significant operational experience with each of the BMDS sensors since the completion of sensor upgrade and development programs.
- The MDA and the BMDS Operational Test Agency Team, however, have not fully accredited models and simulations of the BMDS sensors for performance assessment. Representations of the AN/TPY-2 (FBM) radar, the SBX radar, and the UEWR have been accredited for limited uses. Representations of the Aegis BMD radar, the Cobra Dane radar, and the SBIRS/DSP system have not been accredited. The MDA is analyzing the radar performance data that were collected in the FY12 satellite tracking campaign for its use toward accreditation of multiple radar models and simulations.
- Starting in FY13, the U.S. Air Force will have the responsibility for the sustainment of the Cobra Dane radar and the UEWRs. The U.S. Air Force does not currently gather all of the operational data required for assessing suitability.

Aegis BMD Radar
- In GTX-04e, and in prior ground tests, the MDA demonstrated a capability of the Aegis BMD radar (in its LRS&T mode) to support GMD engagement of intermediate-range and intercontinental ballistic missile threats.
- The Aegis BMD radar provided data that enabled the GMD system to generate sensor cueing and missile engagement plans. However, a quantitative assessment of the Aegis BMD radar LRS&T mode performance was not possible since the MDA used some models and simulations (including the intermediate-range and intercontinental ballistic missile threat models) that were not accredited for performance assessment.
- The MDA has not conducted a BMDS intercept flight test that uses the Aegis BMD LRS&T radar data in real-time as the primary data source for GMD engagement planning. The MDA currently plans to conduct this test during 3QFY14.

AN/TPY-2 (FBM) Radar
- In FTI-01, the MDA demonstrated AN/TPY-2 (FBM) radar capability to provide up-range track data to C2BMC to support engagement of a medium-range ballistic missile by THAAD.
- In the BMDS-level ground tests, the MDA demonstrated AN/TPY-2 (FBM) radar capability to provide real-time track data that supported BMDS situational awareness, BMDS sensor tasking, and GMD engagement planning. However, a quantitative assessment of the AN/TPY-2 (FBM) radar performance was not possible since the MDA used some models and simulations (including the intermediate-range and intercontinental ballistic missile threat models) that were not accredited for performance assessment.

Cobra Dane Radar
- In GTX-04e, the MDA demonstrated interoperability of the Cobra Dane radar with a new version of the GMD Fire Control software. In addition, the MDA demonstrated a capability of the Cobra Dane radar to provide real-time data that enabled the GMD system to generate missile engagement plans and supported GMD system engagement of intermediate-range and intercontinental ballistic missile threats. A quantitative assessment of the Cobra Dane radar performance was not possible since the MDA used some models and simulations (including the intercontinental ballistic missile threat models) that were not accredited for performance assessment.
- Due to its location and field of view, the Cobra Dane radar has not participated in BMDS intercept flight tests. The MDA plans to conduct a target flight test through the Cobra Dane radar field of view in 3QFY15 to support model and simulation accreditation.

SBIRS/DSP System
- SBIRS/DSP system performance and its capability to support BMDS engagement of intermediate-range and intercontinental ballistic missile threats will be provided in the classified appendix of DOT&E's "2012 Assessment of the Ballistic Missile Defense System (BMDS)" report to Congress.

SBX Radar
- In GTX-04e, the MDA demonstrated interoperability of the SBX radar with a new version of the GMD Fire Control software.
- The MDA has demonstrated a capability of the SBX radar to support GMD engagement planning against an intermediate-range ballistic missile target. However, the MDA has not gathered adequate SBX radar performance data against intermediate-range and intercontinental

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ballistic missile threats and targets to enable accreditation of the SBX radar models and simulations that are required for performance assessment.

UEWR/EWR – Beale, Thule, Fylingdales, Clear, and Cape Cod

- Due to their locations and fields of view, the UEWRs at Beale, Thule, and Fylingdales have not participated in BMDS intercept flight tests in an operationally realistic manner. Data from targets of opportunity and ground tests support performance estimates for the current configuration of the UEWRs. These estimates rely on models and simulations that have not been fully accredited for use in performance assessment.
- The MDA and the Air Force have not yet upgraded the EWRs at Clear and Cape Cod Air Force Stations, and these radars are not yet part of the MDA's sensor network.

Recommendations

- Status of Previous Recommendations. The MDA has satisfactorily addressed all but two of the previous sensor recommendations. Although the MDA and Combatant Commanders have made progress on developing concepts of operations for the sensors, this FY09 recommendation remains open pending completion of those concepts and implementation in operational testing. Additionally, while the MDA has specified the Aegis BMD LRS&T radar as the primary data source for GMD engagement planning in an intercept flight test attempt in 3QFY14, this FY11 recommendation remains open pending successful execution of that test.
- FY12 Recommendations. The DOT&E February 2012 THAAD and AN/TPY-2 Radar Operational and LFT&E Report made three recommendations for the MDA and Army to consider for AN/TPY-2(FBM). One of the recommendations aligns directly with the Army materiel release conditions, which are being addressed through a plan agreed upon by the Sensors Product Office and the Army. The following two recommendations from the report remain open.
  1. Perform additional flight testing with multiple AN/TPY-2 (FBM) radars in a single Area of Regard or theater to assess C2BMC's ability to correctly task and coordinate track data from multiple radars.
  2. Conduct independent, dedicated AN/TPY-2 (FBM) Information Assurance testing.

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Live Fire Test and Evaluation

Live Fire Test and Evaluation

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Live Fire Test and Evaluation (LFT&E) Program

DOT&E executed oversight of survivability and lethality test and evaluation for 122 acquisition programs in FY12. Of those 122 programs, 19 operated under the waiver provision of U.S. Code, Title 10, Section 2366, by executing an approved alternate LFT&E strategy in lieu of full-up system-level testing. In addition, Section 2366 also requires DOT&E to report on a program's LFT&E results prior to that program entering into full-rate production.

DOT&E published reports on the following programs during the past year (reports marked with an asterisk were sent to Congress):

LFT&E Reports
- Enhanced Combat Helmet*
- Family of Medium Tactical Vehicles (FMTV) A1P2*
- Stryker Double-V Hull (DVH) Configuration of the Commander's Vehicle (CVV)

Special Reports Regarding LFT&E
- Active Protection Systems (APS)*
- Hellfire Romeo Missile
- Mine Resistant Ambush Protected (MRAP) – All-Terrain Vehicle (M-ATV) Underbody Improvement Kit (UIK)
- Stryker Mobile Gun System (MGS) Engineering Change Order (ECO) Block 3
- BAE-Tactical Vehicle System (TVS) Caiman Mine Resistant Ambush Protected (MRAP) Vehicle.

Combined OT&E/LFT&E Beyond Low-Rate Initial Production Reports
- AH-64D Apache Block III (AB3) Attack Helicopter*
- Mine Resistant Ambush Protected (MRAP) Family of Vehicles: Dash with Independent Suspension System (ISS), MRAP Recovery Vehicle (MRV), Marine Corps Cougar Ambulance*
- Spider XM7 Network Command Munition*
- Stryker Nuclear, Biological, and Chemical Reconnaissance Vehicle (NBCRV)*
- Terminal High-Altitude Area Defense (THAAD) and AN/TPY-12 Radar*

Combined OT&E/LFT&E Assessments
- Family of Medium Tactical Vehicles (FMTV)
- MH-60S Airborne Mine Countermeasures Helicopter and AN/ASQ-20A Mine Detecting Sonar
- Mine Resistant Ambush Protected (MRAP) Family of Vehicles: Navistar Dash Ambulance and MRAP All-Terrain Vehicle (M-ATV) Underbody Improvement Kit (UIK)
- Stryker Double-V Hull (DVH) Configuration of the Engineer Squad Vehicle (ESVV)
- Stryker Double-V Hull (DVH) Configuration of the Scout Vehicle (ICVV)
- Stryker Double-V Hull (DVH) Configuration of the Mortar Carrier Vehicle (MCVV)
- Stryker Double-V Hull (DVH) Configuration of the Medical Evacuation Vehicle (MEVV)

In addition to satisfying acquisition oversight requirements, the LFT&E program funds and executes technical oversight on investment programs that provide joint munitions effectiveness data (Joint Technical Coordinating Group for Munitions Effectiveness). The LFT&E program also develops advanced technologies and analytical methods to increase aircraft survivability (Joint Aircraft Survivability Program), and conducts vulnerability and lethality testing of fielded platforms and weapons systems and improves survivability analysis tools (Joint Live Fire Program). LFT&E investment programs also support quick reaction efforts addressing urgent operational commander's needs.

JOINT TECHNICAL COORDINATING GROUP FOR MUNITIONS EFFECTIVENESS (JTCG/ME)

The Joint Logistics Commanders chartered the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) in 1968 to ensure development of consistent and credible effectiveness estimates for conventional munitions across the DoD. DOT&E oversees the JTCG/ME and provides funding. The JTCG/ME produces and distributes these data in Joint Munitions Effectiveness Manuals (JMEMs). The primary application supported is weaponeering, the detailed technical planning of a weapon strike that occurs at multiple levels in the operational chain of command before actual combat. JMEMs provide computerized tools and data for rapid evaluation of alternative weapons and their delivery against specific targets. In many cases, JMEMs generate collateral damage estimates as a part of the decision criteria for strikes approved at the highest levels of the U.S. Government.

In FY12, the JTCG/ME published two updated JMEMs and a set of Collateral Effects Radii (CER) tables. The JMEM Weaponeering System (JWS) v2.1 software and the JTCG/ME-generated Chairman of the Joint Chiefs of Staff Instruction 3160.01 CER tables are used for operational weaponeering and collateral damage estimates directly supporting operations in the U.S. Africa Command and U.S. Central Command Areas of Responsibility. To provide continued support to operational commanders, as well as DoD targeting and mission planners, the JTCG/ME also developed and incorporated geometric models representative of various targets for use in assessing the effectiveness of weapons. JTCG/ME released the second updated JMEM, JTCG/ME's air-to-air and surface-to-air planning model, the Joint Anti-Air Combat Effectiveness System (J-ACE) v5.1, in July 2012, which includes the data required to assess the survivability of strike aircraft.

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Operational Weaponeering



JWS is the joint source for air-to-surface and surface-to-surface weaponeering, munitions, and target information. JWS evaluates the effectiveness of a multitude of munition-target combinations for numerous air-to-surface and surface-to-surface munitions against a variety of target types in real-time. JWS v2.1 contains the Fast Integrated Structural Tool (FIST). FIST is the JMEM operational-level tool that allows weaponeers to quickly develop geometric models of soft and hardened targets and use those models to evaluate weapons effects. In particular, the tool can then generate weapon effectiveness and damage assessments for infrastructure targets including buildings, bunkers, and tunnels. JWS v2.1 contains approximately 180 new or updated targets, 15 new and updated munitions, new Explosive Equivalent Weights based on blast testing, and an improved 3-D viewer for displaying target models.

Operational Mission Planning

JTCG/ME released J-ACE v5.1 to support operational mission planning, particularly at U.S. Strategic Command (USSTRATCOM). J-ACE simulates U.S. and threat air-to-air and surface-to-air engagements, providing flyout models for U.S. and threat air-to-air and surface-to-air missiles, as well as probability of kill estimates. Previous releases generated pre-computed probability of kill tables given an intercept for selected weapon-target pairings and engagement conditions. Because use of these tables proved tedious, J-ACE v5.1 now provides new Endgame Manager v2.2.0 software and data sets, which allow on-demand calculation of multiple kill levels for specific engagement conditions encountered at intercept. To more effectively support operational mission planning, J-ACE v5.1 also provides a direct interface to force-level simulations. These simulations are used to study tactics, evaluate training, assess the relative performance of missiles, and plan scenarios.



Collateral Damage Estimation

The JTCG/ME supported development and fielding of the Digital Precision Strike Suite Collateral Damage Estimation tool for operational use. This tool displays accredited Collateral Damage Estimate Level effective radii reference tables. Additionally, JTCG/ME personnel trained nearly 250 users at 10 different commands to support collateral damage estimation decisions.

Information Operations

In conjunction with the Air Force Targeting Center, the JTCG/ME assessed fielded and emerging applications for conducting information operations as part of early efforts to develop a capability within JMEM to evaluate the effects of such operations. These efforts included the development of an initial set of simple tools for assessing the effects of selected applications when used to conduct Computer Network Attack, Computer Network Defense, Military Information Support Operations, and Electronic Warfare.

JOINT AIRCRAFT SURVIVABILITY PROGRAM (JASP)

DOT&E sponsors and funds the Joint Aircraft Survivability Program (JASP), which develops techniques and technology to improve the survivability of U.S. military aircraft. The Naval Air Systems Command, Army Aviation and Missile Command, and Air Force Aeronautical Systems Center charter the program. DOT&E establishes objectives and priorities for the JASP and exercises oversight of the program. Working with joint and Service staffs, other government agencies, and industry, the JASP promotes the adoption throughout the Military Services of the most current techniques and technologies for improving aircraft survivability.

The JASP is supporting the Joint Multi-Role (JMR) Technology Capabilities Demonstration (TCD) as a member of the Platform Integrated Product Team. The purpose of the JMR TCD is to demonstrate transformational vertical lift technologies to prepare the DoD to develop the next generation of vertical lift aircraft. JASP was instrumental in establishing assumptions and requirements for the vulnerability analysis used in evaluating the initial three government model prototypes.

The JASP funded 59 development projects ($10.2 Million) and delivered 41 final reports in FY12. The following examples illustrate current JASP efforts in four focus areas: susceptibility reduction, vulnerability reduction, survivability assessment, and combat damage assessment.

Susceptibility Reduction

These efforts addressed urgent aircraft survivability needs emerging from Operation Enduring Freedom, as well as improved aircraft survivability against future threats.

Countermeasure Requirements against New Infrared Seekers.



The JASP, in conjunction with the Naval Research Laboratory (NRL), is performing in-depth analyses of newly obtained threat infrared seekers to develop flare and jammer infrared countermeasures (IRCM). The first objective is to identify

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anomalous behavior seen when certain countermeasures are used against one particular threat. The second objective is to evaluate the effectiveness of current countermeasure technologies, tactics, and techniques when employed against these seekers. The third objective is to develop new tactics and techniques to improve countermeasure performance if the current methods are not sufficient in defeating the seekers. Initial results focused on developing new countermeasure solutions for one threat system.

Advanced Techniques for Radio Frequency Countermeasures (RFCM).



In partnership with the U.S. Air Force Special Operations Command, the JASP is developing and testing RFCM technology and techniques to increase aircraft survivability and situational awareness for Army, Navy, and Air Force special operations rotary- and fixed-wing aircraft. This project assesses the ability of onboard systems to receive, process, and display each operating mode of the threat weapon system; develops RFCM techniques; and demonstrates their effectiveness against state-of-the-art threat radar weapons. Validated threat identification and countermeasure techniques for surface-to-air missile and airborne radar systems are being developed for incorporation in the AN/ALQ-211 Suite of Integrated Radio Frequency Countermeasures on the CV-22, MH-47, and MH-60, and in the AN/ALR-69 radar warning receivers on the C-130.

Omniscient Electronic Attack.



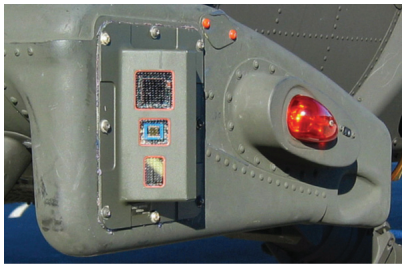
In partnership with NRL, the JASP is demonstrating the use of a Digital Radio Frequency Memory jammer that adapts in real-time to the received radar waveform, rather than identifying the threat/radar mode and selecting electronic attack techniques from a pre-programmed database. The intent is to overcome limitations of pre-programmed response-based electronic attack techniques against advanced, multi-mode, coherent radar threats. If successful, this technique could be implemented on EA-18G Growler aircraft as well as other electronic attack platforms.

ShotSense 3-D Aircraft Hostile Fire Indication (HFI) System.



The JASP and the U.S. Army Communication-Electronics Research Development and Engineering Center supported development of a high performance; low cost, size, weight, and power; uncooled infrared threat detection system for the tracking and classification of small arms, rocket-propelled grenades (RPGs), missiles, and other hostile fires. The initial focus was on ground testing in natural and urban high-clutter environments. Tests demonstrated the ability to detect and classify threats and cue radars for projectile tracking during a Live Fire Demonstration. The DoD and the United Kingdom Ministry of Defence are considering using the system for HFI/Counter-Rocket, Artillery and Mortar applications at forward operating bases. The DoD is also considering the system for use on the U.S. Special Operations Command Little Bird helicopter to provide that small aircraft with hostile fire and missile warning capabilities.

Hostile Fire Indication (HFI) Threat System Geolocation.

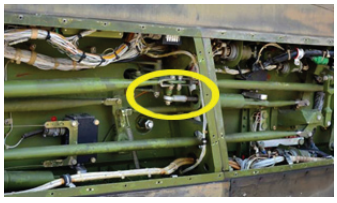


In partnership with the U.S. Army Aviation Applied Technology Directorate, the JASP is developing and testing software algorithms for incorporation in the AN/AVR-2B(V) Laser Warning System enabling the system to perform precise geo-location of hostile fire threats. The algorithms will be applicable to all aircraft using the AN/AVR-2B(V), such as the Apache and Black Hawk helicopters.

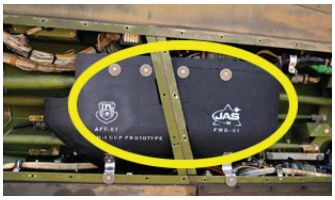
Vulnerability Reduction

Several agencies undertook efforts to develop lighter-weight opaque and transparent ballistic protection systems, fuel containment and related fire protection technologies, and tolerant structures and materials, including self-healing composites.

Critical Component Protection.



AH-1Z Flight Control Bell Crank

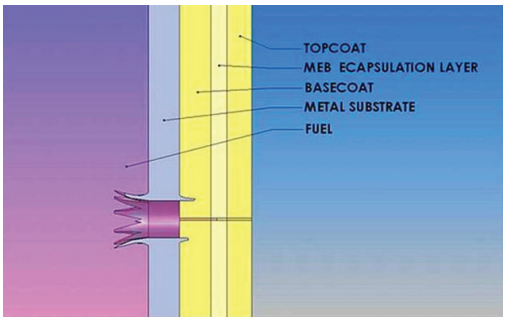


AH-1Z Complex Shape Armor Installation

The U.S. Army Aviation Applied Technology Directorate led a project to manufacture complex, curved ceramic armor for placement at strategic locations on aircraft, improving survivability with minimal weight impact. These installations protect flight-critical aircraft components that when damaged would lead to catastrophic aircraft loss. Due to their complexity, these structurally integrated panels required development of several cutting-edge material and processing technologies. Two implementations were demonstrated: the OH-58D Kiowa Warrior engine bay door and the AH-1Z Cobra helicopter flight control linkage bell-crank. The exposed bell-crank is a point of vulnerability in the flight control system. The complex (multiple curvatures in multiple directions) panel provides ballistic protection. Both implementations successfully increased protection with little or no weight increase and are being evaluated for transition to the fleet.

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Self-Healing Fuel Cell Membrane.



The Naval Air Warfare Center Weapons Division led development of a new self-sealing coating technology. The coating is designed to mitigate leaks from composite structures containing fluid (e.g., wet wings or fuel compartments) when subjected to a ballistic impact. The goal is to seal the fuel cell to a damp seal within two minutes at ambient temperature at a reduced weight compared to current self-sealing fuel bladders. The solution must be suitable for retrofit on fielded aircraft or installation on new aircraft and must work equally well with new alternative fuels. Following successful initial testing, the Air Force selected this solution as a component of the vulnerability reduction design for the future KC-46 tanker aircraft.

Thermal Degradation of Composites.



This project examined the degradation of aircraft structural composite materials due to heat damage caused by short-lived fuel fires. After calibration through mechanical test, evaluations were made of various non-destructive inspection (NDI) methods and their ability to detect incipient thermal degradation. The results of the testing were transitioned to Fleet Readiness Centers for the generation of inspection and repair procedures. The success of this project also led to a U.S.-Germany bilateral research agreement and a new project to validate fire and heat exposure damage data on representative composites used extensively on the F-35. The new effort will also validate the ability of portable NDI techniques to detect equivalent measures of thermal degradation.

Survivability Assessment

The projects in this area develop and maintain components of models and simulations that are widely used to support weapon system acquisition (e.g., design studies, specification development, and specification compliance) and test and evaluation (e.g., test design, evaluation, and assessment).

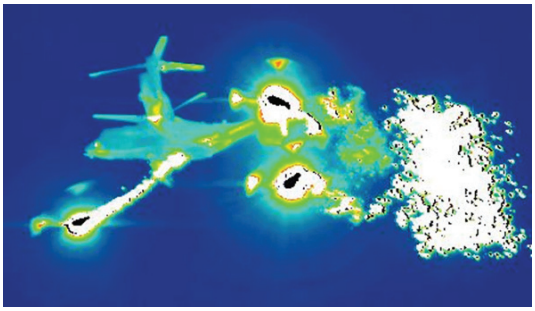
Suite of Anti-Air Kill Chain – Models and Data (SAK-MD).

The JASP, the JTCG/ME, and USSTRATCOM have been working for several years to improve the methods and data employed by USSTRATCOM to plan global strike missions. Initial efforts developed a new methodology to efficiently and consistently assess probability of kill for a large set of blue aircraft and red threat pairs. More recently, the team has concentrated on adding the effects of radio frequency and infrared countermeasures into the methodology and data sets. By coupling widely accepted countermeasure-capable engagement models with fast running operational user-focused models, the team has developed a new benchmark capability for performing aircraft-threat engagement analyses. SAK-MD has been widely distributed as part of the JTCG/ME J-ACE product and, in addition to USSTRATCOM, is used extensively by Air Force, Navy, and Marine Corps aircrews in weapon systems training.

Crew and Passenger Survivability (CAPS).

The JASP continued to advance the development of analysis, data, test capability, and technology for improving aircraft CAPS. This year concluded the initial effort to develop an analytical framework for CAPS evaluation by demonstrating the inclusion of CAPS in two commonly used vulnerability analysis models. The effort also included drafting a report on the state of crew casualty evaluation methodologies and a roadmap for future methodology development. The project will continue to improve CAPS assessment methodologies, test capabilities, and technologies working in partnership with the National Aeronautics and Space Administration, Federal Aviation Administration, and U.S. Army Tank Automotive Research, Development and Engineering Center.

Infrared Countermeasure (IRCM) Modeling.



V-22 Dispensing Flares Clouds

The JASP continued data collection and model development to improve the DoD's IRCM analysis capability against advanced multi-spectral and imaging infrared threats. Current infrared engagement simulations rely on simple flare models that lack the resolution required to address advanced infrared missile seekers. The JASP and Naval Surface Warfare Center – Crane Division are developing physics-based models for pyrotechnic and pyrophoric flares that address combustion, heat and mass transfer, infrared radiation, trajectory, and spatial extent/image presentation; ultimately providing the time evolution of plume or cloud characteristics necessary for analysis of the effectiveness of countermeasures against missiles using advanced infrared seekers. The project is also modernizing the joint modeling and simulation tools, Flare Aerodynamic Modeling Environment, and the Tri-Service Flare Database to improve usability, add 3-D descriptions of air flowing around aircraft, and develop Linux versions of both tools.

Combat Damage Assessment

JASP continued to support the Joint Combat Assessment Team (JCAT) in FY12. JCAT comprises Army, Air Force, Navy, and Marine Corps personnel deployed in support of combat operations. JCAT continued its operation in Afghanistan

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with full-time deployments in Regional Commands – South, Southwest, and East. Iraq and other areas of the world were supported remotely or by rapid deployment from Afghanistan or stateside.

JCAT inspects damaged and destroyed aircraft, acquires maintenance records, and conducts interviews with aircrew and intelligence personnel to develop an accurate and comprehensive assessment of each aircraft combat damage event. They provide consultation to weapons, tactics, and logistics personnel and comprehensive briefings to commanders in charge of daily air operations. These efforts allow battlefield commanders to adjust operational tactics, techniques, and procedures based on accurate threat and damage assessments. As of November 22, 2012, the JCAT had initiated 221 and completed 179 FY12 aircraft combat damage assessments.

The JCAT improved aircraft combat damage incident reporting in the Services and the DoD. The Combat Damage Incident Reporting System (CDIRS) hosted by the Survivability/ Vulnerability Information Analysis Center (SURVIAC) is the repository for all U.S. aircraft combat damage reports. The JCAT worked closely with SURVIAC to upgrade the CDIRS database, its data reduction capability, and links to the JCAT knowledge centers. JCAT and SURVIAC are also working with OSD and U.S. Central Command (USCENTCOM) on an operational demonstration linking both CDIRS and USCENTCOM databases to more quickly identify, assess, document, and distribute aircraft combat damage incident data to the Services and DoD.

The JCAT trains the U.S. aviation community on potential aircraft threats and combat damage, including representatives from the U.S. Military Services, the Department of State, the Department of Homeland Security, the Federal Aviation Administration, the Department of Energy, the Federal Bureau of Investigation, and the Bureau of Alcohol, Tobacco, Firearms and Explosives.

JOINT LIVE FIRE (JLF)

The goal of the Joint Live Fire (JLF) program is to test fielded systems, identify vulnerable areas, understand damage mechanisms, and provide the information needed to make design changes; modify tactics, techniques, and procedures; or improve analytical tools. The need for these tests result from systems being exposed to new threats, being used in new, unanticipated ways, or being operated in new combat environments, thereby requiring an updated assessment of their performance.

JLF supplements LFT&E of systems by testing new threats that the requirements community did not anticipate during original development or old threats employed in new ways. The RPG is an example of a threat employed differently than initially intended. Originally developed as an anti-tank or anti-personnel weapon, hostile forces in Afghanistan often use the RPG as an anti-helicopter weapon.

Aircraft Systems Program

JLF-Air completed nine test series in FY12, with a focus on resolving key modeling and testing deficiencies highlighted in the 2010 Man-Portable Air Defense Systems (MANPADS) Vulnerability Capabilities Roadmap, providing threat characterization data for high-explosive incendiary and armor piercing projectiles, and investigating occupant survivability deficiencies resulting from ballistic events. The JLF program has made significant progress over the last three years in understanding MANPADS threat characteristics and developing a viable test capability for use in LFT&E.

Large Engine Vulnerability to MANPADS.
This project is assessing the ballistic vulnerability of a large turbofan engine to a MANPADS missile impacting from the rear, and using that information to explore subsequent flying qualities of large aircraft. Live fire testing using realistic engagement conditions were achieved by using shotlines representative of real-world encounters, operating the engine at typical thrust levels, simulating the proper amount of external airflow across and through the engine, and accurately controlling the MANPADS missile impact location, velocity, and detonation point.



The project provided test results to the National Aeronautics Space Administration enabling it to conduct flight simulations to determine the flying qualities that can be expected during cruise and landing as a result of the damage witnessed in the test. The project will present simulation results, along with test observations, in a final report to be completed in early 2013.

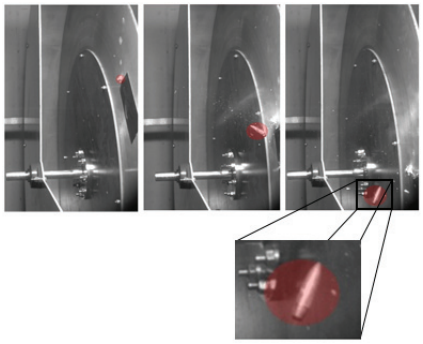
MANPADS Threat Model Development – Fragment and Debris.
This project concluded testing for the MANPADS Threat Model Development test series. This test series was designed to gather data with sufficient quality to improve the accuracy and credibility of MANPADS threat models used to assess and predict aircraft vulnerability. This test collected warhead fragment and debris for two MANPADS that were flown and detonated in the center of a specially instrumented test arena.

Supersonic Rocket on a Rope.
This project is developing a capability to support testing of various platforms' vulnerability to MANPADS missiles. Using this technique, the missile is flown along a set of ropes, acting as guide wires, which are cut just before reaching the intended target. Once cut free, the missile is allowed to free-fly into the target achieving a high-level of precision in hitting

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pre-determined impact points. Prior year tests satisfactorily demonstrated high precision hits. This year's tests also included detonating the MANPADS missile warhead using a range-safe fuze. In 2013, the project will be in its final year and is expected to culminate in a demonstration with three shots using actual MANPADS tactical fuzes, rather than range fuzes, for warhead detonation.

Threat Projectile Characterization.
Several JLF-Air projects focused on collecting threat characterization data for small arms or Anti-Aircraft Artillery (AAA) threats. One such project filled deficiencies in data on the performance of certain fuzes used in 14.5 mm and 23 mm high-explosive incendiary projectiles. A gap in understanding the ballistic performance multiple variations of 7.62 mm and .30-caliber armor piercing/armor piercing incendiary projectiles similarly resulted in a test series to determine the appropriate round for use in experimental ballistic testing.

V_{50} Yaw of Projectiles.

This project is exploring how a projectile, such as those impacting fast moving targets, penetrates typical aircraft materials when impacting the materials at other than normal (i.e., 90 degrees) incidence. Test results will provide immediate feedback on the accuracy of the analytical vulnerability tools now being commonly used and will be used to update the Computation of Vulnerable Area Tool and the Advanced Joint Effectiveness Model. The test concept was successfully demonstrated in 2012 and 40 test events at varying speeds, effectively creating different yaw angles, are underway.

Rotorcraft Sponson RPG Vulnerability.
This project evaluated three technologies for suppressing cabin fires resulting from RPG impacts to sponson fuel tanks adjacent to aircraft cabins. Although large main cabin fires occurred in this testing, the testing demonstrated that some of these technologies are effective in either mitigating or eliminating the resulting fire. This testing focused on cabin environment and occupant survivability. Data from cabin thermocouples, pressure transducers, and mannequins were collected to establish occupant effects. These data, along with an evaluation of the fire suppression technologies tested, will be published in FY13.

Crew Compartment Fire Survivability.
This project characterized the environment of an aircraft main cabin during fires representative of those seen as a result of ballistic events. Baseline testing focused on cabin conditions with no airflow (i.e., all hatches, doors, and windows closed) and the effectiveness of personal fire extinguishers to extinguish those fires. Using a specially modified H-3 helicopter fuselage


developed under this project, data were collected using a comprehensive instrumentation package gathering multiple temperature, oxygen and carbon monoxide levels, and visibility measurements. For each test event, the cause and time to reach an incapacitation threshold were determined.

Ground Systems Programs

Roadmap to Address Hybrid-III Mannequin Sustainment.

This project investigated modification and improvement options for the currently utilized Hybrid-III Anthropomorphic Test Device (ATD). The Hybrid-III ATD is the primary instrument for gathering accelerative injury data from live fire underbody blast testing. This project identified several low cost technical upgrades that will help sustain the Hybrid-III ATD through 2018, at which point the live fire community expects to transition to the Warrior Injury Assessment Manikin (WIAMan) ATD, currently under development.

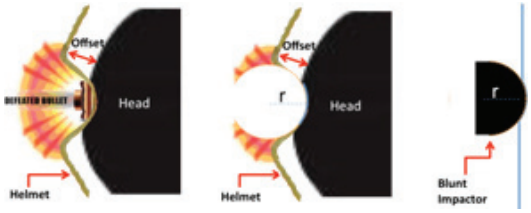
Test and Analysis to Update Warhead Characterization for MK 82 Bomb.
This project conducted a series of five MK 82 general purpose bomb tests to characterize fragment size, speed, and direction. Tests were conducted utilizing the JTCG/ME standard procedures, with fragments collected in recovery bundles and impact speeds measured utilizing electronic triggering panels. The JTCG/ME Systems Characterization Working Group is reviewing the results, which, when accepted, will be utilized for weapon lethality, collateral damage, and risk assessments. This testing was in direct response to requests from operational Commanders employing the MK 82.

Testing to Gather Penetration for Low-Collateral Damage Round.
This project conducted a series of tests with low-collateral damage rounds against plate arrays typical of a light ground mobile target to obtain residual properties of the projectiles (i.e., speed, weight, and orientation after penetration through different materials). Information collected will be utilized to improve the JTCG/ME predictive Projectile Penetration (ProjPen) model. ProjPen is utilized to predict penetrator performance against ground mobile, rotary- and fixed-wing aircraft, and small watercraft. ProjPen currently lacks predictive capability for this type of round and data did not exist to implement that capability.

Behind Helmet Blunt Trauma Skull Injury.
This JLF project is part of a series of experiments to improve the testing and evaluation of military combat helmets. Blunt-ballistic impact tests will be used to develop an injury criterion or risk for behind-helmet blunt trauma, where currently none exist. JLF can

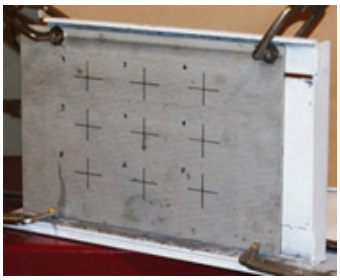
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use the injury criterion to assess the severity of loading, as well as the risk of sustaining injury, with potential to implement this criterion into future testing and evaluation of new protective equipment.



Improvements to Sustained Fire Prediction in Vulnerability/Lethality Analysis Methodologies.
This project assessed the ability of lethality and vulnerability (L/V) models to predict sustained fire as a kill mechanism for ground mobile targets. Analysis of available test data indicates current L/V fire start methodologies under-predict sustained fire resulting from near-field detonations of blast-frag warheads. This initial assessment of fire start predictive capability will compile available relevant test data and reports, assess the current L/V fire start models in light of their underlying empirical data, and propose a way forward for improving the capability of L/V codes to predict sustained fire as a kill mechanism.

Continued Improvement of Material Characterization for ProjPen Modeling.



This project is conducting tests to gather data for small caliber armor piercing incendiary projectiles striking stainless steel plates. Testing is focused on penetration velocities and the gathering of residual masses and velocities of penetrating fragments. This will improve the quality of L/V analyses involving ProjPen. Both the JTCG/ME and JASP utilize ProjPen for the analysis of the damaging effects of small caliber projectiles.

Effects of Buried Homemade Explosive (HME) Performance Variability on Platform and Occupant Survivability.
This project is quantifying the potential variations in the buried blast performance of materials manufactured to represent a typical Homemade Explosive (HME). Similar to many HMEs, the material is a blend of different materials and is granular in nature. The characteristics being investigated arise from the processes required to manufacture the material. Multiple blends at extreme tolerances of acceptable variances in mixtures are being tested in controlled blast experiments. The results of the tests will be used to establish models for the performance of the material. For effects identified as significant (i.e., greater than standard shot-to-shot variability) the explosive models will be used with a full system model to establish the effect on ballistic effects delivered to a vehicle such as those that may be observed during a live fire test.

Sea Systems Program
The Joint Live Fire Sea Systems Program (JLF-Sea) made significant progress in FY12 towards improving the capability to assess the survivability of submarines and surface ships. These projects benefit ship and submarine acquisition programs as well as the fleet of fielded U.S. Navy vessels.

Finnish Fast Attack Craft Testing.
FY12 was the last year of a multiyear, trilateral (United States, Finland, and Germany) cooperative effort to perform damage testing against two aluminum, decommissioned Finnish fast attack craft. The Finnish Navy provided the ships and has conducted testing on their test range in the Baltic Sea and at their test center in Niinisalo, Finland. The objective was to understand the behavior of aluminum structures subjected to various weapon effects. In FY12, shaped charge testing against a section of one of the ships was conducted to study spall and debris from aluminum targets, to perform crew casualty assessments, and to evaluate depth-of-penetration. These tests will fill gaps in our understanding of weapon effects against aluminum ships, and will augment the LFT&E programs for the Littoral Combat Ship and Joint High Speed Vessel.

Vulnerability of Aluminum Structure to Fire.



This project conducted tests to determine if fire insulation and its attachment could be defeated by a major fire. A test article representative of a section of a USS *Independence* class Littoral Combat Ship flight deck was built using specified materials and insulation attachment materials and procedures. The article was then exposed to tests similar to those specified by military standard (MIL STD 3020). Results from this project will fill gaps in our understanding of the vulnerabilities of aluminum structures and their insulation systems to weapon-induced fires.

Crew Casualty Modeling and Simulation Validation Testing.



The objective of this project, jointly funded by the Office of Naval Research and JLF, is to validate injury response functions developed under an earlier JLF project. Three Hybrid-III ATDs were tested on a floating shock platform to collect data on personnel injuries caused by an underwater explosion. The data and observations from this testing will improve the accuracy of crew casualty predictions made as a part of ship live fire vulnerability assessments.

Network Fire Model Enhancements.
This project provided funds to continue development of the NRL network fire model. The model can be used by naval engineers to develop ship designs that limit the spread of fire and smoke. NRL began a two-year effort to improve the model's capability to predict fire characteristics associated with large volume spaces such as hangar and mission bays.

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Sea Bottom Underwater Explosion Effects Testing.
This project, the result of an agreement between the U.S. and German Navies, continues development and validation of simulation tools for assessing ship survivability to various explosive threats. JLF provided funding to conduct underwater explosion testing representing charges located on and near the sea floor to quantify the loading on vessels submerged near the bottom, submerged between the surface and the bottom, and floating at keel depth. This project provides data to increase the fidelity of models, increase the accuracy of survivability assessments, and to address urgent operational needs.



LFT&E SPECIAL INTEREST PROGRAMS

Active Protection Systems (APS)

In response to FY08 legislation, DOT&E tested and evaluated seven foreign and domestic (two foreign, three domestic, and two combined foreign/domestic) APS with the potential to protect wheeled tactical vehicles from RPGs. DOT&E provided a report to Congress and the Department's acquisition leadership in February 2012. This effort concluded that none of the tested APS are currently mature enough for fielding on any U.S. platform and further development, test, and evaluation are required.

Personnel Protection Equipment

DOT&E continued its oversight of the testing of personnel protection equipment. The Services and Special Operations Command (USSOCOM) continue to implement rigorous, statistically-based testing protocols for hard body armor inserts and military combat helmets approved by DOT&E. The Defense Logistics Agency has utilized the hard armor testing protocol in new contracts for sustainment stocks of hard armor inserts. The Army has incorporated the key concepts of statistical confidence and test design into its requirements for its Soldier Protection System. The Navy and Air Force are also implementing statistical testing concepts for soft armor vests.

DOT&E, in partnership with the Services and USSOCOM, is developing a new soft armor vest testing protocol. That protocol is intended to standardize testing and assure that soft armor vests provided to Service members meet common ballistic protection requirements and provide uniform protection on the battlefield. The implementation of this protocol will further increase government oversight of personal protective equipment by requiring soft armor vests (in addition to hard armor plates and combat helmets) to meet rigorous statistical measures of performance.

The National Academy of Sciences' (NAS) Committee to Review the Testing of Body Armor Materials for Use by the U.S. Army published its final report in May 2012. This report completes the NAS' three-phase review of body armor testing that began in 2009 following the release of a critical 2009 U.S. Government Accountability Office report of testing conducted at the Army's Aberdeen Test Center. The final NAS report reviewed a number of topics, including the use of statistically principled testing, measurement standards, and body armor test methodology. The report concluded that the hard body armor test protocol is statistically principled and provides an acceptable minimum DoD-wide body armor test standard. The report notes the need for additional work in the areas of both measurement improvement and characterizing variance in the performance of the clay backing material used during testing to further improve test quality. The Army is currently testing a new clay formulation that, if successful, would eliminate the drawbacks of the clay currently used and described in the NAS report. The report also makes several recommendations for research and investigation into the medical effects of blunt force trauma, and for applying the results of this research to improve body armor test procedures. Both DOT&E and the Army are working to use the results of ongoing medical research into blunt trauma to update body armor test methodologies and procedures. DOT&E has asked the NAS to review and comment on the Department's statistically-based combat helmet test protocol, a 15-month study that is expected to be complete by the end of 2013.

Stryker Double-V Hull (DVH)

The Army initiated the Stryker Double-V Hull (DVH) program in response to Operation Enduring Freedom commanders' requests for improved underbody blast threat protection. Under DOT&E oversight, the Army incrementally developed and tested multiple Stryker DVH configurations over a two-year timeframe. The test and evaluation program directly supported critical fielding schedules, and DOT&E reported to the USD(AT&L) and Army leadership on each Stryker DVH configuration's survivability, effectiveness, and suitability prior to its fielding. Test and evaluation confirmed that DVH configurations significantly improve crew protection against IEDs and demonstrated the retention or improvement of required operational characteristics. Relative to flat-bottom Strykers, Stryker DVH remained equally mobile and capable of supporting a unit's ability to accomplish a mission, while providing improved reliability and maintainability. The results of the test and evaluation program also led to design changes that corrected significant shortcomings in DVH suitability and survivability.

Underbody Blast Testing

DOT&E continues to actively pursue efforts to improve LFT&E employing underbody blast threats. In January 2011, the DoD provided funds to the Army to execute a DOT&E-sponsored five-year research and development program. This program will substantially increase the Department's understanding of the cause and nature of injuries incurred in underbody blast combat events and will develop new instrumentation capable of being

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used to accurately assess such injuries in testing. This program, known as WIAMan (Warrior Injury Assessment Manikin), utilizes expertise across multiple commands and disciplines within the Army to generate a medical research plan from which data will, at pre-determined times, be transitioned to the materiel and test and evaluation communities. These data will feed the design of a biofidelic prototype ATD designed to accurately capture occupant loading from the vertical direction, reflecting the primary load axis to which occupants are exposed in an under-vehicle blast event.

Similarly, as a result of DOT&E efforts, the Army will characterize the performance of a surrogate for the Afghanistan IED threat to enable its use in test, the performance of buried TNT blast threats (current test standard), and the effects of soil composition and condition on full-scale buried test threats. This effort will ensure adequate LFT&E in support of OEF as well as of future acquisition programs.

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Information Assurance and Interoperability

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Information Assurance (IA) and Interoperability (IOP)

In FY12, the DOT&E Information Assurance (IA) and Interoperability (IOP) Assessment Program performed 20 assessments during Combatant Command (CCMD) and Service-level exercises or real-world activities; 3 of these assessments involved units deployed to the U.S. Central Command (USCENTCOM) area of responsibility. The IA/IOP program conducted reduced-scale assessments at U.S. European Command (USEUCOM) and U.S. Africa Command (USAFRICOM) after their scheduled exercises were cancelled in response to actual operational contingencies. Six individual test and evaluation organizations conducted these assessments, which involved all 10 of the CCMDs and all 4 Services. During the year, DOT&E released five major findings reports, and initiated another nine, pertaining to both IA and IOP. Exercise planners in FY12 made increased use of cyber ranges in support of these exercises.

Summary of Findings

Most exercise assessments and tests involved operations largely against low- and mid-level cyber threats and on networks that were only moderately stressed in terms of loading or network degradation; high-level threats were portrayed infrequently. No exercises were seriously disrupted by adversary activities, or disrupted at any length, because adversary teams were generally not permitted to take actions that could disrupt exercises. In the cases where the adversary team portrayed higher-level threats, exercise training audiences frequently misinterpreted these portrayals as maintenance issues, poor system performance, or anomalies.

Overall, the DOT&E IA/IOP program observed cyber effects caused by unresolved interoperability deficiencies, coupled with low-to-moderate level threats that were sufficient to adversely affect the quality and security of mission critical information in a way that could (and where permitted did) degrade mission accomplishment significantly. Therefore, considering both IA and IOP attributes, the Department has not yet developed sufficiently advanced cyber defensive tactics to counter advanced adversary tactics and to consistently operate in degraded cyber environments.

Interoperability: The FY12 IOP assessments documented interoperability problems involving mission critical systems, but these problems hindered rather than prevented mission accomplishment. This is due primarily to system operators who developed workarounds to preserve the critical mission functions. Even though operators accomplished their missions, the workarounds usually increased operator workload, and often degraded efficiency in completing mission tasks. The assessment teams documented effects on the timeliness, accuracy, and efficiency of operational data handling. Operators frequently viewed interoperability problems as maintenance or design issues and therefore did not report, document, or remediate many of these problems. The majority of systems encountered during assessments were not certified for interoperability.

Information Assurance: The overall IA performance observed during the FY12 exercise assessments remains insufficient to prevent and consistently detect compromise and exploitation of the networks exercised. Although regularly able to penetrate and exploit networks, Red Teams reported modest increases in the required level of effort over previous years. While compliance with network standards continues to improve, the IA/IOP program continued to provide low ratings for certain critical compliance areas. In addition, development of the more sophisticated tactics and procedures necessary to counter a determined or well-resourced cyber adversary remains slow. In exercises involving portrayal of more sophisticated threat profiles, the training audiences usually lacked commensurate defensive tactics. Overall, the implementation of Joint Staff guidance on exercise realism has been slow. Network boundary defenses continued to improve in FY12, to include the presence of host-based intrusion detection tools, improved configuration management of networks and security tools, and the infrastructure supporting the networks. In at least one exercise, good network "housekeeping" effectively deterred adversary efforts. However, DOT&E observed reduced rates of compliance in the use of software and hardware backups; and key practices such as port-and-protocol protections, reliable software baselines, remediation of known vulnerabilities, and effective use of system audit logs.

Partnerships and Coordination

DOT&E continued a number of partnerships directly related to the conduct of IA/IOP assessments. These included:

- Collaborating with the Joint Staff and DoD Deputy Chief Information Officer (CIO) concerning oversight and coordination of the IA and IOP Assessment Program. DOT&E provides metrics and observations generated from these assessments to the DoD CIO for use in enterprise-wide IA assessments and programs.
- Coordinating program efforts with USD(AT&L) and Developmental Test and Evaluation (DT&E) as a means of supporting the acquisition and development of information handling systems.
- Creating a standing memorandum of understanding between DOT&E and U.S. Cyber Command (USCYBERCOM) that directs the establishment and operation of the Cyber Assessment Synchronization Working Group (CASWG), as well as information exchange and collaboration in a variety of areas of interest. The CASWG is developing processes to synchronize planning, execution, and reporting among all cyber assessment activities, and especially those supporting exercise assessments.
- Sharing of information and expertise with the Joint Staff's Joint Deployable Analysis Team continues to enhance assessments.

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The partnership collaborated to conduct two assessments in FY12, and further joint assessments are planned for FY13.
- Collaborating with the intelligence community, the National Security Agency, and the Service Information Warfare centers to improve the portrayal of the representative cyber threats during exercises. The Defense Intelligence Agency (DIA) made significant progress in defining advanced and emerging methods of cyber attack, and was instrumental in mapping known adversary activities to the threat portrayals for several FY12 exercises.
- Working with the Naval Postgraduate School to research and develop improved capabilities for network analyses. This partnership includes the design and development of network test tools; instrumentation; training resources and test/evaluation methods; analysis of compliance and performance findings to postulate cause/effect models for use in simulation; and mapping of direct operational effects arising from network performance issues.
- Coordinating with the Defense Information Systems Agency (DISA) to improve and expand the assistance and training available to assessed organizations, including the implementation of a cyber-defense training and assessment suite at several CCMDs.

FY12 ACTIVITIES

In FY12, the six assessing organizations were the Army Test and Evaluation Command; the Navy's Commander, Operational Test and Evaluation Force; the Marine Corps Operational Test and Evaluation Activity; the Joint Interoperability Test Command; the Air Force Operational Test and Evaluation Center; and the Air Force 688th Information Operations Wing. These 6 assessing organizations completed 20 exercises or site assessments under the IA and IOP Assessment Program, and 2 reduced scope assessments at sites where exercise activity was either curtailed or cancelled. These assessments included 13 CCMD and 6 Service exercise assessments (see Table 1). Three assessments involved units deployed in the USCENTCOM area of responsibility.

TABLE 1. INFORMATION ASSURANCE AND INTEROPERABILITY EXERCISE EVENTS IN FY12

EXERCISE AUTHORITY	EXERCISE	ASSESSMENT AGENCY
U.S. Africa Command	Judicious Response 2012 (Exercise Cancelled)	ATEC
U.S. Central Command	AOR Site Assessment #1	ATEC
	AOR Site Assessment #2	ATEC
	AOR Site Assessment #3	ATEC
U.S. Cyber Command	Cyber Flag 2012	ATEC
U.S. European Command	Austere Challenge (Exercise Cancelled)	ATEC
North American Aerospace Defense Command / U.S. Northern Command	Vigilant Shield 2012	688 IOW
	Ardent Sentry 2012	688 IOW & AFOTEC
	Vibrant Response 2012	JITC
U.S. Pacific Command	Terminal Fury 2012	COTF
U.S. Southern Command	PANAMAX 2012	ATEC
U.S. Special Operations Command	Emerald Warrior 2012	ATEC
U.S. Strategic Command	Global Lightning 2012	JITC
U.S. Transportation Command	Assessment During Operations	JITC
U.S. Forces Korea	Key Resolve 2012	ATEC
	Ulchi Freedom Guardian 2012	ATEC
U.S. Army	Full Scope Exercise 2012-4	ATEC
U.S. Navy	Bold Alligator 2012	COTF
U.S. Air Force	Angel Thunder 2012	JITC
	Red Flag 2012-3	688 IOW
U.S. Marine Corps	Ulchi Freedom Guardian 2012 (III MEF)	MCOTEA
	Bold Alligator 2012	MCOTEA

AOR – Area of Responsibility AFOTEC – Air Force Operational Test and Evaluation Center ATEC – Army Test and Evaluation Command
COTF – Commander, Operational Test and Evaluation Force IOW – Information Operations Wing JITC – Joint Interoperability Test Command
MCOTEA – Marine Corps Operational Test and Evaluation Activity MEF – Marine Expeditionary Force

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Several developments in FY12 confirm increasing emphasis across the DoD to prepare to train and operate in a contested cyberspace environment. The Chairman, Joint Chiefs of Staff (CJCS) is preparing additional guidance to amplify the Execute Order (EXORD) issued in FY11 to increase realistic cyberspace conditions in training exercises. Threat portrayal improved during assessed training exercises but with limited progress made towards implementing EXORD requirements. The overall number of instances in which exercise commanders permitted cyber effects to disrupt operations increased, as did the number of sites where these effects were demonstrated; however, the overall effect remains low due to constraints imposed upon Red Teams.

The Defense Intelligence Agency (DIA) Cyber Threat Assessment (CTA) Office continued to make significant progress in defining advanced and emerging methods of cyber attack, and was instrumental in mapping known adversary activities to the threat portrayals for several FY12 exercises. For example, CTA threat assessments for U.S. Pacific Command's (USPACOM) Terminal Fury 2012 contributed to an integrated Red Team employing multiple attack vectors, an opposing force (OPFOR) with a cyber cell that controlled the Red Team and received exfiltrated information, and some of the most realistic cyber play observed to date in an exercise. CTA also has developed a method to assess the shortfalls between the postulated threat and the threat that was actually present in training, which will be a key metric for evaluating implementation of the CJCS EXORD.

To enhance the IA posture of acquisition programs, DOT&E continued to revise and refine the templates and process for assessing the adequacy of IA testing in acquisition Test and Evaluation Master Plans and test plans. These templates facilitate development and review of these documents to ensure that IA is adequately addressed. DOT&E applied the templates and new process to the Test and Evaluation Master Plans for 34 systems, the operational test plans of 13 systems, and related test documents of 8 systems. Additionally, DOT&E IA experts specifically observed IA tests and reviewed data for the following three systems after previously reviewing test documentation:

- Patriot Missile (PAC-3)
- U.S. Navy dry cargo ship (T-AKE)
- U.S. Army Apache Block III helicopter

FINDINGS, TRENDS, AND ANALYSIS

Interoperability

The FY12 assessments found that interoperability issues encountered by the exercise training audience largely hindered, but ultimately did not prevent mission accomplishment. This was primarily because operators developed and executed effective workarounds. The workarounds increased operator workload, and often degraded the efficiency of completing tasks, or degraded timeliness and accuracy of the information generated.

Operators frequently view interoperability problems within systems architectures as maintenance or design issues beyond the control of local authorities. Therefore, many of these problems are not reported, documented, or remediated. More often, local users will develop practices and techniques to work around the lack of a desired/designed automated function. Workarounds include such techniques as:

- Manual transcription of data from one system to another, introducing transcription errors
- Data transfer between systems via portable media, thereby opening both systems to outside malware intrusion
- System re-boot/re-set to trigger update routines, usually resulting in increased delay and latency of operational data

System-to-system interoperability problems remain largely unreported. Over the last two years, slightly less than one-quarter of all systems observed during exercise assessments had been fully certified for interoperability. Of those systems, only two-fifths have ever been previously certified, indicating that almost half of the exercise systems have lapsed in certification or been replaced by uncertified software versions. Configuration management and documentation of observed systems (certified or not) were reported by the system operators to the operational test observers as satisfactory for 9 of every 10 systems. Operators cited system reliability as a problem in almost one-third of all systems reviewed in FY12, an increase over previous years. Several of the findings either reported or under research by DOT&E involve interoperability shortfalls, including:

- AOC Interoperability – software baseline and interoperability certification in the Air and Space Operations Centers lacks centralized configuration management and control. As a result, the Air and Space Operations Centers do not have standard software, and frequently employ locally-produced middleware to accommodate system-to-system interoperation. Furthermore, the version of the Global Command and Control System (GCCS) in use at all of the AOCs had not been fully tested or certified for operational use. (Note: since the release of this finding, the testing and certification of the most recent update for GCCS-Joint is in progress, which includes AOC operational support.)
- Third Party Patching – DoD uses a large number of commercial software suites, ranging from the baseline Windows® Operating System on most desktop computers, Adobe file readers, JAVA script, and other commonly available commercial administrative and business software. DoD does not have a means of central management for updates to these commercial applications, requiring local network authorities to download commercial patches and updates, test, and implement them individually.
- Surveillance Radar Systems – A wide-area surveillance radar system observed during one exercise was found to potentially allow control of the sensor from multiple workstations/roles/accounts within the command and control software that accesses the radar – essentially preventing a stable configuration during operations.

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Information Assurance

Red Teams reported increased difficulty in penetrating network defenses; however, results show that with sufficient time, Red Teams routinely penetrated networks and systems with few exceptions. Detection rates of network intrusions remained low, and the ability of network defenders to detect subsequent exploitations of information was minimal.

The CJCS EXORD of February 2011 to Incorporate Realistic Cyberspace Conditions into Major DoD Exercises directs more realistic cyber adversary portrayals in all major CCMD and Service-level exercises. There is little evidence that the milestones cited in the EXORD (such as identification of critical mission tasks and systems) have been completed.

The level of threats portrayed in assessed exercises in FY12 (see Figure 1) remained similar to previous years, with a modest increase in both high-level portrayals and exercises in which no threat was portrayed (usually onsite/non-exercise assessments without Red Teams). While exercise commanders permitted degraded network operations on almost twice as many unclassified network sites than the previous year, the instances of degraded performance on classified networks declined slightly. In FY12, a quarter of all Red Team activities were directly disruptive to networks assessed, a step forward in the implementation of the EXORD guidance. However, in cases where adversary teams portrayed higher-level threats, exercise training audiences were unable to either develop or demonstrate advanced mitigation or tactics in the face of these threats. As a result, the exercise participants' defensive actions were not well-matched to the threats portrayed, and sometimes exacerbated the negative effects of the cyber threat.

Figure 1: Distribution of Threat Depictions

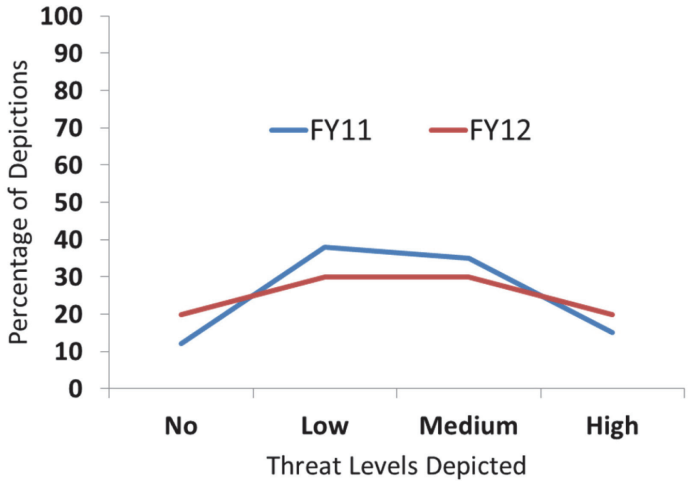


Figure 1: Distribution of threat portrayals in assessed exercises. The majority of threats portrayed in FY12 were low-to-medium capability, and occurred less often than in FY11. A modest increase in high-level threat portrayals was seen at a limited number of exercise sites.

Exercise personnel at times misinterpreted the cyber effects from these more aggressive and disruptive threat portrayals as arising from non-adversary causes such as maintenance shortfalls, system performance problems, or even as artificialities within the exercise construct. As a result, exercise participants either ignored or otherwise did not report significant network events, essentially denying network defenders and leadership critical knowledge of the network status. Additionally, exercise participants perceived the attribution process (confirm whether Red Teams caused the effect) as cumbersome and slow, and in several cases, simply ignored this process, further detracting from the ability to develop a concise and accurate view of the networks under observation.

Most network compliance attributes continue to gradually improve, indicating greater compliance with basic standards (see Figure 2). Network boundary defense compliance continued to improve, including the presence of host-based intrusion detection tools, improved configuration management of networks and security tools, and the overall infrastructure supporting the operational networks. Physical environment, enclave boundary protections, and incident management is improving. The effective use of host-based intrusion detection systems, for example, is increasing.

The ongoing fielding of the Host-Based Security System (HBSS) is improving compliance with having local network protection and intrusion detection; however, the majority of HBSS suites DOT&E observed were found to be incorrectly or ineffectively configured. Enforcement of configuration standards; the deliberate planning for incident responses; and critical network infrastructure practices to include having backup components, supplies, and spares continue to improve. In at least one assessment, a strict enforcement of these basic network requirements resulted in measurably reduced Red Team success. Efforts are also underway at selected CCMDs to document and develop Computer Network Defense playbooks as training and operational tools.

Figure 2: Site Compliance

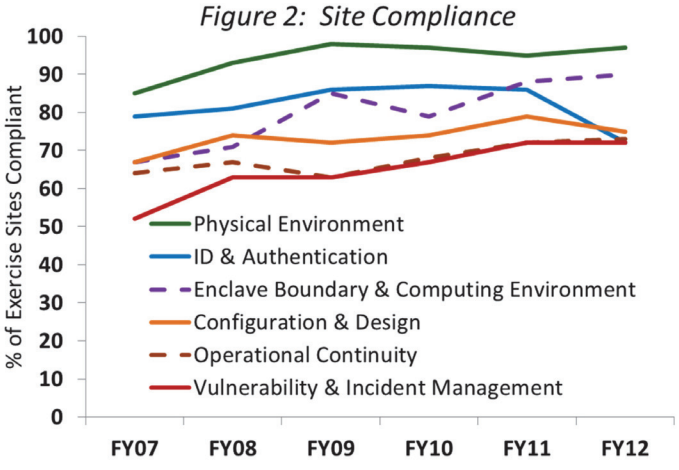


Figure 2: Six-year trend in compliance standards as measured during exercise assessments. Physical environment and enclave protection standards have improved steadily since FY07, but progress in operational network continuity, configuration and design standards, and vulnerability/incident management remain gradual.

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DOT&E observed reduced rates of compliance in the use of software and hardware backups and key practices such as port and protocol protections, reliable software baselines, remediation of known vulnerabilities, and effective use of system audit logs. Exercise authorities rarely shift to alternate sites or systems. Most audit logs did not meet the minimum requirements specified, and the identification and remediation of known vulnerabilities has also declined over the last two years. DOT&E also observed that the experience and formal training levels for network defenders, which increased steadily over the last three years, showed a large influx of new or inexperienced personnel in FY12.

Mission Assurance

During the FY12 assessments, the operational testers analyzed the IA and IOP findings to characterize the operational effects, or potential operational effects, on specific missions. Although cyber-adversary activities posed a high risk to critical operations, exercise authorities seldom permitted disruptions to be fully exercised; the priority to achieve other exercise training objectives remains at odds with exercising in an environment with representative cyber adversaries and consequently degraded systems. In those exercises where operational effects were permitted, the mission impacts included:

- Disclosure of friendly force locations and activities to the opposition force, resulting in fewer adversary losses
- Denial of critical network capabilities during periods of high operational tempo
- Delays in the delivery of operational data

Despite the few permitted and observable impacts to actual missions, DOT&E analysis of the vulnerabilities, intrusions, and compliance trends clearly indicates high-risk to operational tasks and Combatant Commander operational missions. DOT&E analysis indicates that without the development of defensive tactics commensurate with the sophistication of our adversaries, large-scale compromise or loss of operational data and operational systems during high-tempo operations cannot be discounted.

REPORTS

Each of these assessments resulted in a specific report for the Exercise Authority (CCMD or Service) detailing problems found during the exercise and detailed observations and recommendations. In addition to these, DOT&E published five memoranda of findings and initiated research on nine additional areas of concern in FY12. Finding memoranda detail specific shortfalls and vulnerabilities that have the potential to significantly degrade operations and warrant senior leadership attention. DOT&E identified the shortfalls and vulnerabilities to the responsible leadership. Service and CCMDs provided replies to DOT&E detailing mitigation efforts, which then are subject to subsequent re-evaluation and validation in future assessments. During the fiscal year, where observable, DOT&E reviewed or validated in the field solutions to prior findings. New findings released or researched in FY12 are listed below.

Released in FY12:

- Air Operations Center (AOC) Interoperability (released November 2011) – documented the lack of a consistent software baseline and interoperability certification in the Air and Space Operations Centers
- Virtual Secure Enclaves (released December 2011) – documented a promising network security experiment at USPACOM
- Third Party Patching (released January 2012) – documented a lack of central management for security patches on commercial software in use within DoD networks
- Active Directory Pass-the-Hash (released March 2012) – documented a classified investigation into a common hacker technique
- Assessment of DoD IA during Major CCMD and Service Exercises (published April 2012) – documented a detailed follow-up to the FY11 Annual Report, specifically addressing classified IA issues

Research Initiated in FY12:

- HBSS discrepancies in asset management (initiated March 2012 and released October 2012) – investigating a potential common misconfiguration of the system that causes inaccurate or inconsistent results
- Event attribution (initiated May 2012) – investigating the manner in which events detected during an exercise are attributed to either Red Team activity or actual cyber incidents
- Shipboard Systems (initiated July 2012) – investigating a possible vulnerability to afloat systems
- Physical Intrusion Devices (initiated July 2012) – investigating the use of a commonly available hacker tool
- Password shortfalls (initiated July 2012) – investigating common password errors exploited by Red Teams
- Unsecured chat systems (initiated July 2012) – investigating the operational effects of using collaboration tools that can be easily intruded/exploited
- Phishing and misuse of secure socket technology (initiated July 2012) – investigating the operational effects of two common hacker techniques
- Physical Security (initiated July 2012) – investigating multiple instances and causes of failures to physically protect network resources and points of access
- Surveillance Radar Systems (initiated September 2012) – documenting a possible control-of-radar interoperability problem

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FY13 PLANS AND GOALS

DOT&E's goal is to complete at least one IOP and one IA assessment of each CCMD and Service during the fiscal year, with 15 CCMD and Service exercises already identified for FY13 (see Table 2). One of the planned FY13 assessments will involve units already deployed to the U. S. Central Command (USCENTCOM) areas.

The FY13 IA/IOP Assessment Program will focus on the following goals:

- Supporting and monitoring the three-year implementation of the CJCS EXORD, and continuing to improve the realism of portrayed cyber threats during assessments
- Developing and implementing additional improvements to the methods for gathering and assessing the effects on operational missions
- Increasing coordination with USCYBERCOM, DISA, DoD CIO, and other agencies in the scheduling and conduct of assessments
- Continuing to expand the use of the DoD Joint Information Operations Range (JIOR) and other range/test facilities in support of exercise assessments
- Continuing to refine the mission assurance analysis afforded by the IA and IOP findings

TABLE 2. INFORMATION ASSURANCE AND INTEROPERABILITY EXERCISE EVENTS PROPOSED FOR FY13

EXERCISE AUTHORITY	EXERCISE	ASSIGNMENT AGENCY
U.S. Africa Command	Judicious Response 2013	ATEC
U.S. Central Command	AOR Site Assessment	ATEC
	Internal Look 2013	ATEC
U.S. Cyber Command	Cyber Flag 2013	ATEC
U.S. European Command	AOR Site Assessment	ATEC
North American Aerospace Defense Command / U.S. Northern Command	Vigilant Shield 2013	AFOTEC
U.S. Pacific Command	Terminal Fury 2013	COTF
U.S. Southern Command	Integrated Advance 2013	ATEC
U.S. Special Operations Command	Emerald Warrior 2013	ATEC
U.S. Strategic Command	Global Lightning 2013	JITC
U.S. Transportation Command	Turbo Challenge 2013	JITC
U.S. Army	Warfighter 13-4	ATEC
U.S. Navy	Aircraft Carrier Battle Group (CVBG) Assessment	COTF
U.S. Air Force	Blue Flag 2013	AFOTEC
U.S. Marine Corps	II Marine Expeditionary Force	MCOTEA

AOR – Area of Responsibility AFOTEC – Air Force Operational Test and Evaluation Center ATEC – Army Test and Evaluation Command
COTF – Commander, Operational Test and Evaluation Force JITC – Joint Interoperability Test Command
MCOTEA – Marine Corps Operational Test and Evaluation Activity

INFRASTRUCTURE OBSERVATIONS

While exercise commanders permitted degraded network operations on almost twice as many unclassified network sites than the previous year, the instances of degraded performance on classified networks declined slightly. Exercise authorities remain cautious about permitting advanced threat depictions or advanced network effects that may endanger other exercise objectives, or be inappropriate for conduct on live networks.

The use of cyber ranges and laboratories increased in FY12, with four exercises incorporating ranges to support exercise conduct: RED FLAG 2012, CYBERFLAG 2012, TERMINAL FURY 2012, and WARFIGHTER 2012-4. For RED FLAG and CYBERFLAG, the use of the cyber range was integral to the exercise, whereas during the TERMINAL FURY and WARFIGHTER exercises, cyber range use supplemented and enhanced the training scenarios but was not central to the exercises. In all four instances, the use of the ranges permitted more advanced threat and network activities.

The CJCS EXORD of February 2011 directed more realistic cyber adversary portrayals in all major CCMD and Service-level exercises, but did not specify all of the necessary resources to accomplish this tasking. Expanded use of range facilities has been demonstrated to both enhance and expand the ability to depict wider varieties of cyber activities. Furthermore, many DoD networks have transitioned from direct CCMD management and oversight to "ownership" by consolidated cyber service providers or Service component cyber commanders.

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The networks supporting USAFRICOM and USEUCOM, for example, are now consolidated under the Joint Enterprise Network (JEN) for the theater and under the control and management by the Army Signal Brigade in that theater. A number of Air Force networks are similarly consolidating.

All of these consolidations are consistent with the Department's plans for a Joint Information Enterprise, but this has further complicated the tasks of planning and executing realistic assessments. In recent exercises, the assessing agency either experienced critical delays or was unable to obtain approved ground rules, authorizations, or support for cyber adversary activities during the exercise. This was largely due to the cyber component's inability to support the additional activities required by the exercise, or the lack of sufficient agreements with the supported commander to make such commitments on behalf of the Combatant Commander. As DoD continues to consolidate cyber resources, it will be critical for these agencies to control sufficient resources to support exercises to the degree required by the EXORD. Additionally, the demand for "offline" capabilities, such as training, experimentation, development, and test ranges will increase.

DOT&E continues to support the development of methods and environments to exercise and assess advanced actions on appropriate closed-loop cyber ranges. CCMDs used cyber ranges such as the JIOR in four assessed exercise venues, and emphasis will continue for increasing the integration and operational realism of JIOR events associated with DOT&E's IA/IOP assessments in FY13. DOT&E sponsored a distributed cyber-range experiment in July 2012, where the JIOR was used to connect the National Cyber Range (NCR) with other cyber labs, targets, and attackers. NCR capabilities offer substantial increases in network scaling and substantial reductions in the time required for cyber research, development, training, and testing.

At DOT&E's initiative to enhance the operational realism and threat portrayal in exercises and range environments, DoD championed investments to mature the environments and capabilities needed for testing and training with advanced cyber adversaries. The need for this capability is highlighted by the findings contained in the DOT&E classified report dated April 2012. DOT&E recommended integrating four facilities into an enterprise cyber range to speed implementation of the CJCS EXORD, as well as to meet Section 933 requirements for infrastructure to support the rapid acquisition of cyber warfare capabilities.

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Test and Evaluation Resources

Test and Evaluation Resources

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Test and Evaluation Resources

Title 10, U.S. Code requires DOT&E to assess the adequacy of operational and live fire testing conducted for programs under oversight and to include comments and recommendations on resources and facilities available for operational test and evaluation and levels of funding made available for operational test and evaluation activities. DOT&E monitors and reviews DoD and Service-level strategic plans, investment programs, and resource management decisions to ensure capabilities necessary for realistic operational tests are supported. This report addresses the major areas of concern in testing current systems and discusses both resource needs and significant issues for operational and live fire testing. Specific capabilities and test resource areas of concern include:

- General Test Infrastructure
- Next-Generation Electronic Warfare Environment Generator (NEWEG)
- Integrated Technical Evaluation and Analysis of Multiple Sources (ITEAMS)
- Advanced Electronic Warfare (EW) Test Resources
- Cyber Warfare
- Explosive Surrogate for Use in Live Fire Test and Evaluation (LFT&E)
- Tactical Engagement Simulation (TES) and Real Time Casualty Assessment (RTCA)
- Joint Urban Test Capability (JUTC)
- Fifth-Generation Aerial Target
- Automated Test Capabilities for Software-Based Systems
- Steerable Antenna for GQM-163A Supersonic Target Testing
- Additional Electronic Warfare (EW) Simulator Units for Surface EW Improvement Program (SEWIP) Block 2
- Continuing Radio Frequency Spectrum Concerns
- Renewable Energy Infrastructure Impact on Operational Testing

General Test Infrastructure

The DoD budget remains under severe fiscal pressure, and the DoD faces significant budget uncertainty due to legislation limiting Federal spending. In addition to uncertain budgets and funding challenges, the test infrastructure faces technological and policy challenges and risks in maintaining capabilities to test and evaluate the effectiveness, suitability, survivability, and/or lethality of current and future defense systems. The Test Resources Management Center (TRMC) identified a variety of near-term test infrastructure needs in developing the 2012 Strategic Plan for DoD T&E Resources. Some of these needs include:

- Addressing near-term maintenance, sustainment, and modernization needs of T&E facilities across the Services due to obsolescence and equipment deterioration
- Managing the current workforce while shaping future workforce requirements to meet the sophisticated T&E and acquisition challenges brought about by emerging technology
- Developing an investment and operational strategy to produce unmanned and autonomous systems test capability in the air, land, and maritime domains
- Continuing initial efforts to develop a cyberspace test infrastructure capability that provides blue, red, and gray environments with representative threats to offer both defensive and offensive cyber operations

The test infrastructure provides critical support for operational and live fire testing, and DOT&E is working closely with the Deputy Assistant Secretary of Defense, Developmental Test and Evaluation (DT&E)/Director, TRMC to ensure that the DoD retains sufficient core capabilities to conduct realistic testing. DOT&E has also engaged in the DoD budget process to address problems with electronic warfare threat simulators, the cyber range, and body armor testing.

Savings in Test Infrastructure.

Given the current and projected fiscal environment, DOT&E understands fully the need to seek savings in all areas of the Department's activities and infrastructure, including testing and test infrastructure. The need for cost-effective testing is a key reason DOT&E continues to require that test plans incorporate the use of rigorous statistical methods for determining the scope and breadth of operational testing and for evaluating the data produced by that testing. During the past year, the developmental test office has attempted to identify savings that could be accrued within the Department's test infrastructure, as well as by adopting revised testing practices, and has produced a draft "Comprehensive Review of Test and Evaluation Infrastructure." Although adoption of some of the report's proposals for revised practices would be beneficial, the draft report provided to DOT&E for review has serious shortcomings. Savings taken within any of the Department's activities or infrastructure must be based on actions that are clearly defined and can, therefore, actually be taken; must be capable of assignment to specific elements of the defense budget; and, must be based on credible estimates. Unfortunately, the draft report reviewed by DOT&E satisfies none of these important prerequisites.

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Next-Generation Electronic Warfare Environment Generator (NEWEG)

Electronic Warfare (EW) threat simulation capabilities must meet ever-expanding requirements for future strategic, tactical, and support aircraft with electronic combat support systems. These requirements are the result of the increasing sophistication and capabilities of threat radars and the increasing detection and processing capabilities of EW systems, as well as the need for higher-fidelity simulation capability to provide closer correlation between laboratory testing and flight testing. Such a simulation capability would reduce overall test costs and allow greater confidence in laboratory results. To meet these emerging EW requirements, a new generation of EW simulators must make use of state-of-the-art technologies, including modular and scalable architectures, high-speed processing, and integrated radio frequency (RF) subassemblies. The T&E community requires advanced software models to represent platform motion, direction-finding, modulation, and environmental conditions. There is currently no capability to characterize multiple interdependent jammers that simultaneously jam different targets in different bands in different locations in space.

The NEWEG project will use a state-of-the-art, high-fidelity, modular, scalable and reconfigurable EW environment generator and a dynamic multi-beam characterization capability for current and future EW systems testing. It will also establish commonality among DoD stimulators. NEWEG will support both developmental and operational testing and is intended to satisfy shortcomings at Modeling and Simulation and Hardware-in-the-Loop Labs, Installed Systems Integration Facilities, and Open-Air Ranges. The Tri-Service Electronic Warfare Test Capability Study identified these shortcomings in August 2010.

The technical objective of NEWEG is to evolve the state-of-the-art in EW simulation and stimulation technology into much higher-fidelity threat signal simulation. Additional project benefits include establishing commonality between DoD stimulators (leading to improved test repeatability) and continuity between ranges and facilities (resulting in reduced preparation time and cost). NEWEG is intended to:

- Incorporate an open-architecture design facilitating information sharing between EW testers
- Incorporate dynamic jammer recording and analysis
- Include a limited closed-loop threat response capability for Electronic Attack reactivity evaluation
- Allow playback of collected Intelligence/SEI (Specific Emitter Identification) waveforms
- Incorporate an integrated dynamic motion-based RF receive/transmit and analysis subsystem into the Advanced Systems Integration Laboratory (ASIL) at Patuxent River, Maryland

This capability is required for adequate operational testing of F-35 Block 3 in FY17 and beyond. NEWEG development is estimated to cost $23.9 Million to meet the threshold Key Performance Parameters (KPPs) for the system and $33.9 Million to achieve the objective KPPs.

Integrated Technical Evaluation and Analysis of Multiple Sources (ITEAMS)

After the fall of the Soviet Union, U.S. testers were able to acquire foreign military weapon systems for testing U.S. weapon systems. The emergence of new potential adversaries in the past two decades has created a threat situation in which foreign assets are not available for exploitation or testing. The Threat Systems Program (TSP) supports U.S. Service members by providing threat intelligence to ensure operational and developmental testing occurs against realistic threat representations. TSP is a partnership of the intelligence, operational testing, and acquisition communities in the DoD. Under a memorandum of agreement between DOT&E and the Defense Intelligence Agency (DIA), the Test and Evaluation Threat Resource Activity (TETRA), within the Missile and Space Intelligence Center, executes the TSP and provides ongoing intelligence analysis and support for DOT&E threat resources while managing and overseeing a DOT&E investment program for the development of threat resources.

TSP pioneered the use of intelligence deep-dives, going beyond the normal intelligence mission to perform intelligence research and analysis necessary to develop threat simulators. These efforts, known as Integrated Technical Evaluation and Analysis of Multiple Sources (ITEAMS), can result in threat representations such as models and simulations or produce blue-print designs for constructing open-air operational test assets, such as hardware solutions representing a threat capability or function.

During FY12, TSP completed ITEAMS projects on land and sea threats. A scientific and technical intelligence staff translated all source technical intelligence on a widely proliferated battle management and command, control, communication, and computer system into a model to support test and evaluation. The model is intended to provide real-time man-in-the-loop operations in an electronic attack environment. Two projects starting in FY12 will address medium-range surface-to-air missile threats from two different adversaries, leveraging previous intelligence collection and analysis on these systems and their predecessors. These efforts are in addition to recently completed ITEAMS of threat Advanced Air Defense Systems. In FY12, DOT&E authorized funding of 10 new ITEAMS to address critical operational test needs for 2014 and beyond.

Advanced EW Test Resources

In February 2012, DOT&E identified shortfalls in EW test resources that prevent development, testing, and timely fielding of U.S. systems capable of operating successfully against threats that currently exist, are proliferating, and are undergoing an accelerating pace of significant upgrades. Subsequently, DOT&E identified the need for approximately $495 Million in funding from FY13-18 to address these shortfalls and assure the needed test resources would be available in time to support developmental and operational testing of systems including the Joint Strike Fighter. The DOT&E recommendations included accelerating the NEWEG program's production of high fidelity signal generators, upgrading the government anechoic chambers with adequate numbers of signal generators from the NEWEG

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program for realistic threat density, upgrading the Joint Strike Fighter mission data file reprogramming lab to include realistic threats in realistic numbers, providing ITEAMS products needed to guide threat simulations, and developing a combination of open and closed-loop threat simulators in the numbers needed for operationally realistic open-air range testing.

DOT&E participated in a "tiger team" assigned by USD(AT&L) to review the shortfalls identified by DOT&E, which concurred with DOT&E's conclusions and recommended additional enhancements. The combination of improved government-owned anechoic chambers and new open-air range test assets is needed to evaluate the advanced capabilities under development in the Joint Strike Fighter, F-22 Increment 3.2 A/B, B-2 Defensive Management System, Long-Range Strike Bomber, Next Generation Jammer for the EA-18G, Integrated Defensive Electronic Countermeasures upgrades, as well as several other programs. DOT&E is pursuing, along with the TRMC, the necessary actions to acquire the test assets and integrate them into operational test plans. Absent these test resources, development and adequate, realistic testing of the systems cited above will not be possible.

Cyber Warfare

The capacity to assess realistically advanced cyber warfighting capabilities must be increased to keep pace with heightened demand for those capabilities, advancing technologies, and the growing cyber threat. In February 2011, the Chairman of the Joint Chiefs of Staff issued a memorandum directing that all major exercises include realistic cyber adversary elements as a training objective. To comply with this order, more non-major exercises are needed, and these exercises must include realistic cyber adversaries. The Joint Information Operations Range offers a multi-level security environment to integrate and conduct simultaneous cyber activities.

DOT&E identified a $90 Million need over the Future Years Defense Program (FYDP) to upgrade range operations and capacity to conduct additional events, handle larger amounts of message traffic, and portray cyber threats and responses with increased fidelity. Additionally, DOT&E estimates $59 Million over the FYDP is needed to provide additional capabilities for realistic threat development and assessment, as well as additional expertise and training for the Red Teams employing cyber threats during training and test events. Lastly, DOT&E estimates additional funding of $46 Million across the FYDP will support assessments during all appropriate Combatant Commander and Service exercises.

Explosive Surrogate for Use in Live Fire Test and Evaluation (LFT&E)

Title 10, U.S. Code requires realistic survivability testing of combat and tactical wheeled vehicles against combat-realistic threats. DOT&E oversees survivability testing and has concerns about our ability to test operationally significant scenarios involving underbody blast threats, thereby assuring adequate LFT&E of military vehicles now and in the future. The significant concerns include the need to:

- Develop and rigorously characterize the performance of a surrogate for the Home-Made Explosive (HME) threats now prevalent in Afghanistan because of their ease of fabrication and efficacy, both of which argue for the use of HME by enemies in future conflicts. Currently, LFT&E cannot use HME surrogates because the performance of those surrogates (that is, the blast impulse they deliver to a vehicle) vary greatly from test to test for reasons that are not fully understood. LFT&E requires repeatability from test to test, which can be achieved only when the key factors determining the performance of HME surrogates are known and can be controlled.
- More fully characterize the performance of buried TNT devices, which are the standard threats currently used in LFT&E. The blast impulse delivered by buried TNT to a vehicle is repeatable under the relatively narrow set of conditions now used in LFT&E. However, there is a need to test and compare results obtained under more widely varying conditions.
- Characterize how differences in soil composition affect the blast impulse delivered to vehicles undergoing underbody blast testing. The currently used single standard soil presents multiple limitations to testing for numerous reasons. It does not allow for roadbed compaction, realistic under-wheel threat placements, varying moisture content, or varying soil composition. This constrains the LFT&E community's ability to evaluate vehicle vulnerability to underbody blast threats for certain critical, operationally significant scenarios. Additionally, the Army may soon be unable to continue procuring soils that meet the current standard.

Proposed funding of $15 Million for FY13-15 will enable the Army to complete the full scope of effort required to ensure adequate LFT&E of military vehicles against underbody blast threats. Understanding of blast threats will enable improvements to vehicle design and capabilities against underbody blast threats that will save lives in current and future conflicts.

Tactical Engagement Simulation (TES) and Real Time Casualty Assessment (RTCA)

New and upgraded combat systems cannot be adequately evaluated without the exchange of simulated fire between friendly and opposing forces in an operationally realistic environment. These force-on-force battles must contain enough realism to cause Soldiers and their units to make tactical decisions and react to the real-time conditions on the battlefield. Real Time Casualty Assessment (RTCA) is needed to ensure that the simulated engagements have realistic outcomes based on the lethality and survivability characteristics of both the systems under test and the opposing threat systems. Future Tactical Engagement Simulation (TES)/RTCA systems must include critical attributes of real-world combat engagements such as direct and indirect fires, IEDs and mines, realistic battle damage and casualties, a mix of ground and air vehicles, and a competent and capable threat force. TES/RTCA systems must be able to record the time, space, position; and firing, damage, and casualty data for all

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players in the test event. Current TES systems cannot support the simulated engagements or the data collection needed for OT&E.

Past efforts by the Army test community to develop a TES/RTCA capability have failed due to affordability issues. Army Operational Test Command has begun a study to review the operational test requirements for RTCA, examine applicable technologies, and recommend a course of action for future developments. The Army has also initiated work on the Army Tactical Engagement Simulation System (A-TESS) program, which seeks to increase interoperability and provide interface standards for future capability growth of its TES systems. The offices responsible for test and training in the Army are committed to working together toward a future system due to their common requirements and limited budgets. DOT&E supports these initiatives and will continue to require an adequate RTCA system to support the OT&E of combat systems such as the Ground Combat Vehicle, Abrams Tank Modernization, Armored Multipurpose Vehicle, Apache Block III, Joint Lightweight Tactical Vehicle, and Stryker upgrades. The estimated cost to develop this capability is $125 Million.

Joint Urban Test Capability (JUTC)

Operations in urban environments present unique challenges to Service members and their equipment. Degraded mobility, communications, and situational awareness; a large civilian presence; the risk of collateral damage; reduced stand-off distances; and unique threat profiles are some of the obstacles present during urban operations. These challenges justify the requirement that systems be tested in operationally realistic urban environments. The Army-led Urban Environment Test Capability (UETC) study has determined the resources needed to support the T&E of systems operating in urban environments. The UETC summarized this information, along with a study of global urban landscapes, in its final report. The UETC report is the foundation for the Joint Urban Test Capability (JUTC) project being led by the Army and funded through the OSD Central Test and Evaluation Investment Program.

DOT&E is supportive of the JUTC requirement; however, the proposed physical surface urban area of 200 meters by 240 meters will not be large enough to support operational testing of Company size and greater test scenarios. DOT&E recommends that the urban area be expanded to the JUTC objective requirement of 900 meters by 900 meters to support future operational test events. The cost of the current JUTC effort is estimated at $75-95 Million. DOT&E is coordinating with the TRMC on the feasibility of expanding the JUTC to the larger area.

Fifth-Generation Aerial Target

No U.S. aerial target (including the QF-16 currently in development) can replicate fifth-generation fighter characteristics such as low observability or embedded electronic attack. As a result, operationally realistic testing cannot be accomplished for U.S. air-to-air and surface-to-air weapons systems against fifth-generation fighters. Therefore, DOT&E is executing a target design and cost study based on the recommendation of the Defense Science Board with a goal of determining if an affordable Fifth-Generation Aerial Target can be developed. The contractor and Institute for Defense Analysis (IDA) provided preliminary cost estimates in FY12. DOT&E will focus on mitigating risk and resolving cost uncertainty as the study continues in FY13. DOT&E is seeking $60 Million to develop a production-representative prototype(s) to validate cost and performance during flight test in FY15. This capability is required for adequate developmental and operational testing of the Department's ongoing and planned aircraft and missile programs.

Automated Test Capabilities for Software-Based Systems

Current acquisition policy (DoDI 5000.02) requires "manufacturing processes under control" as an entrance criterion for a Milestone C decision for full-rate production. DOT&E now requires an equivalent concept for software acquisitions and software components of a weapon system at IOT&E. Specifically, program managers must demonstrate software system sustainment maturity, including program-conducted T&E in support of routine technology upgrades. A demonstration of sustainment maturity will include a demonstration of applicable test automation and the ability to perform an end-to-end trace of test information from requirements to test scripts and defects.

We anticipate that most programs will take several years to create a software test automation approach that will satisfy the DOT&E requirements. Currently, programs complete test automation and an end-to-end trace of test information on a per program basis at varying levels of adequacy. Very few acquisition programs have mature test automation solutions for regression testing that can be demonstrated at IOT&E, and even fewer programs can create the environments and conditions to validate their regression testing processes. Without substantial help from a central resource, it is likely that most programs will have this deficiency during IOT&E.

The need for software test automation strategies to satisfy DOT&E requirements will create demand for test automation expertise in program offices. Program managers need a resource, such as a center of excellence, to help meet that demand and mitigate problems. A center of excellence will work with vendors and government providers to promote interoperability of Test as a Service (TaaS) and other test automation solutions. This center of excellence is intended to:

- Centralize knowledge of the various automation approaches
- Assist programs in applying software test automation
- Create "in-house" software test automation expertise

A center of excellence may lessen the tendency to use a "stove-piped" approach to testing, may reduce duplicative resources (technological and human), should increase programs' use of existing capabilities, and should improve the consistency and adequacy in the types of testing accomplished. DOT&E estimates the DoD will need $2 Million over the next two years to establish a software test automation center of excellence that will subsequently be self-supported through fees for test services.

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Steerable Antenna for GQM-163A Supersonic Target Testing

A steerable antenna unit is required to provide operationally realistic emissions from the GQM-163A supersonic target that will stay locked on the target ship. This unit is needed to ensure the shipboard EW system has constant track of the incoming target emissions so that Rolling Airframe Missile Block 1 and/or Block 2 missiles can then be launched (and guide on those same emissions) as interceptors. This unit would be similar to the STEERAN unit currently used in the BQM-74E subsonic target. The diameters of the GQM and BQM targets differ greatly, so extensive re-engineering and testing will be needed to adapt the BQM unit to fit the GQM without disturbing the GQM kinematics/maneuverability. This capability is required for adequate operational testing of the CVN-78/Rolling Airframe Missile Block 2 in FY17. Estimated development cost is $10-20 Million. Estimated unit cost is $500 thousand.

Additional EW Simulator Units for Surface EW Improvement Program (SEWIP) Block 2 OT

At present, there exists only one each of the Kappa, Uniform, and Gamma EW simulators. These simulators are flown on Lear Jets against shipboard EW systems. SEWIP Block 2 is the latest EW system under development. Two of these simulators are needed (one for each Lear Jet) so that threat-realistic stream raid profiles can be used to adequately test the SEWIP Block 2 in FY14. An estimated development/procurement cost is $5 Million.

Continuing Radio Frequency Spectrum Concerns

The T&E community competes with commercial and other federal entities for access to the RF spectrum. RF spectrum allocated to commercial uses has increased due to reallocation of the government spectrum and petitioning of the Federal Communications Commission (FCC) for additional frequency assignments. The result is insufficient spectrum to support T&E telemetry operations (primarily in the L and S frequency bands) and FCC restrictions on DoD RF emissions and jamming operations (so as not to interfere with commercial RF use). This problem is exacerbated by the growth in data transmission rates needed as more complex weapon systems are developed (by the U.S., allies, and adversaries) and as the military must demonstrate RF spectrum exploitation to disrupt and deny spectrum access by adversaries. Funding and support from Congress as well as other federal agencies is needed to ensure adequate RF spectrum to support T&E. The objective would be to pursue the following:

- Protect critical T&E RF spectrum bands from reallocation.
- Acquire additional RF spectrum to offset reallocated spectrum. This would include development of a multi-Service implementation plan to ensure acquisition programs and range facilities implement the means to utilize the additional spectrum.
- Develop methods and technologies that more efficiently use the RF spectrum.

TRMC estimates the cost to retain the current capacity of the ranges (i.e., the number of test operations) is on the order of $400 Million over five years due to continued growth of data transmission rates, the associated costs of developing the technologies needed to support these data transmission rates, and continuing encroachment on the spectrum needed for testing.

Renewable Energy Infrastructure Impact on Operational Testing

Testing and evaluation of weapons, sensors, command and control networks, and other sensitive technologies often require an electromagnetic environment free of interference. The proliferation of wind and solar renewable energy projects has had an increasing impact on DoD testing and evaluation in an electromagnetic environment. Although most renewable energy projects are compatible with the DoD test capabilities, in some cases, they can interfere with test range instrumentation resources and systems under test. Collocation of wind and solar power renewable energy projects with test resources is requiring careful evaluation and investigation of a variety of potential mitigation strategies, since many of the Nation's most productive wind and solar energy resources exist in close proximity to some of the DoD's most critical test ranges. For example, wind farms located in the Tehachapi Mountains in California currently restrict the ability to test certain airborne radar systems along west-to-east approach vectors to simulated targets. Additionally, proposed new renewable energy developments in the northern Mojave Desert could more severely affect these tests on the east-to-west approach vector. These renewable energy resources may eliminate the ability of the DoD to validate design parameters of radar systems in the southern California/Nevada region test ranges.

There are known sources of interference with test range capabilities from energy infrastructure projects, such as those identified in California and Nevada. Since DoD is only beginning to evaluate such areas of interference because renewable energy development on a large scale did not occur until recently, more data on interference from the various types of renewable energy projects are needed to determine the significance of its effects. Similarly, research is required to develop interference mitigation techniques and technologies.

DoD has observed interference in the following areas: wind turbines on DoD radar systems, central solar power tower impact on radar cross section evaluation, electromagnetic interference from transmission lines, and physical obstruction from transmission lines.

To address these interference problems, DOT&E is working with the DoD Siting Clearinghouse to evaluate proposed renewable energy and infrastructure projects as well as develop expertise in understanding interference issues and establish a strategy for research that will produce mitigation techniques and technologies to resolve interference issues.

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Joint Test and Evaluation

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Joint Test and Evaluation (JT&E)

The primary objective of the Joint Test and Evaluation (JT&E) Program is to provide rapid solutions to operational deficiencies identified by the joint military community. The program achieves this objective by developing new tactics, techniques, and procedures (TTPs) and rigorously measuring the extent to which their use improves operational outcomes. JT&E projects may develop products that have implications beyond TTPs. Sponsoring organizations submit these products to the appropriate Service or Combatant Command as doctrine change requests. Products from JT&E projects have been incorporated into joint and multi-Service documents through the Joint Requirements Oversight Council process and through coordination with the Air, Land, Sea Application Center. The JT&E Program also develops operational testing methods that have joint application. The program is complementary to, but not part of, the acquisition process.

The JT&E Program has re-engineered its business model in response to a budget reduction starting in FY13. The major change is that project life cycle is reduced to two years from the current three years. To accommodate this shorter timeline, nominating organizations must submit a robust initial nomination package that provides substantial detail on how they will achieve test objectives. The new business model of conducting shorter test projects necessitates establishing permanent test units, managed by operational test agencies, supporting test projects led by the operational sponsor. This new business model reduces the number of staff members needed to support a joint test and improves the stability of personnel assignments.

The program managed six joint tests in FY12 that focused on the needs of operational forces. Projects annotated with an asterisk (*) closed in FY12:

- Joint Advanced Capability Employment (J-ACE)
- Joint Cyber Operations (JCO)
- Joint Deployable Integrated Air and Missile Defense (JDIAMD)
- Joint Integration of Maritime Domain Awareness for Homeland Defense (JIMDA)*
- Joint Jamming Assessment and Mitigation (JJAM)*
- Joint Unmanned Aircraft Systems (UAS) Digital Information Exchange (JUDIE)

The JT&E Program instituted a quick reaction test (QRT) capability in 2003 to respond to the pressing needs of today's deployed forces. QRTs are less than a year in duration and solve urgent issues. The program managed 16 QRTs in FY12:

- Afghanistan Mission Network Coalition Battlespace Management (AMN-CBM)*
- Airborne Maritime Moving Target Indicator (AMMTI)*
- Battlefield Airborne Communications Node (BACN) Intra-Flight Data Link Subsystem and Multi-Domain Integration (BIS-MDI)
- Civil Intelligence Fusion Concept of Operations (CIFC)
- Computer Network Defense Service Provider (CNDSP)
- Joint All-Domain Situational Awareness (J-ADSA)
- Joint Analytical Network Assessment (JANA)*
- Joint Battlespace Awareness via Data Link (J-BADL)
- Joint Beyond Line-of-Sight Command and Control (JBC2)
- Joint Exploitation of Modern Surface-to-Air Missile Systems (JEMS)*
- Joint Military Working Dog (JMWD)*
- Joint Passive Electronic Radio Frequency Emission Classification and Tracking II (J-PERFECT II)*
- Joint Threat Assessment and Negation for Installation Infrastructure Control Systems (JTANIICS)
- Joint Vehicle Protection and Survivability System (JVPSS)*
- Rapid Development and Sustainment of Enterprise Mission Services (RDEMS)*
- Unmanned Aircraft Systems – Airspace Integration (UAS-AI)

The program executes special projects, as directed by DOT&E, which address problems DoD-wide. The program managed one special project in FY12, the Rapid Acquisition by Sniper1K Track and Attack (RASTA).

JOINT TESTS

JOINT ADVANCED CAPABILITY EMPLOYMENT (J-ACE)

Sponsor/Start Date: U.S. Strategic Command/August 2011

Purpose: To develop, test, and evaluate a standardized process to support the Joint Force Commander's ability to employ enhanced, advanced capabilities to overcome complex targeting challenges.

Products/Benefits: The J-ACE-developed products are:

- A repeatable operational employment process that will enhance planning by developing, evaluating, and coordinating concepts of employment (CONEMPs) that can be used by the Joint Staff, Combatant Commands, Services, and National Security Agency to solve complex targeting challenges
- Multiple approved, enhanced, and advanced capability CONEMPs to overcome complex targeting challenges
- Relevant training scenarios and vignettes
- Documented effects associated with techniques against representative targets
- Recommendations to operational concept of operations (CONOPS) and approval process packages

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JOINT CYBER OPERATIONS (JCO)

Sponsor/Start Date: U.S. Pacific Command (USPACOM)/August 2010

Purpose: To develop, assess, and evaluate joint TTPs to employ an adaptive cyber defense Virtual Secure Enclave (VSE) to ensure the protection and availability of critical command and control services.

Products/Benefits:
- Addresses network vulnerabilities of critical command and control services by enabling Joint Task Force Commanders to employ an adaptive cyber defense VSE to protect against, detect, and respond to cyber threats against specific command and control applications at the operational level
- Provides the Commander with situational awareness and cyber defense options to maintain a proactive defensive posture
- Facilitates a systematic approach to warfighting in the cyber domain
- Tests and validates operational effectiveness of Joint Task Force implementation

JOINT DEPLOYABLE INTEGRATED AIR AND MISSILE DEFENSE (JDIAMD)

Sponsor/Start Date: North American Aerospace Defense (NORAD), U.S. Northern Command (USNORTHCOM), Army Space and Missile Defense Command/August 2011

Purpose: To develop joint planning and execution processes and procedures for deployable, integrated air and missile defense (IAMD) for the homeland.

Products/Benefits:
- IAMD process modeling that provides a comprehensive view of the integrated planning and execution process
- NORAD and USNORTHCOM current operations planning processes, checklists, and procedures for IAMD
- Continental NORAD Region and Air Forces North planning and execution TTPs for IAMD
- U.S. Fleet Forces and Third Fleet planning and execution TTPs for naval support of IAMD
- Army North planning and execution TTPs for operational control of ground-based IAMD forces
- 263rd Army Air and Missile Defense Command planning and execution TTPs for IAMD

JOINT INTEGRATION OF MARITIME DOMAIN AWARENESS FOR HOMELAND DEFENSE (JIMDA)*

(Closed October 2012)

Sponsor/Start Date: NORAD and USNORTHCOM/August 2009

Purpose: To develop TTPs for consistent and comprehensive coordination across the distributed maritime community in order to synchronize maritime domain information for key decision makers across the operations centers responsible for homeland defense.

Products/Benefits:
- Integrated maritime domain awareness processes, procedures, and checklists for all participating operations centers
- An online handbook detailing the information and resources available for developing and sharing maritime domain information across the NORAD and USNORTHCOM command and control network and among participating interagency partners
- An online portal, hosted by NORAD and USNORTHCOM, that enables the distributed execution of the maritime domain awareness processes, procedures, and checklists during daily operations at participating operations centers throughout the maritime community

JOINT JAMMING ASSESSMENT AND MITIGATION (JJAM)*

(Closed September 2012)

Sponsor/Start Date: Air Force/August 2009

Purpose: To develop TTPs that mitigate the effects of adversary purposeful interference (PI) on satellite communications (SATCOM) and allow friendly operational forces to effectively sustain operations when SATCOM is degraded or denied.

Products/Benefits:
- Created SATCOM PI mitigation training employing live jamming signals that allowed the SATCOM community of interest to rehearse technical and procedural PI resolution processes
- Established SATCOM PI mitigation TTPs and CONOPS being used by U.S. Strategic Command, USPACOM, and U.S. Central Command (USCENTCOM)
- Improved information exchange, situational awareness, and command and control decision processes which reduced the timeline for detection, attribution, and target nomination from days to hours
- Integrated Joint Space Operations Center space target coordination and nomination processes into theater operations
- Produced a first-generation PI visualization tool to provide key decision makers real-time awareness of events affecting operationally critical SATCOM networks
- Published SATCOM PI Training and Exercise Handbook for Combatant Command planners
- Integrated SATCOM PI Mitigation TTPs into 19 joint and Service publications

JOINT UNMANNED AIRCRAFT SYSTEMS DIGITAL INFORMATION EXCHANGE (JUDIE)

Sponsor/Start Date: Air Force/August 2010

Purpose: To develop, test, and evaluate cross-component UAS information exchange TTPs used to improve joint battlespace situational awareness and target prosecution capabilities for the Commanders at the tactical level of brigade and below.

Products/Benefits:
- Standardize UAS information exchange TTPs and checklists
- Standardize terminology for UAS information exchange

* Project closed in FY12

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- Integrate information portal and situational awareness display technology currently in use by the components to improve the UAS information exchange efficiency
- Introduce the information exchange TTPs to combat training centers and formal training units

QUICK REACTION TESTS

AFGHANISTAN MISSION NETWORK COALITION BATTLESPACE MANAGEMENT (AMN-CBM)*

(Closed January 2012)

Sponsor/Start Date: USCENTCOM and Defense Information Systems Agency (DISA)/January 2011

Purpose: To measure and evaluate the utility of battlespace management TTPs for both joint and coalition forces.

Products/Benefits: Developed a methodology for use by the Afghanistan Mission Network testing organizations enabling them to test and evaluate the utility of TTPs for executing coalition mission threads, and to execute repeatable test events providing reliable quantitative data.

AIRBORNE MARITIME MOVING TARGET INDICATOR (AMMTI)*

(Closed September 2012)

Sponsor/Start Date: U.S. Southern Command/July 2011

Purpose: To develop TTPs for the employment of the Joint Surveillance Target Attack Radar System (JSTARS) Enhanced Land Maritime Mode (ELMM) in support of the counter-narcotics trafficking mission in U.S. Southern Command's area of responsibility. AMMTI will formulate the first TTPs for employment of the JSTARS radar system for open water surveillance.

Products/Benefits:
- Optimized system parameters for JSTARS maritime employment
- Detailed information on the probability of detection and target location error for the specified AMMTI targets
- Mission planning improvements for JSTARS maritime employment
- TTPs for employment of the JSTARS ELMM capability in multiple Combatant Commands
- Flash Bulletin on JSTARS maritime employment considerations

BATTLEFIELD AIRBORNE COMMUNICATIONS NODE (BACN) INTRA-FLIGHT DATALINK SUBSYSTEM AND MULTI-DOMAIN INTEGRATION (BIS-MDI)

Sponsor/Start Date: USPACOM/November 2011

Purpose: To develop and evaluate TTPs for the BIS-MDI, an upgrade to the basic BACN capability that provides interoperability across multi-band voice and datalink communications and bridges widely separated Link 16 networks. This will greatly enhance situational awareness and operational effectiveness, especially between fourth and fifth generation fighter aircraft and surface shooters.

Products/Benefits:
- BIS-MDI fuses sensor information from multiple sources, including fourth and fifth generation platforms, into the Service member's overall common operational picture
- Joint and coalition Service member CONOPS and TTPs for BIS-MDI employment in support of potential USPACOM operations conducted in anti-access and area-denial environments

CIVIL INTELLIGENCE FUSION CONCEPT OF OPERATIONS (CIFC)

Sponsor/Start Date: Joint Staff/January 2012

Purpose: To test and validate the Civil Intelligence Fusion CONOPS. Many intelligence organizations do not dedicate adequate support to collecting and integrating civil information, preventing the Joint Force Commander from obtaining a holistic view of the operational environment.

Products/Benefits:
- Validated and improved CONOPS for fusion of civil intelligence
- New doctrine change requests for consideration
- Connects sources of civil information with planners, operators, and intelligence professionals creating a community of interest
- Provides processes and architecture for improved information sharing resulting in better knowledge of the operational environment

COMPUTER NETWORK DEFENSE SERVICE PROVIDER (CNDSP)

Sponsor/Start Date: DoD Chief Information Office (CIO)/July 2012

Purpose: To develop, document, and formalize Department-level TTPs to ensure the capability exists within DoD CNDSPs to guide day-to-day operations and ensure an acceptable level of performance of DoD CNDSP defenders when facing a capable cyber adversary.

Products/Benefits: The CNDSP QRT will develop a methodical, repeatable, and verifiable framework for measuring the effectiveness of DoD CNDSPs on the Non-secure Internet Protocol Router Network and Secret Internet Protocol Router Network.

* Project closed in FY12

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JOINT ALL DOMAIN SITUATIONAL AWARENESS (J-ADSA)

Sponsor/Start Date: NORAD and USNORTHCOM/June 2012

Purpose: To develop and test necessary TTPs to improve the ability of NORAD and USNORTHCOM senior leaders to gain and maintain comprehensive, integrated all-domain situational awareness and decision superiority.

Products/Benefits: The J-ADSA QRT will develop and evaluate the effectiveness of TTPs to access and analyze the effectiveness of seemingly unrelated cross-domain activities and events to enable the NORAD-USNORTHCOM leadership to make timely decisions.

JOINT ANALYTICAL NETWORK ASSESSMENT (JANA)*

(Closed January 2012)

Sponsor/Start Date: USNORTHCOM/January 2011

Purpose: To develop, test, and validate a mission essential circuit list (MECL) for all inter-landmass command circuit service designators in the Pacific theater, supporting operations plans and critical mission operations, both inside and outside the USPACOM area of responsibility.

Products/Benefits:

- Created a methodology utilizing an analytical hierarchy process to develop standardized inter-landmass MECLs and TTPs for use of MECLs during strategic communication restoration
- Command leadership can now properly sequence restoration efforts based on inter-landmass MECLs to ensure the most important capabilities are restored first

JOINT BATTLESPACE AWARENESS VIA DATALINK (J-BADL)

Sponsor/Start Date: NORAD and USNORTHCOM/August 2012

Purpose: To research and develop TTPs that will focus NORAD, USNORTHCOM, and supporting commands' use of joint global sensor information to provide cuing to address priorities, adjust surveillance assets, or position existing forces in executing the Joint Engagement Sequence against advanced air threats.

Products/Benefits: The expected test product includes TTPs that lay out the processes and procedures for the execution of Joint Engagement Sequence capabilities that can be used operationally by NORAD and USNORTHCOM, as well as by other Combatant Commands and government agencies, against advanced air threats.

JOINT BEYOND LINE-OF-SIGHT COMMAND AND CONTROL (JBC2)

Sponsor/Start Date: Air Force/July 2012

Purpose: To develop and evaluate TTPs so operations centers can better plan and execute integrated employment of Beyond Line-of-Sight Command and Control system of systems to support real-time, bi-directional, full motion video, and collaborative command and control capabilities.

Products/Benefits: The QRT will focus the TTP development on operations at both the Maritime Operations Center and the Air and Space Operations Center in the USCENTCOM area of operations in support of responsive fleet defense and strike operations.

JOINT EXPLOITATION OF MODERN SURFACE-TO-AIR MISSILE SYSTEMS (JEMS)*

(Closed January 2012)

Sponsor/Start Date: Naval Air Weapons Center/January 2011

Purpose: To develop and test TTPs for effectively employing countermeasures to modern surface-to-air missile systems for improving aircrew survivability.

Products/Benefits: The JEMS project provided updates to the Joint Research Assessment and Analysis Center for inclusion in applicable threat simulations. It also produced TTPs and training outlines for incorporation by the Services into applicable aircraft tactics and threat training products.

JOINT MILITARY WORKING DOG (JMWD)*

(Closed April 2012)

Sponsor/Start Date: USCENTCOM/April 2011

Purpose: To develop, test, and validate TTPs to support the ground tactical Commander's use and support of military working dogs while performing counter-IED and counterinsurgency missions.

Products/Benefits: The JMWD QRT developed a single-source document for ground maneuver leaders to plan and execute counter-IED and counterinsurgency missions employing military working dogs. The primary test products included the Integrating Military Working Dogs into Counter-IED and Counterinsurgency Operations Handbook and a quick reference card. JT&E transitioned both of these to the U.S. Army Military Police School with 10,000 copies printed for both training and operational use.

JOINT PASSIVE ELECTRONIC RADIO FREQUENCY EMISSION CLASSIFICATION AND TRACKING (J-PERFECT) II *

(Closed July 2012)

Sponsor/Start Date: NORAD and USNORTHCOM/May 2011

Purpose: To develop and evaluate CONOPS and TTPs for employing DoD intelligence, surveillance, and reconnaissance capabilities that have the potential to improve near real-time situational awareness for decision makers and that will support successful operations against modern strategic threats to the United States and Canada.

* Project closed in FY12

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Products/Benefits:
- Detect, track, and identify strategic air threats to North America
- Outline the actions and methods which implement doctrine and describe how forces will be employed in operations
- Make recommendations to Combatant Commands and applicable national agencies other than NORAD and USNORTHCOM

JOINT THREAT ASSESSMENT AND NEGATION FOR INSTALLATION INFRASTRUCTURE CONTROL SYSTEMS (JTANIICS)

Sponsor/Start Date: Air Force/January 2012

Purpose: To develop and validate a risk assessment handbook for use by installation Commanders to strengthen their industrial control system security posture.

Products/Benefits: The JTANIICS handbook:
- Enables the installation Commander to conduct self-assessments of industrial control system vulnerabilities
- Provides guidelines for assigning priority to vulnerabilities based on mission requirements
- Includes a validated methodology that aids in identifying commonly overlooked systems that can potentially allow unauthorized access to mission-critical and safety-critical systems

JOINT VEHICLE PROTECTION AND SURVIVABILITY SYSTEMS (JVPSS)*

(Closed July 2012)

Sponsor/Start Date: USCENTCOM/July 2011

Purpose: To capture lessons learned and best practices to identify, document, and validate the safety and survivability features of the primary ground combat vehicles used in the USCENTCOM area of responsibility.

Products/Benefits: A handbook and training video that contains TTPs, lessons learned, and best practices that maximize Service member survivability when utilizing Mine Resistant Ambush Protected Vehicles, Strykers, and personnel protective equipment. The handbook targets the individual vehicle operator, crew members, and small unit leader with instructions on how to maximize the effectiveness of the safety and survivability features of their vehicle. These instructions are listed as "do's" and "don'ts" in a graphically intensive, reader-friendly format.

RAPID DEVELOPMENT AND SUSTAINMENT OF ENTERPRISE MISSION SERVICES (RDEMS)*

(Closed July 2012)

Sponsor/Start Date: DoD CIO/July 2011

Purpose: To identify and document impediments to the implementation of the DoD Information Sharing Strategy. The resulting document reflects the lessons learned and updates the CONOPS and TTPs in an RDEMS User Guide, based upon DoD-prescribed standards, specifications, doctrine, and technical processes to enable effective and efficient enterprise information sharing.

Products/Benefits:
- Documented impediments to information sharing at the joint level across Combatant Commands, Services, and other Department organizations
- DoD CIO has taken the impediments for action and is actively working to resolve them
- Product sponsors captured lessons learned from the project use case and updated CONOPS and TTPs in the RDEMS User Guide for use throughout the Department

UNMANNED AIRCRAFT SYSTEMS – AIRSPACE INTEGRATION (UAS-AI)

Sponsor/Start Date: NORAD and USNORTHCOM/January 2012

Purpose: To evaluate a discrete set of flight access profiles from the DoD Airspace Integration CONOPS developed to facilitate UAS integration into the National Airspace System

Products/Benefits: Recommend potential improvements to the CONOPS and provide all test results to the USD(AT&L) UAS Task Force for the purpose of identifying CONOPS gaps revealed by the QRT.

SPECIAL PROJECTS

RAPID ACQUISITION BY SNIPER 1K TRACK AND ATTACK (RASTA)

Sponsor/Start Date: USPACOM/November 2011

Purpose: To develop and test joint TTPs that improve the timely integration of specific target track generating capabilities for tactical fighter aircraft during combat employment in an environment that includes Advanced Electronic Attack waveforms. Concurrent TTP development lays out the process for open architecture changes and additions to the operational flight program for fighter aircraft to enable changes to be made rapidly and inexpensively.

Products/Benefits: RASTA will provide Service members the ability to generate target-quality information to enhance kill chain effectiveness while operating in an Advanced Electronic Attack waveform environment.

* Project closed in FY12

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Countermeasures

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Center for Countermeasures

The Center for Countermeasures (the Center) is a joint activity that directs, coordinates, supports, and conducts independent countermeasure/counter-countermeasure (CM/CCM) T&E activities of U.S. and foreign weapon systems, subsystems, sensors, and related components. The Center accomplishes this work in support of the DOT&E, Deputy Assistant Secretary of Defense (DASD) for Developmental Test and Evaluation (DT&E), weapon system developers, and the Services. The Center's testing and analyses directly support evaluation of the operational effectiveness and suitability of CM/CCM systems.

Specifically, the Center:

- Performs early assessments of CM effectiveness against threat and DoD systems and subsystems.
- Determines performance and limitations of missile warning and aircraft survivability equipment (ASE) used on rotary-wing and fixed-wing aircraft.
- Determines effectiveness of precision-guided weapon (PGW) systems and subsystems when operating in an environment degraded by CM.
- Develops and evaluates CM/CCM techniques and devices.
- Develops and tests new CMs in operationally realistic environments.
- Provides analysis and recommendations on CM/CCM effectiveness to Service Program Offices, DOT&E, DASD(DT&E), and the Services.
- Supports Service member exercises, training, and pre-deployment activities.

During FY12, the Center tested, analyzed, and reported on more than 40 DoD electro-optical systems or subsystems with special emphasis on rotary-wing survivability. The Center participated in operational/developmental tests for rotary- and fixed-wing ASE, PGWs, hostile fire indicator (HFI) data collection, experimentation tests, and pre-deployment/exercise support involving the use of CM/CCM.

Approximately 53 percent of the Center's efforts were spent on ASE and HFI systems, and 7 percent of the Center's efforts were focused on overseas contingency operations support (with emphasis on CM-based, pre-deployment training for rotary-wing units). About 19 percent of the Center's efforts were spent on PGW, foreign system, and other types of field testing not related to ASE, and 15 percent were applied to internal improvement and modernization efforts to enhance test capabilities and efforts to develop test methodologies for use across the Services.

The Center continued to develop multiple test tools for evaluating ASE infrared countermeasure (IRCM) systems and hostile fire signature (HSIG) database models used to support development of HFI systems. In addition to leading test tool development efforts, the Center also developed an ASE T&E methodology guidebook to provide DoD with guidance for planning, executing, and reporting on ASE test events. The Center dedicates about 6 percent of its efforts to providing subject matter expertise to numerous working groups and task forces.

The following activities are representative of those conducted by the Center during the past year.

ASE AND HSI ACTIVITIES

ROTARY-WING TEST EVENTS

Army: Reduced Optical Signature Emissions Solution VII

- **Sponsor:** Department of the Army Technology Applications Program Office, Systems Integration and Maintenance Office, Aircraft Survivability Equipment Cell
- **Activity:** The Center provided test assets and crew to perform effectiveness testing of flares and flare sequences against reactive captive infrared (IR) missiles. These tests evaluated new CM sequences, variations of current CM sequences using improved flares, or different flares within the sequences. The Army used these data to finalize flare sequences on 160th Special Operations Aviation Regiment rotary-wing aircraft.
- **Benefit:** The outcome of this combined effort resulted in verification of the effectiveness of flare sequences used on aircraft deployed in-theater and under development.

Army: MH-60M Initial Operational Capabilities Testing and Training

- **Sponsor:** Department of the Army Technology Applications Program Office, Systems Integration and Maintenance Office, Aircraft Survivability Equipment Cell
- **Activity:** The Center provided Joint Mobile IRCM Test System (JMITS) simulations, reactive captive IR seekers, and test personnel to conduct integrated testing and aircrew training of the aircraft Common Missile Warning Sensor and IR flare dispensers. The performance of the aircraft's IR flare sequence against reactive captive IR missiles was evaluated along with aircrew training in an electronic warfare (EW) threat environment consisting of the JMITS simulations and radio frequency threats. The Army used these data to finalize flare sequences on 160th Special Operations Aviation Regiment MH-60M rotary-wing aircraft and develop tactics, techniques, and procedures for the aircrews.

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- **Benefit:** The outcome of this combined effort resulted in verification of the effectiveness of flare sequences used on MH-60M aircraft and aircrew training in a simulated EW threat environment.

Army: Hostile Fire Indicting System (HFIS) – Army Flight Test 2
- **Sponsor:** U.S. Special Operations Command (USSOCOM), Technology Applications Program Office
- **Activity:** The Center provided a laser system for laser simulations to support a flight data collection event with USSOCOM MH-47 and MH-60 aircraft equipped with the HFIS system at Redstone Arsenal, Alabama.
- **Benefit:** The sponsor used this event to collect background and live fire data from the AN/AAR-57 Common Missile Warning System, AN/AVR-2B Laser Detecting Set, and Helicopter Alert Threat Termination-Acoustics systems installed on representative aircraft.

Navy: Technology Demonstration of the Department of the Navy (DoN) Large Aircraft Infrared Countermeasures (LAIRCM) Interface to the AN/ALE-47 for Smart Dispense and Advanced IR Countermeasure Techniques
- **Sponsor:** Navy Program Executive Officer, Advanced Tactical Aircraft Protection Systems Program Office (PMA 272), and Naval Research Laboratory
- **Activity:** The Center provided JMITS IR stimulations to verify the performance of advanced IRCM techniques and a new interface between the DoN LAIRCM and ALE-47. The Center provided all data collected to the sponsors for their assessments.
- **Benefit:** The data collected from this effort allowed the sponsors to perform early assessments of the new interface between the DoN LAIRCM and ALE-47 for smart dispense techniques. In addition, it allowed the sponsors to assess the performance of the advanced IRCM techniques against reactive IR static threat seekers and modify these advanced IRCM techniques for improved performance.

Navy: Distributed Aperture IR Countermeasures (DAIRCM) MH-60R Test
- **Sponsor:** Naval Research Laboratory
- **Activity:** The Center provided JMITS IR simulations to verify the performance of the DAIRCM jammer against static seekers. The Center provided all JMITS and static seeker data to the sponsor for assessment.
- **Benefit:** The sponsor used the data from this test effort to adjust their jam code, which resulted in better performance against the static seekers.

Navy/Marine Corps: AH-1Z and MV-22 Aircraft Self-Protection Optimization Flight Tests
- **Sponsor:** Naval Surface Warfare Center – Crane Division, with funding from the Aircraft Self-Protection Optimization program
- **Activity:** The Center provided test assets and crew to perform effectiveness testing of flares and flare sequences against reactive captive IR missiles. These tests evaluated new CM sequences, variations of current CM sequences using improved flares, or different flares within the sequences.
- **Benefit:** The sponsors are using the test results on flare sequence effectiveness to enhance the protection of these aircraft against IR Man-Portable Air Defense Systems (MANPADS).

OSD: Rotorcraft Aircraft Survivability Equipment (RASE) Experiment 2012
- **Sponsor:** Assistant Secretary of Defense for Research and Engineering
- **Activity:** The Center served as Experiment Director and radiometric data collector during the RASE 2012 Tower event at the Weapons Survivability Laboratory Remote Test Site, China Lake, California. Fourteen different systems mounted on an SH-60 helicopter installed on a hover stand participated in the experiment.
- **Benefit:** The RASE Experiment is a venue focused on ASE that enhances decision makers' understanding of ASE performance and advances the ASE state-of-the-art testing. The RASE Experiment is expected to improve realism and standardization in the testing of ASE, improve the extent of testing prior to fielding, and provide an opportunity for multiple developers to save costs overall.

FIXED-WING TEST EVENTS

Air Force: LAIRCM Operational Flight Program (OFP)-14X Software Update
- **Sponsor:** 46th Test Wing, Eglin AFB
- **Activity:** The Center provided JMITS missile simulators and crews to perform ultraviolet and two-color IR simulations to collect system response data for assessing the OFP-14X software update. The Air Force conducted the tests at Eglin AFB using a Beechcraft King Air aircraft fitted with a LAIRCM test bed capable of supporting ultraviolet and IR missile warning systems and the Viper™ laser.
- **Benefit:** The testing provided the Air Force with a cost-effective test venue for collecting critical data needed to assess performance of the LAIRCM flight test software prior to installation on the host aircraft.

ROTARY- AND FIXED-WING TEST EVENTS

Air Force, Navy: Advanced Strategic and Tactical IR Expendables
- **Sponsors:** Naval Surface Warfare Center – Crane Division, Air Force Special Operations Command, 46th Test Wing, and Air Mobility Command
- **Activity:** The Center provided test assets and crew to collect test data on eight different aircraft against reactive captive IR missiles. These tests evaluated new flare CM sequences, variations of current flare CM sequences using improved flares, or different flares within the sequences.
- **Benefit:** Sponsors are using these test results on flare sequence effectiveness to enhance the protection of various aircraft against IR MANPADS.

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Army: Seeker Bowl VII

- **Sponsors:** U.S. Army Research Development and Engineering Command, Engineer Research and Development Center, and Aviation Applied Technology
- **Activity:** The Center provided test assets and crew to collect test data on flare protection effectiveness for four fixed-wing and two rotary-wing aircraft against reactive captive IR missiles. The test evaluated the effectiveness of new flare CM sequences or variations of current flare CM sequences.
- **Benefit:** Sponsors are using these test results on flare sequence effectiveness to enhance the protection of various aircraft against IR MANPADS.

HOSTILE FIRE INDICATOR (HFI) DATA COLLECTION EVENTS

Army: Hostile Fire Detection System Signature Ammo Study (SAS)

- **Sponsor:** Program Manager – Aircraft Survivability Equipment (PM-ASE)
- **Activity:** The Center provided radiometric equipment and test crews to collect and reduce signature data on small arms (muzzle, hardbody, and tracer) and rockets (eject, boost, and tracer characteristics) on two separate test events, SAS-W and SAS-3.
- **Benefit:** The results from measured data will determine the variability within ammunition types and country of origin. The Center will use the measured data to develop the DOT&E Threat Resource Activity-sponsored HSIG model, which will integrate into T&E Modeling and Simulation facilities and support Hostile Fire Detection System foreign ammunition purchases for test events.

Navy: Trial Oxidizer 1

- **Sponsor:** Naval Research Laboratory
- **Activity:** The Center provided radiometric equipment and test crews to collect and reduce signature data on small arms and anti-aircraft artillery muzzle flash.
- **Benefit:** This was the first international signature collection trial in cooperation with NATO. The Center will share the collected radiometric data on small arms and anti-aircraft artillery among all participants.

NATO: NATO Threat Data Collection Quick Reaction Assessment (QRA) (Trial PROTEUS)

- **Sponsor:** NATO Air Capability Group 3, Sub-Group 2
- **Activity:** The Center provided trial management, radiometric instruments, and crew during the collection of hostile fire threat signatures at the Poček range near Postojna, Slovenia.
- **Benefit:** This activity provided a venue for seven nations to collaborate and test HFI systems for rapid fielding and to collect threat signature data for use in developing hostile fire models.

CM-BASED PRE-DEPLOYMENT TRAINING FOR SERVICE MEMBER EXERCISES

Surface Attack Training – Nellis AFB, Nevada
Angel Thunder – Barry Goldwater, Arizona
Texas Air National Guard Pre-Deployment Training – San Antonio, Texas
Mobility Air Force Exercise – Nellis AFB, Nevada
Mission Employment Exercise – Nellis AFB, Nevada
Apache Block III Technics, Tactics, and Procedures (TTP) Development Support – Fort Irwin, California
Neptune Falcon – Nellis AFB, Nevada
58th Special Operations Wing Training Support – Albuquerque, New Mexico
4th Battalion 501st Aviation Regiment Training Support – Fort Bliss and Houston, Texas
28th Test and Evaluation Squadron Maritime TTP Development – San Diego, California
Joint Readiness Training Center Training Support – Fort Polk, Louisiana
509th Weapons Squadron KC-135 Support – Roswell, New Mexico

- **Sponsors:** Various
- **Purpose:** The Center's equipment and personnel provided a simulated threat/CM environment and subject matter expertise to observe aircraft sensor/ASE systems and crew reactions to this environment. Specifically, the Center emphasized simulated MANPADS engagements for participating aircraft. Additionally, the Center provided MANPADS capabilities and limitations briefings to pilots and crews and conducted "hands-on" training at the end of the briefings.
- **Benefit:** Provides realism to the training threat environment for the pilots and crews to facilitate understanding and use of CM equipment, especially ASE. The Center provided collected data to the trainers for assisting units in the development/refinement of TTPs to enhance survivability.

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PGW CM ACTIVITIES

Navy: Joint Stand-Off Weapon (JSOW) System

- **Sponsors:** U.S. Navy, Program Manager, Precision Strike Weapons (PMA 201)
- **Activity:** The Center provided camouflage, concealment, and deception countermeasures for two JSOW missile live-fire drops against stationary land targets. The missile drops consisted of camouflage nets or IR smoke pots supplemented with camouflage nets.
- **Benefit:** Conducted regression testing to determine if the JSOW C-1 mission capability regarding stationary land targets has been retained in an IRCM environment given the recent addition of a moving maritime target capability. The IRCM land target test results will provide data characterizing imaging IR seeker performance, which will be presented at the JSOW C-1 Operational Test Readiness Review in 1QFY13.

National Ground Intelligence Center: Foreign Electro-Optical System (FEOS)

- **Sponsor:** National Ground Intelligence Center
- **Activity:** The Center provided a Paveway III semi-active laser guidance section and personnel to collect and reduce data showing the countermeasure effects caused by the FEOS in a field environment.
- **Benefit:** Collected field test data on the FEOS will help aide the exploitation efforts and evaluate the effects on U.S. domestic guided weapon systems when subjected to this foreign electro-optical countermeasure system.

SURVIVABILITY INITIATIVES

HSIG Model

The Center is leading development of an HSIG model to support HFI T&E and modeling efforts. The HSIG model project is sponsored by the Threat Resource Activity and will develop a physics-based, electro-optical model that produces signatures for the 12.7 mm Armor Piercing Incendiary Tracer round and a rocket-propelled grenade (RPG 7). The Center completed development of the first small arms tracer round and RPG models. Model validation and integration to Navy and Army facilities will take place in FY13.

Aircraft Survivability Equipment (ASE)/Hostile Fire Indicator (HFI) Symposium

The Center held the fourth ASE/HFI symposium and workshop that included current Australian, Canadian, New Zealand, United Kingdom, and U.S. threat detection systems briefings; "break-out" coordination sessions; and continued development of a five-nation methodology for ASE/HFI performance testing. This Center-led initiative provides a venue for cross-Service and international discussion on the common problem of Service member protection from threat missile and ballistic hostile fire in theater. The Center has partnered with the U.S. Naval Postgraduate School to develop an academic certificate of training to participants of future international, classified ASE/HFI T&E Training Symposiums sponsored by the Joint Countermeasures T&E Working Group (JCMT&E WG).

Joint Countermeasures T&E Working Group (JCMT&E WG)

The JCMT&E WG is co-chartered by DOT&E and DASD(DT&E) to improve the integration of:

- Aircraft self-protection developments
- Live weapon-fire T&E
- Operational T&E
- Development of standardized test methodologies
- Common instrumentation and standards

This group includes DOT&E, DASD(DT&E), all four of the U.S. Services, Australia, Canada, New Zealand, the United Kingdom, and NATO Air Force Armaments Group Sub-Group 2, as members of a coalition warfare sub-WG. The group is tasked with actively seeking mutually beneficial T&E opportunities to measure performance and suitability data necessary to provide relevant operational information to deploying joint/coalition Service members and for U.S. acquisition decision makers. Specific efforts included the following:

- The JCMT&E WG developed, coordinated, and implemented an eight-year bilateral ASE Cooperative Test and Evaluation Project Arrangement (CTE PA) and its supporting Project Management Plan (PMP) with the United Kingdom. Nations' defense organizations, ASE Program Offices, DT, OT, and LFT&E agencies will now be able to collaborate on common test equipment and procedures, measure operationally relevant ASE data, and improve Service member survivability.
- The JCMT&E WG completed official negotiations and concluded agreement of a bilateral ASE CTE PA and PMP with Australia to expand U.S. T&E capabilities and cooperation. This coordination resulted in the Center's participation in an Australian hostile fire data collection trial that expanded the U.S. threat database and will improve U.S. HFI threat detection algorithms.
- In support of High-Level NATO Multinational Approaches Initiatives, and DOT&E initiatives to NATO, the Center developed, organized, and conducted a highly successful, seven-nation NATO QRA in Slovenia. U.S. Ambassador Joseph Mussomelli praised the Center for coordination with the Embassy and Slovene Forces, and for its planning and execution of this first U.S.-led NATO QRA in Slovenia.
- The Center coordinated the first Technical Meeting of the Multinational Test and Evaluation Program memorandum of understanding in Ottawa, Canada, to initiate negotiations

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of this 10-year agreement between Australia, Canada, New Zealand, the United Kingdom, and the United States.
- In support of NATO sub-group 2 and the Australia, New Zealand, and U.S. agreements, the JCMT&E WG's efforts led to the approval by the Chief of the New Zealand Defence Force to conduct Trial PĀKAI KŌPERE II by SG2 in New Zealand in 2QFY14. The sub-group will ask the Center to provide a Multi-Spectral Sea and Land Test Simulator, IR MANPADS Seeker Test Van, and test personnel to support this effort.

Aircraft Survivability Equipment (ASE) Test and Evaluation (T&E) Methodology Guidebook

The Center created an ASE T&E Methodology Guidebook to provide the DoD with guidance for planning, executing, and reporting on ASE systems' test events. The ASE systems addressed in this guidebook include IRCM, ultraviolet, IR passive missile warning systems, HFI, and Laser Warning Receiver systems.

Program managers and T&E leads should use the guidebook to better understand the process their teams follow, ensure that testing is being conducted using good test objectives, and ensure that the data gathered to evaluate those objectives are valid. Such a guide is especially critical for program managers and test managers/leads new to ASE testing. This guidebook provides suggested processes and procedures for collecting test data, as well as suggested data formats and data products for presenting test data to aid the T&E community in achieving consistency and setting expectations.

Both DOT&E and DASD(DT&E) endorsed the ASE T&E Methodology. As the ASE T&E community converges on common test methodologies and approaches, programs can achieve efficiencies and savings by utilizing common test and range infrastructure, common models and simulation tools, and the ability to share threat weapon data.

Helicopter Survivability Task Force

The Center is participating with the Assistant Secretary of Defense for Research and Engineering to increase aircraft survivability by coordinating Research and Development activities and JCMT&E WG initiatives using tailored projects for DoD programs of record and out-of-cycle emergent Service member projects.

THREAT SIMULATOR TEST AND EVALUATION TOOLS

The Center, in conjunction with the Test Resource Management Center, is nearing completion of the IRCM Test Resource Requirements Study (ITRRS) "refresh." The end product from this effort will be an updated roadmap of prioritized projects necessary to perform T&E of advanced IRCM and HFI systems. The Center completed the original ITRRS roadmap in 2007, which led to several projects being funded by the Central Test and Evaluation Investment Program to fill the identified IRCM T&E gaps. Each product will have a functional description of the project; the priority is based upon Program of Record test schedules, requirements, and Service input.

The Center has continued to develop tools for T&E of IRCM systems funded by the USD(AT&L) Test Resource Management Center, Central Test and Evaluation Investment Program. Currently, the Center is leading the development of the Multi-Spectral Sea and Land Test Simulator (MSALTS) and the Joint Standard Instrumentation Suite (JSIS).
- The MSALTS is a small, mobile missile simulator that can fire while moving and simulate all current tier-one missile threats. The Center has designed the MSALTS to provide simulated signatures for the new and more capable missile warning systems, such as LAIRCM Next Generation, DoN LAIRCM, and Joint and Allied Threat Awareness System. The Center initiated development of the first two systems in September 2011. The Center completed fabrication, assembly, and checkout of most hardware items in FY12; four of eight software builds completed in FY12. Developers plan to execute Government acceptance testing of these MSALTS systems in September 2013.
- The Center has completed a preliminary concept and development plan for the JSIS. The Center intends JSIS to be a comprehensive, turnkey instrumentation package that can be used during hostile fire testing and MANPADS firing events in and outside the U.S. to support model development and validation. The JSIS will provide calibrated signature measurements for T&E (thus enhancing test adequacy) and post-test anomaly resolution. The Center will archive all the data that it collects using JSIS and make them available to the Services for current and future IRCM programs. The Center is actively pursuing JSIS sponsorship via the Central Test and Evaluation Investment Program. In the spring of 2012, the Helicopter Survivability Task Force initiative provided funding to develop equipment that will measure hostile fire munitions' time-space-position information, and ultraviolet signatures. The Services will field this equipment in FY13, fulfilling an immediate JSIS development need.

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A Tutorial on Electro-Optical/Infrared (EO/IR) Theory and Systems

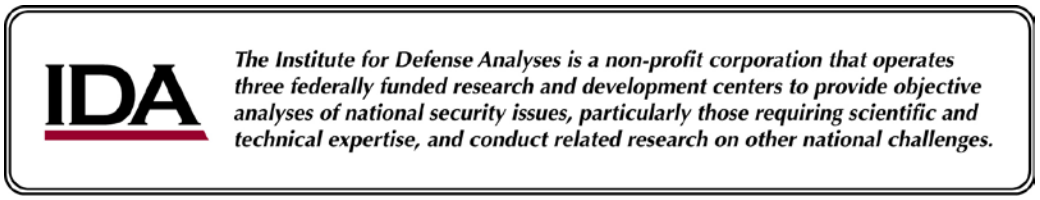
G. M. Koretsky
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M. S. Taylor

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A Tutorial on Electro-Optical/Infrared (EO/IR) Theory and Systems

G. M. Koretsky
J. F. Nicoll
M. S. Taylor

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Executive Summary

This document is an annotated version of a seminar produced by IDA for the Office of the Deputy Assistant Secretary of Defense for Developmental Test and Evaluation. The intent is to provide general background on electro-optical/infrared (EO/IR) phenomenology and systems. The paper begins with a discussion of the factors affecting emission, transmission, reflection, and absorption of light, including most importantly, the role of the atmosphere. It continues with a discussion of various applications, including detection of point targets and imaging of extended targets. The use of EO/IR for tracking targets is also covered, as are some recent technological advancements. Finally, sections are dedicated to the topics of sampling, aliasing, and reconstruction, and issues in color cameras.

Because the objective of the seminar was to inform people with various levels of experience and range of backgrounds, the introductory material strives to provide the basic building blocks for understanding the more sophisticated concepts raised later. This exposure should also help Action Officers in daily activities, such as reviewing and commenting on Test and Evaluation Master Plans (TEMPs), test procedures, and test result interpretations.

Included in this information are factors that should be considered in designing test procedures and recorded during testing because they provide context to the observed results. These include target-background contrast and intensity of the illumination source (for bands where reflected light is dominant), target temperature (for bands where emitted radiation dominates), visual range, and operating altitude of the platform on which the EO/IR sensor is integrated.

Performance of an EO/IR sensor depends upon the optics, detector, and display, in addition to factors mentioned above. Hence it is unwise to evaluate the potential utility of an EO/IR sensor from specifications alone, that is, without using a detailed engineering model. Nevertheless, all other things being equal, it can be argued that, for an imaging sensor designed to recognize or identify targets, it is better to have a focal plane array with smaller detector elements, assuming the optics modulation transfer function (MTF) is not limiting the overall system MTF. This follows because the improved resolution of such a design will enhance range performance if the ground sample distance is the limiting factor. In a similar “rule of thumb” vein, optics with larger focal lengths provide the potential for better resolution, assuming the detector’s MTF is not limiting the overall system MTF. This comes at the expense of reducing the sensor’s overall field-of-view. However, we stress that it is difficult to anticipate a priori how all of the factors affecting image quality interact; hence we recommend the use of modeling and detailed system analysis to interpret potential sensor performance.

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This document is divided into seven sections as follow:

1. EO/IR Basics
2. Non-Imaging EO/IR Systems (Point Targets)
3. Imaging EO/IR Systems (Extended Targets)
4. Tracking
5. Latest Trends in EO/IR System Development
6. Aliasing
7. Issues in Bayer Color Cameras

A brief summary of each section follows.

EO/IR Basics

EO/IR systems cover a wide range of distinct technologies based on the targets and mission to be accomplished. Target phenomenology often dominates the choice of spectral band. For example, missile launch detection depends on the very hot missile exhaust, which produces significant radiation in the ultraviolet (UV) spectral region. The band choice is also influenced by the vagaries of atmospheric transmission and scattering. EO/IR missions divide roughly into dealing with point targets and extended fully imaged targets. For point targets, the challenge is to extract the target from a complex and cluttered background. For fully imaged targets (images of tanks, for example), the contrast between target and background is a critical parameter. The ability to detect dim targets, either point or extended, is a measure of the system's sensitivity. The resolution of a sensor is a measure of its ability to determine fine detail. Measures of resolution depend on the precise task. Use of eye-chart-like calibration targets is common in DoD applications. EO/IR sensors may be divided into scanning sensors, which use a limited number of detectors to scan across the scene, and staring sensors, which use large numbers of detectors in rectangular arrays.

Non-Imaging EO/IR Systems

Non-imaging point target EO/IR systems focus on the task of detecting targets at long range. For these applications, details of the target are irrelevant; for example, for IR sensors, only the total energy emitted matters, not the precise temperature and size of the target separately. The available energy can vary over many orders of magnitude, from the engine of a small UAV to an intercontinental ballistic missile (ICBM) launch. Comparison of the available energy at the sensor to the noise level of the sensor provides the central metric of sensor performance, the noise equivalent irradiance or NEI. The problem of extracting the target from background clutter is addressed in two basic ways: through the choice of sensor band and algorithms. For missile launch detection, for example, one may use the "solar blind" UV band. The transmission in this band is very poor, and the general background is reduced to a level of near zero. However, the very bright missile signature is strong enough to still provide a useable signal. Algorithms for separating a point target from a structured background are a continuing source of improvement in performance, but their complexity may make their evaluation challenging.

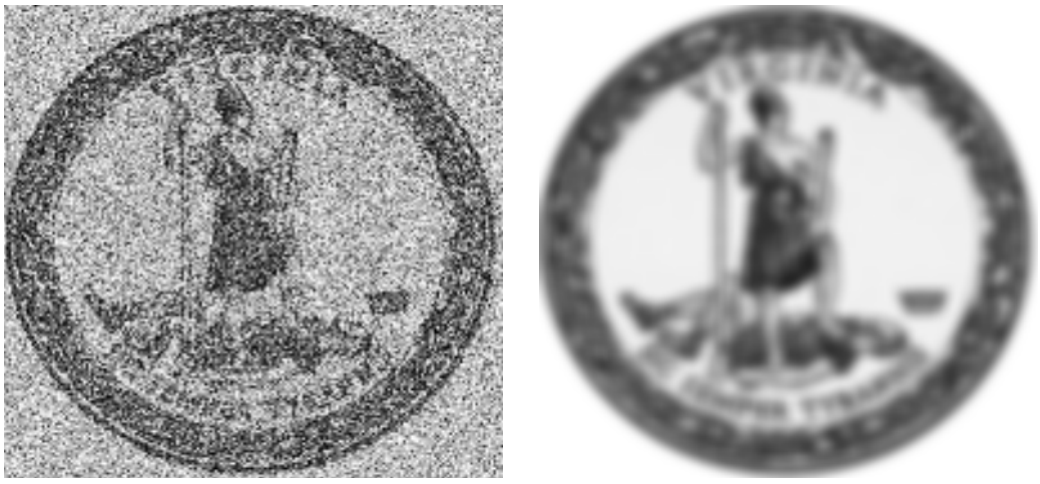
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The effectiveness of imaging systems can be degraded by many factors, including limited contrast and luminance, the presence of noise, and blurring due to fundamental physical effects. As a mathematical description of image blur, the MTF can be broken down into each component of the sensing, such as optics, detector, atmosphere, and display. This provides insight into the sources and magnitude of image degradation.

There are many ways to evaluate and describe the quality of an image, the use of which is determined by details of the application. Two examples have a broad application and a long history.

1. The Army Night Vision and Electronic Sensors Directorate (NVESD) maintains models for predicting image quality based on the targeting task performance (TTP) metric.[1] This provides a rule-of-thumb for the number of bar pairs required on target to have a 50-percent probability of detecting, recognizing, or identifying the target.
2. The strategic intelligence community uses the National Imagery Interpretability Rating Scale (NIIRS) to evaluate the quality of still imagery. NIIRS is a qualitative scale, running from 0 to 9. Tables are published associating rating levels with tasks for EO, IR, synthetic aperture radar (SAR), civil imagery, multispectral imagery, and video. NIIRS can be estimated by the General Image Quality Equation (GIQE), an empirical model that has been designed to predict NIIRS from sensor system characteristics.

Each of these approaches represents a balance between two of the fundamental limits to any EO sensor: the resolution (how small) and the sensitivity (how dim) – that is, how small an object or feature can be usefully seen and how low can the signal be before it is overwhelmed by the noise. Figure ES-1 shows a comparison of a noise-limited case and a resolution-limited case.



ES-1. Noise and Resolution Limited Images

[1] The TTP metric is the successor of the Johnson criteria. See page 30 for additional discussion.

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In modern digital sensors, these classical factors have been joined by a third, the sampling or pixelation of the sensor, as shown in Figure ES-2.



ES-2. Sampling Limited Image

The design of a sensor is a tradeoff between these three factors, placed in the context of characteristics of the target and environment. While in a balanced design, each of the factors needs to be evaluated. For any given sensor and state of the technology employed, it may be the case that the sensor is signal-to-noise limited; in this case, the S/N ratio is the single-most important parameter and rules-of-thumb may be developed to focus on S/N for the target and environment. In other cases, the sensor is resolution limited, and the characterization of the optics (the MTF) is the most important; an ideal sensor is said to be diffraction-limited, able to respond to spatial frequencies up to the diffraction limit, λ/D, where λ is the wavelength at which the sensor operates and D is the diameter of the optics. For these cases, rules-of-thumb may be developed that focus on the optical system. For sensors that are limited by the pixelation, the "Nyquist limit" is determined by the separation between detectors, S; the highest spatial frequency that can be correctly measured by the sensor is 1/2S. In these cases the Nyquist frequency may be an appropriate rule-of-thumb.

These trades can be followed in the history of personal cameras from the film era to the most modern Nikon or Canon. In the film era, the user could trade between sensitivity and resolution by changing the film used: so-called fast film (TRI-X) was sensitive but had a coarse grain size, limiting the resolution. It was useful for pictures in dim light or when high shutter speeds to photograph moving subjects were needed. In brighter light or for slowly moving objects the photographer might choose a slow film (PAN-X) that had a fine grain size but was not very sensitive. On top of this choice, the photographer could choose lenses with different f-numbers (to change sensitivity), different focal lengths (to change resolution), and different prices (to improve MTF).

In the last 2 decades, digital cameras have replaced film cameras in many applications. The earliest digital cameras were limited both by sensitivity (detectors were noisy) and by sampling. In consumer terms, the sampling resolution was specified by the

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number of pixels; early cameras were 1 megapixel, about 1,000 by 1,000 detectors replacing the film. The need for relatively large detectors (10-20 μm) was driven by lack of detector sensitivity; the resulting reduction in resolution compared to the better films that had film grains of 2-3 μm was a consequence of this, rather than a technological limit to producing smaller detectors. As detector technology evolved, the noise in each detector was reduced (improving S/N and allowing dimmer light or faster motion) and the number of pixels was increased. Today, personal cameras can have 36 megapixels or more and begin to rival the finest grain films for resolution with detectors of 4 μm or smaller. The best personal cameras began as sensitivity and sampling limited; but as those barriers were overcome, they have returned to being resolution limited as determined by the quality of the optics. As these changes have taken place, the simple rules-of-thumb that characterize the camera have also changed.

The same three elements are present in all EO systems, but there is no unique balance point between them. This is determined by the state of technology but also the mission the sensor is trying to accomplish. Personal cameras emphasize images of people at close to moderate ranges; the signal is determined by reflected light, the noise by the technology of the detectors. Missile launch detection systems are looking for extremely bright points of light in a cluttered background. Infrared systems depend on the self-emission of the target (hot engines on aircraft and tanks) and are often limited by the environment (the transmission of the signal through the air). No matter what the sensor is, the evaluation of the sensor system involves characterizing it with the three metrics of noise, resolution, and sampling.

Tracking

EO/IR sensor systems are often paired with a tracker. Examples of point target trackers include systems to track missile launches and infrared search and track systems, both discussed above. Many different algorithms are used to implement point trackers. Although different, they all involve the same basic steps: track initiation, data association, track smoothing, and track maintenance. Conversely, image-based trackers are used to track mobile objects on the ground [e.g., intelligence, surveillance, and reconnaissance (ISR) missions] or for aim point selection. Usually with image-based trackers, the target is initially located by a human operator viewing a display. After the target is acquired, a feedback control loop (track loop) continuously adjusts the gimbal to keep the target in the center of the sensor's field of view. Common image-based tracker algorithms include edge detection, centroid tracking, area correlation tracking, moving target indicators (MTI), multi-mode trackers, and feature-based algorithms.

Latest Trends in EO/IR System Development

Driven by missions such as Persistent Surveillance, an important recent trend in EO/IR sensors is the development of large-area, high-resolution cameras. For sensors operating in the visible band, this is simpler than for those operating in the mid-

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wavelength infrared (MWIR) or long-wavelength infrared (LWIR) bands. In the visible band, silicon can be used for both sensing material and for readout electronics. This eliminates issues such as potential thermal mismatch between the two. For EO systems, it is also possible to group individual cameras together and then combine separate images into one. The current state of the art in MWIR focal plane arrays (FPAs) is roughly 4,000 by 4,000 detectors; for LWIR FPAs, it is closer to 2,000 by 2,000. The ARGUS sensor being developed by DARPA has 1.8 gigapixels. To reduce the amount of thermally generated noise in LWIR FPAs, these cameras operate at low temperatures. The required cryogenic equipment has important Size, Weight, and Power (SWaP) implications at the system level and can affect system reliability. To address this need, considerable effort has gone into development of uncooled sensors. Another recent development is the use of so-called III-V superlattices that use alternating layers such as aluminum gallium arsenide and gallium arsenide (AlGaAs/GaAs) and that allow one to change the device's spectral response by changing individual layer thicknesses. The short-wavelength infrared (SWIR) band extends from 1.0 μm to 3.0 μm. This radiation, often referred to as "airglow" or "nightglow," is non-thermal radiation emitted by the Earth's atmosphere. Military applications of SWIR include low-light/night-vision imaging, detection of laser designators, covert laser illumination, laser-gated imaging, threat-warning detection, ISR, and covert tagging. Hyperspectral imaging allows one to simultaneously gather both spatial and spectroscopic information for more accurate segmentation and classification of an image.

Aliasing

Aliasing is an almost inescapable feature of staring focal plane array sensors. Aliasing refers to the artifacts associated with sampling systems. They can range from Moiré patterns[2] to ambiguously interpreted images of objects with complicated patterns of light and dark. The presence of aliasing in a system gives rise to a general rule based on the Nyquist frequency, which identifies the resolution of a system with the size of a sample (or pixel) on the target. This underrates the importance of other determiners of resolution such as the MTF. Performance may be better or worse than that suggested by Nyquist, depending on the task. The combination of MTF and aliasing can lead to some unintuitive tradeoffs. For example, poorer MTF may actually improve performance in some tasks if aliasing is a significant problem. For imaging systems with aliasing, the display of the sensor information becomes important, especially if the image is zoomed so that one display pixel is used to represent a single sensor sample value. An improper reconstruction of the sensor data can degrade performance. For all aliased systems, an understanding of the reconstruction algorithm is an important aspect of any system including a human operator.

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[2] Moiré patterns are interference patterns that are often the result of digital imaging artifacts. See page 59 for additional discussion.

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Issues in Bayer Color Cameras

The use of Bayer pattern color cameras in imaging systems to reduce cost and data rate requirements may introduce additional dependence on algorithmic choices. In contrast to full color cameras, a Bayer camera does not have a color detector for all 3 colors (red, green, blue) at each location (a 12 “megapixel” Bayer sensor has 6 million green, 3 million red, and 3 million blue detectors). An algorithm is used to interpolate the missing values to produce a complete three-color image. This color aliasing is more severe than the aliasing intrinsic to any staring focal plane. Fortunately, in the natural world, color information is usually relatively immune to aliasing effects. However, a large number of different algorithms of varying complexity may be employed by a sensor manufacturer. Depending on the tasks to be performed and the details of the image, the algorithm may induce new artifacts that complicate system evaluation. Ideally, the user could be given some control over the interpolation algorithm to match it to the task.

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A Tutorial on Electro-Optical/Infrared (EO/IR) Theory and Systems

EO/IR Missions

- **Point targets**
  - **IRST (infrared search and track) and visible analogs. Detection and tracking of aircraft at long range against sky backgrounds.**
    - **Ship-based and fighter-based IRST systems have been developed in the past.**
    - **Applications to homeland security and anti-UAV.**
  - **Missile launch warning. Detection of missile launch events and tracking against ground backgrounds.**
    - **Satellite and aircraft based**
- **Extended targets**
  - **ISR systems**
    - **Satellite, manned aircraft, unmanned aircraft**
    - **Any and all bands**
    - **Usually oriented close to vertically or side-to-side**
  - **Target acquisition and surveillance**
    - **Night vision goggles**
    - **Vehicle or aircraft mounted FLIRs (Forward Looking Infrared)**
    - **Usually oriented approximately horizontally with variable look-up or look-down angles**

The most basic division in EO/IR sensors is between point and extended targets. A **point target** is one that is small enough, compared to the resolution capabilities of the sensor, to appear as a single point. The defining characteristic of an **extended target** is the presence of internal detail. Rather than detecting a point, the sensor presents an image of the target. The distinction between point and imaging targets is not the same as between non-imaging and imaging sensors. One can imagine a point target mission that scans the sky looking for a bright spot without ever forming an image (the original Sidewinder air-to-air missile seeker would be such as system); however, some imaging sensors form an image of the sky and then look for bright spots within the image.

Infrared search and track (IRST) systems represent a class of systems for which the targets remain point targets. The term primarily refers to IR sensors dedicated to detecting aircraft at long range. Aircraft are typically hotter than the sky or cloud background against which they are seen and appear as a bright point. Although originally conceived as an air-to-air aircraft finder or a ship-to-air missile finder (to detect anti-ship cruise missiles), the same approach has applications for homeland security and anti-unmanned aerial vehicle (UAV) search. Another class of systems is missile-launch detection systems. In this case, the launch is signaled with a very hot flash that can be

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detected. In this case, the background is likely to be the ground rather than the sky for IRST systems; this affects the algorithms used to extract the target and even the band (wavelength) of the EO/IR sensor.

The extended target applications include intelligence, surveillance, and reconnaissance (ISR) systems providing long-term imaging of the ground, usually from a vertical perspective (e.g., surveillance satellites, UAV), and target acquisition systems in tactical systems [night vision goggles, tank forward-looking infrared (FLIR) systems], typically a more nearly horizontal view.

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Parameters

- **For all EO/IR systems**
  - **Optical properties (resolution)**
  - **Sensitivity/noise**
  - **Digital artifacts**
  - **Detector properties**
  - **Processing**
- **The importance of some parameters varies with mission**
  - **Target characteristics**
  - **Platform characteristics**
  - **For automated systems (IRST), algorithms for detecting targets (high probability of detection with limited false alarms)**
  - **For observer-in-the-loop systems, displays**
- **For example, ISR systems**
  - **Very high resolution (small instantaneous field of view, IFOV) to achieve good ground resolution from high altitudes**
  - **Field of view**
    - **A 100-megapixel array with 1-foot ground sample distance covers only a 2 mile x 2 mile patch of ground**
    - **Older film cameras have 140 degree fields of view with a 72 mile wide x 2 mile image!**

The definition of each of the terms mentioned above will be developed over the course of this paper.

It may be surprising to see film discussed in the 21st century; however, in some ways, film remains unsurpassed.

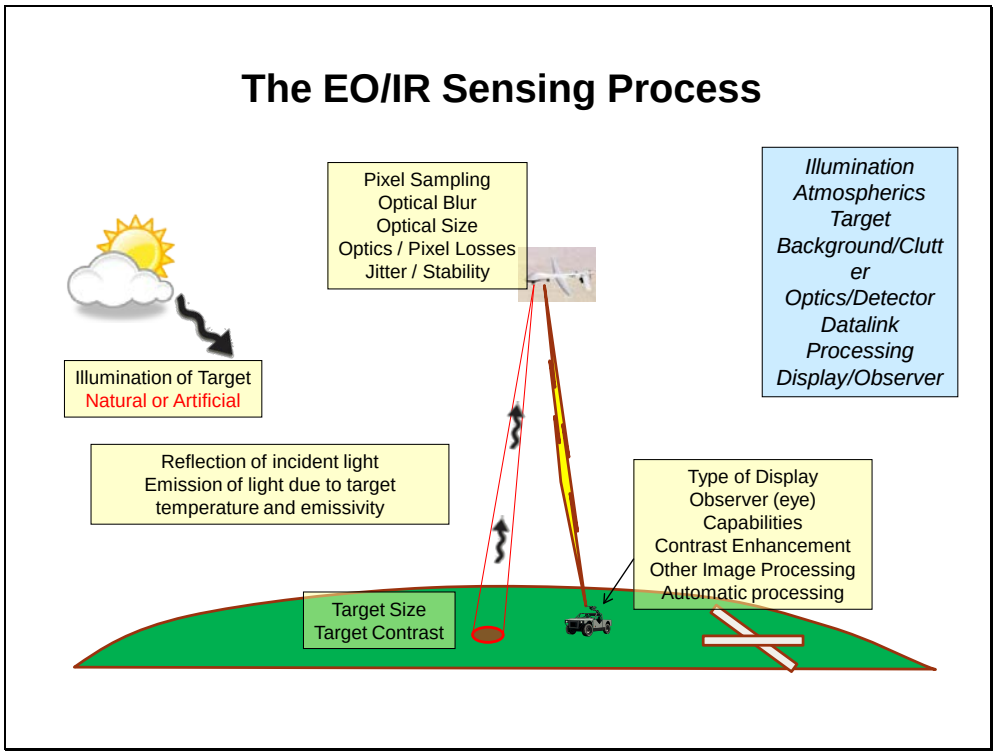
Developed in the early 1960s, the U-2's Optical Bar Camera (OBC) gave the spy plane an edge that has yet to be matched by its prospective successor: the Global Hawk unmanned aircraft. The film camera, which is mounted in a bay behind the aircraft's cockpit, captures high-resolution panoramic images covering an area 140 degrees across.

The OBC gets its name from its slit assembly, which forms the camera's bar. Unlike a conventional camera, in which an aperture opens and closes to allow light to expose the film (or, in the case of a digital camera, a charge coupled device chip), the slit exposes a roll of film mounted on a 3-foot-diameter rotating spindle. The entire lens assembly, with a 30-inch lens, rotates around the longitudinal axis of the aircraft to provide a field of view that extends 70 degrees to either side of the aircraft's flight path.

The OBC carries a roll of film measuring some two miles in length and weighs around 100 pounds. Each frame is 63 inches long by 5 inches wide.

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A. Basics



EO/IR systems are often plagued by the difficulty of providing precise predications of performance: in EO/IR, the answer is "It depends."

The majority of EO/IR systems (laser systems are the conspicuous exception, but searchlights are still used as well, and night vision goggles can be used with artificial illumination) are passive; that is, they are dependent on the illumination of the target by sunlight or moonlight (even sky shine) or the target's own emission of light. This is in contrast to radar systems that provide their own illumination. In addition, the EO/IR photons travel through a hostile medium, the atmosphere, which can refract, absorb, or scatter them. EO/IR is, in general, sensitive to the environment. Also, the target's characteristics can be quite important and variable, depending on the target temperature and even the paint used on the target. This variability poses a problem to the designer, tester, and operator.

The designer has more control over the sensor's design parameters, datalinks used to transfer information, and displays on which, for imaging sensors, the scenes are presented to the human operator.

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Electro-optical/ Infrared Systems

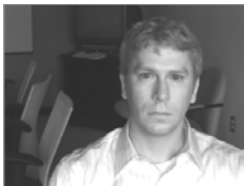
- **EO/IR systems cover the range from UV through visible and IR.**



- **The wide range of EO/IR systems share some similarities:**
  - **Lenses and mirrors rather than antennas**
  - **Dependence on the environment**
- **Although film systems remain in the inventory and are still preferred for some missions, new EO/IR systems will be digital.**
- **The band chosen reflects the phenomenology of the target.**



LWIR: emitted radiation



SWIR: reflected radiation

Image Source:

D. G. Dawes and D. Turner, "Some Like It Hot," *Photonics Spectra*, December 2008.

The category of EO/IR sensors extends from the ultraviolet at a wavelength of 0.25 micrometers (μm) (which can be useful for very hot missile launch detection applications) through the visible region to the infrared region (wavelengths up to 14 μm or even greater). The design wavelength band is determined by the expected targets and mission.

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Reflected and Emitted Light

- **The energy coming from the target and background is a mixture of reflected and emitted light.**
  - **Reflected light is the predominate element for visible sensors but also contributes in near-IR, short wave-IR, and mid-wave-IR.**
    - **Depends on natural or artificial illumination (for example, night vision goggles rely on ambient light in the near-IR).**
  - **With artificial illumination, essentially any wavelength may lead to significant reflection.**
  - **Emitted light is a natural feature of all objects: the amount of light radiated and at what wavelengths it is concentrated depends on the temperature and emissivity of the object.**
  - **Reflectance and emissivity vary with wavelength.**
    - **Snow is highly reflective in the visible but highly emissive in the IR.**
  - **Incident radiation is either reflected, transmitted, or absorbed.**
    - **For opaque objects, the radiation is either reflected or absorbed.**
    - **In equilibrium energy that is absorbed is also emitted (but perhaps at a different wavelength).**

As noted in the chart, the choice of wavelength is connected to the balance of emitted versus reflected light. One obvious difference is that human operators are accustomed to how objects appear in reflected visible light. The short wave IR, which almost entirely depends on reflected light, produces images that are very like visible images; mid-wave IR, less so; and for long-wave IR, the images seem unnatural in some aspects.

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Planck's Law

- **Planck's law determines the energy radiated as a function of the wavelength, temperature, and emissivity (ε). The peak wavelength varies with temperature: higher temperature => shorter wavelengths.**
  - **For objects near room temperature (300 K), the radiation peaks in the LWIR (long wave Infrared: 8-12 μm). For most natural objects ε is close to 1.**
  - **In MWIR (mid-wave infrared: 3-5 μm) and most natural scene objects there is a mixture of emitted and reflected light. Emitted component increases with higher temperature.**
  - **In SWIR (short-wave infrared: 1-3 μm), there is a mixture of emitted and reflected radiation.**
  - **NIR (near infrared: 0.7-1.0 μm) depends upon reflected light and artificial illumination.**
  - **In the visible, the radiance is almost entirely reflected light for typical temperatures (but things can be red or white hot!).**
  - **UV applications depend primarily on emitted energy of very hot objects.**
- **Radiance is conventionally measured in either:**
  - **Watts/cm²/ster; or**
  - **Photons/sec /cm²/ster** $L_{watts} \approx L_{photons} \frac{hc}{\lambda_{sensor}}$

Emitted radiance (L) of blackbody[3] with temperature T and emissivity ε between λ_1 and λ_2 is given by:

$$L_{\text{photons}} = \int_{\lambda_1}^{\lambda_2} \varepsilon(\lambda) \frac{2c}{\lambda^4} \frac{1}{e^{hc/kT\lambda} - 1} d\lambda$$

$$L_{\text{watts}} = \int_{\lambda_1}^{\lambda_2} \varepsilon(\lambda) \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/kT\lambda} - 1} d\lambda \approx L_{\text{photons}} \frac{hc}{\lambda_{\text{sensor}}}$$

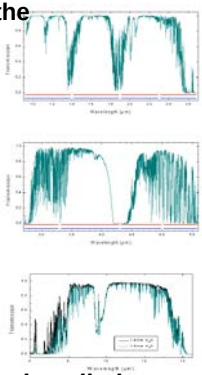
For most modern EO/IR sensors, the photon representation is the more appropriate because the detectors are essentially photon counters. However, very early IR systems and some modern uncooled systems are bolometers, measuring the energy of the signal rather than the number of photons. For these systems, the radiance in terms of watts is the more useful. The terminology can be quite confusing and care must be taken to keep the units straight.

[3] A blackbody is an idealized physical body that absorbs all incident electromagnetic radiation, regardless of frequency of angle of incidence. A blackbody at constant temperature emits electromagnetic radiation called blackbody radiation. The radiation is emitted according to Plank's law, meaning that it has a spectrum that is determined by the temperature alone and not by the body's shape or composition. (wiki)

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Atmospheric Effects

- **Only the radiance within specific atmospheric transmission windows is usually useful: in some cases, systems exploit the edges of the atmospheric window.**
- **The atmosphere absorbs energy, particularly in IR and UV.**
  - **The details of the absorption depend on the water vapor, CO_2, smokes….**
  - **The deep valleys (for example between 4-4.5 μm, at 9.5 μm) define the broad bands but there is a lot of fine structure that can be important for some applications.**
  - **These determine the transmission, t, of the signal through the atmosphere.**
- **The atmosphere scatters energy, particularly in the visible (fog, haze).**
  - **Depends strongly on the distribution of aerosol.**
  - **Energy from the target scattered out of, other energy scattered into, the line of sight.**
- **The atmosphere also radiates (primarily in the LWIR): this is called "path radiance."**
- **Each of these reduce the contrast between the target and the background.**
- **Elaborate models have evolved to predict transmission, scattering, and path radiance, paced by the improvement in computational speeds.**



The complicated structure of the atmospheric transmission curves reflects the fact that the atmosphere is a mixture of different molecules with each species having its own set of absorption and emission lines. Because it is a mixture, the curves will depend on, for example, the absolute humidity (the water content of the air). Pollutants such as ozone or discharges from factories can be relevant, as can aerosols suspended in the air, including water (ordinary haze and fog), sand, dirt, and smoke.

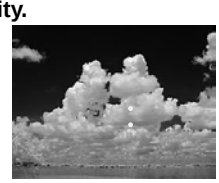
Although it is common to assume a simple exponential decay of transmission with range (so-called Beer's Law), it is never safe to do so without checking the more elaborate calculations involving individual absorption lines, rather than averages over bandwidth ranges. The dependence of EO/IR on transmission is the primary factor that makes the predicting and testing of EO/IR systems challenging.

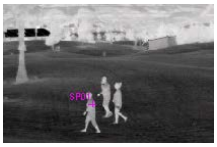
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Contrast and Clutter

- **Separating targets from the background depends on the contrast: is the target brighter/darker than the background?**
  - **The contrast is reduced by the transmission loss and may be masked by scattered energy or path radiance.**
  - **Transmission loss increases with the range and is frequently limiting factor in sensor performance (overwhelming naïve resolution estimates).**
  - **Atmospheric variation is a primary cause of variability in performance.**
  - **EO/IR sensors that perform well in clear weather will be degraded by dust, smoke, clouds, fog, haze, and even high humidity.**
- **Even with sufficient contrast, the target must be extracted from the background.**
  - **Non-imaging or point target detection: locating the dot in the complicated image (there are 4 added dots in image).**
  - **Imaging systems: the people in the foreground are easy to see, but are there people in the trees?**
- **These concepts will be revisited in more detail in later charts.**







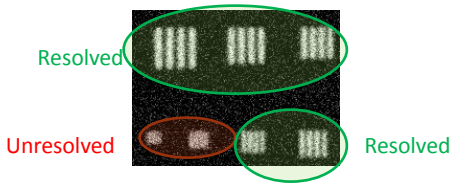
Contrast can be defined in different ways depending on the application. At its most basic, it is simply the difference in sensor output between the target and background $C_{differential}$ = (T-B). In other applications, it may be normalized to be dimensionless and between 0 and 1, $C_{relative}$ = (T-B)/(T+B). This relative contrast is particularly common in display applications, partly because it reflects some features of human vision. The eye adapts to the overall illumination of a scene so that the relevant parameterization is the relative contrast. One speaks of a target that is 10 percent brighter than the background, for example. One may also see $C_{alternative}$ = (T-B)/B.

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Resolution and Sensitivity

- **Resolution and sensitivity are the basic elements of a sensor description.**
- **Resolution has many definitions depending on what task is to be done, but they are usually related to being able to make distinctions about the target.**
  - **Rayleigh resolution criterion: Separating two images of a star (point target)**

    Unresolved  Resolved 
  - **Bar targets: what is the smallest group of bars that can be resolved?**



- **Resolution depends on the image contrast, which may be limited by the sensor's sensitivity: the signal must be greater than the noise.**

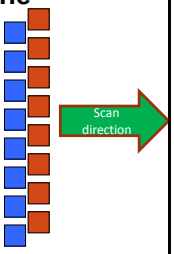
There are many different definitions of resolution, each of which is connected to a specific task. For example, mathematically, the Rayleigh criterion requires the signal from one point (star) to fall to zero. Two stars are resolved when one star is located at the first zero point of the other. The Sparrow criterion for stars only requires that there be a dip in the brightness of the combined image; so two stars may be resolved on the Sparrow criterion, but not on the Rayleigh criterion.

Although the use of a calibration target with bar groups of different sizes is relatively standard, the results of a test will depend on the number of bars in a bar group, the aspect ratio of the bars, and the instructions to the test subject explaining the criterion for declaring a bar group resolved.

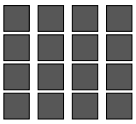
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Types of Digital Systems

- **EO/IR digital systems can be divided into scanning and staring systems.**
- **Scanners use a linear array of detectors (1 to a few rows). The image is developed by scanning the linear array across the scene.**
  - **The number of rows of detectors may be > 1 to provide:**
    - **Staggered phasing to reduce sampling artifacts (aliasing)**
    - **Additional signal gathering**
    - **Multiple wavelength bands**
  - **2nd generation FLIRs used a vertical array of detectors scanned horizontally using scan mirrors.**
  - **Pushbroom line scanners use linear arrays that are scanned by the motion of the aircraft.**



- **Starers use a rectangular array of detectors that capture an entire image at time.**
  - **Modern systems (both EO and IR) are moving to staring arrays.**
  - **Limitations include relatively small field of view, complexity of multi-band systems, and aliasing.**



- **Behind the detectors are the read-out circuits.**
  - **Readout time determines "frame rate": how many images/sec.**
  - **Can also limit the integration time, sensitivity.**

Historically, the difficulty in manufacturing large square or rectangular focal plane arrays has meant that many sensors used scanning designs. There is a general migration from scanning to staring sensors. However, in some cases, a line-scanner may still provide the best solution. For example, if one wants a number of different colors or bands, a line-scanner can simply add more rows of detectors for the additional colors. Although some technologies provide, for example, a two-color IR array, achieving four or more colors requires a complicated design with multiple staring arrays. For applications requiring a wide field of view, it may be easier to create a 10,000-element linear array for a line-scanner than a 1-million element detector staring array.

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Basics Summary

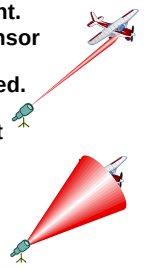
- EO/IR systems cover a wide range of distinct technologies based on the targets and the mission to be accomplished. The target phenomenology may dominate the choice of spectral band. For example, missile launch detection depends on the very hot missile exhaust, which produces the majority of radiation in the UV. The band choice is also influenced by the vagaries of the atmosphere (transmission and scattering).
- EO/IR missions divide roughly into dealing with point targets and fully imaged targets. For point targets, the challenge is to extract the target from a complex clutter background. For fully imaged targets (images of tanks, for example), the contrast between the target and the background is a central parameter. The ability to detect dim targets, either point or imaged, is a measure of the system's *sensitivity*.
- The *resolution* of a sensor is a measure of its ability to determine fine detail. Measures of resolution depend on the precise task. The use of eye-chart-like calibration targets is common in DoD applications.
- The technology used in EO/IR sensors may be divided into scanning sensors, using a limited number of detectors that scan across the scene, and staring sensors, using large numbers of detectors in rectangular arrays.

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B. Non-Imaging EO/IR Systems

Non-Imaging EO/IR systems

- **Non-imaging systems refer to unresolved or point targets.**
  - **The simplest example of a point target is a star: in the sensor, a star produces an image that is called the point target response, impulse response, or blur circle. It may cover more than one detector element.**
  - **An unresolved target is any object that produces an image in the sensor comparable to that of a star: there is no internal detail.**
  - **For a resolved target, some amount of internal detail can be recovered.**
  - **The rule of thumb is that a target is resolved if the sensor can put multiple detector fields of view on the target; unresolved if the target is entirely contained within one instantaneous field of view (IFOV).**
  - **IFOV = detector size (d) / focal length (fl)**
- **For a point target, the only signature characteristic is the amount of energy emitted in a specified direction or radiant intensity measured in watts/ster or spectrally (as a function of wavelength) watts/ster/μm**
  - **Radiant intensity ≈ Area target * radiance = $A_T * L_T$**
  - **L_T is the power per unit solid angle per unit *projected* source area.**
  - **Radiant intensities for small aircraft (UAV) are the range of 0.05 watts/ster in MWIR and 0.25 watts/ster in LWIR.**
  - **For ballistic missiles the signatures are much higher, megawatts/ster.**
- **Radiant intensity of the target is compared to that of the background: radiant intensity contrast $\approx A_T * (L_T - L_{Background})$**



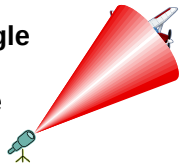
Instead of using watts/ster,[4] it is sometimes more convenient to describe the photon flux, photons/sec/ster. The common unit for IR systems is the watt, but, for visible systems, photons/sec is often employed.

The instantaneous field of view (IFOV) is a fundamental sensor parameter. At range R, a single IFOV covers a distance D = IFOV*R. As an example, detectors for visible digital cameras (Nikon, Canon) are about 10 μm in size. With a 100-mm lens the IFOV = $(10*10^{-6})/(100*10^{-3}) = 10^{-4}$. At a range of 1,000 meters, the IFOV covers 10 cm. If the target were 1 meter x 1 meter, we might say there were 10 x 10 = 100 IFOVs on target; this is usually replaced with the sloppier phrase, 100 pixels on target.

[4] The steradian is a unit of solid angle. It is used to quantify two-dimensional angular spans in three-dimensional space, analogously to how the radian quantifies angles in a plane. (wiki)

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Non-Imaging Applications



- **Air-to-air (Sidewinder) — First Sidewinders had a single detector behind a rotating reticle. Modern air-to-air missiles use focal plane arrays but, at long range, the target is a point target.**
- **IRST (Infrared Search and Track)**
  - **Air-to-Air — Permits passive operation of aircraft. Limited by cloud clutter background.**
  - **Surface (Sea)-to-Air — Radar detection of sea-skimming cruise missiles may be adversely affected by environment effects. IR has different environmental problems and may provide a supplement to radar.**
  - **Surface (Ground)-to-Air — For identification and tracking of small aircraft (UAV) EO/IR may offer advantages in resolution.**
- **Missile launch detection**
  - **Usually based on missile plume detection**
  - **Tactical warning systems**
  - **Strategic warning (DSP/SBIRS)**

The reticle was an engineering marvel. A reticle rotating disk has a pattern of transparent and opaque sectors. For a point target, the rotating pattern provided a blinking signal that could be distinguished from the background (clouds or sky), which did not vary as much. Further processing of the shape of the blink actually provided sufficient information to guide the missile to the target, directing it to maneuver up, down, left, or right.

However, the problems of clutter rejection and dependence on atmospheric conditions are barriers to IRST use.

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At the Sensor

- **At the source, the radiant intensity contrast is**

$$\Delta RI = A_T(L_{\text{target}} - L_{\text{background}}) = A_T \Delta L$$

- **Neglecting atmospheric transmission, the total signal (watts or photons/sec) at the sensor will be**

$$\text{Signal/sec} = \frac{A_{optics}}{4\pi R^2}\Delta RI$$

where A_{optics} is the area of the sensor lens and R is the range

- **Including the effects of transmission**

$$\text{Signal/sec} = \frac{A_{optics}A_T}{4\pi R^2}\int_{\lambda_1}^{\lambda_2}\tau(\lambda,R)(L_{\text{target}}(\lambda) - L_{\text{background}}(\lambda))d\lambda = \frac{A_{optics}}{4\pi R^2}\int_{\lambda_1}^{\lambda_2}\tau(\lambda,R)\Delta RI\ (\lambda)d\lambda$$

- **The irradiance of the target (measured in watts/cm² or photons/sec/cm²) is defined by**

$$Irradiance = \frac{1}{4\pi R^2}\int_{\lambda_1}^{\lambda_2}\tau(\lambda,R)\Delta RI\ (\lambda)d\lambda$$

- **The sensor integrates this signal over a time, T_{int}.**

$$\text{Signal} = A_{optics}T_{int}Irradiance$$

For any sensor to be evaluated, the first step in understanding the expected performance is to understand the signal produced by the target. The signal provided by a point target is particularly easy to understand. The example introduces several generally useful concepts. The radiant intensity contrast is a characteristic of the target at the source; using the photon (rather than watt) description, it represents the number of additional photons/sec/ster being radiated (or reflected) because the target is there.

$$\Delta RI = A_T\left(L_{target} - L_{background}\right) = A_T\Delta L$$

The number of these photons that arrive at the sensor is determined by the range and the area of the optics.

$$photons/sec = \frac{A_{optics}}{4\pi R^2}\Delta RI$$

To separate out sensor characteristics from the target and environment, this is rewritten as

$$photons/sec = A_{optics}Irradiance$$

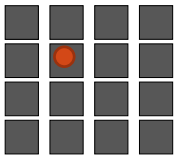
The vast majority of sensors add up the photons received over some integration time so that the signal finally is

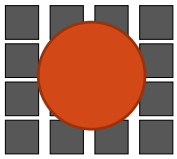
$$Signal = Number\ of\ photons = A_{optics}T_{int}Irradiance$$

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In the Sensor

- **The signal is not necessarily captured by a single detector, even for a point target.**
  - **If (most) of the received energy lies within a single detector, it cannot be located more precisely than ½ a detector width.**
  - **If the energy is spread out over several detectors, the location can be made to a small fraction of the detector size if there is sufficient signal-to-noise ratio (SNR).**
  - **The "ensquared energy" is the fraction falling on the primary detector (typical designs are for ensquared energy ≈ 1/3).**





- **Finding point targets is easy if the target is bright and viewed against a dim background (stars against a dark sky): this is not usually the case.**
  - **Non-imaging systems employ detection algorithms of varying complexity to extract possible point targets from the scene.**
  - **All such algorithms have both a probability of detection (p_d) and a false alarm rate (FAR).**
  - **The performance of these algorithms depends on the SNR, the difficulties of the environment, and the detector performance characteristics.**

The analysis of the signal given on the preceding chart implicitly assumed that all the photons from the target were easily counted. This would be the case if all the photons landed on a single detector. However, even if the point target image (or "blur circle") is small compared to the detector, the spot may land on the boundary between detectors so a fraction of the signal falls on one detector and another fraction on another. In the worst case, the signal would be reduced to ¼ of the nominal value, divided among four detectors. The detection algorithms used in this limit may look at the detector output of several detectors to increase the detection range.

In the other limit, the size of the blur circle may be large compared to the detector. Surprisingly, this can be an advantage in some point target applications if the expected signal level is high enough. For a tiny blur circle, one can only say that the target is located somewhere in the field of view of that detector. If the blur circle covers several detectors, a model of how the signal should vary from detector to detector can allow an estimate of the location of the target to a fraction of an IFOV. This is also called "sub-pixel localization."

In most applications, the detection algorithms are as important in determining performance as the sensitivity of the detectors and IFOV. The point targets may be seen against a complicated clutter background; simply looking for a hot spot may produce an unacceptable number of false alarms.

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Noise

- **The noise associated with a single detector is relatively straightforward.**
  - **Noise due to the average background**
  - **"clutter noise" may be incorporated into the description**
  - **Other noise**
- **Background noise**
  - **In the absence of a target, photons still arrive on the detector. On average (using the photon flux form of the radiance).** $N_{ave} = \frac{A_{detector} A_{optics} T_{int}}{\pi f l^2} L_{background}$
  - **This number will vary statistically even for a constant background, providing a contribution to the noise of** $N_{ave}^{1/2}$
  - **If this is the primary contribution to the noise, the sensor is called *background limited*.**
- **Clutter noise — In many cases, the variation of the background can be incorporated into the noise. If this is dominant, the sensor is *clutter limited.*** $\delta N_{clutter} = \frac{A_{detector} A_{optics} T_{int}}{\pi f l^2} \delta L_{background}$
- **Adding in any other noise, the total noise is** $Noise^2 = N_{ave} + \delta N_{clutter}^2 + Other^2$

In EO/IR sensors, estimating and characterizing noise and clutter is a vital element for understanding system performance. The use of a "clutter-noise" term is a common first order attempt to incorporate the clutter into performance estimates. However, since the scene is processed through a series of algorithms (which, in some applications may be quite complex), the effect of clutter has to be considered after the algorithms are run, not before. Estimates of performance require substantial testing or laboratory testing with scene simulators, the use of which must be examined carefully to ensure that the simulator presents the relevant features of the clutter. What sort of clutter is relevant depends on the algorithms!

To be more precise, the $L_{background}$ should include not only the background radiation at the target but also the so-called "path radiance," radiation emitted between target and sensor by the atmosphere.

$$L_{total} = L_{background}\ (at\ target) + \ path\ radiance\ (between\ target\ and\ sensor)$$

This issue arises again on pages 28 and 35.

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Noise Equivalent Irradiance (NEI)

- **For simplicity, assume all the signal is received on a single detector. Then the signal-to-noise ratio would be given by**

$$SNR = \frac{A_{optics} T_{int} Irradiance}{Noise}$$

- **The irradiance that would provide an SNR=1 is called the *noise equivalent irradiance*.**

$$NEI_{photon} = \frac{Noise}{A_{optics} T_{int}} \qquad NEI_{watts} = \frac{Noise}{A_{optics} T_{int}} \frac{hc}{\lambda_{sensor}}$$

- **Note that the relationship between NEI and the system parameters depends on whether the system is background or clutter limited.**
- **The actual signal and noise at the *output* of the algorithm used for target detection will differ from the signal and noise used here.**

Noise equivalent irradiance (NEI) is an example of a number of similar figures of merit. For example, the irradiance of a target depends on the difference in the radiance of the target and background. For a system that utilizes the target's temperature and its emitted radiation, the radiance difference can be considered to be attributable to the difference in temperature between target and background. If the temperature difference is relatively small, the irradiance will be proportional to the temperature difference, ΔT.

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Dealing with the Environment

- **Spectral band**
  - **For some applications (detecting and tracking aircraft), one chooses a spectral band with good transmission.**
  - **For some applications with very bright targets (missile launch detection), the clutter problem is so severe that a band might be chosen with poor transmission to suppress background clutter.**
- **Algorithms for extracting the target from the background may be spatial (essentially suppressing low spatial frequencies), temporal (subtracting two images to cancel non-moving clutter), or spatial-temporal combinations.**
  - **Simple algorithms may have large false alarm rates. For example, cloud edges may produce false targets with simple spatial algorithms.**

EO/IR systems are often dominated by environmental effects. Normally one chooses a band with good transmission, but, with good transmission, one can see all the clutter as well as the target. By choosing a band with poor transmission, very bright targets can still be seen but the clutter becomes invisible. If this trick isn't used, the targets must be separated from the background by means of detection algorithms. Any detection algorithm is associated with both a probability of detection (P_d) and a false alarm rate (FAR). Typically, internal parameters, or "thresholds" in the algorithm, permit the designer to trade off probability of detection and false alarm rate. The curve relating the two is termed the "ROC curve"; ROC is an acronym of ancient origin for "receiver operating characteristic." Testing and evaluating the detection algorithm is difficult because of the wide range of potential clutter backgrounds. Some systems may employ scene simulators that use models of background clutter to produce a wide range of scenes purported to span the circumstances of the real system in the real environment.

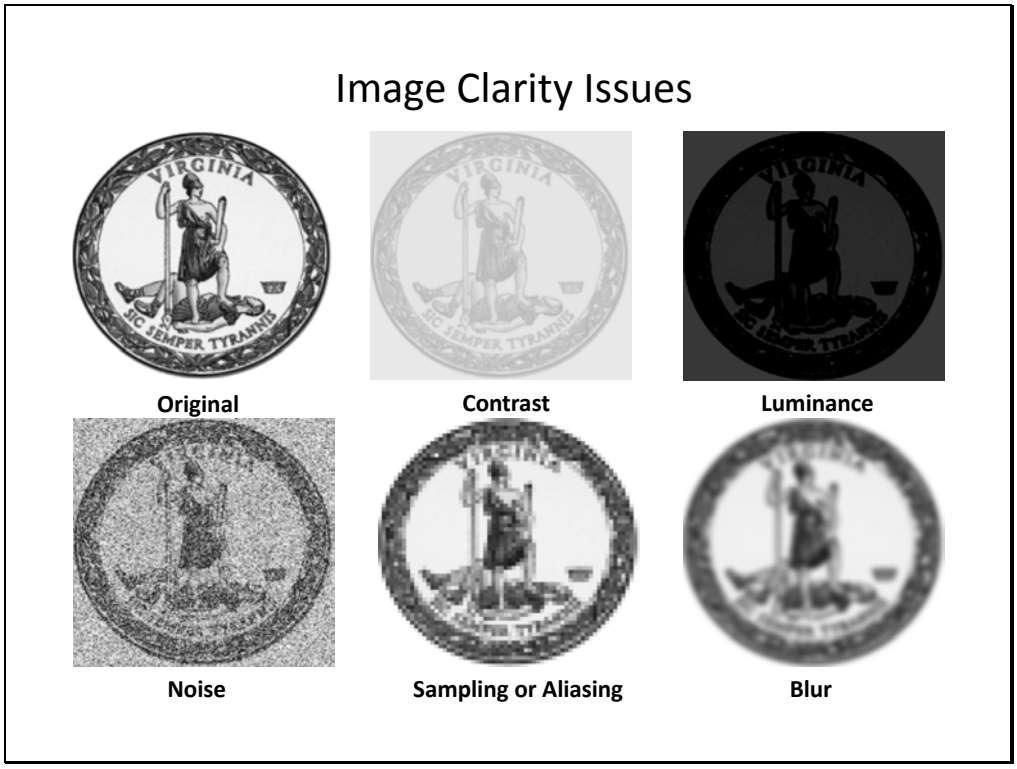
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Point Target Summary

- Non-imaging, point target EO/IR systems focus on the task of detecting targets at long ranges. For these applications, the details of the target are irrelevant; for example, for IR sensors, only the total energy emitted matters, not the precise temperature and size of the target separately. The energy available can vary over many orders of magnitude, from the engine of a small UAV to an intercontinental ballistic missile (ICBM) launch.
- Comparison of the available energy at the sensor to the noise level of the sensor provides the central metric of sensor performance, the noise equivalent irradiance or NEI.
- The problem of extracting the target from the background clutter is addressed in two basic ways: through the choice of sensor band and algorithms. For missile launch detection, for example, one may use the "solar blind" UV band. The transmission in this band is very poor and the general background is reduced to a level of near invisibility. However, the very bright missile signature is strong enough to still provide a useable signal. Algorithms for separating the point target from the structured background are a continuing source of improvement in performance, but their complexity may make the evaluation challenging.

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C. Imaging EO/IR Systems



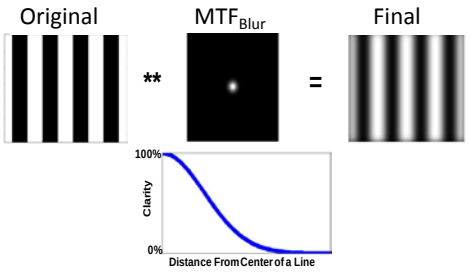
The choice of optics and detector affect the magnification provided and image clarity. Image quality includes measures of:

- Contrast – Degree of difference between lightest and darkest portions of image
- Luminance – Brightness of image
- Noise – Random signal from sources outside the image itself
- Sampling – Digitization due to binning of signal into pixels
- Blur – Smearing of image due to diffraction and/or imperfect focus (e.g., due to jitter).

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Modulation Transfer Function (MTF)

- **The MTF is a mathematical description of image blur: the MTF is the Fourier transform of the image of a point source.**
- **Many components of the optical system can be represented by individual MTFs representing the impulse response of each part.**
- **Total system MTF is a product of the individual MTFs that describe each component of the sensing**
  $MTF_{system} = MTF_{optics} * MTF_{detector} * MTF_{atmosphere} * MTF_{display} * MTF_{other}$
- **If the MTF is known (or equivalently, the blur function) one can convolve the original scene with the blur to determine the effect of the optics on the image**

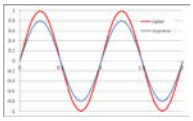


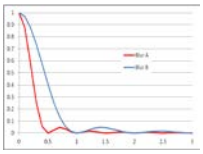
The ability to calculate or estimate the different Modulation Transfer Function (MTF) factors varies. For perfect or "diffraction limited" optics, the MTF has a well-known analytic expression. For realistic optics, the different aberrations that reduce the MTF can be modeled well; computer-based ray-tracing programs can predict relatively accurately the overall optical MTF. The detector and display can be modeled accurately as well. However, the atmospheric effects are represented by statistical models and are a source of uncertainty. For any specific system, the "other" effects (including, for example, focus error) will often be represented empirically.

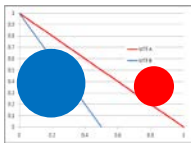
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Modulation Transfer Function (MTF)

- **The Modulation Transfer Function (MTF) is the single-most important characteristic of an optical system.**
- **The MTF is simply the frequency response of the system:**
  - **The image of a target can be decomposed into sinusoids of different frequencies; knowing how the system responds to each frequency separately characterizes the system.**
  - **If the signal has a component of A sin(2pfx) and the response is 0.8 * A sin(2pfx), then the MTF(f)=0.8.**
- **In general, the wider the MTF(f), the better the resolution**
  - **The blur circle or impulse response is the Fourier transform of the MTF(f): wide MTF ⇔narrow blur circle.**
  - **A rule of thumb is that the resolution limit of the system is at the frequency for which MTF(f) = 0.1.**
  - **Blur circle is short-hand for the shape of the impulse response: there is typically a smooth oscillating form.**
- **Every element of the total system can affect the MTF**
  - **Optics themselves**
  - **Film grain or detector size**
  - **Vibration**
  - **Atmospheric distortions**
  - **Electronics including display**
  - **Human eye!**





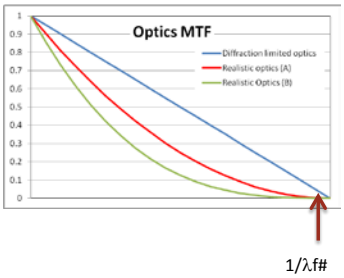


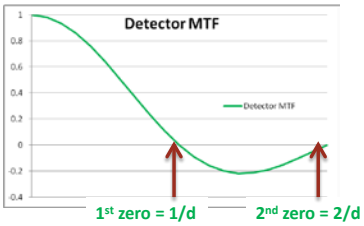
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Optics and Detector MTF

- **The primary contributors to the MTF curve in modern systems are the optics MTF and the detector MTF.**
- **The ideal, or diffraction limited, optics MTF establishes a maximum spatial frequency of**
  - **D/λ (measuring in cycles/radian) or**
  - **1/λf# (measuring on the focal plane in cycles/m)**

  where D is the diameter of the optics and f# is the f-number, f#=focal length/ D.
  - **The diffraction-limited MTF is nearly a straight line, but lens aberrations will reduce the MTF.**
- **The ideal (square) detector MTF = sinc(pfd)**
  - **Sinc(x)=sin(x)/x**
  - **d= detector size**
  - **Zeros of detector MTF = n/d, n = 1, 2,…**
- **System design will determine relative location of detector MTF zero and optics MTF zero.**
  - **Optics are typically "better" λf# < d.**
  - **This can lead to sampling artifacts or "aliasing."**



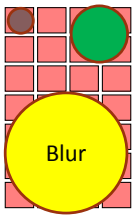


Classical MTF measurements in the laboratory are made more complicated by aliasing effects. One approach to overcome aliasing is to displace the image of the calibration target to provide different sample phasing (see p.60). For examples of other efforts made to work around the sampling artifacts, see Research Technology Organization Technical Report 75(II), *Experimental Assessment Parameters and Procedures for Characterization of Advanced Thermal Imagers.*

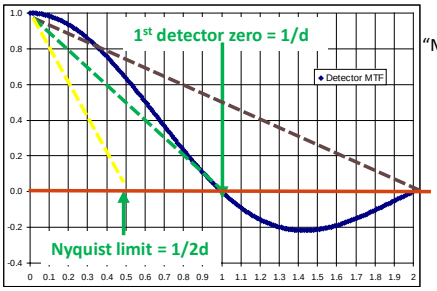
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System Design

- **Standard staring focal planes *always* the potential for aliasing.**
  - **A system is not aliased if the maximum frequency is less than half the sampling frequency = $f_{Nyquist}$.**
  - **For detectors of size d, for staring arrays the sample frequency is 1/d so the maximum frequency should be < $f_{Nyquist}$ = 1/2d.**
  - **But the *first* zero of the detector MTF = 1/d.**
- **By degrading the optics (increasing the size of the blur circle), contrast is lost but aliasing is reduced.**
- **This major system trade will be discussed in detail in Section F.**



High Optics MTF



"Matched" Optics MTF

Nyquist Optics MTF

Aliasing refers to the inability to correctly represent spatial frequencies higher than the Nyquist frequency of a digital system. This will be discussed in detail in Section F.

This chart provides an initial discussion of why modern staring systems are typically aliased. For a staring array of square detectors, the detector MTF is given by

$$MTF_{det}(f) = sinc(\pi fW) = \frac{sin(\pi fd)}{\pi fd}$$

The detector MTF therefore extends to all frequencies. The *first* zero of the detector MTF is at f = 1/d; subsequent zeros are at multiples of that frequency, f = m/Wd m= 1, 2, 3….

However, the Nyquist frequency for such an array is $f_{Nyquist}$ = 1/2d. Even if the frequencies beyond the first zero of the MTF are ignored (because of their diminishing amplitudes), the system is under-sampled by a factor of 2.

This may be modified by the consideration of the optics MTF, represented here by straight lines (correct for a square not circular lens!). If the blur circle of the detector (first zero) fits inside the detector, the optics MTF extends to 2/d (and is zero for high frequencies). This would mean being four times under-sampled (maximum frequency 4 x Nyquist). Degrading the optics until the blur occupies four detectors leads to the "matched optics" condition for which the optics MTF zero coincides with the first detector zero. Only if the blur occupies 16 detectors does the optics MTF zero match the Nyquist limit.

As shown in the preceding examples and to be developed further, this elimination of all potential aliasing reduces the system MTF (contrast) significantly. Most design trades permit some aliasing in order to preserve useable image contrast.

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Minimum Resolvable Temperature

- **Minimum Resolvable Temperature (MRT) is a system performance measure developed in the 1970s to balance two system characteristics**
  - **Sensitivity, measured, for example, by the noise equivalent temperature difference (NETD)**
    - **This was defined as the difference of the temperature between a (large) object and the background required to have a signal that produced a signal-to-noise ratio (SNR) of unity: SNR = 1**
  - **Resolution, either measured in terms of the system modulation transfer function (MTF) or the size of a detector instantaneous field of view (IFOV)**
    - **For example, resolution defined as the spatial frequency, f, at which the MTF(f) = 0.1**
    - **IFOV = detector size / focal length**
- **MRT is defined in the laboratory with a 4-bar target**
  - **Bar in 7:1 ratio so whole target represents a square**
  - **The size of the target and the laboratory optics defined a specific spatial frequency as seen by the device, f.**
  - **The 4 bars are maintained at a specified temperature above the background and inner bars.**
  - **The temperature of the bars is lowered until the technician can no longer discern all four bars.**
  - **This temperature was the minimum resolvable temperature MRT(f).**



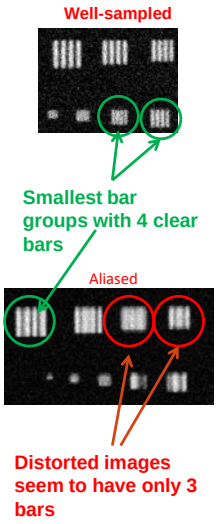
In classical noise equivalent temperature difference (NETD), the signal was compared to a measure of the temporal noise of the system (as measured through a standard electronic filter). In modern staring focal plane arrays, other noise sources must be considered. For example, each detector in the array will generally have a different response; this is called detector non-uniformity. Although an effort is made to provide non-uniformity correction, any residual non-uniformity represents a static spatial pattern noise. In addition, individual detectors may be uncorrectable, noisy, or dead.

The NVESD has introduced a three dimensional (3D) noise model to describe noise components in the temporal and two spatial dimensions.

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MTF/MRT and Sampling Artifacts

- **The sampling artifacts of modern staring focal plane arrays make the definitions of the MTF (and hence, MRT) somewhat problematic for modern systems.**
- **The first image shows a "well-sampled" image.**
  - **Depending on the human observer, the smallest pattern that is resolved (counting 4 bars) is one of the two circled bar groups.**
  - **This sensor will have an MTF (and MRT) that can be measured by classical approaches**
- **The second image is "aliased".**
  - **The bar groups are distorted and only the largest group is resolved**
  - **Modified techniques are required to measure (rather than model) the MTF and MRT.**
- **Mission performance will be between the Nyquist and un-aliased limits. See discussion in section on aliasing and notes page below.**



One approach taken by NVESD[5] and others to represent the effect of aliasing on the MTF is to represent the MTF of the sampled system by squeezing (scaling) the MTF of the corresponding unsampled system.

The factor $R = 1 - k\,SR$, where SR is a metric representing the spurious response. The value of the constant k may vary with task (detection, recognition, identification) and different forms of the SR metric have been used. $H(f)$ is the Fourier transform of the reconstruction function used. See Section G on aliasing.

Another approach is to treat aliasing as a noise term.[6]

An extension of the MRT task, the Minimum Temperature Difference Perceived (MTDP) has been introduced in Germany. This provides an extension beyond Nyquist.

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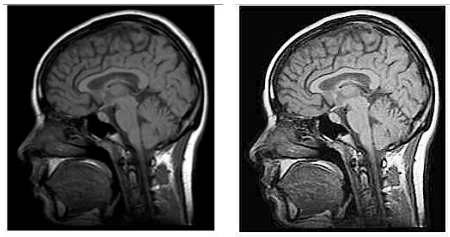
[5] Driggers, Vollmerhausen, and O'Kane, *SPIE*, Vol. 3701, pp. 61-73, 1999.

[6] Vollmerhausen, Driggers and Wilson, *JOSA-A*, Vol 25, pp. 2055-2065, 2008.

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Knobs

- **From a user perspective and a testing perspective, controls over the digital image may affect performance significantly.**
  - **In some missions, there may be insufficient time to explore alternative processing approaches.**
  - **The effects of alternative processing are not completely modeled so performance may be better or worse than expected from standard models.**
- **Basic controls include gain and level, but many options could be made available to the user/tester.**
- **"Photoshop" operations**
  - **Sharpening**
  - **Histogram manipulation**
  - **Zooming interpolation (reconstruction)**
  - **Color balance**
- **Hidden algorithms**
  - **Producing full color images from Bayer cameras**
  - **Combining images from multiple lens**
  - **Combining images from multiple frames**
- **Red items will be discussed more completely in the appendixes.**



Original | Sharpened & equalized

Performance metrics can be affected even by simple gain and level adjustments.

$$Contrast = (Signal - Background)/Background = (S-B)/B$$

is unaffected by a change of scale (gain) but is changed dramatically with a level shift:

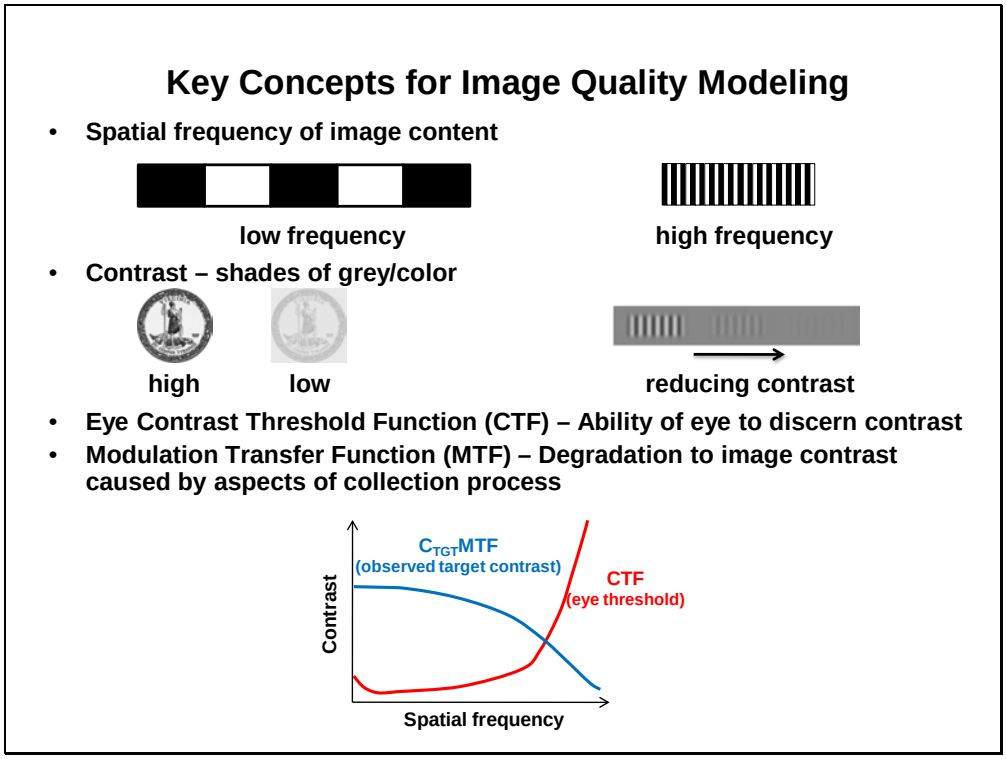
$$Contrast = ((S-L) - (B-L))/(B-L) = (S-B)/(B-L).$$

$$Signal\text{-}to\text{-}noise\ (SNR) = (S-B)/Noise$$

is unaffected by gain or level as long as values are not truncated or saturated.

In some applications, gain and level may not be under user control.

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Considering bar targets, as in the discussion of minimum resolvable temperature (MRT), increasing spatial frequency (i.e., reducing the width of the bars) generally has a negative effect on the human eye's ability to resolve targets, as does reducing contrast (the difference in brightness between light and dark bars). A convenient way to capture the interaction between spatial frequency and contrast is to plot the eye contrast threshold function (CTF) in a graph of contrast versus spatial frequency. Such a plot shows that as the bars become narrower, greater contrast is required to distinguish black bars from white bars.[7]

The shape of the modulation transfer function in the contrast versus spatial frequency plot shows that, as spatial frequency increases, the ability of a system to transfer or portray contrast differences diminishes. The better the system (including optics, detector, atmosphere, and display) is, the shallower is the drop off of the curve with increasing spatial frequency.

[7] Interestingly, at very low spatial frequencies, more contrast is required to distinguish bars, just as at higher spatial frequencies.

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Evolution of Tactical Models for Predicting Image Quality

- **Johnson Criteria: Started with experiments conducted by John Johnson, an Army Night Vision Laboratory [later renamed Army Night Vision and Electronic Sensors Directorate (NVESD)] scientist, in the 1950s**
  - **In the 1950s, sensors were analog (film, TV). Johnson Criteria had to be translated into the digital sensor world.**
- **Targeting Task Performance (TTP): Today NVESD maintains community-standard models that predict the image quality and associated probabilities of detection, recognition, and identification for various vehicles and dismounts with differing backgrounds in the visible and infrared regions of the electromagnetic spectrum.**

Visible – Solid State Camera and Image Processing (SSCamIP) Performance Model

IR – Night Vision Thermal and Image Processing (NVThermIP) Performance Model

In 1957 and 1958, John Johnson at the Army Night Vision Laboratory developed a series of experiments to analyze the ability of observers to perform visual tasks, such as detection, recognition, and identification. He came up with general rules for the number of bar pairs required on target to have a 50-percent probability of performing each of these tasks. Over time, this approach has evolved to account for the increasing sophistication of today's EO/IR sensors. The Army Night Vision and Electronic Sensors Directorate (NVESD) maintains models for predicting image quality based on the targeting task performance (TTP) metric, the successor to the Johnson criteria. Very recently, the visible and IR models, known as Solid State Camera and Image Processing (SSCamIP) and Night Vision Thermal and Image Processing (NVThermIP), respectively, have been combined into one software package, known as the Night Vision Integrated Performance Model (NV-IPM).

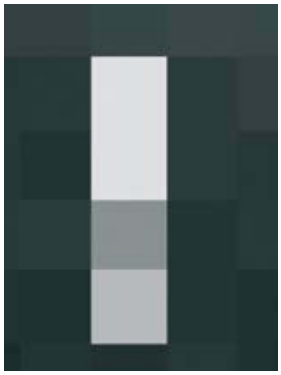
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Johnson Criteria

- How many pixels are required to give a 50% probability of an observer discriminating an object to a specified level?
- Experiments with observers yielded the following
  - Detect (determine if an object is present) 1.5 pixels
  - Recognize (see what type of object it is; e.g., person, car, truck) 6 pixels
  - Identify (determine if object is a threat) 12 pixels
- These are the number of pixels that must subtend the critical dimension of the object, determined by statistical analysis of the observations
  - Critical dimension of human 0.75 m
  - Critical dimension of vehicle 2.3 m
- Hence for a human, the requirements are
  - Detect 2 pixels/meter
  - Recognize 8 pixels/meter
  - Identify 16 pixels/meter
- For a man who is 1.8 m x 0.5 m, this corresponds to requirements of
  - Detect 3.6 pixels tall by 1 pixel wide
  - Recognize 14.4 pixels tall by 4 pixels wide
  - Identify 28.8 pixels tall by 8 pixels wide

As an example, the Johnson criteria can be applied to determine the number of pixels in an image required to detect, recognize, and identify a human subject. The calculations shown here are illustrated by the images on the chart below.

Images Illustrating Johnson Criteria



Detect: Something is present.



Recognize: A person is present.



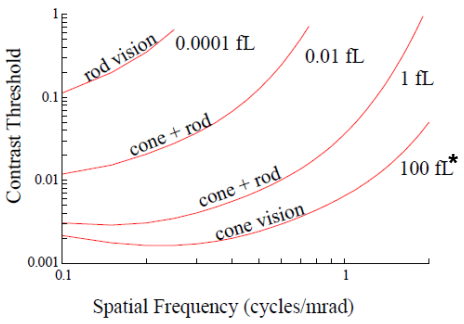
Identify: The person is holding an object that may pose a threat.

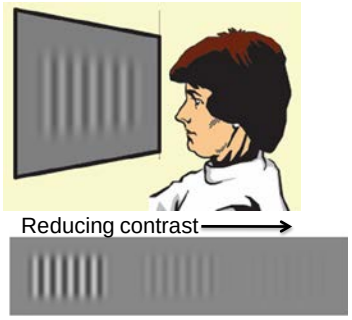
Source: FLIR Technical Note at http://www.flir.com/uploadedFiles/ENG_01_howfar.pdf

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Eye Contrast Threshold Function (CTF)

- **One of the most common and useful ways of characterizing human vision**
  - **One-dimensional sine waves are displayed to observer.**
  - **For a given luminance level and signal spatial frequency, CTF is the minimum perceivable contrast vs. visual acuity (resolution).**
  - **Derived from two-alternative forced choice experiment: observer must choose between sine wave and blank field.**
  - **Repeat procedure for different average luminance levels.**
  - **Conduct tests at varying spatial frequencies to derive curves shown below.**

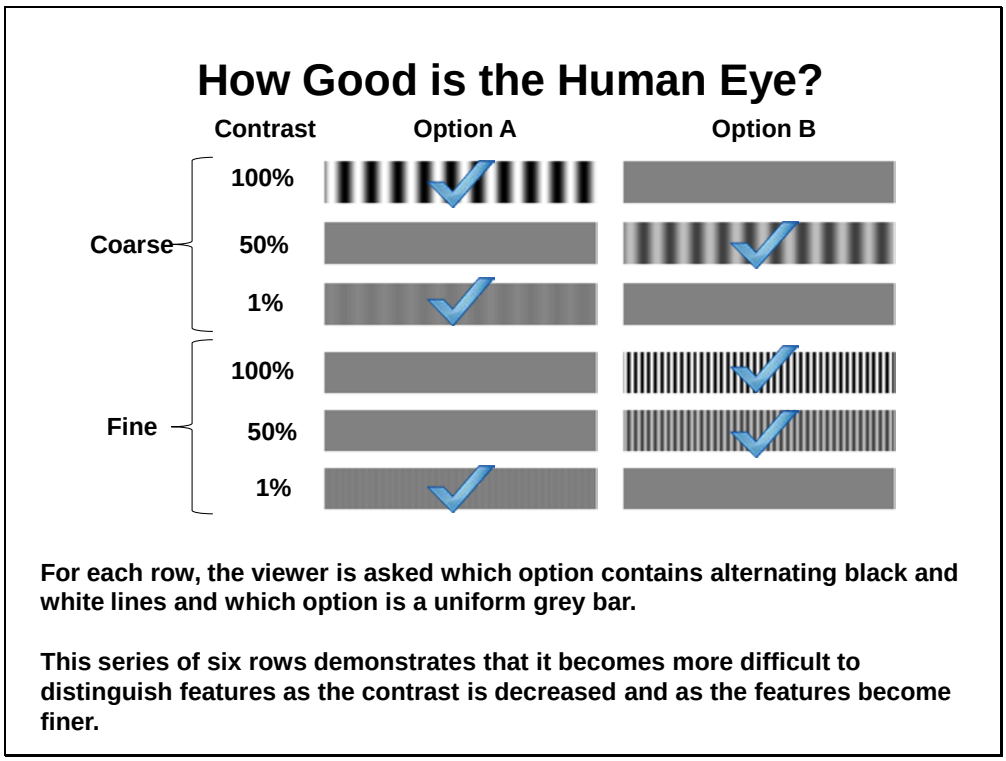




*fL: luminance is expressed in units of foot-Lamberts

The eye contrast threshold function has been measured by repeated experimentation on a large group of observers. The experiment entails showing two fields to the observers. One field contains alternating black and white bars, and the second is constant gray of the same total luminance. The observers are asked to identify which of the images contains the alternating bars. This experiment is repeated as the contrast of the bar pattern is changed, while keeping the total luminance constant. The contrast at which 75 percent of the observers correctly identify the bar pattern is considered the threshold for that level of luminance. (The threshold is set at 75 percent because in a two-alternative forced choice experiment such as the one described here, the right answer will be selected 50 percent of the time simply by chance.) By conducting this experiment at varying spatial frequencies (i.e., bar spacings), one of the curves shown above can be measured. Differing levels of luminance give rise to the series of curves shown above.

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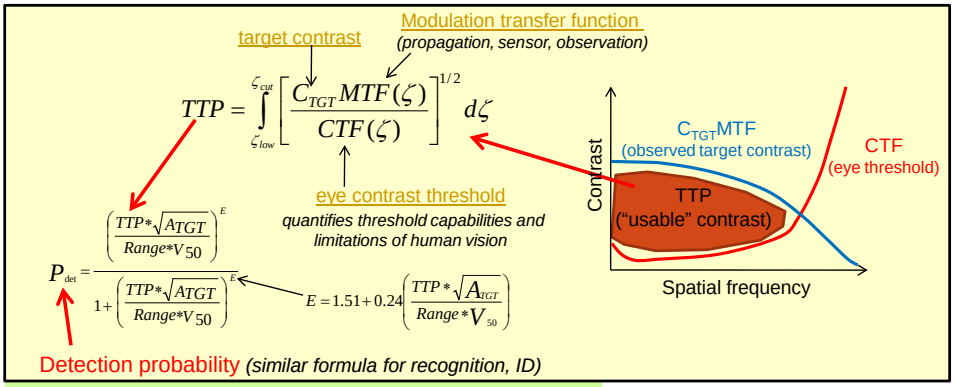


An example of the experiment described in the previous chart is displayed here.

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Approach to Measuring Sensor Effectiveness

- **Night Vision Lab model (SSCAM, NVTHERM) estimates of target detection/recognition/ ID probability based on the TTP (targeting task performance) metric, which has supplanted Johnson criteria**
  - **TTP = difference between target-background contrast and the eye's capability to distinguish contrast**
    - **Summed over all spatial frequencies**
    - **C_{TGT} is a function of range**
  - **Experimental data are "curve fit" based on the TTP value**



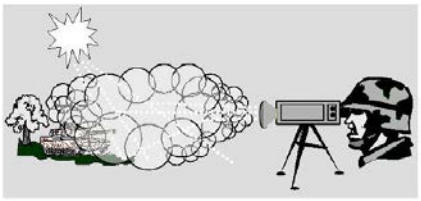
Source: "The TTP Metric," Vollmerhausen and Jacobs, NVESD

The TTP metric used by NVESD captures the difference between the target-background contrast and the eye's ability to distinguish that contrast. The square root functional form ensures that excessive amounts of "usable" contrast are not given too much weight in the metric. The probability of detection, recognition, or identification is related to the TTP, target size, target-sensor range, and V50 through the target transfer probability function, which is a logistics curve with an exponent determined by curve fitting. The task difficulty parameter, V50, is analogous to the Johnson N50 value that represents the number of resolvable cycles on the average target for a 50-percent probability of detection/recognition/identification. For each target type in a set of target options, V50 is determined by a series of calibration experiments involving human perception of the original image and images degraded by a known amount.

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Target Contrast

- **C_{TGT-0} is the zero range contrast value for a target on a background.**
  - **In visible, this is a measure of the difference in reflectivities between target and background.**
    - **e.g., contrast for individual wearing white against concrete background is less than contrast for individual wearing black against same background.**
  - **In IR, this is a measure of the difference in target and background temperatures.**
- **The apparent target contrast at a distance is related to C_{TGT-0} via the extinction coefficient β from Beer's Law.**
  - **$C_{TGT} = C_{TGT-0}\, e^{-\beta x}$ where β is in km^{-1} and x is the range from target to sensor in km.**
  - **Does not account for imaging through non-homogeneous media, such as the atmosphere.**
- **Apparent target contrast is degraded by scattering of light into the path between target and sensor.**
  - **This depends on the amount of aerosols and other particulates present, as well as any other potential sources of scatter, and it is particularly sensitive to the relative positions of the sun, target, and sensor.**
  - **Army uses sky-to-ground ratio concept to account for this.**



The zero range target contrast is a measure of the inherent contrast between the target and the background, independent of the distance between the target and sensor. In the visible, the contrast at each wavelength is integrated over the visible portion of the electromagnetic spectrum to determine the zero range target contrast. In the infrared, the contrast is due to the difference in thermal emission between target and background. The zero-range contrast is then attenuated by atmospheric effects, which can be treated as homogeneous or modeled in a complex computer program, such as MODTRAN (MODerate resolution atmospheric TRANsmission). The apparent target contrast is also degraded by scattering of light into the path between target and sensor.

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Sky-to-Ground Ratio (SGR)

- **SGR is related to transmittance τ via** $\tau = \frac{1}{1 + SGR(e^{\beta x} - 1)}$
- **SGR is a measure of the scattering of light into the path between target and sensor.**
- **In clear conditions with low relative humidity where direct sunlight is not close to the target-sensor path, a value of 1.4 may be used for SGR.**
- **SGR approaches 10 or greater when direct sunlight is near the target-sensor path.**
- **Extinction coefficients as a function of wavelength are tabulated for urban, rural, and maritime models.**
- **Combined with representative SGRs, this allows for calculation of transmittance in a range of environmental situations.**

The Army has introduced the concept of sky-to-ground ratio (SGR) to account for the scattering of light into the path between target and sensor. Values of SGR typically range from 1.4 in clear conditions with low relatively humidity to well over 10 when the path radiance is high, due to multiple scattering events, as would be encountered when the sun is shining directly on the target-sensor path or in a forest under overcast conditions.

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National Imagery Interpretability Rating Scale (NIIRS)

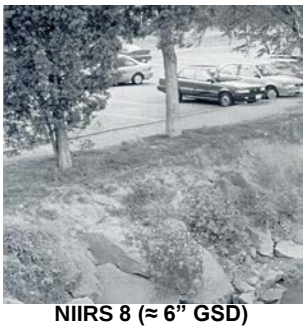
- **Standard used by the strategic intelligence community to judge the quality of an image (versus the Johnson criteria/TTP approach used by the tactical intelligence community).**
- **NIIRS of particular image is based on judgment of imagery analysts, guided by updated published scale of representative examples.**
  - **e.g., NIIRS = 5 means can identify radar as vehicle-mounted or trailer-mounted**
- **NIIRS can be estimated from General Image Quality Equation, derived from curve fitting.**



NIIRS 4 (≈ 6' GSD)



NIIRS 6 (≈ 2' GSD)



NIIRS 8 (≈ 6" GSD)

The strategic intelligence community uses the National Imagery Interpretability Rating Scale (NIIRS) to evaluate the quality of still imagery. NIIRS is a qualitative scale, running from 0 to 9, with guidance for imagery analysts provided in the form of a table of example operations that could be performed at various NIIRS values. The table for visible NIIRS values is provided on the following chart. There are also tables for IR NIIRS, synthetic aperture radar (SAR) NIIRS, civil imagery NIIRS, multi-spectral NIIRS, and video NIIRS.

NIIRS can be estimated with the General Image Quality Equation (GIQE), an empirical model that has been designed to predict NIIRS from sensor system characteristics. In the visible, the GIQE takes the form

$$\text{NIIRS} = 10.251 - a \log \text{GSD} + b \log \text{RER} - 0.656\, H - 0.344\, (G/\text{SNR})$$

where GSD is the ground sample distance
RER is the relative edge response
H is the overshoot,
G is the gain,
SNR is the signal-to-noise ratio,
$a = 3.16$
$b = 2.817$ for $\text{RER} < 0.9$ and $a = 3.32$, $b = 1.559$ for $\text{RER} \geq 0.9$.

The only change to the GIQE in the IR is that the constant term is 10.751, rather than 10.251. The GSD, RER, and overshoot will be defined and discussed in subsequent charts.

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Definition of NIIRS Levels (Visible)

Table 1. Visible NIIRS Operations by Level—March 1994[a]

Rating Level 0

Interpretability of the imagery is precluded by obscuration, degradation, or very poor resolution.

Rating Level 1

Detect a medium-sized port facility and/or distinguish between taxiways and runways at a large airfield.

Rating Level 2

Detect large hangars at airfields.

Detect large static radars (e.g., AN/FPS-85, COBRA DANE, PECHORA, HENHOUSE).

Detect military training areas.

Identify an SA-5 site based on road pattern and overall site configuration.

Detect large buildings at a naval facility (e.g., warehouses, construction halls).

Detect large buildings (e.g., hospitals, factories).

Rating Level 3

Identify the wing configuration (e.g., straight, swept, delta) of all large aircraft (e.g., 707, CONCORD, BEAR, BLACKJACK).

Identify radar and guidance areas at a SAM site by the configuration, mounds, and presence of concrete aprons.

Detect a helipad by the configuration and markings.

Detect the presence/absence of support vehicles at a mobile missile base.

Identify a large surface ship in port by type (e.g., cruiser, auxiliary ship, noncombatant/merchant).

Detect trains or strings of standard rolling stock on railroad tracks (not individual cars).

Rating Level 4

Identify all large fighters by type (e.g., FENCER, FOXBAT, F-15, F-14).

Detect the presence of large individual radar antennas (e.g., TALL KING).

Identify, by general type, tracked vehicles, field artillery, large river crossing equipment, wheeled vehicles when in groups.

Detect an open missile silo door.

Determine the shape of the bow (pointed or blunt/rounded) on a medium-sized submarine (e.g., ROMEO, HAN, Type 209, CHARLIE II, ECHO II, VICTOR II/III).

Identify individual tracks, rail pairs, control towers, switching points in rail yards.

Rating Level 5

Distinguish between a MIDAS and a CANDID by the presence of refueling equipment (e.g., pedestal and wing pod).

Identify radar as vehicle-mounted or trailer-mounted.

Identify, by type, deployed tactical SSM systems (e.g., FROG, SS-21, SCUD).

Distinguish between SS-25 mobile missile TEL and Missile Support Van (MSV) in a known support base, when not covered by camouflage.

Identify TOP STEER or TOP SAIL air surveillance radar on KIROV-, SOVREMENNY-, KIEV-, SLAVA-, MOSKVA-, KARA-, or KRESTA-II-class vessels.

Identify individual rail cars by type (e.g., gondola, flat, box) and/or locomotive by type (e.g., steam, diesel).

Rating Level 6

Distinguish between models of small/medium helicopters (e.g., HELIX A from HELIX B from HELIX C, HIND D from HIND E, HAZE A from HAZE B from HAZE C).

Identify the shape of antennas on EW/GCI/ACQ radars as parabolic, parabolic with clipped corners or rectangular.

Identify the spare tire on a medium-sized truck.

Distinguish between SA-6, SA-11, and SA-17 missile airframes.

Identify individual launcher covers (8) of vertically launched SA-N-6 on SLAVA-class vessels.

Identify automobiles as sedans or station wagons.

Rating Level 7

Identify fitments and fairings on a fighter-sized aircraft (e.g., FULCRUM, FOXHOUND).

Identify ports, ladders, vents on electronics vans.

Detect the mount for antitank guided missiles (e.g., SAGGER on BMP-1).

Detect details of the silo door hinging mechanism on Type III-F, III-G, and III-H launch silos and Type III-X launch control silos.

Identify the individual tubes of the RBU on KIROV-, KARA-, KRIVAK-class vessels.

Identify individual rail ties.

Rating Level 8

Identify the rivet lines on bomber aircraft.

Detect horn-shaped and W-shapted antennas mounted atop BACKTRAP and BACKNET radars.

Identify a hand-held SAM (e.g., SA-7/14, REDEYE, STINGER).

Identify joints and welds on a TEL or TELAR.

Detect winch cables on deck-mounted cranes.

Identify windshield wipers on a vehicle.

Rating Level 9

Differentiate cross-slot from single slot heads on aircraft skin panel fasteners.

Identify small light-toned ceramic insulators that connect wires of an antenna canopy.

Identify vehicle registration numbers (VRN) on trucks.

Identify screws and bolts on missile components.

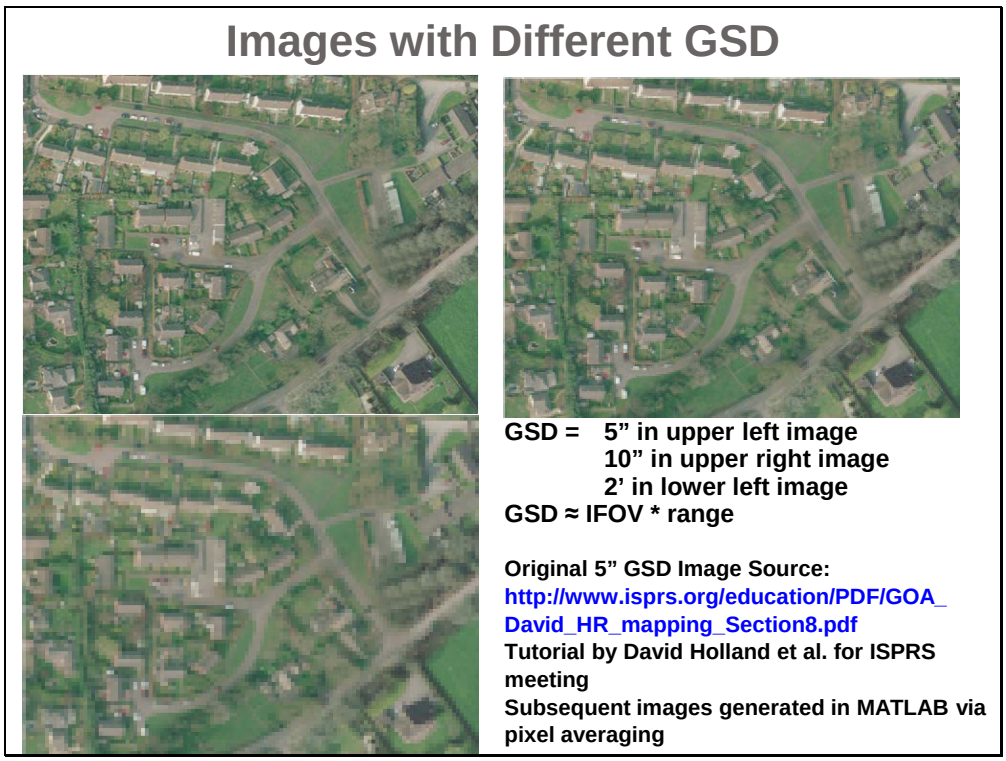
Identify braid of ropes (1 to 3 inches in diameter).

Detect individual spikes in railroad ties.

Source:

J.C. Leachtenauer et al., *Applied Optics*, **36**, 8322 (1997).

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Ground sample distance (GSD) is the dominant term in the GIQE and ultimately provides an upper limit to the image quality, since all information in the area defined by the horizontal and vertical GSDs is incorporated into a single pixel. The GSD is defined by

$$GSD = ((P_P * x)/F_L)/\cos\theta$$

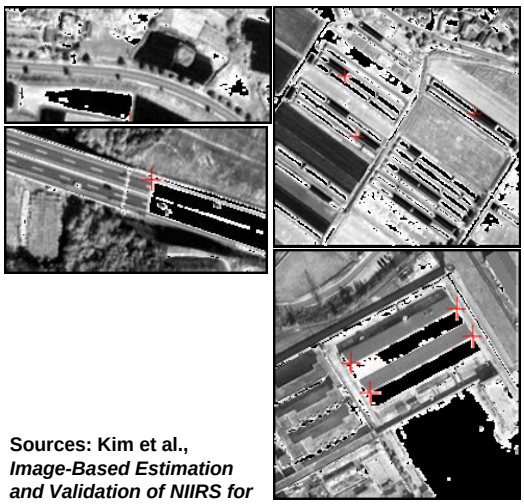
where P_P is the pixel pitch
x is the slant range
F_L is the focal length
θ is the look angle, measured between nadir and the sight line.

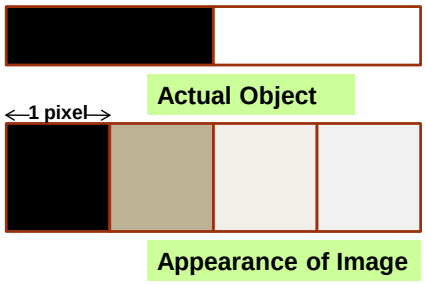
For non-square pixels, the vertical and horizontal GSDs differ and are specified separately.

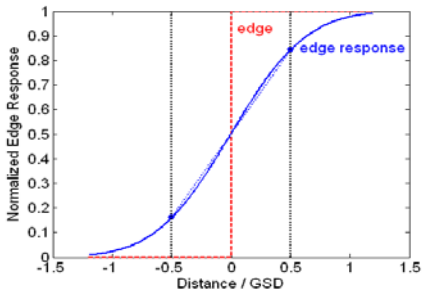
The blurring of the original image as adjacent pixels are averaged together is evident in comparing the image in the upper left quadrant to that in the upper right quadrant and finally to that in the lower left of the figure.

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Relative Edge Response







Sources: Kim et al., *Image-Based Estimation and Validation of NIIRS for High-Resolution Satellite Images*, 2008.
Blonski et al., *Spatial Resolution Characterization for Aerial Digital Imagery*, 2006.

The relative edge response is a measure of blur and is defined to be equal to the difference in the normalized edge response 0.5 pixels to either side of an edge. In a perfect image where a completely black area is adjacent to a completely white area, the pixel on one side of the edge has a luminance of one whereas the pixel on the other side has a luminance of zero. In reality, blurring of the black and white portions occurs in the vicinity of the edge. Edge analysis is conducted on real images to ascertain values of relative edge response (RER) for actual sensors.

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Overshoot

Overshoot: the introduction of artifacts, such as halos, through excessive use of a digital process to make images appear better by making edges sharper

Original Image



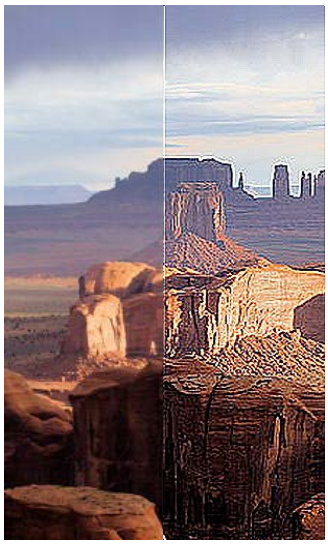
Sharpened Image



Observe that the bottom image has been "brightened" by a digital process (MTF correction)

Source: Imatest
(http://www.imatest.com/docs/MTF_appearance.html)

Original | Over-sharpened



Overshoot is due to excessive use of a digital process to sharpen imagery at edges (MTF compensation). It is defined to be the value of the peak normalized edge response in the region 1-3 pixels from the edge, unless the edge is monotonically increasing in that range, in which case, it is defined as the edge response at 1.25 pixels from the edge. This term partially offsets the improvement in NIIRS that a really sharp edge response provides.

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Imaging EO/IR Systems Summary

- The effectiveness of imaging systems can be degraded by many factors, including limited contrast and luminance, the presence of noise, and blurring due to fundamental physical effects.
- MTF is a mathematical description of image blur and can be broken into each component of the sensing, such as optics, detector, atmosphere, and display, providing insight into the sources and magnitude of image degradation.
- The Army NVESD maintains models for predicting image quality based on the TTP metric, the successor to the Johnson criteria, rules of thumb for the number of bar pairs required on target to have a 50-percent probability of detecting, recognizing, or identifying the target.
- The strategic intelligence community uses NIIRS to evaluate the quality of still imagery.
  - NIIRS is a qualitative scale, running from 0 to 9.
  - Tables are published associating rating levels with tasks for EO, IR, SAR, civil imagery, multi-spectral, and video.
  - NIIRS can be estimated by the GIQE, an empirical model that has been designed to predict NIIRS from sensor system characteristics.

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D. Tracking

Tracking Point Targets (1)

- **Point trackers are used, e.g., to track missile launches or in infrared search and track systems.**
- **Although different algorithms are used to implement a tracker, they all go through the same basic steps:**
  - **Track Initiation**
  - **Detection-to-Track Association (or Data Association)**
  - **Track Smoothing**
  - **Track Maintenance.**
- **Track initiation is the process of creating a new track from an unassociated detection.**
  - **Initially all detections are used to create new tracks, but once the tracker is running, only those that could not be used to update an existing track are used to start new ones.**
  - **A new track is considered tentative until hits from subsequent updates have been successfully associated with it.**
  - **Once several updates have been received, the track is confirmed.**
    - **During the last N updates, at least M detections must have been associated with the tentative track (M=3 and N=5 are typical values).**
  - **The driving consideration at this stage is to balance the probability of detection and the false alarm rate.**

Trackers are designed to follow the position of a target by responding to its emitted or reflected radiation. Most EO/IR tracking systems contain the following components:

- A sensor that collects radiation from the target and generates a corresponding electrical signal
- Tracker electronics that process the sensor output and produce a tracking error signal
- An optical pointing system (e.g., a gimbal) that allows the sensor to follow target motion
- A servo and stabilization system to control the gimbal position.

Examples of point target trackers include systems to track missile launches and infrared search and track systems. Many different algorithms are used to implement a point target tracker. Although different, they all involve the same basic steps:

- Track Initiation
- Data Association
- Track Smoothing
- Track Maintenance.

Track initiation involves creating a new track given a new unassociated detection. Initially all detections are used to create new tracks, but once the tracker is running, only those hits that could not be associated with an existing track are used to start new tracks. A new track is considered tentative until hits from subsequent updates have been

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successfully associated with it. Tentative tracks are typically not shown to the operator to prevent potential false tracks from appearing on the screen. This, of course, causes some delay in first reporting a track. Once several updates have been received, the track is confirmed. The most common criterion for promoting a tentative track to a confirmed track is the so-called "M-of-N rule," which states that during the last N updates, at least M plots must have been associated with the tentative track (M=3 and N=5 are typical values). The driving consideration at this stage is to balance the probability of detection and the false alarm rate.

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Tracking Point Targets (2)

- **In the data association step, the tracker must determine which hits should be used to update which tracks.**
  - **A given hit may be used to update one track, or a hit can be used to *tentatively* update several tracks.**
  - **The latter approach recognizes the uncertainty surrounding to which track the detection belongs.**
  - **This produces multiple versions of each track which are eventually "pruned."**
- **Data association can be done in a number of ways:**
  - **By defining an "acceptance gate" around the current track location and then selecting either the closest hit in the gate to the predicted position, or the strongest hit in the gate.**
  - **Statistical approaches that choose the most probable location of a hit can also be used.**
- **In the track-smoothing step, the latest track prediction is combined with the associated hit to provide a new estimate of the target location.**
  - **Algorithms of differing complexity and computational load can be used, including alpha-beta trackers, Kalman filters, and multiple hypothesis tracking.**
- **Track maintenance involves deciding whether to terminate a track.**
- **Common approaches include:**
  - **If the target was not seen for the past M consecutive update opportunities**
  - **If the target was not seen for the past M out of N most recent update opportunities**
  - **If the target's track uncertainty has grown beyond a certain threshold.**

In the data association step, the tracker must determine which hits should be used to update which tracks. This is a trivial exercise in the case where only a single target is being tracked. For those cases in which multiple targets are being tracked, a given hit may be used to update one track, or it can be used to tentatively update several tracks, recognizing that uncertainty exists in knowing to which track the detection actually belongs. This produces multiple versions of each track that are eventually "pruned." Either way, the first step in the process is to update all the existing tracks by predicting their new position based on the most recent state estimates (e.g., position, heading, speed, acceleration, etc.) and the assumed target motion model (e.g., constant velocity, constant acceleration, etc.). Having updated the estimates, it is possible to try to associate the new detections to the existing tracks. Data association can be done by defining an acceptance gate around the current track location and then selecting either the closest hit in the gate to the predicted position, or the strongest hit in the gate. Alternatively, statistical approaches that choose the most probable location of a hit can also be used.

Once a hit has been associated with a track, the next step involves combining the track prediction and the associated detection to generate a new estimate of the target's location, as well as to provide a revised estimate of the errors in this prediction. A variety of algorithms can be used for this process, including:

- Alpha-beta tracker
- Kalman Filter
- Multiple hypothesis tracker (MHT)
- Interacting multiple model (IMM).

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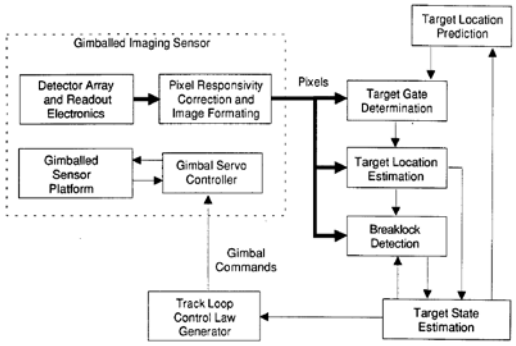
The track maintenance step involves deciding whether to terminate a track. If a track was not associated with a hit during the data association phase, there is a chance that the target may no longer exist. Alternatively, however, the sensor may simply have failed to see the target at that update, but will find it again on the next one. Common approaches to deciding on whether to terminate a track include:

- If the target was not seen for the past M consecutive update opportunities (typically M=3 or so)
- If the target was not seen for the past M out of N most recent update opportunities
- If the target's track uncertainty has grown beyond a given threshold.

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Tracking Extended Targets (1)

- **Image-based trackers are used, e.g., to track mobile objects (cars) on the ground (ISR) or for aim point selection.**
- **The target is initially located either by a human operator viewing a display or by some form of automatic target recognition system.**
- **After the target is acquired, the tracking system locks on to it and maintains LOS autonomously.**
- **A feedback control loop (the track loop) continuously adjusts the gimbal to keep the target in the center of the sensor's field of view.**



  - **Target location estimation analyzes the sensor's imagery to determine the position of the target in sensor coordinates.**
  - **The target location estimate is usually computed on a small sub-image (the gate) to reduce the effects of clutter and noise and to reduce the processing requirements.**
  - **Having estimated the target's location, the processor generates the gimbal commands to correct the sensor's LOS.**
  - **The sensor generates a new video stream and the process repeats.**

Image-based trackers are used to track mobile objects on the ground (e.g., in ISR missions) or for aim point selection. Like point target trackers, image-based tracking systems include a sensor, tracker electronics, and an optical pointing assembly. With image-based trackers, a human operator initially locates the target by viewing a display. After the target is acquired, a feedback control loop (the track loop) continuously adjusts the gimbal to keep the target in the center of the sensor's field of view.

A generic tracking system is illustrated in this chart. Imagery from the sensor is passed to the track processor. The target location estimation process analyzes the imagery to determine the position of the target in sensor coordinates. This is done on a small sub-image (the gate) to reduce the effects of clutter and noise and to reduce the processing requirements. Having estimated the target's location, the processor generates the gimbal commands to correct the sensor's line of sight (LOS). The sensor then generates a new video stream and the process repeats.

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Tracking Extended Targets (2)

- **No universal tracking system exists that can meet performance requirements specified for all applications.**
- **Common Tracker types (target location estimation) include:**
  - **Edge Detection Trackers: Identifies points in the image where the brightness changes abruptly thereby defining edges of the target**
  - **Centroid Trackers: Determines target aim point by computing the geometric centroid of the target**
  - **Area Correlation Trackers: Compare patterns via an autocorrelation function to develop an error signal**
  - **Moving Target Indicators (MTI): Subtracts the present video frame from the preceding one to isolate moving targets**
  - **Multi-mode Trackers: Combine point, area, and MTI schemes together as necessary**
  - **Feature Based Trackers: the most current trend in advanced tracker development.**
- **General Lock-on Requirements include**
  - **Signal-to-Noise Ratio**
  - **Signal-to-Clutter Ratio**

  Determine fundamental performance limits
  - **Contrast**
  - **Pixels on Target**

  Set by designer to achieve more stable tracking in clutter
- **Kalman filtering can provide optimum position estimate in noisy environments.**
  - **Often used in trackers required to follow maneuvering airborne targets from high performance aircraft platforms.**

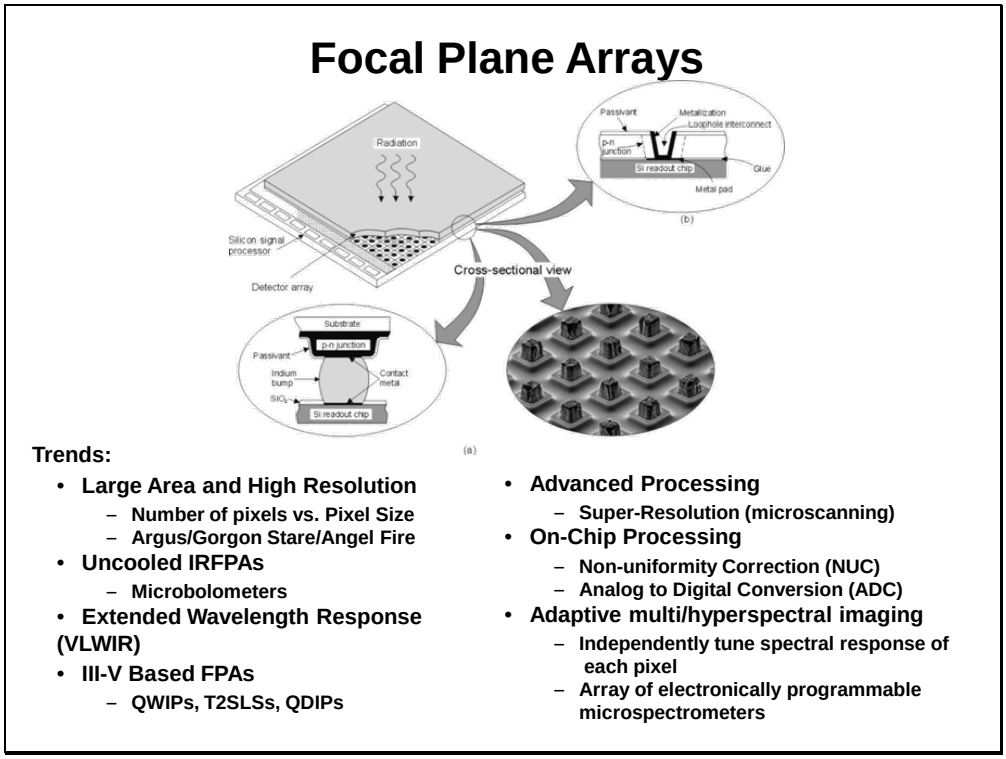
The heart of the tracker is in the feedback control loop or the track loop. Common image-based tracker algorithms include: edge detection, centroid tracking, area correlation tracking, moving target indicators (MTIs), multi-mode trackers, and feature-based algorithms.

Tracking Summary

- Examples of point target trackers include systems to track missile launches and infrared search and track systems.
- Many different algorithms are used to implement point trackers. Although different, they all involve the same basic steps: track initiation, data association, track smoothing and track maintenance.
- Image-based trackers are used to track mobile objects on the ground (ISR missions) or for aim point selection.
- Usually with image-based trackers, a human operator initially locates the target by viewing a display.
- After the target is acquired, a feedback control loop (the track loop) continuously adjusts the gimbal to keep the target in the center of the sensor's field of view.
- Common image-based tracker algorithms include: edge detection, centroid tracking, area correlation tracking, MTIs, multi-mode trackers, and feature-based algorithms.

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E. Latest Trends in Sensors



Driven by missions such as Persistent Surveillance, an important recent trend in EO/IR sensors is the development of large-area, high-resolution cameras. For sensors operating in the visible band, this is simpler than for those operating in the mid-wavelength infrared (MWIR) or long-wavelength infrared (LWIR) bands. In the visible band, silicon can be used for both the sensing material and for readout electronics. This eliminates issues such as the potential thermal mismatch between the two. For EO systems it is also possible to group individual cameras together and then combine the separate images into one. The current state of the art in MWIR focal plane arrays (FPAs) is roughly 4,000 by 4,000 detectors; for LWIR FPAs, it is closer to 2,000 by 2,000. The ARGUS sensor being developed by DARPA has over 2 gigapixels.

To reduce the amount of thermally generated noise in LWIR FPAs, these cameras operate at low temperatures. The required cryogenic equipment has important Size, Weight, and Power (SWaP) implications at the system level and can affect system reliability. For some applications, a small lightweight camera that does not consume much power is required. To address this need, considerable effort has gone into the development of uncooled sensors. A recent NVESD program to develop uncooled microbolometers with detectors as small as 17 μm and array formats as large as 1024 x 768 is addressing the tradeoff between device sensitivity and temporal response. The goals of the program are a sensitivity of 35 mK and a time constant of 10 ms.

The detector material of choice for LWIR applications is mercury cadmium telluride (HgCdTe). The spectral band of these devices is determined by adjusting the

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composition of the material, which can be difficult for longer cut-off wavelengths. An alternative approach involves the use of so-called superlattices of III-V semiconductors. This device structure consists of alternating layers of, e.g., gallium arsenide (GaAs) and aluminum gallium arsenide (AlGaAs). For these compounds, the spectral cut-off wavelength is changed by altering the layer thickness, which can be done very precisely.

In the past, sensor performance was limited by detector quality, due to detector material and fabrication. The improvement in these areas has reached the point where future gains in system performance will be achieved through advanced processing techniques. One such technique is known as super-resolution. The objective of super-resolution is to increase the spatial resolution of the sensor without physically altering the optics or focal plane. The technique involves the use of successive frames from a spatially under-sampled imager to process and construct a higher-resolution image. A number of fielded systems incorporate this concept to improve range performance. An example is the Lockheed Martin's Hawkeye system. This system is gimbaled and includes an indium antimonide (InSb) MWIR FLIR. The super-resolution algorithms result in range performance improvements of the order of 20 percent to 40 percent, depending on which optical field of view (FOV) the system is using. The Northrop Grumman LITENING AT pod also utilizes similar algorithms in an application for tactical jet aircraft targeting pods.

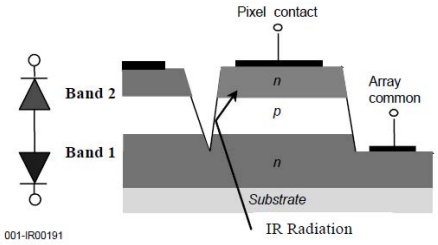
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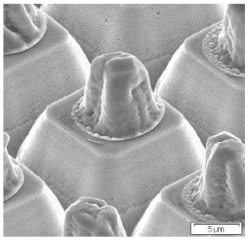
Army Third Generation FLIR

Third-Generation imager specifications

Array format		1280 x 720
Full Frame Rate		60 Hz
Window frame rate (64 x 64)		480 Hz
F/#		F/2.5 and F/6.0
Pixel pitch		20 μm
Spectral Band-pass	LW:	7.8-10.5 μm
	MW:	3.4-5.0 μm
NEΔT @ F/6.0, 300K	LW:	35 mK
	MW:	35 mK
NEΔT @ F/2.5, 300K	LW:	25 mK
	MW:	25 mK
Dynamic Range		>78 dB
Scene temperatures		227K to 360K
Operating temperature		>80 K

- **Benefits of Gen 3 FLIR**
  - **Better day signatures (MWIR band)**
  - **Better transmission (always have the best band)**
  - **Better countermeasure rejection (against single band lasers)**
  - **Longer range identification (NFOV MWIR Channel)**
  - **Faster Search (WFOV LWIR has shorter integration time)**
  - **Less Motion Smearing (LWIR has shorter integration time)**
  - **Wider Dynamic Range (LWIR channel has more sensitivity)**
  - **Opportunity for Multi-color fusion**
- **Disadvantages of Gen 3 FLIRs**
  - **Increased Cost and Complexity**
    - **Two-color FPAs**
    - **Dual cold shield design**
    - **Dual channel optics**
    - **More signal processing**

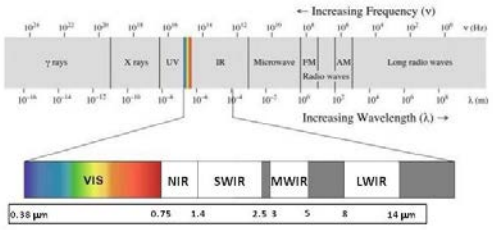




An example of a proposed system that incorporates many of the developments described on the preceding chart is the Army's third-generation FLIR. The FPA is a large format (1280 x 720) staring array with a detector pitch of 20 μm. In addition, the device architecture, which is shown above, allows operation in both the MWIR and the LWIR spectral bands. The system has a dual F/# optical system (F/2.5 and F/6.0). The key advantage of two-color imaging infrared focal plane arrays (IRFPAs) is the ability to more easily detect and identify obscured targets in cluttered backgrounds. Other advantages are listed above. These come at the expense of increased cost and complexity.

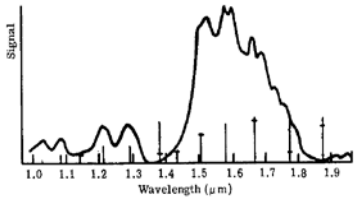
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SWIR Imagers (1)



The infrared spectrum





- Radiance of the night sky
  - The origins and expected intensities of hydroxyl (OH) are shown by the vertical lines

- Military Applications of SWIR Imaging
  - Low Light / Night Vision Imaging
  - Detection of Laser Designators
  - Covert Laser Illumination
  - Laser Gated Imaging
  - Threat Warning Detection
  - ISR
  - Covert Tagging
- Size, Weight and Power

As discussed on page 7, the infrared portion of the electromagnetic spectrum is generally subdivided into numerous bands, including the near-infrared (NIR), the short-wavelength infrared (SWIR), the mid-wavelength infrared (MWIR), the long-wavelength infrared (LWIR), and the very long-wavelength infrared (VLWIR). The SWIR band extends from 1.0 μm to 3.0 μm and is defined by the carbon dioxide (CO_2) and water (H_2O) absorption lines at both the short- and long-wavelength ends of the band.

Radiation in the SWIR band is often referred to as “airglow” or “nightglow” and is non-thermal radiation emitted by the Earth’s atmosphere. Its spectral radiance is of the order of 1 μW/(cm2∗Sr∗μm) with a spectral distribution characteristic of molecular emission. The primary source of this emission was identified by A.B. Meinel in 1950 as rotation-vibration bands of the hydroxyl (OH) molecule.

Military applications of SWIR imaging include low-light/night-vision imaging, detection of laser designators, covert laser illumination, laser-gated imaging, threat-warning detection, ISR, and covert tagging.

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SWIR Imagers (2)



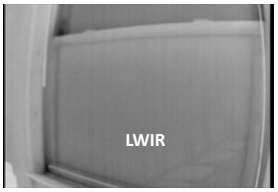


- An image of a hotel in haze (range = 2.4 km)
- Scattering due to haze primarily affects visible systems, scattering due to fog and dust can affect both visible and IR radiation.
- Which band performs better in a given situation depends on the details of the aerosol present.





- SWIR sensors rely primarily on reflected radiation similar to visible cameras.
- SWIR cameras produce finer resolution than imagers operating in the LWIR.
- This can lead to improved target ID.
- SWIR imagers can be combined with illuminators for imaging inside buildings and caves.





- Most glass is opaque for $\lambda > 3.5$ μm.
- Glass windows are transparent in the SWIR band but not in the LWIR.
- Some transparency in the MWIR but poor optical transmission degrades the image.
- This is significant operationally but also has significant system implications.

Image Sources: Goodrich Corp., and Sensors Unlimited, Inc., "The Advantages of SWIR Imaging," http://www.sensorsinc.com/images.html; *Photonics Spectra* magazine

The frequency range where light scattering is most prominent depends upon the size of the particles/aerosols doing the scattering. Haze refers to obscuration of the lower atmosphere due to particles/aerosols in the 0.01 – 0.1 μm size range. For fog and dust, the particles/aerosols are larger; typically, 0.5 – 100 μm for fog and 1 – 100 μm for dust.

The ability of a SWIR camera to image through haze is illustrated in the top two figures, which show both a visible and a SWIR image of a hotel in haze at a range of roughly 2.4 km. The image was taken in late afternoon before dusk about 150 feet above the ground. As can be seen, the hotel is barely discernible in the visible, but is relatively clear in the SWIR band. The reason for this difference is that, in hazy conditions, the scattering efficiency for visible light is much higher than it is in the SWIR band; consequently, the longer wavelengths of the SWIR band transmit more readily.

Sensors operating in the SWIR spectral region detect differences in ambient light reflected from the target and background, similar to a camera operating in the visible. Thus a SWIR image looks much more like a visible image than does one produced by a thermal imager. This is illustrated in the middle pair of figures above. These figures also show the increased resolution possible with a SWIR camera compared to that with a long-wavelength infrared imager. This increased resolution, in turn, leads to improved target identification.

Optical glasses are transparent to light with wavelengths from around 0.2 to 3.5 μm. The optical transmission then goes to zero and stays at zero through the LWIR and very long wavelength infrared (VLWIR) spectral regions. This poor transmission is a result of strong absorption due to the presence of water and hydroxyl ions. Thus glass windows are not transparent in the LWIR but are in the SWIR spectral band. With some MWIR

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cameras, it is possible to see through glass, but the poor optical transmission significantly degrades the image. The difference between the LWIR and SWIR spectral bands in terms of their ability to image through glass is illustrated in the bottom pair of figures. This is important not only from an operational point-of-view where it is often necessary to image into and out of windows, windshields, etc., but it also has significant system implications. The fact that standard glass optics and lenses can be used in the SWIR band is an important advantage in terms of cost and complexity compared to both MWIR and LWIR, which require optical systems that use more exotic materials such as germanium (Ge) and sapphire (Al_2O_3).

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Multi-Spectral and Hyper-Spectral Sensors (1)

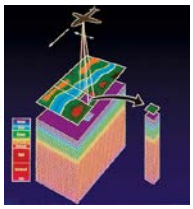
- **Multi-spectral and hyper-spectral sensors offer more than red, green, and blue.**
  - **Multi-spectral typically means up to 8-12 bands,**
  - **Hyper-spectral > 50 bands,**
- **For multi-spectral systems, the bands are chosen with very specific applications in mind.**
  - **Chlorophyll, algae, sediment**
  - **Oil spills, fire detection**
- **For hyper-spectral systems, custom band choices may be offered.**
- **Multi-spectral and hyper-spectral sensors typically scan across the direction of flight.**
- **If the number of bands is small, 5-8, pushbroom scanners can be used.**



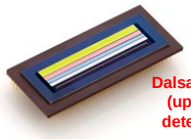
AMS Bands	Band Edges
1 VIS	0.43 – 0.47 um
2 VIS	0.48 – 0.52 um
3 VIS	0.52 – 0.56 um
4 VIS	0.56 – 0.62 um
5 VIS	0.62 – 0.68 um
6 NIR	0.68 – 0.76 um
7 NIR	0.76 – 0.88 um
8 NIR	0.88 – 1.05 um
9 MWIR	3.0 – 5.4 um
10 LWIR	8.5 – 12.5 um

Argon Enhanced Airborne Multispectral Scanner
(0.6 mr IFOV)





Argon Airborne Hyperspectral Scanner
(1.25 or 2.5 mr IFOV)



Dalsa 5-band chip
(up to 12,000+
detectors wide)

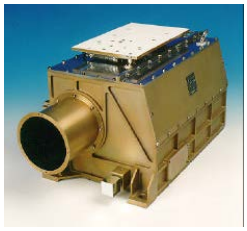
Multi-spectral sensors produce images with a few discrete and somewhat broad spectral bands, e.g., Vis, NIR, MWIR, and/or LWIR. Hyper-spectral sensors, on the other hand, collect image data simultaneously in dozens or hundreds of narrow, adjacent spectral bands. These measurements make it possible to derive a continuous spectrum for each image cell. So a sensor with only 20 bands could also be hyper-spectral if it covered the range from 500 to 700 nm with 20 bands each 10 nm wide. A sensor with 20 discrete bands covering different parts of the Vis, NIR, SWIR, MWIR, and LWIR spectra would be considered multi-spectral.

Hyper-spectral sensors collect information as a set of images, one for each spectral band. These spectral images are then combined and form a 3D hyper-spectral data cube for processing and analysis – in other words, the spatial data are in the XY plane; the spectral data, the Z-axis. These systems typically have only moderate spatial resolution in each of up to 200 spectral sub-bands, with each spectral sub-band having a width of about 10 nm.

Hyper-spectral images are produced by instruments called imaging spectrometers. The most common approach to creating a hyper-spectral data cube takes advantage of 2D FPAs. The camera first maps an image strip onto a row of pixels on the FPA. Each pixel in this row is simultaneously spread into a Z column of spectral data and then that (spectral) frame is read. Then the imager scans to the next row. This is repeated until a 2D spatial image (in the X-Y plane) is built up. Thus, for example, a 320 x 240 array could capture 320 spatial pixels with 240 spectral sub-bands associated with each pixel. The point of obtaining an image cube is to allow one to compare the spectral intensity plot obtained from each pixel with a stored library of spectral reflectivity data.

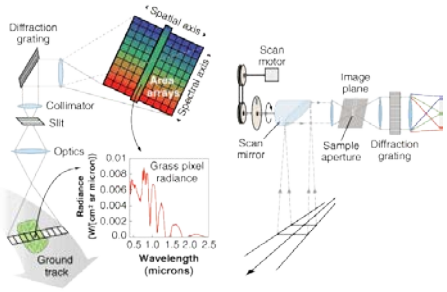
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Multi-Spectral and Hyper-Spectral Sensors (2)



- **VIMS is located on the Cassini Orbiter to provide 2D hyperspectral high resolution images to study Saturn's rings.**
- **VIMS makes use of a reflective telescope and pushbroom imaging with a pointable primary mirror.**
- **The spectral range is from 325 to 1025 nm, with spectral resolution of 1.46 nm.**

- **The objective is to allow one to compare the spectral intensity plot obtained from each pixel with a stored library of spectral reflectivity data.**
- **Challenges remain:**
  - **Atmospheric transmission correction**
    - **Altitude Dependency**
    - **Supporting Meteorological Instrumentation**
    - **Measurement Latency**
  - **Database development**
    - **Material Spectra Libraries**
    - **Weathering Effects on Materials**
    - **Possible CMs (design camouflage materials that match the background)**



Military systems are largely focused on the SWIR spectral band for two reasons. First, most materials have high reflectivities in this region, and their reflectivity spectra differ strongly due to material-dependant molecular-absorption bands. Second, the strong solar illumination available during the day provides the very high signal levels needed to achieve an adequate SNR given the lack of light when working in very narrow spectral bands.

Numerous hyper-spectral data collection systems have been developed – most designed for airborne usage, but some are satellite mounted. Much of the development work in this area is in the field of remote sensing. A typical system might have 200 spectral bands each with 10-nm spectral resolution. In addition, the system might may have 1 mrad spatial resolution and provide a 50 to 70 degree sweep. For systems operating in the SWIR band, the FPA is typically InGaAs or HgCdTe while those operating in the MWIR band use HgCdTe or InSb FPAs.

The primary advantage to hyper-spectral imaging is that, because an entire spectrum is acquired at each point, the operator needs no prior knowledge of the sample, and post-processing allows all available information from the dataset to be mined. Hyper-spectral imaging can also take advantage of the spatial relationships among the different spectra in a neighborhood, allowing more elaborate spectral-spatial models for a more accurate segmentation and classification of the image.

The primary disadvantages are cost and complexity.

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Latest Trends Summary

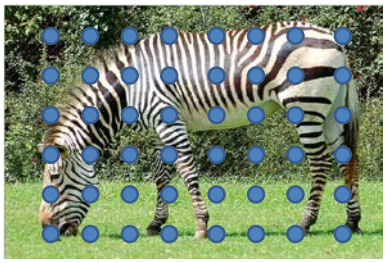
- Missions such as persistent surveillance are driving the need for high resolution sensors with extremely large FOVs.
- Uncooled microbolometers with detectors as small as 17 μm and array formats as large as 1024 x 768 will be important for applications with difficult SWaP constraints.
- The use of so-called III-V superlattices, such as AlGaAs/GaAs, allow one to change the spectral response of the device by changing the layer thickness.
- Because detector materials are operating close to theoretical limits, future gains in system performance will be achieved through advanced processing, such as super-resolution.
- The SWIR band extends from 1.0 μm to 3.0 μm and is defined by the CO_2 and H_2O absorption lines at both the short- and the long-wavelength ends of the band.
- Radiation in the SWIR band is often referred to as “airglow” or “nightglow” and is non-thermal radiation emitted by the Earth’s atmosphere.
- Military applications of SWIR imaging include low-light/night-vision imaging, detection of laser designators, covert laser illumination, laser-gated imaging, threat-warning detection, ISR, and covert tagging.
- Hyper-spectral imaging allows one to simultaneously gather both spatial and spectroscopic information for more accurate segmentation and classification of an image.

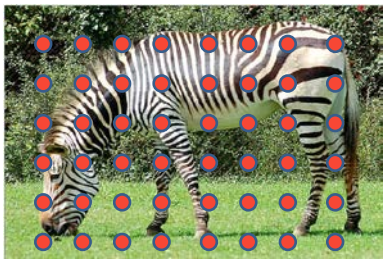
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F. Sampling, Aliasing, and Reconstruction

Background

- **Most modern sensors are "sampled" producing an array of numbers that represent an image (like the CD representation of music).**
- **This is in contrast to older technologies, such as film or image intensifiers (both still used), which represent the image continuously (like a vinyl LP or audio tape).**
- **Because the (at least conceptually) continuous image is sampled, the data depend on the placement of the samples, or the "phase" of the samples as shown in the figures below: the blue and red circles denote different possible samplings of the image.**
- **The image artifacts produced by the sampling are collectively referred to as "aliasing."**





GSD, the distance on the ground between samples, is often used as shorthand for the resolution and hence performance of a digital system. Although the resolution is usually not far from the GSD, this over-simplifies the problem. For example, if the system is *unaliased* (which is possible for sufficiently high sampling or sufficiently poor optics), the resolution will be poorer than the GSD. How much poorer will be determined by the optics and detector MTF. If the system is *aliased*, the resolution will be determined by how the aliasing affects task performance; it may be greater or lesser than indicated by the GSD.

It is commonplace to assert that spatial frequencies below the Nyquist limit will be accurately reproduced; although true for non-aliased systems, this depends on the task for aliased systems. In general, one may expect the probability of task performance will degrade as the Nyquist frequency is approached.

Similarly, the task may be able to be performed above the Nyquist frequency, but, in many cases, the performance continues to degrade as the frequency increases above Nyquist. Often, task performance is statistical: for some phases of the sampling, the task is performable; for others, not.

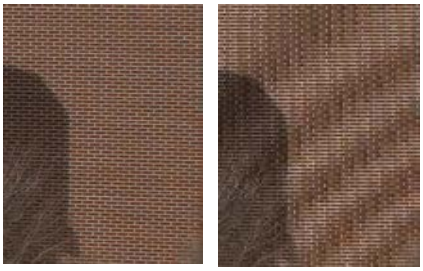
Finally, it is insufficient to compare the "characteristic dimensions" of the object of interest with the GSD. Real objects represent a range of spatial frequencies ranging above and below characteristic dimensions. A complete analysis must take this into account or be made in the spatial, not frequency, domain.

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How Does Aliasing Look?

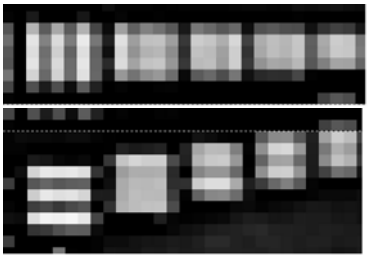
- **The Moiré pattern. The strong high spatial frequency information represented by the brick pattern produces a low-frequency oscillating pattern and distortions of the high-frequency pattern (brick shape).**

Unaliased versus aliased:



- **Interruptions of linear features: the telephone lines are intermittently revealed.**





- **Confusions of detail. The bar target consists of groups of 3-bars. Sampling effects can wipe out the pattern or even make it appear as a 2-bar pattern.**

The images above[8] illustrate what aliasing looks like in an image. The top left image shows an accurate, high-sample rate, depicting a very regularly patterned image. Each brick is clearly delineated and each brick is of the correct size. The top right image is down-sampled version of the one on the left. When sampling the brick, a sample may not land on the white mortar between bricks that define the brick's outline. The net result of such coarse sampling is the introduction of waves of alternating dark and light, termed a "Moiré pattern." The precise location of the bands depends on exactly how the samples fall; this is termed "phasing" of the samples.

A close examination of the image will also show apparent distortions of the apparent shapes of the bricks, which also varies depending on the position of the brick on the wall, which determines the phasing of the samples.

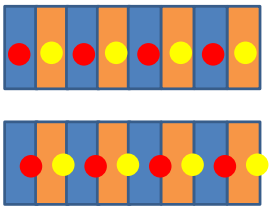
If the task is to determine the size and shape of the bricks or to confirm that each brick is the same size, then the task is severely affected by aliasing. If the task is to determine whether the wall is brick or cinder block, the task is not affected by aliasing at all.

[8] Source: Widipedia.

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Where does Aliasing come from?

- **In the figure**
  - **The red samples see a solid blue expanse.**
  - **The yellow samples see a solid orange expanse.**
  - **The answer depends on the *phase* of the samples:**
    if the samples were shifted, we might get brown with either the red or yellow samples.



- **At least in the first case, combining both red and yellow samples would provide a correct interpretation of the image (blue-orange-blue)**
  - **We can (usually) represent correctly anything with 2 samples per "cycle."**
  - **This is the folk version of the Nyquist theorem.**
- **Some of the effects can only be explicated by looking at the math.**

As noted several times in the preceding charts, *aliasing* is the result of sampling. The figure shows a blue-and-orange striped "target." If only the samples shown as red circles in the upper figure were included in the sampled data set, the image would be interpreted as being entirely blue; if only the samples shown as yellow circles were taken, the target would be entirely orange. The red and yellow samples differ only in their phase with respect to the pattern of the target.

For the phases in the top image, if one had both red samples and yellow samples, one would have correctly deduced that the target had blue and orange panels. This corresponds, in a quick-and-dirty version of the Nyquist sampling theorem, to having (at least) one sample per characteristic feature.

One needs, in general, to have more than one sample per characteristic feature. This is illustrated by the lower figure, which has the same number of samples (red and yellow) as the upper figure but for which the samples are shifted – they have a different phase. In this case, each sample overlaps an equal amount of blue and orange; the structure is again lost and the color distorted.

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Sampling and Reconstruction

- **All digital systems are sampled systems.**
  - **For a given continuous signal *g(x)*, there is a set of sample locations {x_m} and sample values $g_m = g(x_m)$.**
  - **The sample locations are typically (but not always) chosen to have a uniform spacing between samples.**
    $x_m = x_0 + m*S$ where S = sample separation and x_0 the initial phase
  - **The sampled signal could be represented as a series of delta functions or we can "reconstruct" the signal with smoother functions.**

$$g_{delta}(x) = \sum_m g_m S\delta(x - x_m) \qquad g_{reconstruction}(x) = \sum_m g_m h\,(x - x_m)$$

- **In the Fourier (frequency) domain, if the Fourier transform of the original signal *g(x)* is *G(f)* then (letting $x_0 = 0$ for convenience)**

$$G_{delta}(f) = \sum_{n=-\infty}^{\infty} G(f - nf_s) \qquad G_{reconstruction}(f) = H(f)\sum_{n=-\infty}^{\infty} G(f - nf_s)$$

  - **Where H(f) is the Fourier transform of the smooth reconstruction function.**
  - **The sampled signal consists of the original plus an infinite series of sideband copies of the original.**
  - **The reconstruction controls how one deals with the sidebands and is an important part of the evaluation of any sampled system.**

Digital systems are a subset of sampled systems. However, the digitization (quantization) is separable from sampling itself. Similarly, other techniques, such as fast Fourier transforms (FFT), although extremely useful for real-time processing, are irrelevant for the primary issues addressed in this series of presentations.

Digital signal processing emphasizes the direct manipulation of the digitized samples, transforming, for example, a N x N array of samples representing an image into another N x N array of modified samples. The emphasis here, in contrast, is on the continuous perspective.

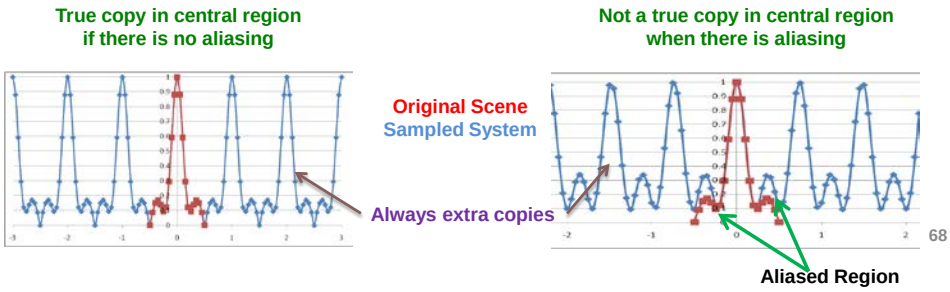
The samples are taken from a continuous function; the goal is to extract the most information possible from those samples (without introducing artifacts) about the continuous image. In addition, having, at least conceptually, reconstructed the original image, the image can be manipulated in a variety of ways using the wider range tools available for a continuous image. These manipulations include, but are not limited to, smoothly interpolating the image so that it can be added to other images or corrected for various image distortions.

These manipulations may actually be done (indeed, *must* be done in practice) by digitally manipulating another array of data that is larger than the original array (MN x MN). However, the manipulations can be represented theoretically by smooth transformations, and the re-digitization needed to perform the calculations is a logically separate part.

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Unaliased and Aliased Systems

- **In the most desirable case, the original signal is separated from the copies. This is the *unaliased* case. The original information is present and, in principle, recoverable.**
  - **This requires that the original signal, *G(f),* is band-limited with a maximum frequency, f_{max} : and that the sample rate is sufficiently high.**
  - **The sampling rate must be twice the maximum frequency to keep the copies from overlapping.**
  - **The Nyquist frequency is defined as ½ the sampling rate.** $f_{\max} < f_s / 2 = f_{Nyquist}$
- **When these conditions do not apply, the copies will overlap: the region of overlap is the aliased part of the frequency domain.** $f_{\max} > f_{Nyquist}$
  - **Moiré patterns and other sampling anomalies are now inevitable.**



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No signal with finite support (so no real image in a camera) is literally band-limited. However, within the approximation that there is an effective maximum frequency, f_{max}, a particular input frequency, f_{input}, is unaffected by the aliased sidebands if $f_{max} < f_s /2$. If $f_{max} < f_s$, some region of frequencies is unaliased. This is important for some applications. For example, in point target detection (such as missile launches), the source image on the focal plane is determined by the optical blur of the system so that, if the system is not too aliased (meaning that the blur circle is not too small), the blur will cover more than one detector. It is therefore possible to estimate (if the background clutter and noise are not too high) the target's location by a suitable average of the different sample values.

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Ambiguity in Aliased Systems

- **If the system is aliased, with $f_{max} > f_{Nyquist} = 1/2S$, the sampling itself is ambiguous: the samples cannot distinguish between frequencies above Nyquist and frequencies below Nyquist**
  - **Samples at x= m*S**
  - **Let $f_{+/-} = f_{Nyquist}$ +/- *df***

  For $g(x) = A\cos(2\pi f_+ x) + B\cos(2\pi f_- x)$

  the sample values, g_m, are given by:

  $$g_m = (-1)^m (A+B)\cos(2\pi m S \delta f)$$

  the samples cannot distinguish between the higher and lower frequency.
- **The delta-function reconstruction gives equal weight to f_+ and f_-**
- **Non-trivial reconstructions address the ambiguity by trying to assign relative weights to the higher ($f > f_{Nyquist}$) and lower frequencies ($f < f_{Nyquist}$).**
  - **Most reconstructions favor the lower frequencies.**
  - **In some cases, the higher frequencies might be the real ones!**
- **There is no absolute theoretical approach to take: it will depend on the task.**

It is commonly stated that frequencies higher than Nyquist "cannot" be represented and that frequencies below Nyquist can be reliably represented. Both statements are over simplifications. Even in the unaliased case, a correct statement of the sampling theorem is that, if the original signal lies entirely in one interval [M $f_{Nyquist}$, (M+1) $f_{Nyquist}$], then it can be perfectly reconstructed.

If the signal was known to consist entirely of frequencies above Nyquist, then the frequencies below Nyquist should be eliminated.

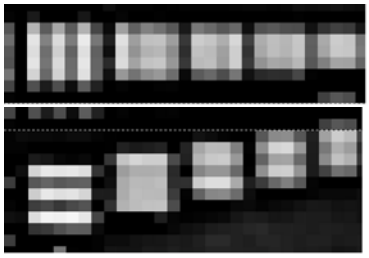
The problem is that frequencies above and below Nyquist produce the same samples for cosines and samples differing only by an overall phase for sine terms.

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Aliasing in Imaging Systems

- **The challenge in understanding aliasing in imaging systems is the conflict between two extremes (using the staring focal plane design case).**
  - **The useful MTF might extend to the first zero of the detector MTF = 1/d.**
  - **The Nyquist limit = 1/2d.**
- **A factor of 2 difference exists in these two naive estimates of performance, which could correspond to a 2X difference in range.**
- **The performance usually lies between these two limits: the "correct" performance estimate depends on the task to be performed (or the test to be executed).**
  - **In the left figure, both the phone lines and the truck grill show signs of aliasing, but no problem of interpretation occurs because information is sufficient.**
  - **In the right figure, aliasing confuses image interpretation.**

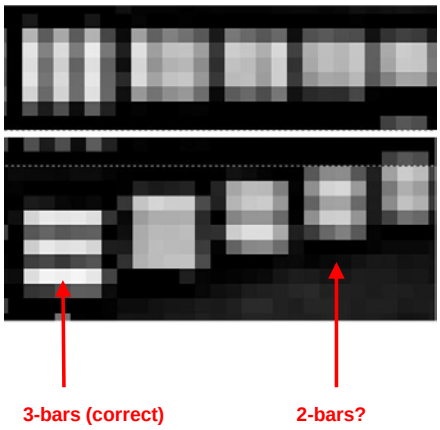




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Digital Image of a Calibration Target

- **Digital images can be hard to interpret at the limits of resolution.**
- **Naively, we might think the resolution task corresponds to one pixel on a white bar, the next pixel on the black space, and so on.**
  - **But a *bar group* of a calibration target has a wide frequency range.**
  - **3 rectangular bars do not make a sine wave.**
- **The left most image of a bar group corresponds to the naive resolution case: detector width, W = sample spacing, S = bar size**
- **Remaining images are quite bizarre**
  - **These represent cases where W = S > Bar**
  - **Equivalently, the notional bar group frequency (1/(2 Bar)) > ½ S**
  - **We are "past Nyquist," *in the aliasing region***



Depending on the task we can still "resolve"

The model will distinguish between the detector width, W, and the sample spacing S. For the standard staring sensor, S=W. The image depends on the relationship between S and W and the width of a bar in the bar group, B.

The naive Nyquist theorem would suggest that the target should be resolvable if the sample distance is less than the bar width: S < B. However, this leaves open the question of how good task performance will be "beyond Nyquist" when S > B.

The question is complicated by the fact that a bar target is not a pure sine wave with wavelength 2B; it is a combination of many frequencies both above and below Nyquist. A simple frequency-based threshold will not address the question.

As indicated in the figure, the 4th horizontal bar group could be interpreted as a resolved 2-bar bar group. The task definition determines whether or not this bar group should be considered to be resolved.

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Task Definition

- **For simple tasks, one can construct a model of task performance.**
- **Consider defining resolution for bar targets.**
  - **The result will depend on whether 2-bar, 3-bar, 4-bar, etc., targets are used.**
  - **The system output is examined to see if it produces the anticipated up-down-up pattern of a 2-bar target or up-down-up-down-up of 3 bars.**
  - **The task can be varied by asking whether or not the pattern has to be completely clearly seen: should we define task completion as seeing 3-bars and 2 spaces for a 3-bar target, or seeing at least one clear space?**
- **This may seem artificial, but it represents a range of possible tasks and can be computed explicitly.**
- **The following charts show the probability of task performance as a function of how much *higher* than the Nyquist limit one tries to go.**
  - **Depends on the MTF of the system (detector MTF and optics MTF).**
  - **For some sample phases, the task can be performed; for others, it cannot.**
- **In general, performance above Nyquist is stochastic: for any task and frequency above Nyquist, there is some probability of performing the task.**
  - **With multiple opportunities (as in video) or with redundant information (the truck grill), the Nyquist limitation can be overcome.**

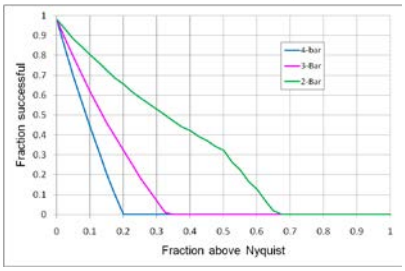
Allowing an N-bar target to be called resolved when fewer than N bars can be counted may seem unusual. However, it is the basis of the MTDP figure of merit used in the German TRM3 model in the infrared case (proposed as a replacement for the MRT). It is based on the perception of the standard four-bar test pattern but accepts that fewer than four bars are resolvable beyond the Nyquist frequency.

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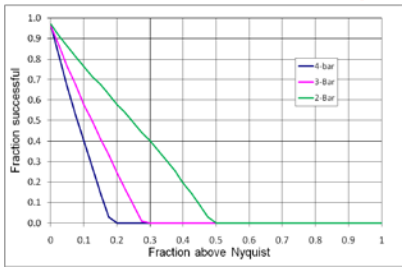
Results

- **Basic tasks of resolved 2-bar, 3-bar, and 4-bar targets (seeing all bars and spaces).**
- **For all tasks, the probability of task performance is 100% at and below Nyquist, but declines as the frequency increases.**
  - **The left chart shows results with "perfect" optics (using the detector MTF only).**
  - **The right chart adds "matched optics" MTF (with optics MTF zero located at first detector zero).**
- **For matched optics and the 2-bar task, the average expected performance will be 1.25 x the Nyquist limit.**

Detector MTF only



Detector MTF and "matched optics"



Results depend on task definition and optics MTF, not just the sampling limit!

If the more exotic task definitions are used, the performance extends even further.

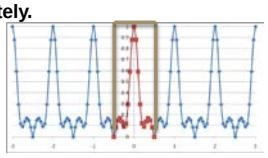
For matched optics, and the "see one space in a four-bar target" task, performance extends to 1.5 x Nyquist.

- 50 percent of the possible sample phasing will permit accomplishment of the task.
- If more than one image is available, giving more opportunities to succeed, even higher performance at higher spatial frequencies is possible.
- This is the source of "super-resolution" (better to say "super-sampling") techniques but also applies to video.

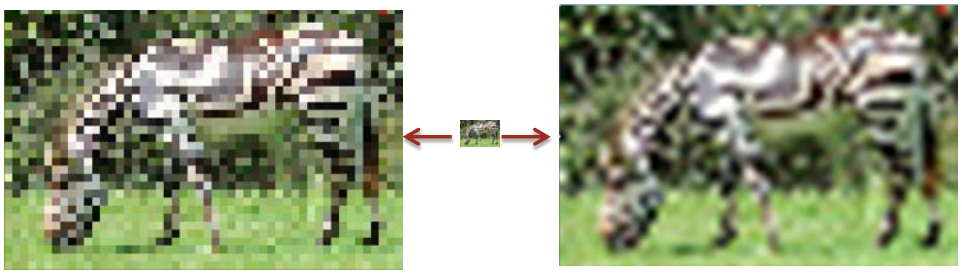
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Reconstruction

- **The reconstruction of an image (how it is displayed when there are more display pixels than image samples) has an effect on its interpretability.**
  - **For *unaliased* images, there is a unique best way to reconstruct an image.**
    - **Since the sidebands don't overlap, can filter sidebands completely.**
    - **Corresponds to using a sinc function (sinc(x)=sin(x)/x)) to interpolate between samples.**
  - **For *aliased* images, there is always some image ambiguity.**
    - **IDA document on best least squares fit (IDA Document D-4122).**
    - **In practice, cubic convolution interpolation frequently is a good choice.**



- **Reconstruction typically becomes an issue when images are examined at the highest resolution – when the image is zoomed**



Given a sampled system to be viewed by an observer or manipulated by an algorithm, the image must be *reconstructed* from the samples. The samples are only a list of numbers, not an image. Reconstruction can be done poorly and must be considered carefully to optimize the performance of the sensor. How reconstruction algorithms are designed depends on the sampling, detector, and optics.

There is some evidence[9] that the loss of performance due to sampling artifacts depends primarily on aliased sidebands at frequencies greater than Nyquist.

$$MTF_{sampled-system}(f) = MTF_{unsampled-system}(f/R); R = 1 - kSR_{out-of-band}$$

$$SR_{in-band} = \frac{\int_{-f_s/2}^{f_s/2} |\sum_{n\neq 0} MTF_{unsampled-system}(f - nf_s)H(f)|df}{\int_{-\infty}^{\infty} |MTF_{unsampled-system}(f - nf_s)H(f)|df}$$

$$SR_{total} = \frac{\int_{-\infty}^{\infty} |\sum_{n\neq 0} MTF_{unsampled-system}(f - nf_s)H(f)|df}{\int_{-\infty}^{\infty} |MTF_{unsampled-system}(f - nf_s)H(f)|df}$$

$$SR_{out-of-band} = SR_{total} - SR_{in-band}$$

[9] Ph.D. dissertation of Steven K. Moyer, Georgia Institute of Technology, as well as NVESD and Driggers, Vollmerhausen, and O"Kane, *J. Opt. Soc. Am. A*,Vol. 16, No. 5,May 1999.

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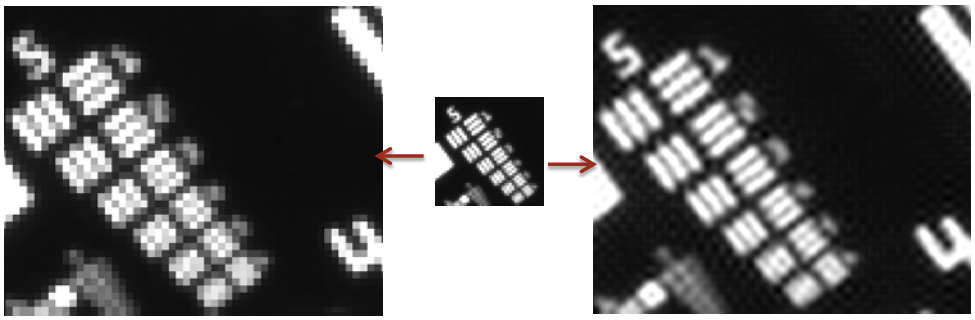
where *H(f)* is the Fourier transform of the reconstruction function. Using a reconstruction close to the sinc interpolation would significantly reduce the effects since the in-band spurious response would be zero. An IDA study[10] suggested that the least squares approach might provide an additional margin of performance (since the reconstruction is superior to the sinc reconstruction), but a complete human observers study has not been performed.

[10] *Wiener Interpolation Function for Aliased Imagery*, IDA Document NS-D-4122, October 2010.

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Zooming

- **In many practical cases, dealing with zooming is a matter of training.**
  - **Don't over-zoom: If "jaggies" appear, one has zoomed too far.**
  - **Jaggies represent unphysical information from the aliased signal sidebands.**
- **Why does the size matter?**
  - **One's eyes cannot see the jaggies unless one zooms: eyes act as reconstruction filters.**
- **A proper reconstruction can reduce the need for training and improve performance: performance on calibration targets can be improved 20%.**



Reconstruction appears most often in the context of zooming in on an image. Zooming implies that more than one display pixel is used for each sample, and therefore a reconstruction approach must be made, no matter whether the choice is apparent to the user. It is important to recall that the appearance of the image can depend on the size of the displayed image. The small image, for which the pixel boundaries are difficult to perceive, is more interpretable than the larger version of the same image. In the large version, pixilation (or jaggies) is very distracting if viewed directly especially for the 45-degree patterns shown. (The square pixel reconstruction is not compatible with the rotated image).

Experienced observers can be trained not to "over zoom." A general rule is to stop zooming *just* as jaggies become visible. However, the existence of jaggies at any zoom level is an artifact of the reconstruction approach. In the terminology of in-band versus out-of-band aliasing, jaggies, which are seen when over-zooming, are part of the out-of-band spurious response.

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System Trades: MTF versus Sampling

- **Reducing the overall MTF reduces contrast but also reduces the risk of aliasing artifacts.**



For a high sampling rate, the high MTF image is clearly the superior image.



High MTF/High Sampling Rate **Low MTF/High Sampling Rate**



For a low sampling rate, the low MTF image may be the more useful image.

Same reconstruction used on all 4 images



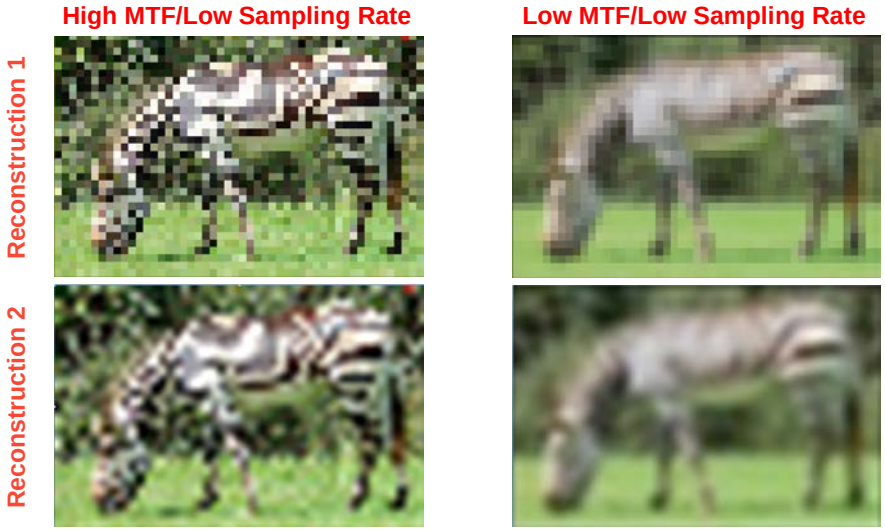
High MTF/Low Sampling Rate **Low MTF/Low Sampling Rate**

The effect is illustrated with the task of reading license plates. The high MTF when combined with a high sampling rate is the best image. However, if the sampling rate is lowered, the high MTF image has the higher contrast but the low MTF image is more readable.

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System trades: Reconstruction vs. MTF

- **These sensor trades depend on *how* the digital information is displayed.**



This section addresses the question of how digital samples should be represented in a final image. This is directly relevant for humans observing the image, but this can also matter if multiple images are to be combined. The images on the top row are low sample rate images with high and low MTF. In this case, the sample values are displayed (reconstructed) with more than one display pixel (pixel is a word for a "picture element" and properly should be used only in the context of the display of an image) for each sample. Each sample is represented by a small square of pixels, each having the same pixel value. This results in the appearance of "pixilation." The severe aliasing of the upper left image may lead to the lower MTF upper right image being preferred.

The second row uses the same sampled data and again represents each sample with more than one pixel. However, in this case, the pixel values are not the same for each pixel in the small square: they vary according to a reconstruction algorithm. The distracting pixelation effects are removed and the images may be more interpretable.

It is important to stress that the lower row is not "blurred" compared to the upper row. The appearance of sharp edges (particularly in the upper right), which may suggest higher sharpness, is an illusion. The sharp edges are an artifact of the "pixel replication" algorithm used to display the image and are not a real part of the image.

As the images show, choosing a reconstruction algorithm can be an important factor in image interpretability.

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Consequences

- **A complete MTF characterization and not merely Nyquist arguments are needed to evaluate the anticipated performance.**
- **Performance at frequencies below Nyquist are less likely to be disrupted by sampling effects, but can be (Moiré patterns are low-frequency artifacts produced by strong high-frequency content of the scene).**
- **Performance above Nyquist will define the ultimate limiting performance (maximum range at which any specified task can be performed).**
- **Performance may range from 1.25 to 1.5 x the Nyquist limit.**
  - **Multiple images (giving multiple looks) will extend performance.**
  - **Even single images with multiple effective sample phases may permit task performance.**
  - **Improvements may extend to 2 * Nyquist.**



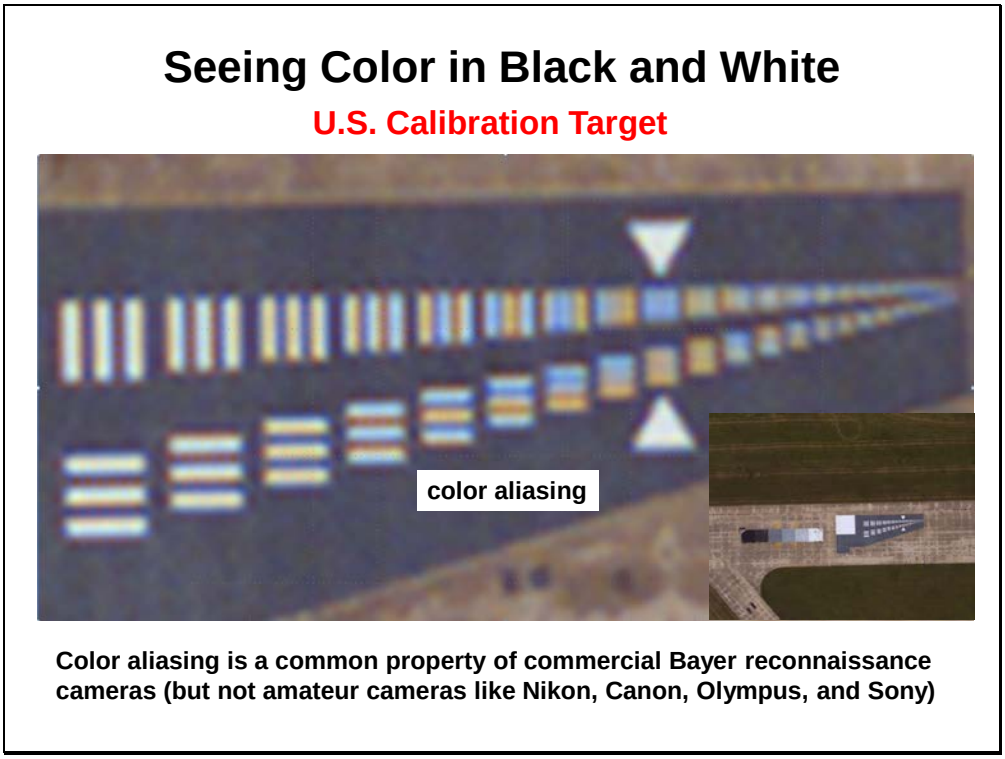
- **Performance above Nyquist will depend crucially on the task.**
  - **Toy tasks such as reading calibration targets are susceptible to analysis.**
  - **The relationship of these tasks to military tasks is uncertain.**
  - **Testing should endeavor to have a mix of analyzable tasks (for system characterization) and operational tasks.**
  - **Operational tasks at "higher" levels such as target identification (rather than simply detection) are hard to define in fully analytical terms.**

Sampling, Aliasing, and Reconstruction Summary

- Aliasing is an almost inescapable feature of staring focal plane array sensors and refers to the artifacts associated with sampling systems. They can range from Moiré patterns to ambiguously interpreted images of objects with complicated patterns of light and dark.
- The presence of aliasing in a system gives rise to a commonly used rule of thumb based on the Nyquist frequency, identifying the resolution of a system with the size of a sample (or pixel) on the target. This underrates the importance of other determiners of resolution such as the modulation transfer function or MTF. Performance may be poorer than that suggested by Nyquist or better than Nyquist, depending on the task. The combination of MTF and aliasing can lead to some unintuitive tradeoffs: poorer MTF may actually improve performance in some tasks if aliasing is a significant problem.
- For imaging systems with aliasing, the display of the sensor information becomes important, especially if the image is zoomed so that one display pixel is used to represent a single sensor sample value. An improper *reconstruction* of the sensor data can reduce performance. For all aliased systems, an understanding of the reconstruction algorithm is an important aspect of any system including a human operator.

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G. Color Aliasing in Bayer Cameras



The purpose of this section is to discuss additional issues that arise from the use of Bayer pattern cameras. In addition to the aliasing usually associated with digital sensors, Bayer pattern cameras may have color aliasing.

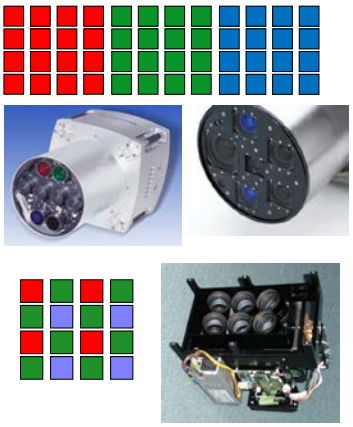
Just as the aliasing of a monochromic camera may be addressed by different reconstruction functions, the effects of the color aliasing depend on the deBayering (or demosaicing) algorithm used to generate the interpolated red, green, and blue values.

In the image shown, the combination of sensor MTF and demosaicing algorithm have produced severe color aliasing. The white bars on the black background of the calibration target appear to have colors, a blue-green and orange. At the triangular fiducial marks, the bars of the target are blurred together to form blue-green or orange blurs.

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Color Systems

- **Full color systems have multiple lenses (Intergraph DMC , Vexel UltraCam) or beam splitters (Leica ADS-80) with separate arrays for each color.**
- **Bayer systems use arrays of mixed red, green, and blue detectors ("pixels").**
  - **Cheaper**
  - **Exploits consumer electronics for arrays**
  - **Large fields of view using multiple Bayer arrays**
  - **Lower storage and bandwidth requirements.**
- **Bayer systems have color aliasing in addition to ordinary aliasing: the space between red samples is 2 x detector size.**
  - **For a "4 megapixel" array, only 1 million red, 1 million blue, and 2 million green.**
  - **An algorithm is required to produce 4 million R,G, B values.**
  - **The algorithm will affect system performance, including resolution.**



Full color systems have separate focal planes for each color (red, green, blue and, in some cases, near infrared). Since the focal planes are separate, they require separate optical paths.

In some cases, this is performed by completely separate lens systems as illustrated in the upper photograph. On the left, the UltraCam by Vexel uses separate optics for red, green, blue, and infrared, supplemented by four additional panchromatic lenses for higher resolution. On the right is the DMC II by Intergraph, which uses one panchromatic camera and the four additional red, green, blue, and near infrared.

For line-scanners, such as the Leica ADS-40, a single primary optical system can include a beam splitter separating the light into different bands directed to different rows of detectors.

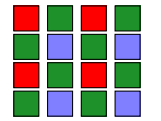
Bayer pattern cameras can be less complex and expensive than full-color cameras. By providing color information in a single focal plane (at the cost of increasing the sample distance for each color), significant savings can be made.

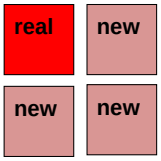
For both types of color cameras, additional complexity may be introduced to provide a wider field of view. The lower photograph shows a multi-lens system [manufactured by the Russian firm NPO KSI (Scientific Production Union – KSI)] that uses several Bayer pattern focal planes with each lens, interleaving them to form a final image.

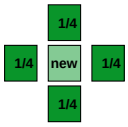
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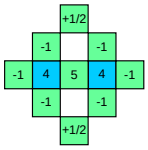
Bayer Patterns

- **Providing a full set of R, G, and B values at each site is called "deBayering" or "demosaicing."**
- **There are many different approaches to deBayering**
  - **Linear interpolations:**
    - **Band-by-band (missing G pixels depend only on G pixels)**
    - **Cross-band (missing G pixels depend on G and R/B pixels)**
  - **Hue based – Assuming G pixels provide brightness and then use R/B pixels to determine hue (colorizing)**
  - **Gradient estimators – Avoiding averaging across an edge**
  - **Other approaches use non-linear techniques (median filters)**
  - **Etc.**
- **Approaches can be simple, using only the nearest neighbors or complex with a larger number of measured values involved**









B at green in
B row, R column

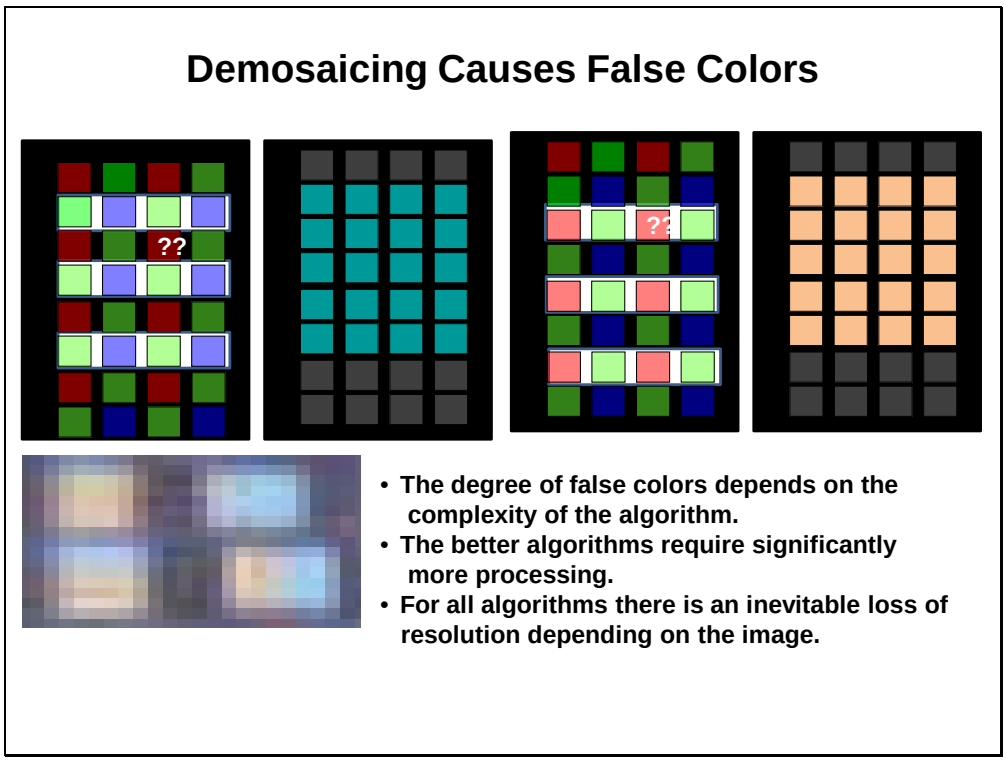
DeBayering is the process of generating by some algorithm estimates of the sample values that would have been produced by a full-color array. For example, for each red sample value, three additional sample values must be produced.

An enormous range of algorithms exist for deBayering. However, in contrast to the Wiener filter, there is no established theoretical basis for choosing one algorithm over another. The filters can be linear: averaging sample values from the measured detectors to interpolate new values. This can be done for each color separately, but it has been found useful by some authors to mix colors, using the intensity of green samples as indicators of brightness and using those values to influence nearby red interpolated values. An example will be shown in a subsequent chart.

Another algorithm uses the more numerous green values to estimate the panchromatic brightness of the scene, and then using the red and blue values to estimate the color. This may work on scenes that are not too dramatically colored.

Other algorithms try to identify gradients or edges to avoid interpolating across a gap in brightness.

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The source of the blue-green and orange errors on the black-and-white calibration target can be understood in the simple nearest-neighbor linear deBayering algorithm. Imagine that the detector locations fell on the white stripes as shown at the left, with only blue and green detectors on the white stripes and red detectors always on the black background.

Consider a red site between two of the white stripes. There is no red value at that site, so in the simple algorithm, the red value in the final result will be zero. However, both blue and green values will be assigned since there are blue and green neighbors.

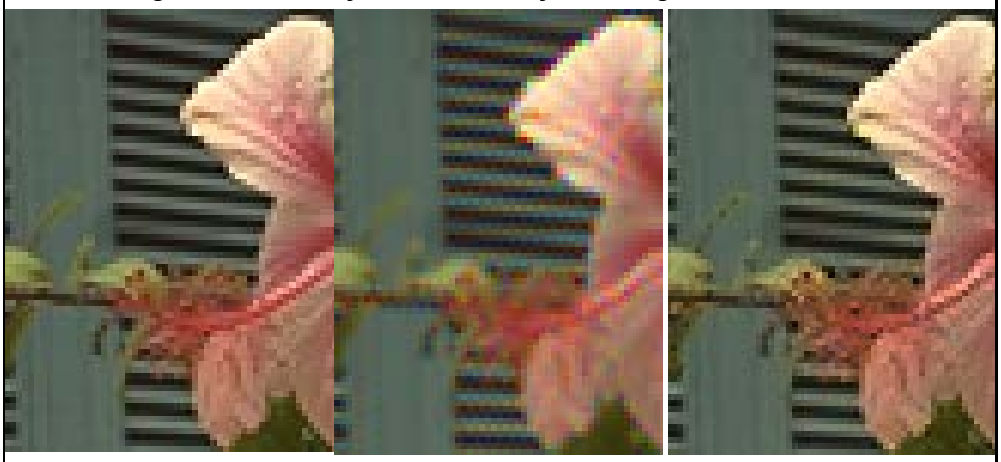
Similarly, along the white stripe, no red values will be assigned, but both blue and green values will be assigned at each point.

The result will be a blue-green color assigned along the white bars and along the black spaces between the bars. The bars will disappear into a blue-green smear.

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Interpolation Errors

- **Original and two Bayered then deBayered images**



Original (full-color camera) | **Bayered: DeBayered with simple linear interpolation** | **Bayered: DeBayered with Microsoft interpolation**

Figures reproduced from Malvar, et al.

The left figure shows a high-resolution full-color image. A Bayer camera version can be produced by selecting only the red, green, or blue values from each pixel.

The middle image uses simple nearest neighbor linear-interpolation. The image shows characteristic blue-green and orange structure along the bars of the shutters. The authors' own, more elaborate algorithm eliminates or diminishes the color aliasing errors and is shown on the right.

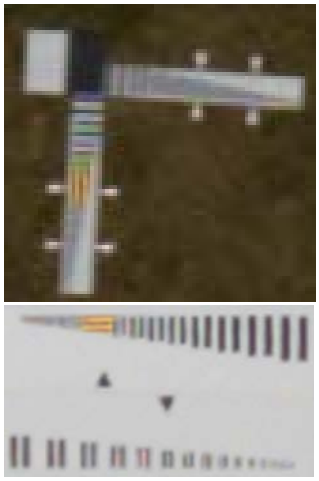
Just as some image interpreters prefer the jaggies of pixel-replication zooming (primarily because of familiarity but also because allows recognition of over-zooming), some interpreters prefer the image with color aliasing to the apparently superior image produced by the Microsoft algorithm.

As in the case of zooming, there is no way to avoid *some* algorithm for deBayering, and there is no reason not to use more sophisticated algorithms.

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Exotic Bayer Artifacts

- **Colors can go beyond blue-green and orange.**
  - **Notice that the horizontal bars on the left are apparently vertical (and orange)**
- **The Bayer artifacts may extend over long distances depending on how large a region is used for the interpolation.**
  - **In the lower image, the top row of bars has a small separation between groups of bars; the demosaicing algorithm connects across different bar groups producing the dramatic colors.**
  - **By separating the bar groups, the Bayer anomalies are removed.**
- **The Bayer artifacts will depend on the algorithm and the objects imaged!**



The presence of color artifacts depends upon both the demosaicing algorithm and the scene.[11] In general, algorithms with less color aliasing are more expensive computationally.

Color Aliasing in Bayer Cameras Summary

- The use of Bayer pattern color camera in imaging systems in order to reduce cost and data rate requirements may introduce additional dependence on algorithmic choices. In contrast to full-color cameras, a Bayer camera does not have a color detector for all three colors (red, green, blue) at each location (a 12 "megapixel" Bayer sensor has 6 million green, 3 million red, and 3 million blue detectors). An algorithm is used to interpolate the missing values to produce a complete three-color image.

  This color aliasing is more severe than the aliasing intrinsic to any staring focal plane. Fortunately, in the natural world, the color information is usually relatively immune to aliasing effects. However, a large number of different algorithms of varying complexity may be employed by a sensor manufacturer. Depending on the tasks to be performed and the details of the image, the algorithm may induce new artifacts that complicate the evaluation of the system.

Ideally, the user could be given some control over the interpolation algorithm to match it to the task.

---

[11] Patrick C. Hytla, *Demosaicing Algorithm Performance for the Open Skies Treaty* (White Paper), Sensor Systems Division, University of Dayton Research Institute, Dayton, OH, May 25, 2011.

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Appendix A
Acronyms and Terms

Acronyms

3D	three dimensional
ADC	Analog to Digital Conversion
Al_2O_3	sapphire
AlGaAs	aluminum gallium arsenide
CO_2	carbon dioxide
CTF	Contrast Threshold Function
DSP	Defense Support Program
EO	electro-optical
FAR	false alarm rate
FFT	fast Fourier transform
FLIRS	forward-looking infrared systems
FOV	field of view
FPA	focal plane array
GaAs	gallium arsenide
Ge	germanium
GIQE	General Image Quality Equation
GSD	ground sample distance
H_2O	water
HgCdTe	mercury cadmium telluride
ICBM	intercontinental ballistic missile
IFOV	instantaneous field of view
IMM	interacting multiple model
InGaAs	indium gallium arsenide
InSb	indium antimonide
IR	infrared
IRFPA	infrared focal plane array
IRST	infrared search and track
ISR	intelligence, surveillance, and reconnaissance

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L	emitted radiance
LOS	line of sight
LWIR	long-wavelength infrared
MHT	multiple hypothesis tracker
MODTRAN	MODerate resolution atmospheric TRANsmission
MRT	minimum resolvable temperature
MTDP	minimum temperature difference perceived
MTF	Modulation Transfer Function
MTI	moving target indicator
MWIR	mid-wavelength infrared
NEI	noise equivalent irradiance
NETD	noise equivalent temperature difference
NIIRS	National Imagery Interpretability Rating Scale
NIR	near-infrared
NUC	Non-uniformity Correction
NVESD	Night Vision and Electronic Sensors Directorate
NV-IPM	Night Vision Integrated Performance Model
NVThermIP	Night Vision Thermal and Image Processing
OBC	Optical Bar Camera
OH	hydroxyl
P_d	probability of detection
RER	relative edge response
SAR	synthetic aperture radar
SBIRS	Space-Based Infrared System
SGR	sky-to-ground ratio
SNR	signal-to-noise ratio
SSCamIP	Solid State Camera and Image Processing
SWaP	Size, Weight, and Power
SWIR	short-wavelength infrared
TTP	Targeting Task Performance
UAV	unmanned aerial vehicle
UDRI	University of Dayton Research Institute
UV	ultraviolet
VLWIR	very long-wavelength infrared
μm	micrometer

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Terms

Aliasing	A consequence of modern digital sampling. Introduces distortions into the image.
Bayer pattern color camera	Focal plane includes a mixture of detectors for red, green, and blue.
deBayerization (demosaicing)	Interpolating missing red, green, and blue values for a Bayer camera.
Detector	Photo-sensitive device for measuring incident radiation.
Detector size	Detectors are typically square with size ranging from 4 (visible) to 25 m (IR)
Detector pitch	The spacing between detectors. The detector size is ≤ the detector pitch.
Full color camera	Separate focal planes for red, green, and blue detectors. Contrast with Bayer camera.
Luminance	A measure of emitted or reflected light per area, expressed in units of foot-Lamberts or candela per square meter.
Minimum Resolvable Temperature (MRT)	An IR performance measure giving the temperature difference required to resolve features at different spatial frequency.
Modulation Transfer Function (MTF):	The frequency response of an optical system including the optics, lenses, vibration, etc.
Nyquist frequency	½ the sampling rate of a digital system. If the highest spatial frequency in a scene is less than the Nyquist frequency, the system is unaliased.
Pixel	Properly, a displayed "picture element." Loosely, a detector or sample.
Radiance	The energy radiated or reflected by an object.
Reconstruction	The process of taking digital data and displaying it or interpolating it.
Sample	The result of digitizing the output of a detector.
Sampling rate	The spacing between digital samples. May be expressed in angular terms or spatial terms.

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14. ABSTRACT

This paper begins with a discussion of the factors affecting emission, transmission, reflection, and absorption of light, including most importantly, the role of the atmosphere. It continues with a discussion of various applications, including detection of point targets and imaging of extended targets. The use of EO/IR for tracking targets is also covered, as are some recent technological advancements. Finally, sections are dedicated to the topics of sampling, aliasing, and reconstruction, as well as issues in color cameras.

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THESIS

ENHANCING ENTITY LEVEL KNOWLEDGE REPRESENTATION AND ENVIRONMENTAL SENSING IN COMBATXXI USING UNMANNED AIRCRAFT SYSTEMS

by

James C. Teters II

September 2013

Thesis Advisor: Imre Balogh
Second Reader: Peter Nesbitt

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Current modeling and simulation techniques may not adequately represent military operations using unmanned aircraft systems (UAS). A method to represent these conditions in a combat model can offer insight to the use and application of UAS operations, as well as understanding the sensitivity of simulation outcomes to the variability of UAS performance. Additionally, using combat model simulations that do not represent UAS behavior and conditions that cause this variability may return misleading or incomplete results. Current approaches include explicit scripting of behaviors and events. We develop a proof of principle search, targeting, and acquisition (STA) model for use with UAS within COMBATXXI, leveraging existing STA research conducted at the MOVES Institute at the Naval Postgraduate School. These dynamic behaviors are driven by events as they unfold during the simulation run rather than relying on preplanned events as in the scripted approach. This allows these behaviors to be highly reusable since they do not contain scenario or incident specific information. We demonstrate the application of the new STA model in a tactical convoy scenario in COMBATXXI. A design of experiments and post analysis quantifies the sensitivity of the measures of effectiveness of success to conditions contributing to variability in UAS performance.

14. SUBJECT TERMS UAS, UAVs, Unmanned Aircraft Systems, Unmanned Aerial Vehicle, Sensors, Electronics & Electronic Warfare, Information Systems Technology, COMBATXXI, HTNs, Hierarchical Task Networks, Ontology, Reasoning, Knowledge Representation, Training			**15. NUMBER OF PAGES** 145
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B.A., Marshall University, 2002

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ABSTRACT

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List of Acronyms and Abbreviations

AGL	Above Ground Level
AI	Artificial Intelligence
AK-47	Avtomat Kalashnikova
AT	Anti-Tank
AO	Area of Operations
AOI	Area of Interest
AMSAA	Army Materiel Systems Analysis Activity
BDE	Brigade
BSL	Behavior Specification Language
CO	Company
COE	Center of Excellence
COMBATXXI	Combined Arms Analysis Tool for the 21st Century
COP	Command Outpost, Common Operating Picture
DFP	Deployable Force Protection
DOE	Design of Experiments
DoD	Department of Defense
EOD	Explosive Ordnance Disposal
EO	Electro-Optics
FT	Feet
FOB	Forward Operating Base
FOL	First-order logic
FOR	Field of Regard
FOV	Field of View
GCS	Ground Control Station
HMG	Heavy Machine Gun
HMMWV	High-Mobility Multipurpose Wheeled Vehicle
HQ	Headquarters
HTN	Hierarchical Task Network
KB	Knowledge Base
KPH	Kilometers Per Hour
KR	Knowledge Representation
IED	Improvised Explosive Device
IN	Infantry
IR	Infrared
IOT	In Order To
ISO	In Support Of
ISR	Intelligence, Surveillance, Reconnaissance
LNA	Local National Army
MCCDC	Marine Corps Combat Development Command

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M	Meters
MM	Millimeters
MOVES	Modeling, Virtual Environments and Simulation
MSR	Main Supply Route
M&S	Modeling and Simulation
NAI	Named Area of Interest
NPS	Naval Postgraduate School
NVESD	Night Vision and Electronic Sensors Directorate
PBIED	Person-Borne IED
PLT	Platoon
OEF	Operation Enduring Freedom
OP	Observation Post
OWL	Web Ontology Language
RIP	Relief-In-Place
RPG	Rocket-Propelled Grenade
RPK	Ruchnoy Pulemyot Kalashnikova
SA	Small Arms
SPG	SPG-9 Kopye
SOCOM	United States Special Operations Command
STA	Search and Target Acquisition
SWA	Southwest Asia
TTPM	Targeting Task Performance Metric
TRAC	United States Army TRADOC Analysis Center
TRADOC	United States Army Training and Doctrine Command
UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
USAF	United States Air Force
USG	United States Government
UXO	Unexploded Ordnance
WFF	Well Formed Formula
WSMR	White Sands Missile Range
WWII	World War II
W3WC	World Wide Web Consortium

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Executive Summary

Current modeling and simulation techniques may not adequately represent military operations in respect to unmanned aircraft systems (UAS), to include the unmanned aerial vehicle (UAV) and its human operator. The performance of a UAS in the field can vary greatly, and this performance can have an enormous affect on the outcome of a military operation. This complex and variable behavior may be sensitive to considerations not represented in contemporary combat models. These conditions can include, but are not limited to, pilot training and experience. Combat models may require a means to model the effects of this behavior, particularly when analyzing the skill or efficiency of a UAS in providing information to other entities in the scenario.

A method to represent these conditions in a combat model can offer insight to the use and application of UAS in operations, as well as understanding the sensitivity of simulation outcomes to the variability of UAS performance. Additionally, using combat model simulations that do not represent UAS behavior and conditions that cause this variability may return misleading or incomplete results. Understanding when and how to model these conditions contributes to quality simulation and analysis.

Current approaches include explicit scripting of behaviors and events. Combat models, including Combined Arms Analysis Tool for the 21st Century (COMBATXXI) [1], provide opportunities for analysis. The ACQUIRE model is the most prevalent in U.S. Army simulations, allowing for the modeling of sensors used for search and targeting and acquisition (STA) [2]. Hierarchical Task Networks (HTNs) allow for automated planning based on changing environments in the simulated world [3]. Ontologies can show the effects that detailed information may play on decision making when utilizing a UAS. This thesis proposes using dynamic behaviors to include hierarchal task networks, ontologies, and sensor models to represent the inherent complexity of a UAS in a simulation. We developed a proof of principle search, targeting and acquisition (STA) model for use with UAS within COMBATXXI leveraging existing STA research conducted at the Modeling, Virtual Environments and Simulation Institute (MOVES) at the Naval Postgraduate School. We showed that this methodology can result in analysis that gives insight into the effects the capabilities of a UAS offer regarding deployable force protection (DFP). An ontology provides a means of representing pieces of information that, when combined with reason, was able to output relevant knowledge of the world and affect the out-

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come. This study used a scenario where understanding the ability to identify a target has a relationship to successful execution.

We demonstrated application of the new STA model in a tactical convoy scenario in COMBATXXI. The ability to model a UAS in a working environment is fundamental to a study concerning tactical convoy operations. A design of experiments and post-execution analysis quantified the sensitivity of the measures of effectiveness of success to conditions contributing to variability in UAS performance. Future work is given to identify possible studies that can extend this research.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The United States Military is considered the most powerful and effective fighting force when fighting a traditional red on blue, symmetrical war. Since the September 11, 2001, attacks, our enemies have been successful in mitigating our fighting strength through the use of improvised explosive devices (IEDs). The ability to counter such threats demand an adaptable and resilient force. Modeling and simulation (M&S) plays a vital role in developing scenarios that help leaders make decisions that can have lasting impacts on the battlefield. It is key that M&S provides decision makers with more fidelity and plausible results when studying the potential effects of systems used in theater.

1.2 RESEARCH PROBLEM

Current modeling techniques do not adequately provide the means to modify and measure the effects of changing the properties inherent to human/machine components and processes in an unmanned aircraft system (UAS). This research proposes an innovative way to represent the value of information and training in a constructive simulation, COMBATXXI (Combined Arms Analysis Tool for the 21st Century). Sensors in COMBATXXI do not allow for accurate modeling of IED detection when deploying UAS in a doctrinally correct manner. This may result in improper system deployment, overconfidence of capabilities, or unrealistic expectations causing more harm than good to our Soldiers. This study will attempt to model decision making capabilities of a UAS in COMBATXXI, utilizing newly developed sensor modeling, dynamic planning methods, and ontology based reasoning.

1.3 MOTIVATION

The ability of a unit to effectively perform its mission is dependent on many factors including presence, posture, and safety. The U.S. Army relies on force protection at all times. Unmanned aerial vehicles (UAVs) are gaining in prevalence use since the War on Terrorism began after the tragic events of 9-11. As of 2010, Unmanned Aircraft Systems (UAS) are in use at echelons below battalion and below [5, p. 21]. Analyzing the effective use of a UAS can be performed using the U.S. Army's high-resolution simulation COMBATXXI. This simulation models scenarios ranging from squad level building clearing operations to brigade-size amphibious assaults [1].

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COMBATXXI is extremely important for analysis of systems and can be improved to represent the dynamics of a UAS's information-gathering and its effects. Understanding how information and training affect decision making may provide better insight on how we train, equip; and employ systems such as a UAS based on this new prototype. The study utilizes a new means of creating behaviors in COMBATXXI by way of Hierarchical Task Networks (HTNs).

1.4 OBJECTIVES

In order to develop a means to represent information and study the effects of UAS operator skills when using this operation, we identify the following objectives:

- Utilize HTNs to assist in the formulation of behaviors more representative of complex systems in operation.
- Describe a new method to represent knowledge in COMBATXXI through use of an ontology and a new nontraditional sensor model.
- Gather more knowledge on the effects of information fidelity and varying capabilities of sensors utilization of Unmanned Aircraft Systems in a deployable force protection scenario.

1.5 THESIS ORGANIZATION

Chapter 1 lays out the plan to completion. The motivation for the thesis is given and provides the reader with guidance in the direction the study will take in order to answer the research questions.

Chapter 2 provides a review of the UASs that the U.S. Army has in operation and other systems used elsewhere in the Department of Defense (DoD). The development of target acquisition models used in simulations is discussed. Hierarchical task networks are described to provide the reader with an understanding of the value they provide to the developer when compared to previous methods. A brief history of knowledge representation (KR) and its applications are discussed as well.

Chapter 3 details the methodology used in the thesis from its inception to completion of the study. Novel ideas of using HTNs and an ontology approach are discussed, providing the reader with a new method in KR implemented simulations.

Chapter 4 describes the modeling of the Raven (unmanned aircraft of the Raven UAS) using a new STA model. This chapter discusses how an ontology of an IED could allow an entity

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to make a “realistic” determination of a threat based on the knowledge it is given through the sensor provided by the new STA model.

Chapter 5 provides overall conclusion of the research and a discussion of possible further work.

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CHAPTER 2:
LITERATURE REVIEW

2.1 U.S. MILITARY UNMANNED AIRCRAFT SYSTEMS IN OPERATION AND SIMULATION

This chapter provides a review of the UAS in use by the U.S. Military. This includes systems that the U.S. Army has in operation and other systems only being used by other members of the U.S. Armed Forces. A short history of IEDs, their makeup, and means of detection will be examined along with the development of target acquisition models used in simulations. Hierarchical task networks are described in detail to provide the reader with an understanding of the value they provide to the developer when compared to previous methods. A brief history of knowledge representation and its applications are discussed as well.

2.2 UNMANNED AIRCRAFT SYSTEM

The term UAV (unmanned aerial vehicle) is the term most popularly used when discussing an unmanned aircraft that flies with a remotely located pilot. The UAV is part of a system-of-systems called an unmanned aircraft system. According to the U.S. Army [5, p8] "a UAS is comprised of an unmanned aircraft (UA), payload, human operator, control element, display, communication architecture, life cycle logistics, and the supported Soldier." A UAS is capable of bringing the Warfighter value added service with systems such as electro-optical (EO) and infrared (IR) sensors to enhance intelligence, surveillance, and reconnaissance (ISR) capability. According to the U.S. Army 2010 UAS Roadmap, the five different groups of UASs being used are based on the following UA attributes: weight, altitude, and airspeed, see Figure 2.1 [5, p. 12]. These attributes were approved by the Joint Chiefs of Staff on November 25, 2008 [5, p. 12].

2.2.1 Raven RQ-11B

Ravens offer ISR capabilities for units at brigade (BDE) and lower echelons and currently sees high usage in oversea deployments. A report provided to Congress in 2012 reports that the U.S. Army, Navy and United States Special Operations Command (SOCOM) has 5,346 RQ-11 vehicles in the inventory [6, p. 8]. The characteristics of this UAS are given in Figure 2.2. This hand-launched UAV flies low and slow with cruising speeds between 17–44 knots (Figure 2.3). It scans areas of interest (AOI) at an operating altitude of approximately 100–500 feet (30–152

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UAS Category	Max Gross Takeoff Weight	Normal Operating Altitude (Ft)	Airspeed	Current Army UAS in Operation
Group 1	< 20 pounds	< 1200 above ground level (AGL)	<100 Knots	RQ-11B Raven
Group 2	21-55 pounds	< 3500 AGL	<250 Knots	No current system
Group 3	< 1320 pounds	<18,000 mean sea level (MSL)		RQ-7B Shadow
Group 4	> 1320 pounds		Any Airspeed	MQ-5B, MQ-1C
Group 5		> 18,000 MSL		No current system

Figure 2.1: Categories of Unmanned Aircraft Systems [5, p. 12]. The U.S. Army UAS categorization is from the "DoD 2009-2034 Unmanned Systems Integrated Roadmap" [5, p. 3]. As of 2010 the Army does not have a Group 2 UAS.

meters) above ground level (AGL). The sensor package allows the operator to gather data via EO or IR cameras using a continuous pan with a +10- to -90-degree tilt. "The [Raven] can be operated manually or programmed for autonomous operation" [7]. The Raven would be the ideal asset for ISR capabilities for any squad-size mission (based on its specs) such as searching for IEDs along a route at known locations.

2.2.2 Scan Eagle

The Scan Eagle UAS is a Group 2 category UAS that performs missions for the U.S. Air Force and the U.S. Marine Corps (see Figure 2.4). This UAV operates at altitudes up to 16,000 feet AGL (above ground level) and can stay aloft for more than twenty hours at speeds between 48–70 knots. The Scan Eagle payload consists of a high-resolution day/night camera and thermal imager. It catapults into operation with a launch and recovery system called Skyhook. This system requires four personnel (two operators, two maintainers) to run [10].

2.2.3 RQ-7B Shadow

The RQ-7B Shadow UAS belongs to the UAS Group 3 category. This UAV can fly to altitudes of 15,000 feet AGL for nine hours of flight. Cruising speed is 90 knots with loitering capabilities at 65 knots. The unmanned aircraft can carry up to 80 pounds of sensors [11]. Figure 2.5 shows a RQ-7 Shadow catapult from its hydraulic rail launcher.

2.2.4 MQ-1C Gray Eagle

The MQ-1C Gray Eagle (also known as "Warrior") belongs in the Group 4 category. It is the upgrade of the MQ-1 Predator. The "M" and "Q" designation mean "multi-role" and "unmanned," respectively. It has a wingspan of 56 feet and a length of 28 feet. This system can perform ISR

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Standard Payloads	Dual Forward and Side-Look EO Camera Nose, Electronic Pan-tilt-zoom with Stabilization, Forward and Side-Look IR Camera Nose (6.5 oz payloads)
Range	10 km
Endurance	60–90 minutes (Rechargeable Battery)
Speed	32–81 km/h, 17–44 knots
Operating Altitude (Typ.)	100–500 ft (30-152 m) AGL, 14,000 ft MSL max launch altitude
Wing Span	4.5 ft (1.4 m)
Length	3.0 ft (0.9 m)
Weight	4.2 lbs (1.9 kg)
GCS	Lightweight, Modular Components, Waterproof Softcase, Optional FalconView Moving Map and Mission Planning Laptop Interface, Digital Video Recorder and Frame Capture
Launch & Recovery Method	Hand-Launched, Deep Stall Landing

Figure 2.2: RQ-11B Specifications from Aerovironment [7]. The RQ-11 can fly "low and slow" traveling only 17 to 44 knots which equates to 30 to 60 mph. It is very lightweight 4.2 pounds, making it easy to employ by hand-launching.

and communications relay missions, or be equipped with four Hellfire missiles. It has the ability to fly to 29,000 feet and stay aloft for 25 hours with a maximum speed of 167 knots, see Figure 2.6 [13].

2.2.5 MQ-9 Reaper

Introduced in 2001, the Reaper primarily performs the role of intelligence collection in support of strike, coordination, and reconnaissance missions [15]. It does not belong in the U.S. Army's inventory but can support army missions. The Reaper is a Group 5 UAS with a 66-foot wingspan and is 36 feet. from nose to tail. Its maximum takeoff weight is 10,500 pounds. The hand-thrown Raven weighs a minuscule 4 pounds comparatively. The Reaper (Figure 2.7) flies at a maximum altitude of 50,000 feet and cruises at approximately 230 miles per hour (200 knots) at ranges up to 1,250 miles. It can fire Hellfire missiles or guided bombs, depending on mission requirements.

2.3 IMPROVISED EXPLOSIVE DEVICES

In this section, we provide a definition of an IED, its components, and means of detection in order to assist in making the IED ontology for the scenario to be used in the study.

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Figure 2.3: Marine preparing to hand launch the 4.2lb Raven UAV. From [8] The tripod in the back is part of Aerovironment's Ground Control System (GCS), which "improves situational awareness of the ground, provides operators cue to potential threats, and enhances airborne intelligence, surveillance and reconnaissance (ISR)" [9].

2.3.1 History of IEDs

The history of IEDs goes farther back than the "Global War on Terror." They are a direct ambush weapon extremely effective in killing soft targets such as troops and/or lightly armored vehicles such as the High-Mobility Multipurpose Wheeled Vehicle (HMMWV). The DoD states that, "An IED is a device placed or fabricated in an improvised manner incorporating destructive, lethal, noxious, pyrotechnic, or incendiary chemicals and designed to destroy, incapacitate, harass, or distract. ...[the IED] may incorporate military stores, but is normally devised from nonmilitary components" [17, pII-14]. According to the *Washington Post* [18] as of August 29, 2013, 2,503 out of 6,668 [fatalities] 37.5% were caused by IEDs in support of Operation Iraqi Freedom and Operation Enduring Freedom. If an IED explosion does not kill the entire crew in the vehicle, there is a very strong chance that survivors will likely suffer from tramatic brain injury (TBI), loss of limb, burn trauma, etc. The ability to detect and defeat (making IEDs inoperable once found) is paramount to current and future mission successes.

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Figure 2.4: Scan Eagle and launch system. From [10]



Figure 2.5: RQ-7B Shadow taking off. From [12]

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Figure 2.6: U.S. Army Gray Eagle in flight. From [14]



Figure 2.7: MQ-9 Reaper in flight with landing gear down. From [16]

2.3.2 Makeup of IEDs

In general, an IED [19, para 6-71] is made up of the following components:

1. Main charge (explosive)
2. Casing (materials around explosive)

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3. Initiators (what triggers the explosion)
   (a) Command wired
   (b) Radio controlled
   (c) Victim operated
   (d) Timed

2.3.3 Detection of IEDs

It is crucial that modeling detection of IEDs be performed to make it easier for U.S. Army leadership to understand the most beneficial ways to mitigate their effects when using UASs such as the Raven RQ-11B. The most dangerous way of detecting IEDs visually is from close proximity fewer than 5 meters. At distances of 100 meters or more detection is much safer, but more difficult. The enemy is continuously adapting their means of implementing IEDs, which make detection more difficult. Shepherd states in [20] that IEDs were first buried underground, then placed in and behind objects above ground, and then below ground again. Later, they were found hidden in dead animals by the road, vehicles (vehicle-borne IEDs or VBIEDs), and humans (person-borne or PBIEDs). The enemy then began countering our mitigation by placing the IEDs underneath culverts or burying them underneath the roadway. One can see that winning the IED battle is a zero-sum game that costs millions of dollars, and more importantly, the lives and limbs of our soldiers.

According to Shepherd [20] there are four methods to detecting IEDs:

1. "Observing the [observation post] or triggerman."
2. "Identifying the explosives [IED indicators such as loose soil, wires, containers out of place, etc.] or where they are hidden."
3. "Gathering intelligence from the local population."
4. "Being attacked."

Shepherd [20] says that while leaders can use dismounts in staggered column formation or dismounted with vehicles in traveling overwatch, it is not always practical. Another means of detecting IEDs from a safe distance is through the use of unmanned aerial vehicles (UAVs). He sums up the use of aerial reconnaissance below when detecting IEDs:

> [UAVs] assigned to cavalry troops, as well as scouts in helicopters, can provide successful aerial reconnaissance. Aerial surveillance can move quicker and provide

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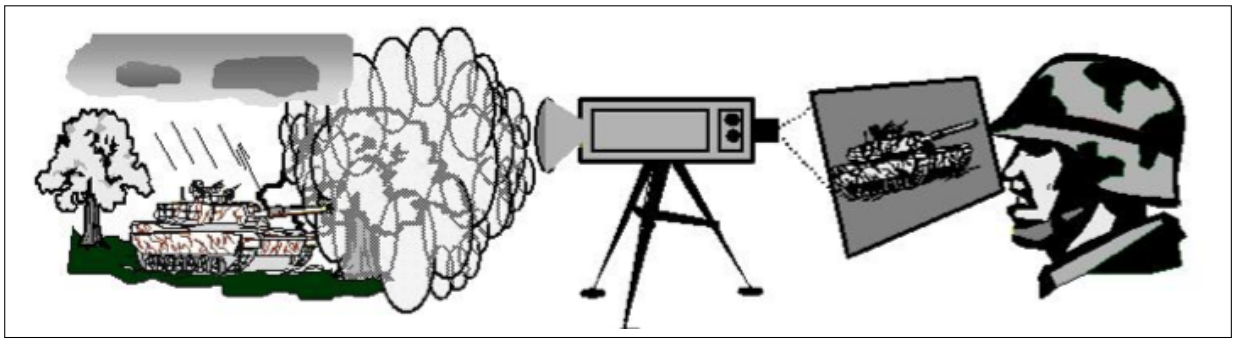


Figure 2.8: Soldier looking through an image device in order to identify an object. From [21, p. 1] This illustrates the point that the M&S community has to take real instruments and tools–like a camera–and create an abstraction (model) the light waves hitting the tank bouncing into the lens of the sensor (here a camera) and then travel back to observer's eyes.

> advanced warning to reconnaissance elements on the ground. Scout elements on the ground can then move forward to confirm or deny information provided by air elements. [20]

This concludes the discussion regarding the makeup and some detection methods for IEDs. Employing UASs to assist in detection of IEDs appears to be useful and promising. Since aerial reconnaissance is important during military operations, it may be necessary to develop methods of modeling this in a simulation. Next, we will look at how human sight has been modeled in the context of target acquisition modeling. This provides a better understanding of the dynamics and limitations of modeling human eyesight in current simulations.

2.4 TARGET ACQUISITION MODELING

In order to engage the enemy, one has to know the enemy's whereabouts. Throughout history, commanders on land or at sea continue to deploy sentries/patrols to gain knowledge of the enemy's location. Since WWII the use of electro-optic (EO) devices have become widespread, and are being utilized ubiquitously throughout the military. Vollermerhausen and Jacobs state: "The history of modeling EO imagers traces back almost 60 years to the pioneering work of Otto Schade... and [he] specifies that an EO image must be produced based on the capabilities and optical characteristics of the eye" [21, p. 9]. Schade had shown that it is possible to model the eye and created an analog model of the eye, which is "patterned after a television system" [22, p. 721]. Objective methods are used to test these characteristics and the "numerical values obtained by calculation...require correlation with the subjective impressions: graininess, tone

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scale, and sharpness" [21, p. 9]. While his work is pioneering and a great foundation for modeling EO systems, it has been proven to be "complex and difficult to adapt to changing conditions" [21, p. 10]. Figure 2.8 illustrates a soldier looking through an image device to assist in his/her ability to assess whether an object is a threat or not. Not only is the human eye itself complicated, but adding to this complexity is trying to model photons hitting an object like a tank, bouncing into a device (UAV sensor), which in turn takes that image and makes a duplicate image. However, the M&S community is asked to come up with ways to best represent this real phenomena in simulations.

2.4.1 Johnson Criteria

Johnson Criteria assists analysts in understanding the critical dimensions necessary for an observer to "see" a target. The United States Army Night Vision and Electronic Sensors Directorate (NVESD) state: "John Johnson, a Night Vision scientist, worked to develop methods of predicting target detection, orientation, recognition, and identification. Johnson worked with volunteer observers to test each individual's ability to identify targets through image intensifier equipment under various conditions" [23]. His models allow the ability to create predictive models of imagery systems. Johnson believed that alternating lines of a fixed width and spacing enable one to characterize the level of detail that can be discerned from an object. The thinner the line and closer the spacing, the more detail a person can perceive. He developed thresholds of line pairs to predict a person's ability to perform detection, orientation, recognition, and identification [21, p. 7]. The Johnson Chart can be found in Appendix A, which shows the minimum number of line pairs for the probability of 50% of observers to obtain detection, orientation, recognition and resolution when looking at the target. Figure 2.9 illustrates the number of pixels needed for detection, recognition and identification of a human being. It makes sense that the level of detection, recognition, and identification is proportional to the number of pixels that cover the respective area of acquisition. Vollmerhausen and Jacobs [21, p. 7] also state:

> The Johnson metric uses limiting bar-chart resolution as an indicator of sensor goodness for target acquisition purposes. Predictive accuracy of this metric is best when comparing "like" sensors and conditions. The metric is not compatible with many features found in modern sensors. For example, it is not compatible with sampled imagers. Further, the Johnson metric fails to predict the impact of frequency boost on range performance.

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The Johnson Criteria allows for the modeling of target acquisition predictability for different sensors currently in use by the U.S. Army. The metric does have its limitations that may inhibit accurate prediction of what humans will see when using imagery systems. The ACQUIRE model performs target acquisitions in COMBATXXI and requires the Johnson Criteria critical dimension for target detection. Since the Johnson Criteria are in need of an update to reflect the effects of STA when operating UASs, it may be beneficial to understand more about ACQUIRE and possibly construct a model without using the Johnson Criteria.

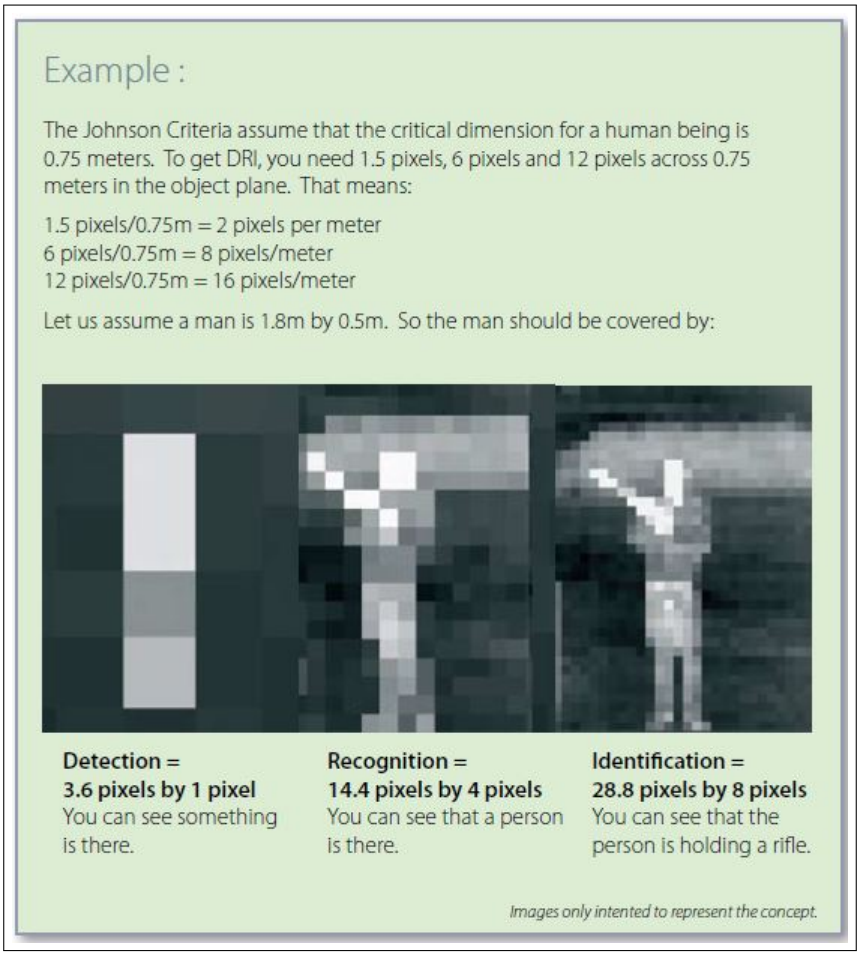


Figure 2.9: Illustration of number of pixels required for detection, recognition, and identification of a human being. From [24, p. 3]

2.4.2 ACQUIRE

The most prevalent target acquisition model the U.S. Army operates in combat simulations is the ACQUIRE model. The ACQUIRE model was formulated in 1990 and is a continuation of the Johnson Criteria [25, pp. 1-2] According to Darken [26, p. 263] "ACQUIRE computes the

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detection probability as a function of the brightness...of the target, the brightness of the background of the target, and the subjective size of the target, in terms of its 'number of resolvable cycles.'" The ACQUIRE model uses physical sensor characteristic data and human perceptual data along with environmental factors to compute a probability of detection for a specific observer-target configuration. In combat models such as COMBATXXI, this data coupled with a stochastic process allows for determining an actual outcome of a simulated observation. For example, ACQUIRE computes the probability that one will see a target given a target's range and the entity's sensor as .78. COMBATXXI then randomly draws a (uniform) number from 0–1 (where all values between 0 and 1 have an equal chance of being selected). If the number drawn is equal or less than .78 the simulation says that target is "seen" otherwise, the target is not seen even though there is clear line of sight between the sensor and the target.

LTC Baez [27] identifies some major drawbacks to the ACQUIRE model:

- "Current [model has] not been calibrated or developed for close-in targets within 200 meters" [27, p. 5].
- "Simulated soldiers can scan large fields of regard (FOR) quicker and make significantly quicker detections and identifications than a real soldier" [27, p. 5].
- Unvalidated workarounds have been made for limitations such as moving targets, multiple targets, clutter effects, color effects.
- Lack of updated visual perception experiments for targets not in database (i.e., components of IEDs).

These four items listed above hinder the ability to accurately predict the detection of targets by a UAS modeled in this study. The UAS that will be modeled in COMBATXXI for this study is the Raven RQ-11B. The Raven generally operates between altitudes of 30–152 meters [7]. When operating the Raven soldiers scan the hand-held screen and probably do not always detect (within a reasonable amount of time) objects such as a person holding a cell phone, misplaced box along the road, wires coming out of the ground. To compound the problem, there are no known human experiments that have been run to accurately model the detection of items using a sensor such as this UAS.

2.5 COMBATXXI

The Combined Arms Analysis Tool for the 21st Century (COMBATXXI) is a detailed event-driven simulation developed by U.S. Army Training and Doctrine Command White Sands Mis-

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sile Range (TRAC-WSMR) and Marine Corps Combat Development Command (MCCDC). The COMBATXXI User's Guide describes this simulation as "A Joint, high-resolution, closed-form, stochastic, discrete event, entity level structure analytical combat simulation" [1, p. 14]. Some of the major model functions include "Ground Combat (Light and Heavy Forces), Future forces, Fixed-wing and rotary wing" [1, p. 14]. One of the goals of COMBATXXI is to provide "a simulation that can represent information flow in a way that allows the analysis of its impact on operational effectiveness" [1, p. 14].

Behaviors of entities in COMBATXXI can be specified by model users using [1, p. 317]:

- Orders
- BSL (Behavior Specification Language, the native scripting language in COMBATXXI).
- Python scripts

Orders are the easiest for the programmer to use and are grouped into compound orders to perform more complex actions. BSL provides more complex behavior structures and a way to connect to complex internally defined behaviors. However, BSL restricts access to certain objects and data outside the model, which limits its use of making complex, dynamic behaviors. Python allows for the most flexible method of developing dynamic, "realistic" behaviors in COMBATXXI. To the non-programmer this may be seem a little intimidating. Figure 2.10 relates the types of behavior being programmed to the difficulty of implementation. The next section provides information on how this study will utilize dynamic planning methods and tools to assist in creating these dynamic behaviors.

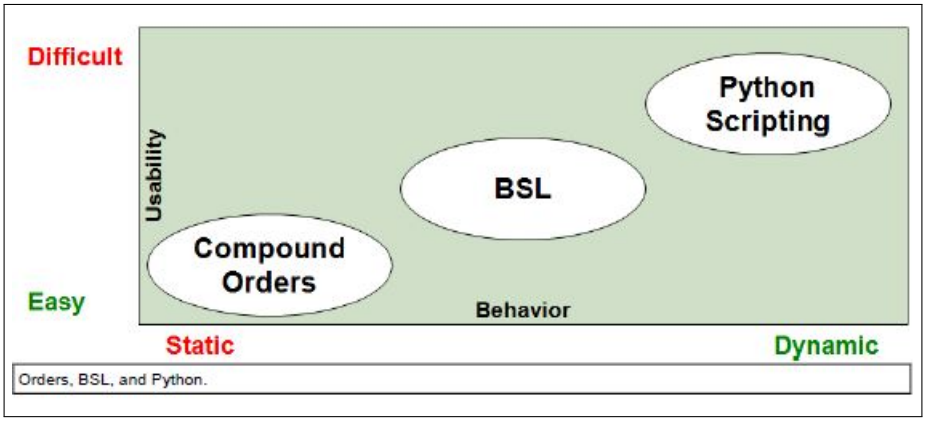


Figure 2.10: Relationship of behavior (static, dynamic) vs usability (easy, difficult) when considering different programming methods in COMBATXXI. From [1, p. 317]

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HTN Tasks and Shapes	
Tasks	Shape
Primitive Task	
Compound Tasks	
Goal Tasks	
Constraint Node	

Table 2.1: HTN Task and Nodes. From [30]

2.6 HIERARCHICAL TASK NETWORKS

The father of modern-day hierarchical task networks is Earl Sacerdoti, who describes HTNs as "procedural nets" [28]. HTNs are a means of planning actions in a program via the traversal of a series of networks in order to reach a goal. Sohrabi, Baier, McIlraith [29] state: "the planner is provided with a set of tasks to be performed, possibly together with constraints on those tasks. A plan is then formulated by repeatedly decomposing tasks into smaller and smaller subtasks until primitive, executable tasks are reached." Traditional HTNs consider what is to be the desired state of world, finds the plan (based solely on the current state of the world) which then is executed to reach the goal state (the desired state of the world).

2.6.1 Basic Terminology of HTNs

In order to fully appreciate the potential of HTNs, some basic terminology must be defined. *Primitive tasks* are tasks that cannot be broken down any further. A *compound task* consists of a collection of tasks that may be primitive or complex. *Goals* or *goal tasks* represent the final world state the HTN is trying to achieve. *Constraints* are the conditions that must be true in order to execute a specific branch of the HTN. See Table 2.1 for the graphics that correspond to an HTN task and/or nodes.

HTN trees are read from left to right and then top to bottom. Traversal of the HTN is complete once the goal node is reached. If the goal node is not reached, then the HTN might not finish and thus the goal state is never reached. Proper HTN fabrication allows for goal nodes to always be reached [3]. In the next section, an example of a static HTN in operation provides an opportunity to understand traditional automated planning.

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2.6.2 Example of Static HTN Planning

A HTN creates a plan to implement the behavior of someone going to the store (see Figure 2.11). The plan is based on the current state of the world and is valid as long as the state of the world does not change; remains static. The traversal of this tree illustrates the methodology of HTNs. First, the "Go to Store" compound task begins execution. Next it moves to the first and only constraint "Find Keys." If "Find Keys" has value of "True" then the tree traverses to the first primitive (non-compound) task "Get in Car." After this task the program automatically executes "Drive to Store." Once "Arrive at Store" executes, the goal has been reached and the HTN terminates. Going back to the "Find Keys" constraint node, if one does not have keys (value of "Find Keys" constraint has value of "False") then the "Walk to Store" primitive task is reached and then "Arrive at Store" performs and the HTN terminates. Using HTNs this way is great if and only if the conditions (known state of the world) have not changed since the plan was formulated and execution was started. But cars do break down and/or run out of gas. Road construction causes detours resulting in alternating course (changing plan) in order to ensure that the goal "Go to Store" is met. To address these types of problems, modifications need to be made to the HTN methodology. In the next subsection the use of dynamic planning is discussed.

2.6.3 Example of Dynamic HTN Planning

If the state of the world changes after a developed plan starts execution the entity may never reach its goal. To account for a possible change, the programmer may add an interrupt goal to force the HTN planner to reassess and replan actions to ensure a feasible plan is made. Interrupt nodes for this demonstration are labeled red. Balogh et al. state that interrupt nodes serve two purposes: "represent tasks that takes some time to complete and are likely places where the plan become invalid and allow for the 'lazy generation' of the plan only part of the plan needs to be generated" [3, p. 4]. In addition to the interrupt node, the idea of a replan event needs to be introduced. A "replan event" will cause the tree to "suspend execution of the current plan and reevaluate the HTN being used to determine how the plan should be changed based on the current state of the world" [30, slide 13].

Looking at Figure 2.12, it displays the "Go to Store" task with the addition of interrupt goals. For this example the idea is that one is at home (at the start of execution) and along the way to the store, a problem will arise causing the planner to account for this unexpected event, which would normally cause the plan to be void and the goal never met. The replan event indicates

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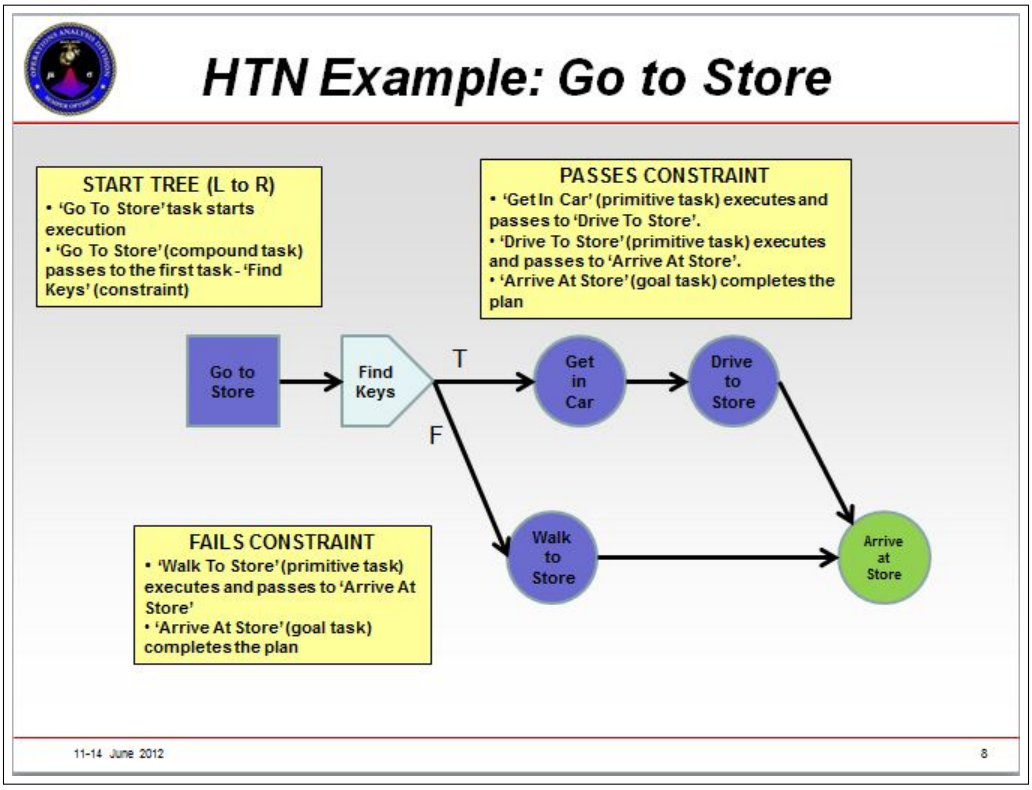


Figure 2.11: Planning to go to store without accounting for changes in the environment. From [30, slide 8]

that a state is reached where a change in the state of the world could occur and the whole plan will re-evaluate. When an interrupt node is hit, the execution of the tree halts, pending a replan event causing the tree being reevaluated. The replan event for this tree is "Stopped Moving." First the "Go to Store" compound task executes and reaches the "At Store?," which has a value of "False." Next the "At Home?" (interrupt node) has value "True" and tree planner moves to constraint node "Find Keys." Since that is true "Get in Car" task is planned, which then triggers the interrupt node "Drive to Store," causing the planner to stop executing. Since the replan event "Stop Moving" was triggered after "Drive to Store" event executed, the tree re-executes at the root node "Go to Store." The tree looks at constraint node "At Store?," whose value is "False," then moves to "At Home?" constraint node whose value is also "False" then plans an "Walk to Store" node. The "Walk to Store" node triggers the "Stop Moving" event causing the tree to be executed again. The task "Go to Store" executes and moves to constraint node "At Store?" being "True" causing the "Arrive at Store" goal node to execute allowing tree to be completed and finished. The interrupt node allows the tree to stop executing to allow for replan triggers to

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cause the tree to form a new plan in order to reach a goal.

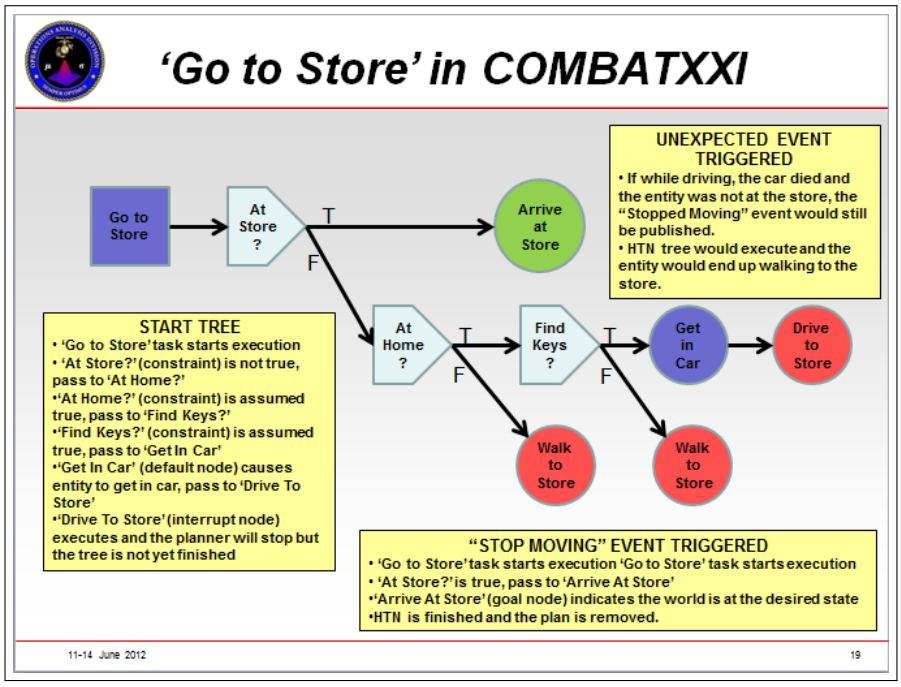


Figure 2.12: Going to store with an interrupt node. From [30, slide 19]

2.7 KNOWLEDGE REPRESENTATION

Information can be pieces of fact and fiction that describe the world around us. Knowledge is the collection of information that allows for intelligible action to take place. It is imperative that one knows how to apply knowledge and relate it to ideas that can accurately reflect the message one is trying to convey. Brachman and Levesque say knowledge representation is "the field of study concerned with using formal symbols to represent a collection of propositions believed by some putative agent" [31, p. 4]. Davis, Shrobe, and Szolovits see knowledge representation (KR) as "a surrogate, a substitute for the thing itself, that is used to enable an entity to determine consequences by thinking rather than acting that is, by reasoning about the world than [*sic*] taking action on it" [32, p. 17]. They explain one of the most interesting aspects of reasoning is that one must decide what the surrogate represents and what level of fidelity is the surrogate given when describing the entity [32, p. 18]. Their example consists of an entity planning on assembling a bicycle. There are different parts of the bicycle the person would have to think about (internally) that exist (externally) [32, p. 18]. Ways of representing knowledge via computers have been around for over fifty years. Some means of KR have included "neural networks, theorem proving and expert systems" [33]. In order to communicate

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an idea effectively, one needs to be able to speak in a manner that both parties can understand (a common language). There are languages (old and new) that have been adopted and created to help present the understanding of the world. A unique problem with Artificial Intelligence (AI) is that a program needs to have precise understanding of what the digit "2" is versus the string "too." We, as humans, must know how and when to use "2" and "too" when talking to one another. For example, concepts such as aircraft, flying, and travel can be closely related or very far apart. It all depends on the idea that you are trying to represent. If one is trying to plan a trip to Disneyland the first thought is the modes of "travel." Travel could happen by driving, sailing, swimming (if you are a good swimmer) or flying. By flying, concepts such as "soaring," "being lighter than air," "flapping of wings" may come to mind. However, since the context is in the realm of transporting a person from their home town to Disneyland, it is most likely that "flapping of wings" is not the true method of flying in this scenario. A depiction of being enclosed in a fuselage resembling something like a Boeing 737 or Airbus 350 and soaring through the clouds may be more accurate. The aircraft engineer might visualize movement of air molecules over the wings creating lift opposing the downward force of gravity. There are infinite ways to represent knowledge, unlike many problems that have a constrained solution space. Below are some areas that have been used to formally represent knowledge.

2.7.1 Propositional Calculus

Propositional calculus (aka propositional logic) is said to have been first created by the philosopher Aristotle [34]. In general, it is made up of symbols, truth symbols, and connectives. Propostional logic "is the branch of logic that studies ways of joining and/or modifying entire propositions, statements or sentences to form more complicated propositions, statements or sentences" [34]. These propositional sentences declare if the proposition is true or false [34]. Well-formed formulas (WFFs) are legal sentences in PL. Table 2.2 shows the symbols and well-formed fumulas. Propositional logic is concerned with the assigning of truth-values to a proposition (true or false). A PL sentence cannot be both true and false. The "Internet Encyclopedia of Philosophy" provides a very thorough review of Propositional logic [34].

2.7.2 Predicate Calculus

Predicate calculus allows one to tie relationships together and make clearer connections to objects, persons, ideas,...etc. Sentences are formed in predicate calculus just like they are in propositional calculus using the same connectives as found in Table 2.2. In propositional logic the atoms "P" and "Q" represent a proposition that only has meaning to itself and itself alone.

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Symbols of Propositional Calculus		
Propositional Symbols	P Q	“The sun is shining.” “Today is Friday.”
Truth Symbols	true false	“True” "False"
Connectives	$\neg$ $\wedge$ $\vee$ $\rightarrow$ $\equiv$	negation, “not” conjunction, “and” disjunction, “or” implication, “if...then...” equivalence, “equivalent to”
Well-Formed Formulas (WFFs)	P, Q, R $\neg$ P P $\rightarrow$ Q P $\wedge$ Q $\equiv$ R	Propositions "not P" "P implies Q" "P and Q is equivalent to R"

Table 2.2: Propositional Calculus Symbols.

However, with predicate calculus, values can be assigned to the propositions individually, which allows the ability to make new inferences by explicitly referring to the values assigned to the symbols. If “X” is a variable representing hours of the day and sentence “weather(X, sunny)” is true then literally one is expressing “the weather is sunny all the hours of the day.” Two new symbols are introduced in predicate calculus: the universal quantifier, $\forall$, and existential quantifier, $\exists$. The universal quantifier states that a sentence is true for all values of the variable. The existential quantifier states that there exists at least one value of the variable that make a sentence true. Luger states, “A major challenge for AI programmers is to find a scheme for using these predicates that optimizes the expressiveness and efficiency of the resulting representation” [35, p. 60]. Table 2.3 shows the power of representing “knowledge” using predicate calculus. Predicate calculus allows for a formalized fabrication of information enabling the structuring of knowledge bases, which will be shown later in the thesis.

2.7.3 Semantic Networks

A semantic network can be used to represent knowledge by using meaningful relationships with nodes and arcs. According to associationists, “when humans perceive an object, that perception is first mapped into a concept. This concept is part of our entire knowledge of the world and is connected through appropriate relationships to other concepts” [35, p. 229]. AI pioneers Collins and Quillian fabricate a semantic network based on human information and storage times. It is said that by using inheritance, humans are able to decrease the size of needed knowledge

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Predicate Calculus and the English Language	
If it does not rain on Monday, Tom will go to the mountains.	¬weather(rain, monday)→go(tom, mountains)
Emma is a Doberman pinscher and a good dog.	gooddog(emma)∧isa(emma, doberman)
All basketball players are tall.	∀ X (basketball_player(X) →tall(X))
Some people like anchovies.	∃X (person(X, anchovies))
If wishes were horses, beggars would ride.	equal(wishes, horses)→ride(beggars)
Nobody likes taxes.	¬∃X likes(X, taxes)

Table 2.3: English sentences being used in predicate calculus. After [35, p. 60]

base by this form of abstraction. Figure 2.13 shows a Collins and Quillan hierarchy of two distinct type of birds, characteristics of birds, and how they both relate to animals representing the idea of inheritance. A node could represent concepts such as objects, ideas, or situations. The arc represents the relationship between two objects, ideas or situations. Figure 2.13 shows a representation of how human information could be stored in memory of a computer via a semantic network. This is why it is important to understand how a semantic network can be built to better understand beings, ideas, and the relationships they share.

2.7.4 Ontologies

An ontology is a way of creating our knowledge base (KB) of the world and having the agent of interest act upon the knowledge it knows of the world and make new inferences. We can use predicate calculus to help create the "facts"' of our known world. *Merriam-Webster* defines ontology as "a branch of metaphysics concerned with the nature and relations of being" [37]. Brachman and Levesque state "[ontology represents] the kinds of *objects* that will be important to the agent and the *properties* those objects will be thought to have, and the *relationships* among them" [31, p. 32]. There are software programs that can assist in developing simple to rather complex ontologies that would be otherwise impossible for a human to store in his or her brain. The Web Ontology Language (OWL) is a high-level knowledge-based language used to construct knowledge base for many domains. It allows for machines (computers) to automatically process information based on the predicate's expressiveness. Childers discusses the benefits of using ontologies "[because ontologies]...allows programs to understand, process, and infer new information from coherent data" [38, p. V]. An ontology should assist in the creation of a knowledge base enabling a better understanding of the importance of acquiring accurate and useful information such from sensors in a UAS.

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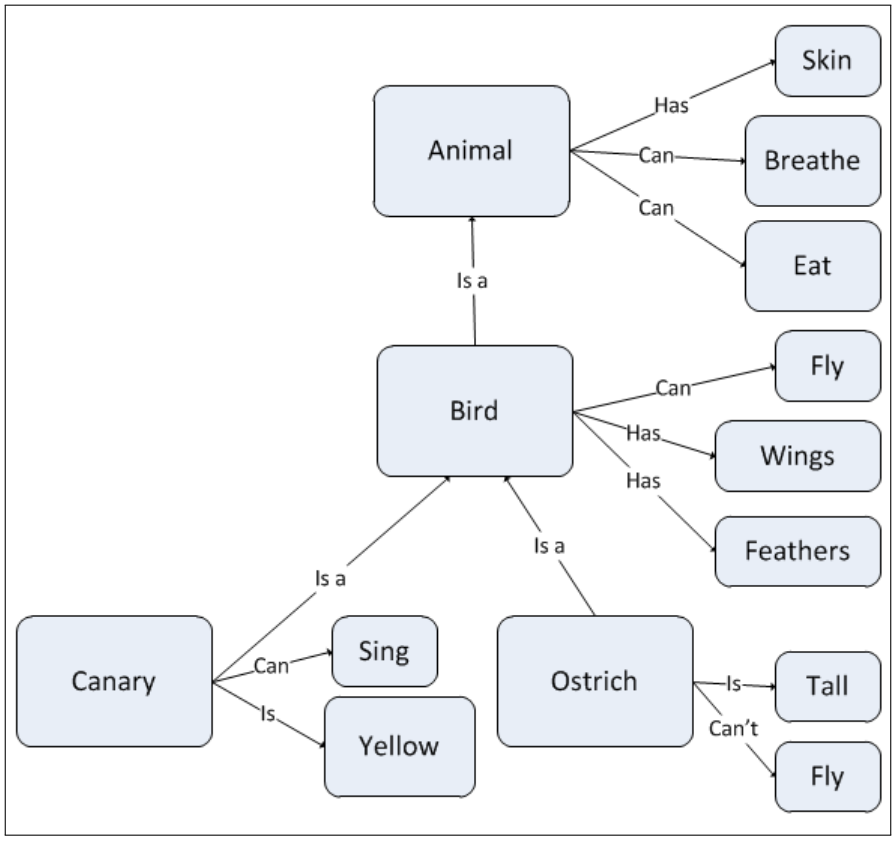


Figure 2.13: Semantic Network from Collins and Quillian modeling how information would be stored in a computer. This is a modified remake of their illustration. From [36, p. 241]

2.8 SUMMARY

The DoD has use for many types of UASs, of which one is reconnaissance. There are methods to model the sensors and sensing systems on these aircraft, however, they have drawbacks. In modeling, there are many ways to represent knowledge and decision making.

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CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

The methodology begins with developing a scenario that implements the Raven UAS in an typical Southwest Asian (SWA) environment. HTNs form the basis for planning and creating behaviors of the entities in the scenario. The creation of design of experiments and an ontology assist in measuring the effects of UAV operator skill and decision making.

3.2 SCENARIO

In order to understand the capabilities, limitations, pros and cons of an UAS, it is imperative that we consider the context of its usage. For this thesis, the scenario takes place in Southwest Asia. The 5-Ws (who, what, when, where and why) give the reader the understanding of what kind of mission will take place. Below is a brief description of the scenario [39] to be modeled in COMBATXXI. It represents a scenario that a small unit living on a combat outpost (COP) may have to perform while conducting operations with a host nation's army in SWA (see Appendix B).

- Who: Squad of U.S. Forces from COP Ramrod consisting of 7 vehicles and 1 RQ-11B RAVEN UAS.
- What: Conduct Resupply Run to Outpost X-Ray
- When: 0800 Hours Local Time
- Where: On an unimproved route consisting mainly of dirt and some gravel.
- Why: To resupply a joint American/Host Nation Outpost consisting of approximately 30 personnel.

Along the route there are areas known to have a higher than normal likelihood of containing an IED. There are four named areas of interest (NAIs) that have an equal chance of having an IED. For this study the real IED can be found in NAI # 2. The Raven UAS provides the added ability for the convoy commander to search the area at a safer distance than without a Raven. In the study it is assumed that a convoy will not see signs of a possible IED until they are within close proximity of one (approximately 50 meters). The mission can be seen in Figure 3.1 with NAIs and the convoy's start and end points labeled.

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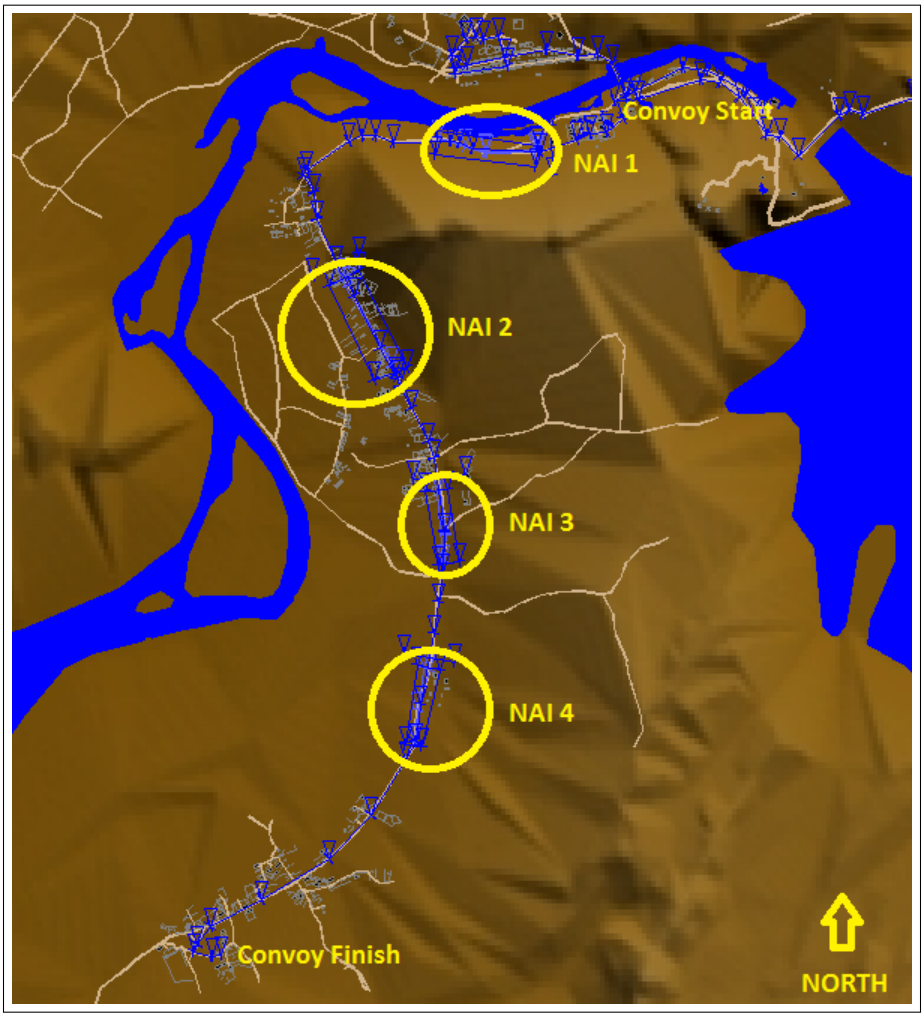


Figure 3.1: Mission Overlay in COMBATXXI.

When the convoy passes each phase line (PL) at the start of each NAI, they will stop and deploy the Raven. It will search each NAI by flying along a pre-determined path in search of an IED, see Figure 3.2. An object representing the IED will only detonate with an assigned standard uniform probability of .8 given that a convoy entity enters IED's sensor range of 10 meters. If an object is outside of the 10 meter range, the IED will never activate. The Raven UAS will defeat the IED if 1) the UAV detects the object that "could" be an IED (based on new UAV sensor model) and 2) the operator believes that the object detected *is* an IED and takes appropriate action by calling the unexploded ordnance clearing team (EOD). Calling EOD will always result in a 60-minute time penalty and IED being destroyed. If the convoy is hit by an IED, then mission is over. Success is the ability for convoy to safely arrive without taking any casualties.

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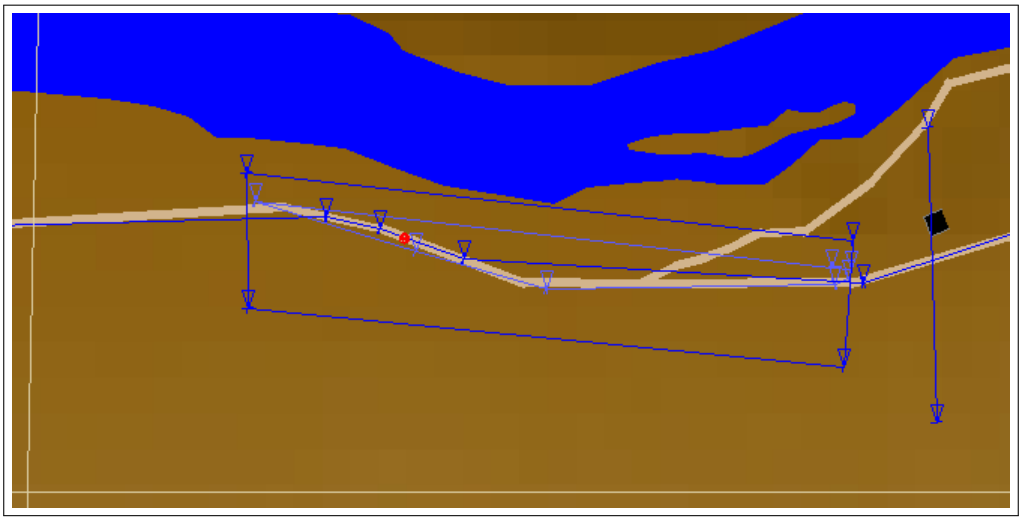


Figure 3.2: Screen shot of NAI 1.

Next, the research will look in to developing behaviors of our entities in the COMBATXXI scenario.

3.3 FORMULATION OF BEHAVIORS

The study uses HTNs to define behaviors for the entities modeled in the research. A tool called "Behavior Studio," developed by the MOVES Institute, provided for formation of behaviors. HTNs promise to make coding behaviors less time intensive, more efficient, etc., and in doing so allow for quicker formation of behaviors to be analyzed. An HTN tree is one separate entity that has a root node and at least one goal node. Each tree is organized with an initialization branch and execution branches. The execution branches consist of **`events`** and **`modelEvents`**. The events generally consist of events that are organic to the planner, whereas modelEvents plans for the execution of events directed by COMBATXXI exclusively. The list of trees for this study are as follows, with a broad description of the behavior to be modeled.

- **`ConvoyMoveInFormation`**: Behavior of moving convoy along the route.
- **`OperateIED`**: Behavior enabling detonation of IED when appropriate.
- **`OperateUAS`**: Behavior for operation of the UAV and convoy.
- **`UAVSensor`**: Behavior of the Raven UAV sensors.

3.3.1 Moving the Convoy HTN

The behavior tree labeled **`ConvoyMoveInFormation`** is responsible for ensuring the convoy reaches its final destination (Outpost X-Ray), see Figure 3.3. When the tree executes it

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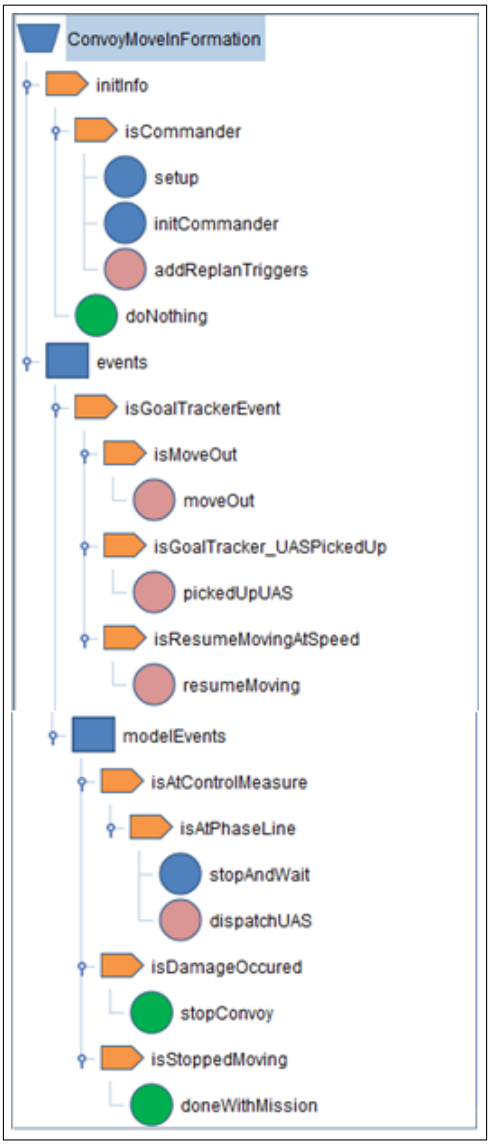


Figure 3.3: **`ConvoyMoveInFormation`**Tree. This tree will form a plan to get the convoy from the COP Ramrod to OP X-Ray.

first "initializes" using the **`initInfo`** and runs to the first condition **`isCommander`**, which tells that there are the NAI phaselines to pay attention to and schedules a "Move Out" event. Then several replan triggers are added for the tree listen to via **`addReplanTriggers`** node. The **`doNothing`** node tells the tree to end planning if someone other than the commander is assigned this tree. Once the **`initInfo`** branch completes, the execution is interrupted and is waiting for a replan event.

When a replan event occurs different nodes may execute. The **`moveOut`** node orders the convoy

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to move out. The **pickedUpUAS** interrupt node informs the convoy commander if the UAS (Raven) is physically back with convoy. If the UAS has not seen any artifacts that could be dangerous (such as potential IEDs) it schedules an "ResumeMovingAtSpeed" event. If the condition **isResumeMovingAtSpeed** is true the plan passes to the **resumeMoving** interrupt node that has the convoy resume normal convoy speed.

Next, moving on to **modelEvents** node, if conditions are true in nodes **isAtControlMeasure** and **isAtPhaseLine** then the convoy will come to a "halt" (**stopAndWait**). Raven dispatches in search of IEDs, respectively. The **dispatchUAS** interrupt node will assign the **OperateUAS** tree to the the UAV entity to execute and search the current NAI.

If the **isDamageOccured** node is "true," then the convoy has been hit by an IED, meaning the mission is over and the plan terminates appropriately. And finally, if the convoy has reached its final destination, the **doneWithMission** node is executed and the tree terminates. The complete **ConvoyMoveInFormation** tree can be seen in Appendix C.

3.3.2 Operating the IED HTN

The HTN tree labled **OperateIED** forms the behavior of the improvised explosive device. Figure 3.4 shows the tree in its entirety. First the tree jumps into the **initInfo** node and checks to see if the object is a real IED (**isRealIED**) by checking to see if probability of detonation is greater than 0. If object is not an IED the tree moves to goal node **setIsNotIEDInfo** and finishes. However, if **isRealIED** condition is "true" the tree moves to the **startObservation** node, activating the IED if convoy entity is within the activation (sensor) range of IED. Next the **addReplanTriggers** executes and ensures **OperateIED** tree is replanned if entities enter IED's area of interest (AOI), the simulation publishes a "GoalTracker_Detonate Now" event. Now moving along into the **events** branch, the IED detonates as long as "doGoalTracker_DetonateNow" is true. The IED will detonate with a probability (0.8 for the study) passed in as a parameter and is ALWAYS catastrophic (no survivors). The **modelEvents** node schedules a replan trigger called "GoalTracker_DetonateNow" when the second vehicle enters the IED's killzone. The complete **OperateIED** node can be seen in Appendix D.

3.3.3 Operating the UAS HTN

The HTN tree **OperateUAS** forms the behavior of operating the UAS, see Figure 3.5. Like earlier HTNs, the tree first initializes and adds replan triggers that will cause the tree to replan when the UAS is finished searching or scanning the NAI. Next, the tree plans routes for

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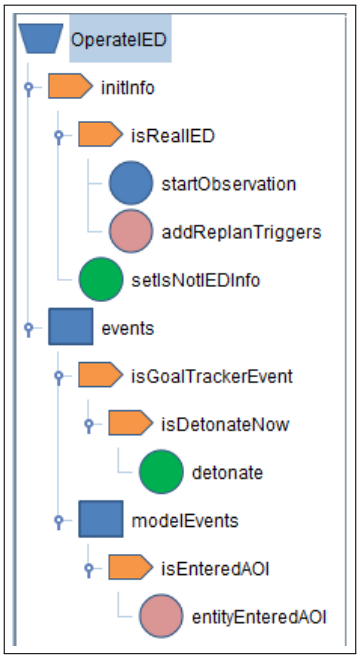


Figure 3.4: **`OperateIED`**Tree. Picture of **`OperateIED`** HTN.

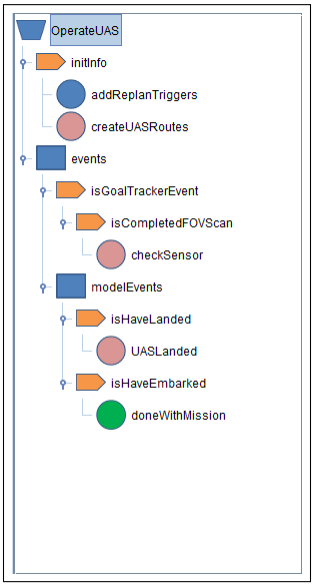


Figure 3.5: **`OperateUAS`**Tree. Picture of **`OperateUAS`** HTN.

the UAV to operate, see interrupt node **`createUASRoutes`**. Moving to **`events`** node, the branch is responsible for checking the sensor for objects found once it finishes scanning. The **`isCompletedFOVScan`** checks if UAV scanning its field of regard (FOR). If **`isCompletedFOVScan`** has value of "true" then the interrupt node **`checkSensor`** executes. In this node, if the UAV

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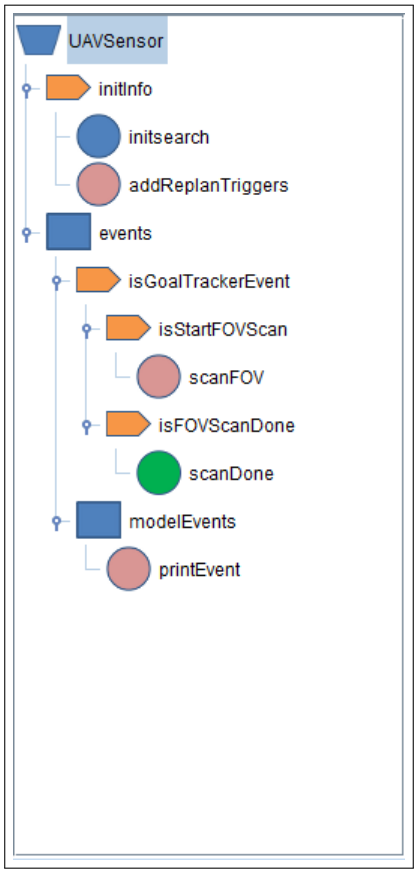


Figure 3.6: **`UAVSensor`** Tree.

entity has not returned to the convoy or is greater than 100 meters out from vehicle it disembarked, the tree will push the UAV sensor tree to **`UAVSensor`** tree where the UAV entity continues its search of FOR with necessary parameters.

When the tree traverses down to the **`modelEvents`** once the constraint node **`isHaveLanded`** is true, the **`UASLanded`** node executes–meaning that the Raven UAV has landed. Lastly, once the UAV embarks the convoy (it just completed its mission), then the goal node **`doneWithMission`** executes and the human operator determines if this is either an IED or not an IED. A more detailed depiction of the tree can be given in Appendix E.

3.3.4 UAV Sensing HTN

The **`UAVSensor`** HTN is responsible for modeling the sensor of our Raven UAV (see Figure 3.6). The goal here is to model a user observing through a single field of view. First the tree initializes and the **`initsearch`** node computes a scan time for the FOR (field of regard),

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which is simply what the person is focusing on the screen. The field of view (FOV) is the entire screen that the observer cannot see due to the eyes abilities to only focus on a few degrees at a time. Moving down into the **events** branch if the **isGoalTrackerEvent** node and **isStartFOVScan** node are true the interrupt node **scanFOV** executes. In this node, the UAV searches for objects on the ground using an EO sensor. It has the probability of detecting objects in its path based on the distance. Looking at the **isFOVScanDone** node is true, it passes to the goal node **scanDone**. This node finishes the tree and the "observations" will be looked at in the **OperateUAS** node (mentioned earlier) for determination if it is or is not an IED. A more detailed depiction of the tree in its entirety can be found in Appendix E.

3.4 UAV NOTIONAL SENSOR MODEL

To achieve the representation of a UAS modeling the effects of operator skill, we need a sensor. The sensor must be able to report to the **OperateUAS** HTN (representing human behavior) all possible IEDs. Currently the sensor in COMBATXXI is overly sensitive and cannot determine if an object found is an IED unless it is hard-scripted into that object as a real IED. Therefore the study uses a simple notational sensor developed by Imre Balogh (see Appendix F). The UAV sensor model can detect objects in COMBATXXI using some simple geometry and probability. Looking at Figure 3.7 one can see how the UAV detects an object. Probability of detection is based on the value of *r*. For this model the limit to detect an object is 220 meters. If the range of an object is 110 meters then the observer has a .50 chance of detecting object given that it is in the field of view of the sensor. Next, the study will look at the idea of creating a knowledge base (an ontology) that would assist the UAS operator in making decisions based on clues such as "disturbed earth," and "loose wires," instead of finding an object and flipping a coin to say that it is or is not an IED (as explained for COMBATXXI).

3.5 ONTOLOGY OF IED

Ontologies are a useful way of expressing knowledge of the world. They help to formalize an understanding of what objects will be represented and the relationships the objects share together [31, p. 32]. The agent in this study is the UAS and its ability to discern threat-type based on information received.

3.5.1 Developing an Ontology

This study seeks to develop a constraint that will allow our HTN to categorize the objects it observes. This categorization defines a state based on indicators in the ontology. This perceived state determines the selection of behaviors to follow in the HTN.

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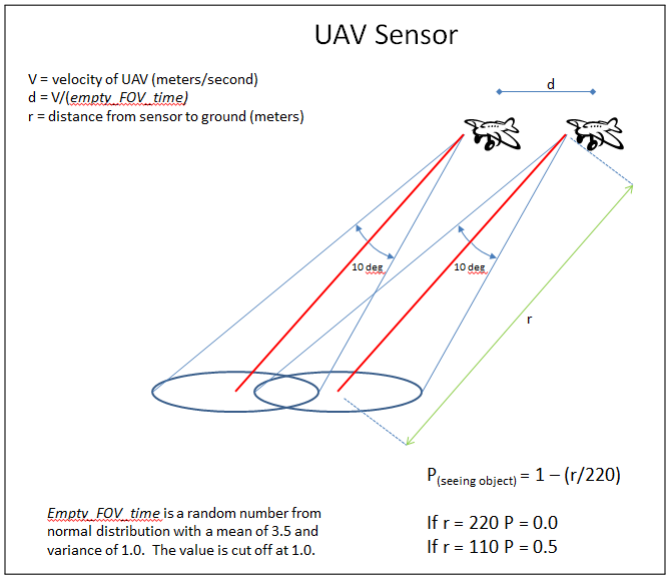


Figure 3.7: A depiction of the UAV Sensor Model used in this study. Courtesy from Imre Balogh [40].

This research uses the free, open-source program Protégé 4.3 to create a knowledge base (KB) of the world of IEDs [4]. According to the Protgé website, "Protégé implements a rich set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats"[4]. There are two methods that ontologies can be formed: (1.) Protégé-Frames editor "*frame-based*, in accordance with the Open Knowledge Base Connectivity protocol (OKBC)" and (2.) Protégé-Owl editor, which "enables users to build ontologies for the *Semantic Web*, in particular the W3C's [(World Wide Web Consortium)] Web Ontology Language OWL" [4]. The W3C website states "The OWL can be used to explicitly represent the meaning of terms in vocabularies and the relationships between those terms" [41]. The study uses Protégé-OWL editor (version 4.3, build 304) to create the IED ontology. According to the Protégé-OWL website, "OWL ontology may include descriptions of classes, properties and their instances. Given such an ontology, the OWL formal semantics specifies how to derive its logical consequences, i.e., facts not literally present in the ontology, but entailed by the semantics" [4]. These logical consequences are derived by using the reasoner. A reasoner is "a piece of software able to infer logical consequences from a set of asserted facts or axioms" [42]. This study uses the Fact++ (fact plus plus) description logic (DL) reasoner.

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3.5.2 Representing Information in an OWL Ontology

There are three main concepts when building an OWL ontology: classes, properties, and instances. The screen you see in Figure 3.8 shows the Protégé 4.3 user interface; the tabs used to create the ontology along with the reasoner are circled.

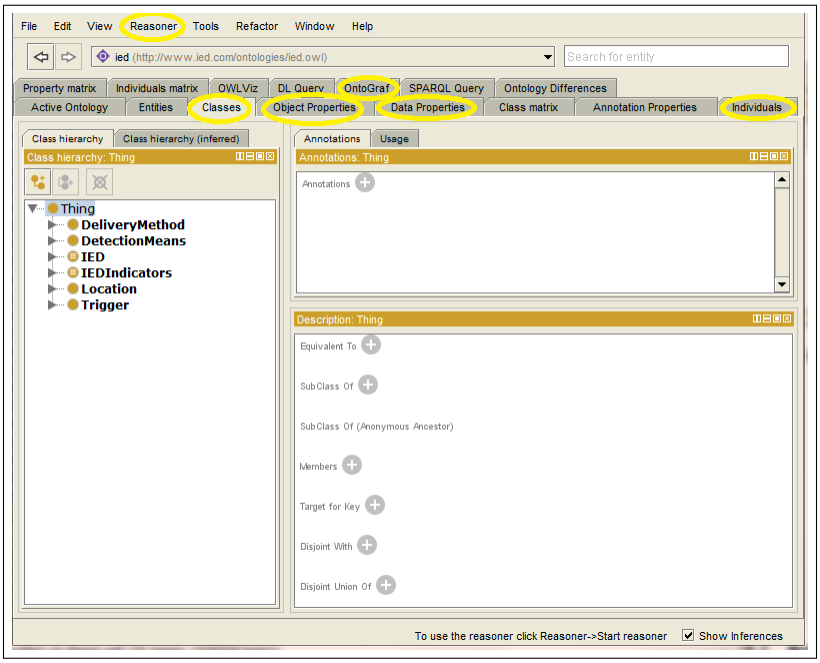


Figure 3.8: Screen picture of Protégé 4.3 program with the main tabs used circled. The Classes tab is shown.

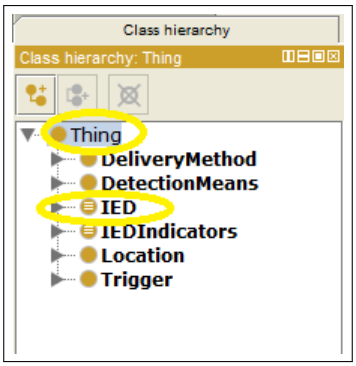


Figure 3.9: **`Thing`** class shown with its subclasses. **`IED`** class is a subclass of class **`Thing`**.

3.5.3 Defining Classes in IEDOntology

For this research, a preliminary ontology of IEDs was developed. The ontology is not fully defined, but provides a limited set of class and property definitions to demonstrate use of the

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ontology and automated reasoning to make inferences about detected IEDs based on information reported from human or automated observers in the battlespace.

In the Ontology (see Appendix G), the main classes can be seen in Figure 3.9.The **IED** class is shown (circled) with the other classes in the IED ontology. The main class is always the **Thing** class [43, p. 15]. The ultimate goal is to classify something as being some type of "IED," but in order to have a better understanding of the makeup of an IED, it is imperative that its sibling classes be defined first. The first sibling of class **IED** is the **DeliveryMethod**, which defines

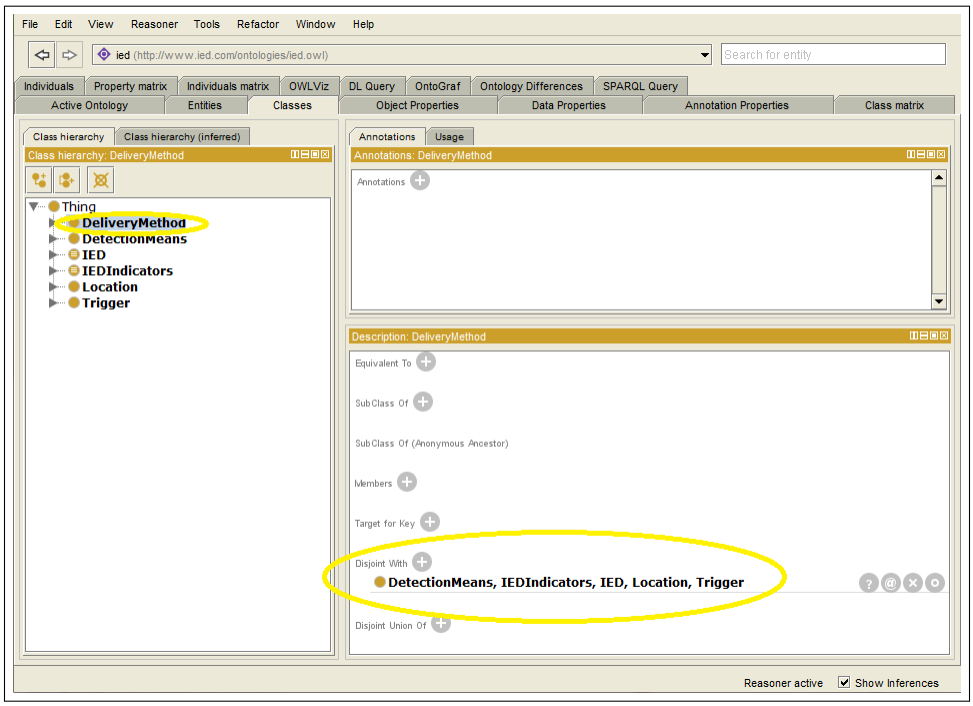


Figure 3.10: **DeliveryMethod** class shown with its disjoint sibling classes.

delivery method of an IED to its intended target (via human, package, or vehicle). The classes **Human**, **Package**, and **Vehicle** are subclasses of the parent class **DeliveryMethod** and are siblings to each other. This class is marked as disjoint from its sibling classes in the class hierarchy, as shown in Figure 3.10. We do not make them disjoint because the reasoner will fail. We make them disjoint because they truly are disjoint from each other. That information is used by the reasoner for its processing. The **Human** class is seen as a subclass of **DeliveryMethod**, disjoint with siblings **Package**, **Vehicle**, see Figure 3.11. It is not too difficult to understand how the tree can assist in visualizing the hierarchy of a class such as **DeliveryMethod**. The class **DetectionMeans** is a means of finding an IED, but is not explicitly used in defining an IED. The **IEDIndicators** class is a depiction of objects that a

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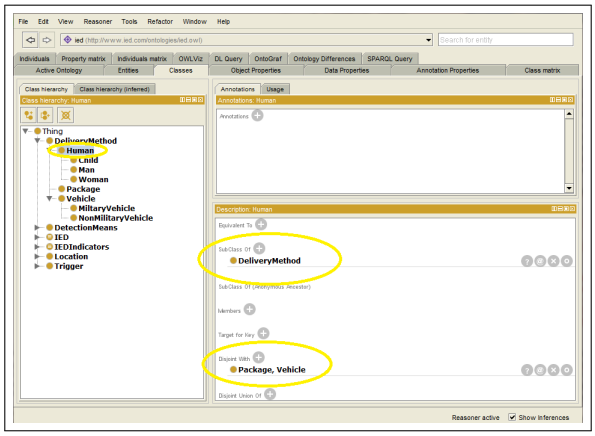


Figure 3.11: **`Human`** class shown with its disjoint sibling classes.

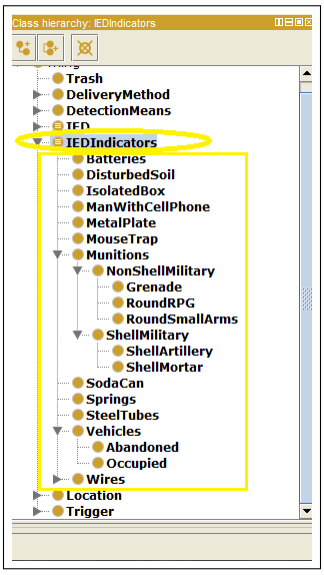


Figure 3.12: **`IEDIndicators`** class shown with with its subclasses contained in the yellow box.

user may be able to see when utilizing a UAS such as a Raven (see Figure 3.12). The **`Trigger`** class represents means to initiate an IED, see Figure 3.13. It would be plausible for a user of a UAS to see these types of objects while scanning an NAI for an IED. In **`Trigger`** class the subclass **`CellPhone`** is highlighted, notice that it is disjoint with its siblings.

3.5.4 Defining Properties in IED Ontology

Properties are what relate an individual to another individual in the ontology. An individual is an instance of a class. For example if there was a class “Dog” containing an individual named “Rascal” and he belongs to individual “John” from class “Owner,” “John” would share the

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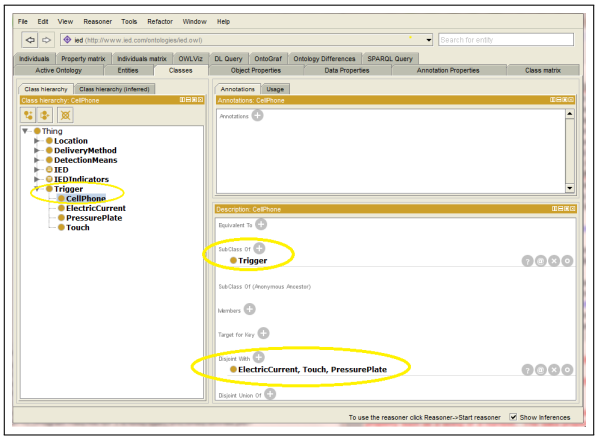


Figure 3.13: **`Trigger`** class with subclass **`CellPhone`** highlighted.

object property "hasPet" with individual "Rascal." In predicate calculus this takes on the form **`hasPet`**(**`John`**,**`Rascal`**). The same logic applies to defining an IED. There are four object properties that make up an IED ontology. The tutorial states "properties link individuals from the *domain* to individuals from the *range*" [43, 33]. Below are the four object properties defined in this ontology:

- **`hasDeliveryMethod`** Domain: **`IED`** Range: **`DeliveryMethod`**
- **`hasIEDIndicators`** Domain: **`IED`** Range: **`IEDIndicators`**
- **`hasLocation`** Domain: **`IED`** Range: **`Location`**
- **`hasTrigger`** Domain: **`IED`** Range: **`Trigger`**

The object property **`hasDeliveryMethod`** has three subproperties:

- **`hasHumanDeliveryMethod`** Domain: **`IED`** Range: **`Human`**
- **`hasPackageDeliveryMethod`** Domain: **`IED`** Range: **`Package`**
- **`hasVehicleDeliveryMethod`** Domain: **`IED`** Range: **`Vehicle`**

The **`hasLocation`** object property is selected in the Object Properties tab (see Figure 3.14) The **`Functional`** box checked implies that each individual in the **`IED`** class can be related to only one individual from **`Location`** class. The second class of properties in an OWL-Ontology are datatype properties. Datatype properties "...can be used to relate an individual to a concrete data value that may be typed or untyped" [43, 76]. The two data properties are **`hasIEDIndicatorName`** and **`isConfirmed`**, which are further summarized below:

- **`hasIEDIndicatorName`** Domain: **`IEDIndicators`** Range: **`string`**

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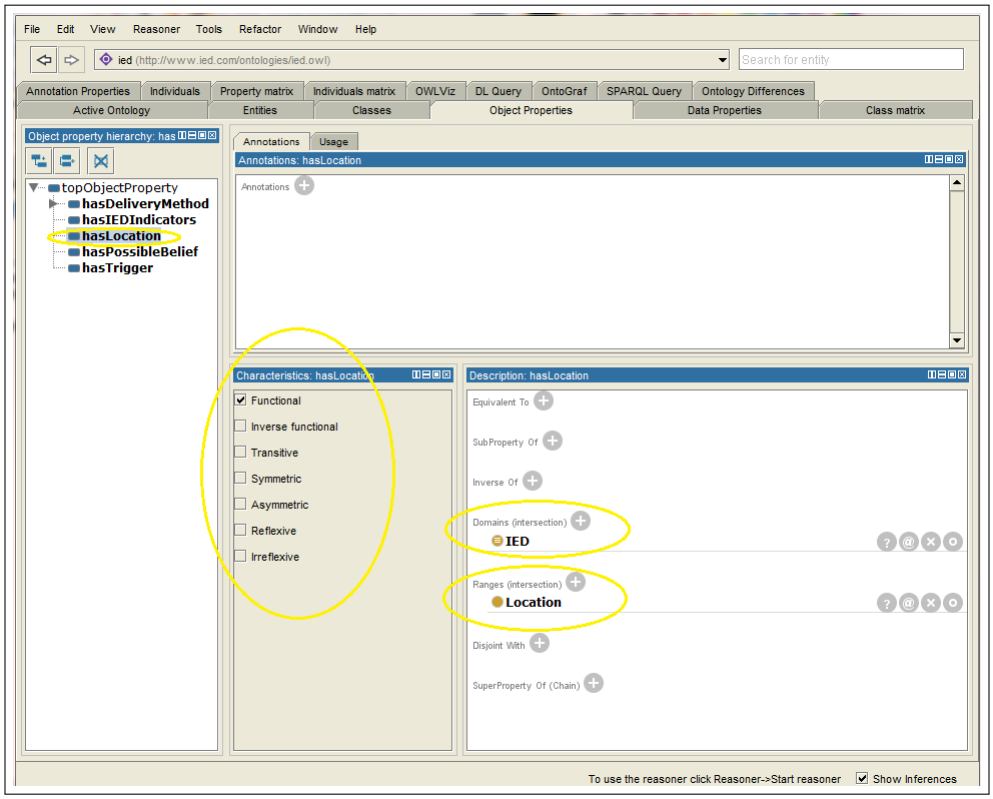


Figure 3.14: The **`hasLocation`** object property is selected with Domain **`IED`** and Range **`Location`**. The **`Functional`** box is checked as well.

- **`isConfirmed`** Domain: **`IED`** Range: **`boolean`**

The **`hasIEDIndicatorName`** range "string" will allow user to manually input some type of name for an **`IEDIndicator`** such as "dirt, iPhone, iron pipe." The **`isConfirmed`** allows the user to set if an **`IED`** indivdual is a confirmed IED (**`isConfirmed`** value equals "true") or not a confirmed IED (**`isConfirmed`** value equals "false").

3.5.5 Deeper Look in to IED Class

Now that the definition of classes and properties has been given, it is time to look further into **`IED`** class. The idea is to have the UAV sensor "see" objects ("clues") in its environment and the operator would take the "clues" and classify something as an IED. In order for something to be classified as being a member of the IED when using Protégé-Owl, the class has to be *necessary and sufficient* aka **Defined Class** [43, p. 55]. A necessary condition is one that needs to be present to be able to make the classification, but may need other conditions [43, 53]. A sufficient condition is one that by itself is enough to make the classification without needing other

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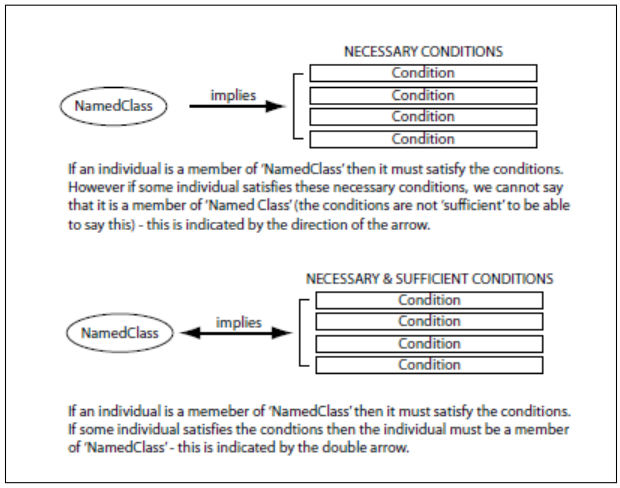


Figure 3.15: Necessary and Sufficient description. Taken from Pizza Tutorial [43, p. 56].

conditions to be true [43, 56]. See Figure 3.15 for an illustration of necessary and sufficient conditions. A class that is defined is indicated by white lines in the orange node circle [43, 57]. The necessary and sufficient criteria for **IED** class is seen in Figure 3.16. The word *some* represents an existential restriction. This says that there is a relationship between individuals of IEDs that has "at least one" relationship along the property (for example) "**hasDeliveryMethod**" to an individual that is a member of the class "**DeliveryMethod**" [43, 59]. The "and" represents an intersection where all of the object properties overlap. Next, we will look at the three different types of IEDs based on how they are delivered: Package (**PackageIED** class), Suicide/Human (**SBIED** class), and Vehicular (**VBIED** class).

The **PackageIED** class is a subclass of **hasPackageDeliveryMethod** and **IED** and it inherits the same four characteristics of an IED based on being a subclass of **IED**. The **PackageIED** class represents delivery by some package, one that is not a suicide bomber (SBIED) or vehicular (VBIED). One can see that it is also disjoint with its siblings **SBIED** and **VBIED** (see Figure 3.17). The **SBIED** class is a subclass of **IED** and **hasHumanDeliveryMethod some Human**, and like its sibling **PackageIED** it inherits the four properties that make an IED an IED. It is also disjoint with **VBIED** and **PackageIED** (see Figure 3.18). The purpose of **SBIED** is to represent characteristics of a suicide-borne IED. A suicide borne IED delivery could be performed by a child (**ChildSBIED**), Woman (**FemaleSBIED**) or a man (**MaleSBIED**). Since **ChildSBIED** is a subclass of **SBIED** it inherits the properties of **SBIED**, which is defined in the middle of the "Description: ChildSBIED" box labeled

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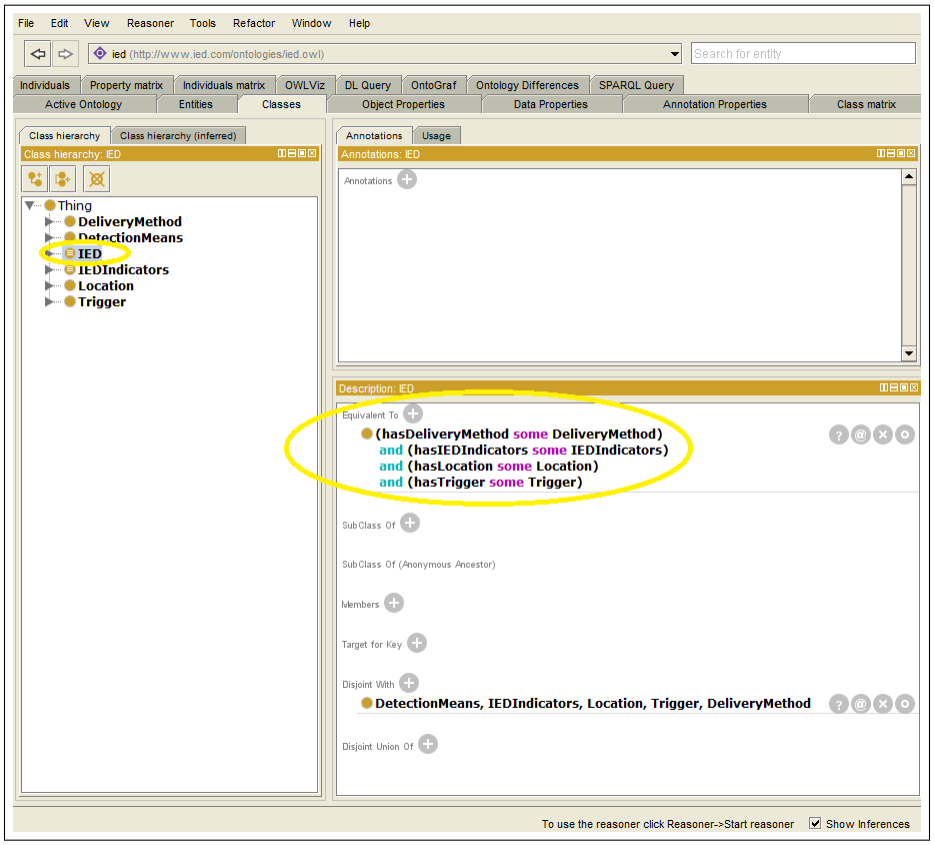


Figure 3.16: The "Equivalent To" box is highlighted showing what must be true in order for an individual to be a member of the **IED** class.

"Sub Class of (Anonymous Ancestor)." The property that explicitly defines **ChildSBIED** is **hasHumanDeliveryMethod** and qualifies the delivery method as a child with the "some child" clause. It is also disjoint with its siblings **MaleSBIED** and **FemaleSBIED**. The classes **MaleSBIED** and **FemaleSBIED** are similar to **ChildSBIED** with **hasHumanDeliveryMethod** qualified as Female and Male, respectively. The **VBIED** class is a subclass of **IED** and **hasVehicleDelivery** and like its siblings **PackageIED** and **SBIED** it inherits the four properties that make an IED an IED. It is also disjoint with **SBIED** and **PackageIED** (see Figure 3.19). The purpose of **VBIED** is to represent characteristics of a vehicle-borne IED. The class **ConfirmedIED** is to be used when an operator sees characteristics of an IED (via UAV) and calls EOD, who then "confirms" that it is a real IED. It inherits the properties of **IED** and has the value **isConfirmed** with a "true" value. The **ConfirmedIED** is disjoint with its siblings **SBIED**, **VBIED**, and **PossibleIED** (see Figure 3.20). If the IED is not confirmed, it will then be classified as a "PossibleIED," which is discussed next.

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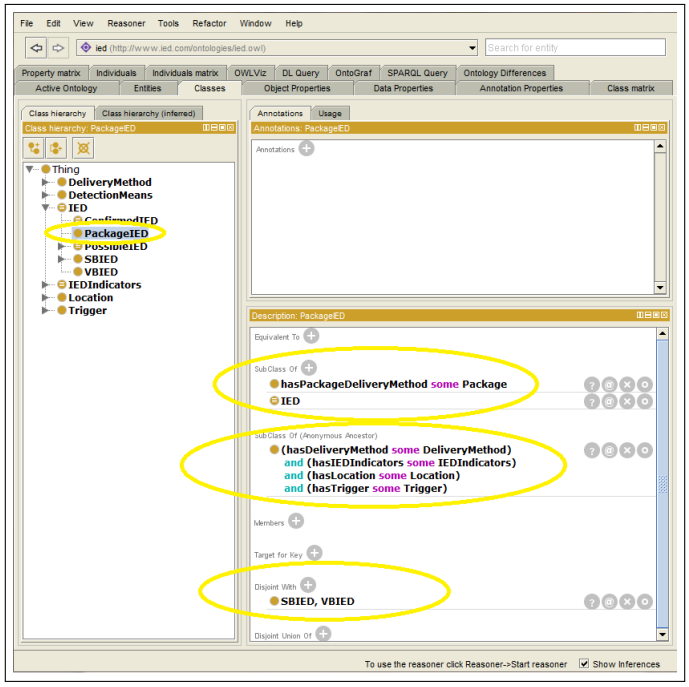


Figure 3.17: **`PackageIED`** shown.

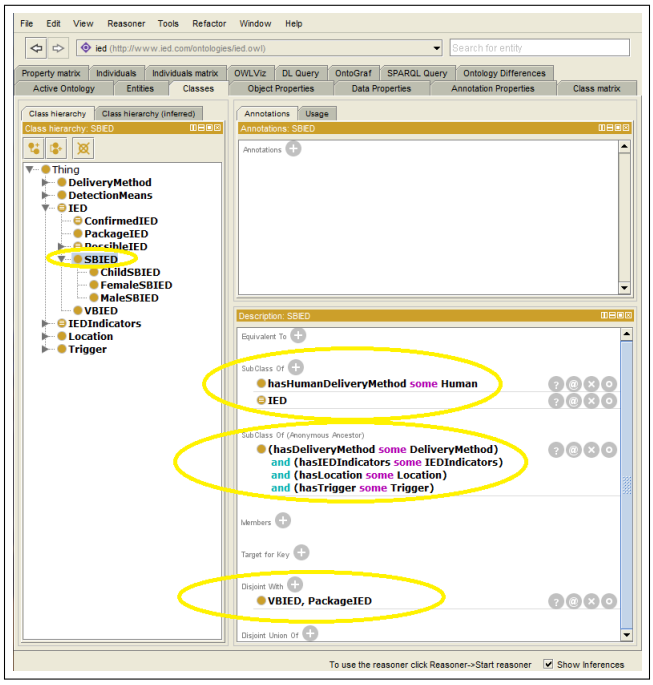


Figure 3.18: **`SBIED`** shown.

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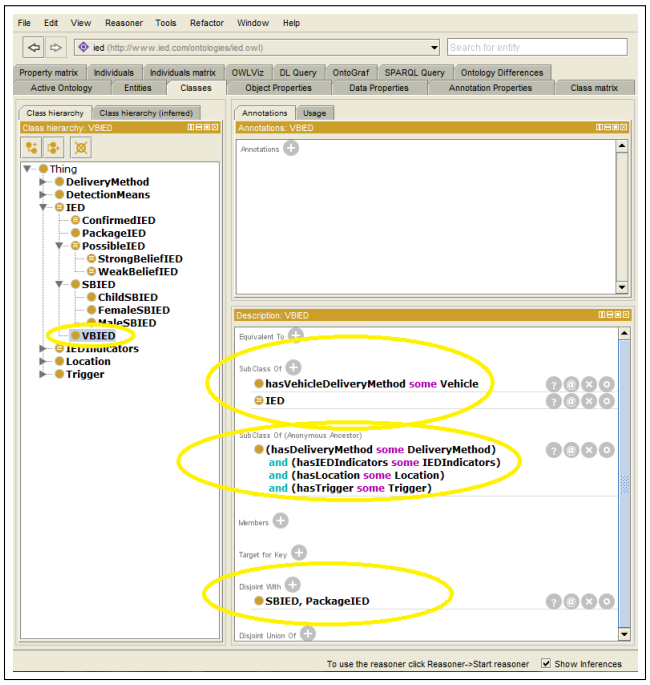


Figure 3.19: **`VBIED`** shown. A vehicle borne IED delivery happens by a vehicle via **`hasVehicleDeliveryMethod`**.

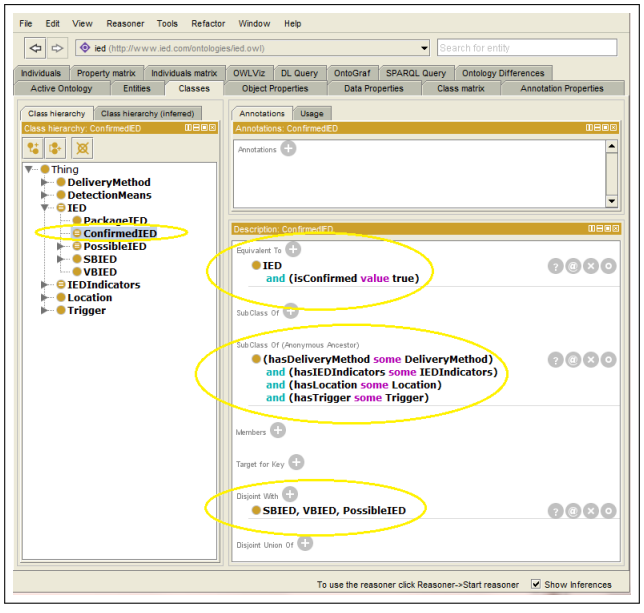


Figure 3.20: **`ConfirmedIED`** shown.

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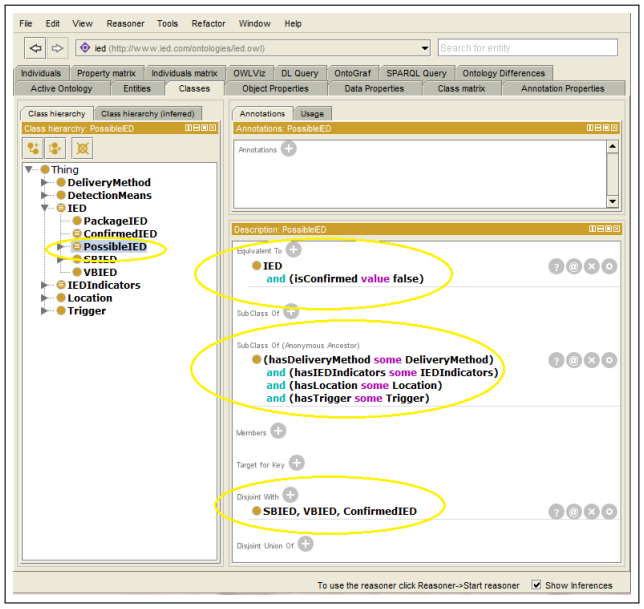


Figure 3.21: **`PossibleIED`** shown.

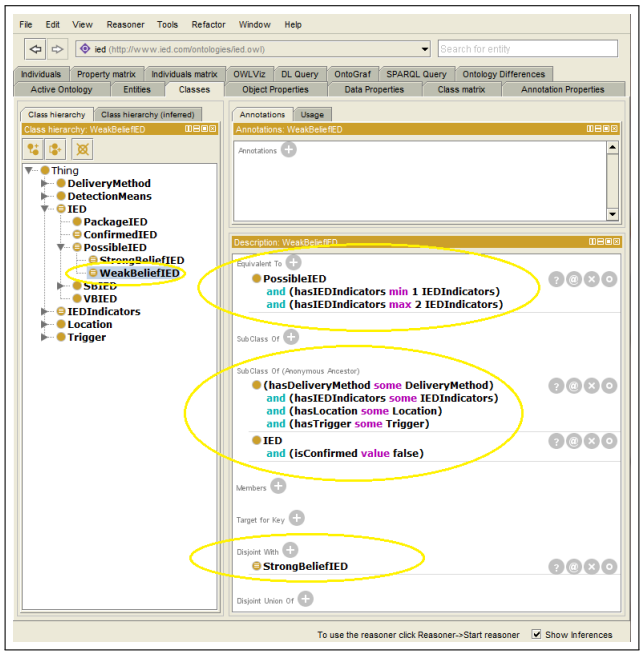


Figure 3.22: **`WeakBeliefIED`** shown.

The **`PossibleIED`** is a subclass of **`IED`** and has the property **`isConfirmed`** with a “true” value. In theory if an IED is not a “ConfirmedIED” it will always be classified as a "PossibleIED" (see Figure 3.21). A **`WeakBeliefIED`** inherits all of the properties of a type **`PossibleIED`** with the exception of its own specific requirement in “Equivalent to” box

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(circled on top portion of "Description" window, see Figure 3.22). A **`WeakBeliefIED`** is a type of IED that has a minimum of 1 IED indicator and a maximum of 2 IED indicators. It is using a new restriction called the universal restriction *only*. The universal restriction states "*if* a relationship exists for the property then it must be to individuals that are members of a specific class" [43, p. 60]. The goal is to create an individual with a minimum of 1 and maximum 2 "IEDIndicators" and have the reasoner classify it as a "WeakBeliefIED." The minimum and maximum are a type of cardinality restriction. The tutorial states: "A Cardinality Restriction specifies the *exact* number of P relationships that an individual must participate in" [43, p. 73]. The assumption is that you would need a few indicators such as loose soil and wires together at some specific location along a route of travel to have a UAS operator to possibly take a closer look at what they are scanning on the ground. If more than two indicators are found, the reasoner will classify the object as a "StrongBeliefIED," which is described next. A **`StrongBeliefIED`** inherits all characteristics of a **`PossibleIED`** with the addition of a third "IEDIndicator." Therefore in the "Equivalent To" box the addition of object property **`hasIEDIndicators min 3 IEDIndicators`** is necessary. The idea is to show that an operator that sees "loose soil," "box," and "wires" would probably think that there is a higher suspicion of being a true IED versus only seeing two or fewer indicators. The properties of a **`StrongBeliefIED`** can be found circled in the "Description: StrongBeliefIED" box, see Figure 3.23.

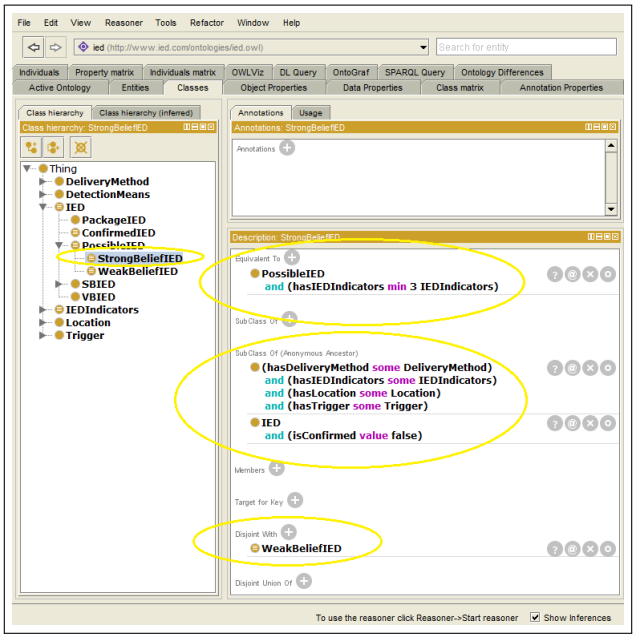


Figure 3.23: **`StrongBeliefIED`** shown.

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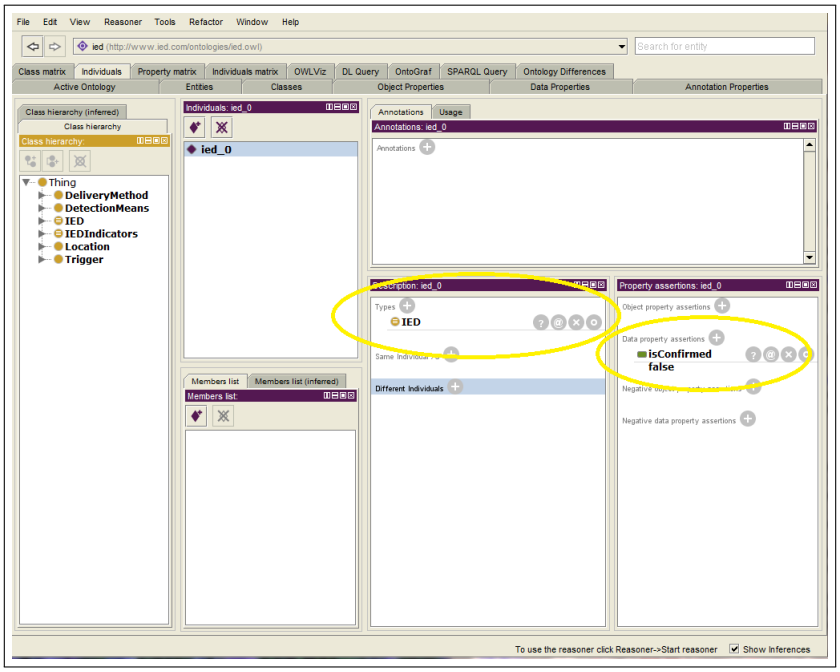


Figure 3.24: **`ied_0`** individual shown.

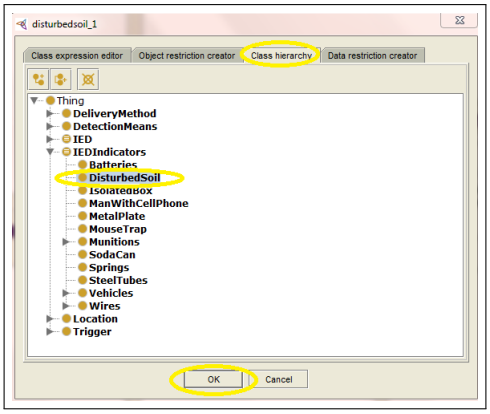


Figure 3.25: **`disturbedsoil_1`** individual being assigned type **`DisturbedSoil`**.

3.5.6 Defining Individuals in IED Ontology

The study will now look at creating individuals in the ontology that will allow the reasoner to show if the created individual can be classified as a "PossibleIED," "StrongBeliefIED," "WeakBeliefIED," or "ConfirmedIED." Individuals can be created in the "Individuals" tab. All individuals in Protégé are identified with a purple diamond and are written in lowercase. In order for the reasoner to classify (infer) an individual as being a member of a certain class, the class

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of which it is a member needs to be a "defined" class, otherwise the reasoner will not properly classify (infer) its relationship to a particular class. First, the individual **ied_0** is created, see Figure 3.24. It is given the type **IED** and Data property assertion **isConfirmed** with value "false." This represents an object that has been detected but no indicators have been identified. The second IED individual will have with it two IED Indicators: "disturbed soil" and "wires." These indicators will need to be created individually so we can assign them as object properties to individual **ied_1**. First IED Indicator is named **disturbedsoil_1**, assigned class type **DisturbedSoil** and given **hasIEDIndicatorName** "dirt" string. To assign the type **IED** click on "Types" "+" sign and select "Class Hierarchy" and select "ok." (see Figure 3.25). Next, assign data property assertion type string "dirt" to **disturbedsoil_1** indicator. See Figure 3.26 for assigning "dirt" to indicator **disturbedsoil_1**. One could change "dirt" to "dog" and the reasoner would not care, assigning "dirt" makes it easier for the user to follow along. The second IED Indicator is named **wires_1** it is assigned the **IEDIndicator**

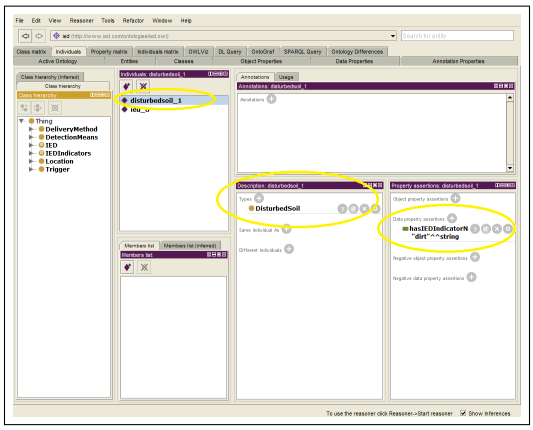


Figure 3.26: **disturbedsoil_1** indicator being assigned string "dirt" shown.

subclass **Wire** and given the data property assertion string "wire" (see Figure 3.27). The second IED individual, **ied_1** is like **ied_0** except the individuals **disturbedsoil_1** and **wires_1** are assigned as "object property assertions," and since this is not a "confirmedIED" it is assigned data property **isConfirmed** with value "false." (see Figure 3.28). To assign the IED Indicators select "Object property assertions" underneath "property assertions window" and click on "+" sign. Next assign the two indicators to **ied_1** (see Figure 3.29). The third and final indicator is defined with object property **hasIEDIndicator** with type string and individual assigned the name as **isolatedbox_1** to represent a box alongside the road. There is no change in how you assign it a type and data property assertion. See Figure 3.30 for **isolatedbox_1** individual screenshot. The third IED individual is **ied_2** it has 3 IED

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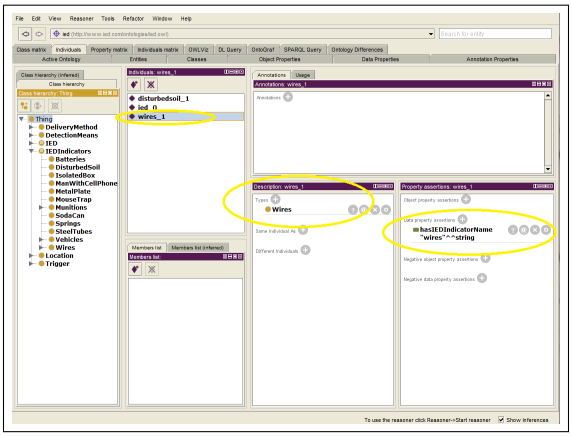


Figure 3.27: **`wires_1`** individual shown.

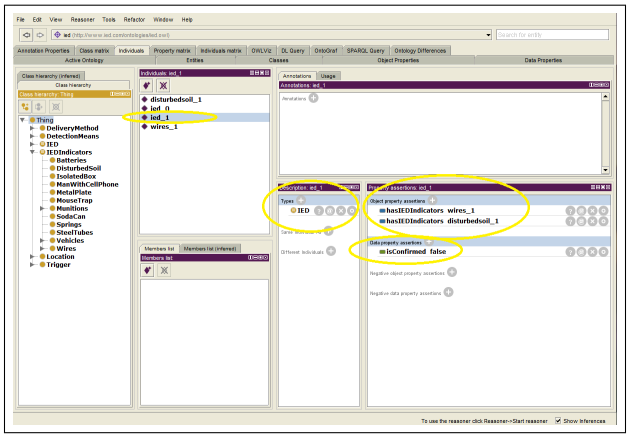


Figure 3.28: **`ied_1`** individual shown.

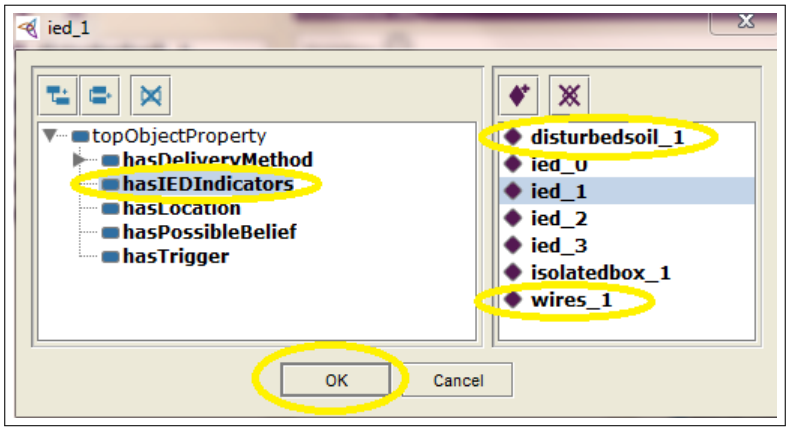


Figure 3.29: Assigning IED Indicators to **`ied_1`**.

Indicators and “isConfirmed” value set to “false” (see Figure 3.31). This is an individual that an operator has been able to associate three characteristics of this “Possible IED.”

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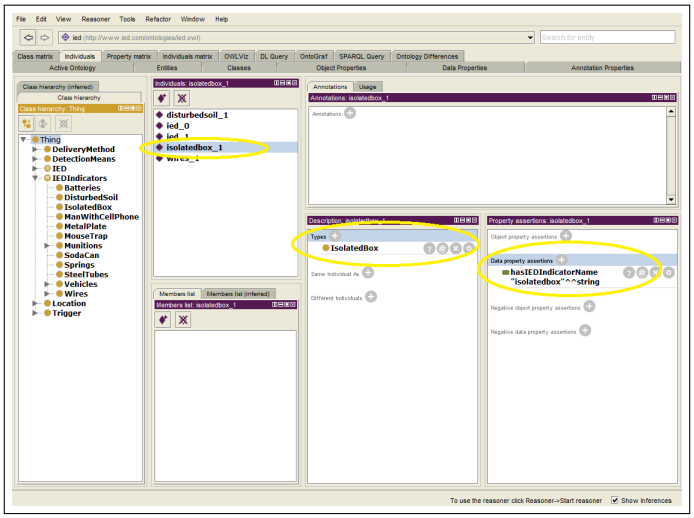


Figure 3.30: **`isolatedbox_1`** individual shown.

Since it is not confirmed yet, the data property **`isConfirmed`** is set to “false.” The fourth and

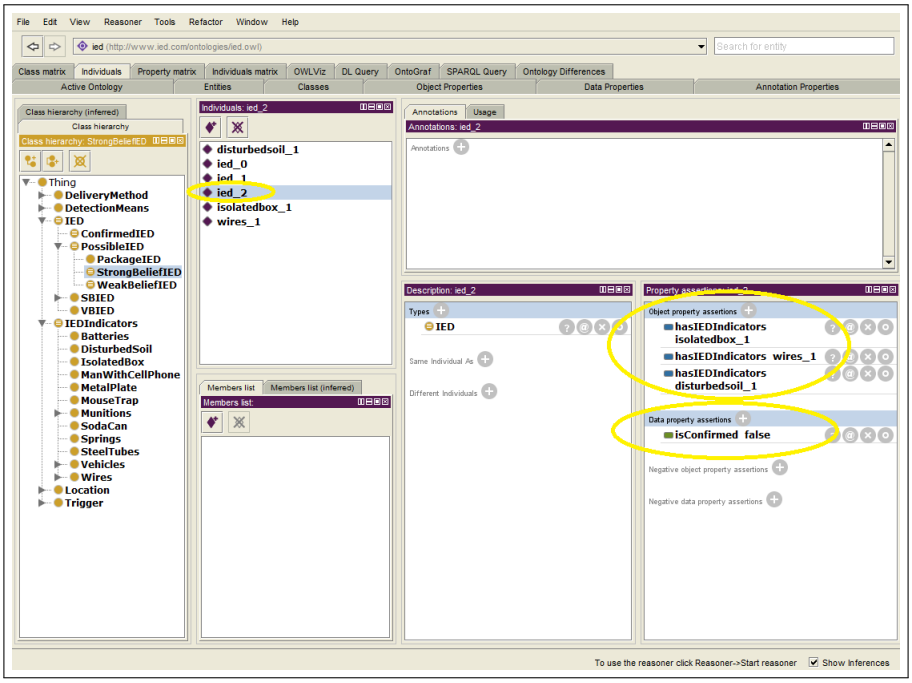


Figure 3.31: **`ied_2`** individual shown.

final IED individual is **`ied_3`**, which is just like **`ied_2`** except this IED has been confirmed by EOD to be a legitimate IED, therefore the **`isConfirmed`** data property assumption is set to "true" (see Figure 3.32).

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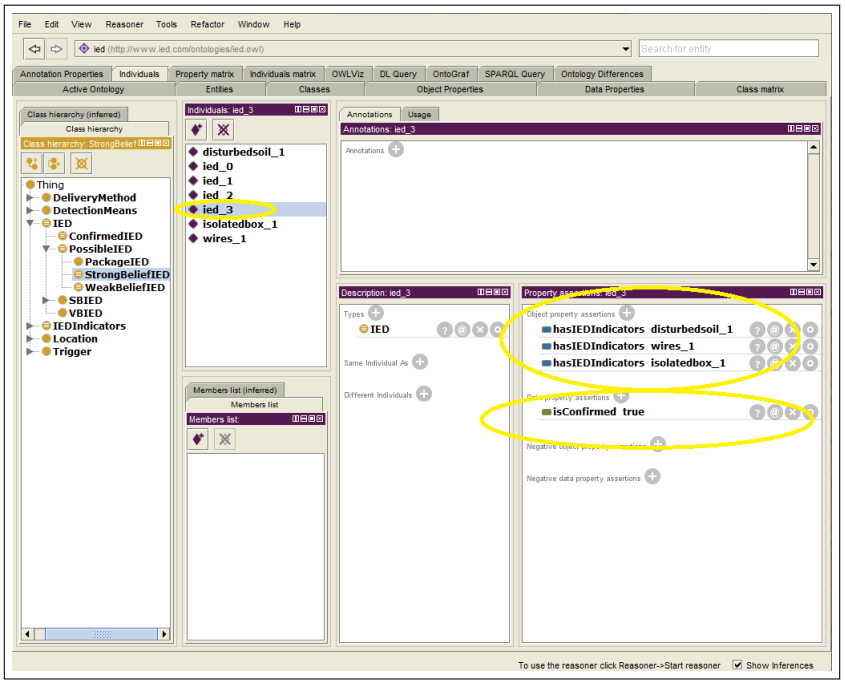


Figure 3.32: **`ied_3`** individual shown.

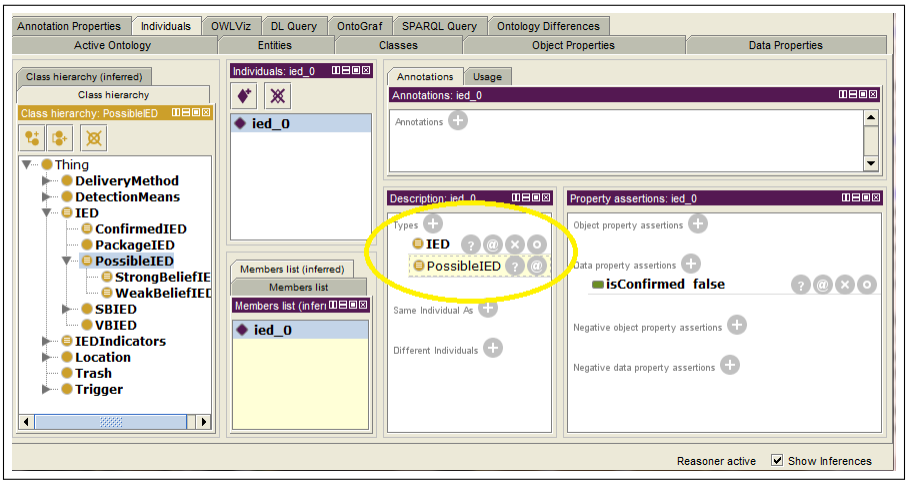


Figure 3.33: Reasoner classifies object “Possible IED.” based on its object and data properties.

3.5.7 Classifying an IED Using the Reasoner

The experiment will now model the behavior of a UAS’s ability to make a decision based on the information that it receives from its sensors. In this experiment, the sensor (UAV) is collecting data that falls into the categories of “IED Indicators.” Pieces of information that an operator may or may not be able to see using the UAS is represented as individuals. The reasoner is used to establish the level of confidence in what is seen based on the amount of information

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the operator is able to see using his/her UAV. The UAV is flying looking for threats along the way. The operator detects an object (called **ied_0**), however, he/she cannot identify what it is. Because **ied_0** does not have any indicators the reasoner should and does classify this object as a "PossibleIED" (see Figure 3.33). As the operator continues to look at the object

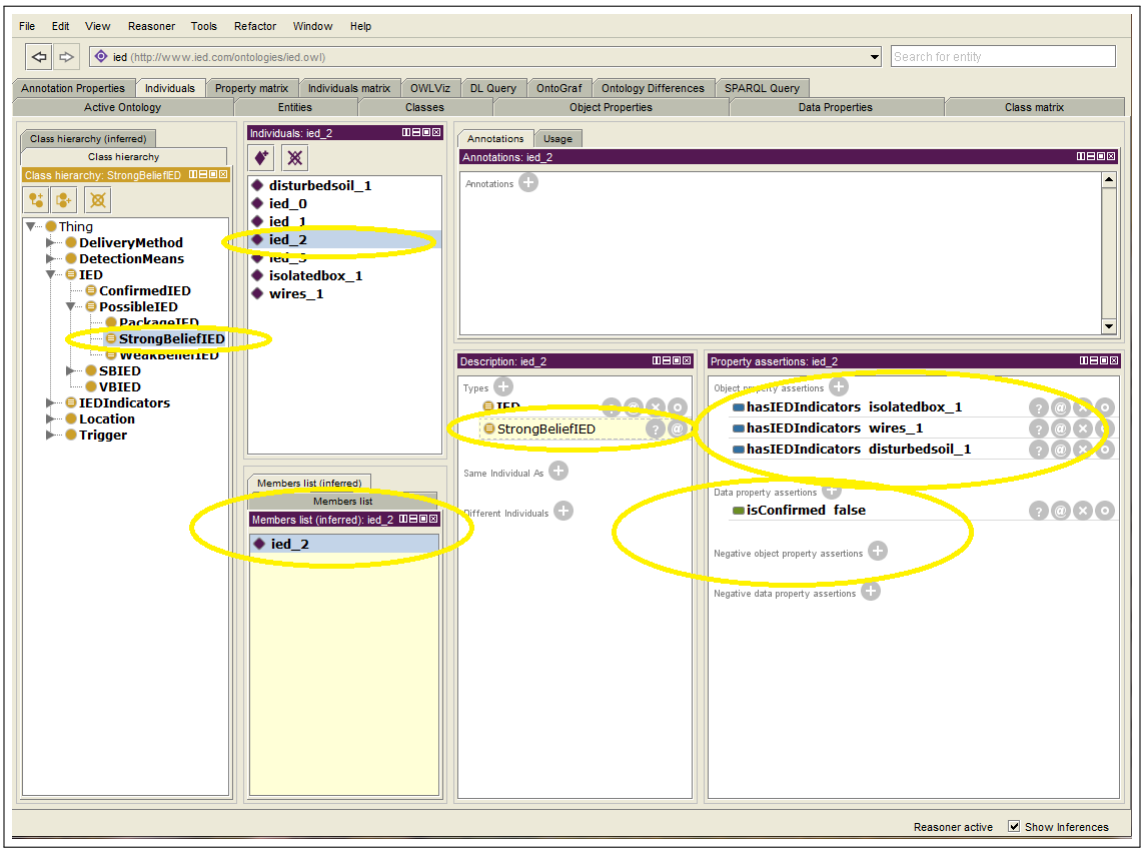


Figure 3.34: Reasoner classifies object as “Strong Belief IED.” based on properties associated with **ied_2**.

they see IED indicators such as disturbed soil, wires, and now a box (making the user feel more confident about what is seen) causing the reasoner to classify this object (now called **ied_2**) as a “Strong Belief IED” (see Figure 3.34) since there are three indicators. The convoy commander cordons off the area and calls for the EOD to investigate this strong belief, possible IED. Once EOD arrives, having looked at the same characteristics that the operator has, confirms that object (now called **ied_3** is a “real IED” and classifies it as a “Confirmed IED” (see Figure 3.35).This device is neutralized by EOD and a highly possible catastrophic kill is prevented.

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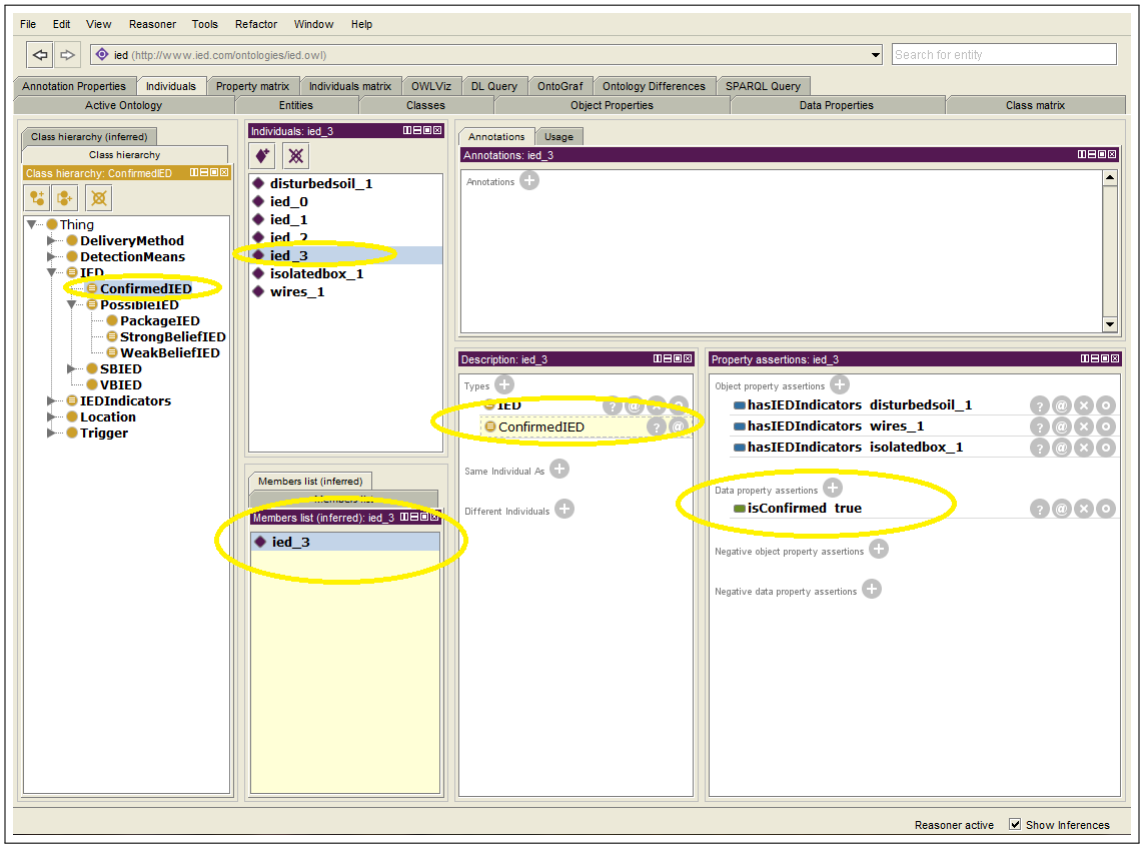


Figure 3.35: The "possible, strong belief IED" has been confirmed an IED by explosive ordnance disposal (EOD).

3.6 DESIGN OF EXPERIMENTS

The goal of Design of Experiments is to see if the effects of training on mission success can be shown in COMBATXXI utilizing the HTNs and UAV Sensor model. The mission objective is to arrive at Outpost X-Ray safely (as mentioned in section 3.2). The only true IED (located in NAI #2) detonates with probability 0.80 and will always kill the second vehicle in the convoy when detonated, the other three NAIs each have a single non-IED object. The mission will be over if: (1) Convoy reaches final destination without hitting IED (Mission Complete or MC) or (2) Convoy hits IED (Mission Failure). Success (MC) can only happen if IED is detected and defeated (UAS used effectively) or IED does not go off (probability 0.20) given IED is undetected (worse case). The UAV sensor [40] has a likelihood of detecting the object with probability 0.50 if the range from the sensor to the IED (r) is 110 meters and probability 0 if r is 220 meters or greater. Time to clear an IED is 60 minutes.

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The factors affecting mission success are False Positive (α) and False Negative (β), with levels ranging from 0.0 to 1.0. Experiments run at six values for each (0.0, 0.2, 0.4, 0.6 0.8, 1.0), for a total of 36 design points. Each design point is run 100 times for a total of 3600 observations (n). Below are the definitions for False Positive and False Negative:

- If False Positive (α) 0.0 then UAS ALWAYS identifies a non-IED object as a non-IED.
- If False Positive (α) 1.0 then UAS ALWAYS identifies non-IED as an IED.
- If False Negative (β) 0.0 then UAS ALWAYS correctly identifies IED as an IED.
- If False Negative (β) 1.0 then UAS ALWAYS incorrectly identifies IED as a non-IED.

Best case is when alpha and beta are 0.0 and 0.0. This represents an operator that both correctly classifies an object as being an IED or something that is truly not an IED (trash), reducing risk (less time exposed), and saving resources (UXO clearing team not called).

Worst case is when alpha and beta are 1.0 and 1.0. This represents an operator who always incorrectly detects an object as an IED and unnecessarily wastes resources to "clear" a non-IED, adding more time to convoy being exposed outside the wire, while at the same time always misidentifying real IEDs, leading to a high failure rate.

Metrics to measure the effects of alpha and beta are:

- Mean Mission Success Rate
- Mean Time to Complete Mission | Mission Complete
- Risk = 1/MC% x Mean Time to Complete Mission | Mission Complete

3.6.1 Summary

The concept of using an ontology and implementing it in order to demonstrate a different approach in measuring the sensing ability of a UAS is discussed. The DOE will determine if it is possible to model the positive and negative effects of being trained and untrained (changing values of alpha and beta) given the UAV sensor model detects the object. In the next chapter, the research will perform an analysis on data to be collected.

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CHAPTER 4:
ANALYSIS

4.1 INTRODUCTION

We demonstrate the utility of our approach through analysis of the proof of concept scenarios. The findings show how the scenario results are sensitive to changing parameters False Positive (α) and False Negative (β) in our sensor model. This proof of concept scenario would be useful to a decision maker interested in evaluating the potential impact of training on the effective use of UAVs.

4.2 DESIGN OF EXPERIMENTS ANALYSIS IN COMBATXXI

The analysis will investigate the effects of α and β at six levels each (0.0, 0.2, 0.4, 0.6, 0.8, 1.0), mentioned earlier in chapter 3 "Methodology" The goal is to identify what combinations of alpha and beta give us the highest Mean Mission Success Rate, lowest Mean Time to Complete Mission | Mission Success, and to help quantify Risk.

4.2.1 Mean Mission Success Rate

This section is about measuring the mean success rate for the 3600 observations. A heat map is utilized to communicate results. Boxplots help to show noise and meaning to support the findings on α's and β's effects on Mission Success Rate. Looking at Figure 4.1 we can see that the highest completion rate is 0.84 and occurs when β is 0.0, and is independent of α

False Positive (α) Parameter

False Negative (β) Parameter	0.0	0.2	0.4	0.6	0.8	1.0
0.0	0.84	0.84	0.84	0.84	0.84	0.84
0.2	0.74	0.74	0.74	0.74	0.74	0.74
0.4	0.57	0.57	0.57	0.57	0.57	0.57
0.6	0.46	0.46	0.46	0.46	0.46	0.46
0.8	0.29	0.30	0.29	0.29	0.29	0.29
1.0	0.20	0.19	0.19	0.19	0.19	0.19

Mean Mission Success Rate per 100 trials

Figure 4.1: Heat Map of Mission Success Rate versus parameters False Positive (α) and False Negative (β). Notice that the Mission Success Rate does not change as alpha increases from 0.0 to 1.0, which demonstrates that the False Positive parameter α does not have an effect on mission success. Mission failures occured even with β at zero because on some trials the UAV never sees the IED, and as a result the IED was not identified.

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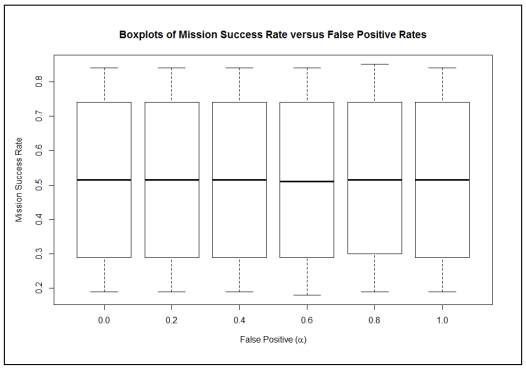


Figure 4.2: Boxplot of Mission Success Rate versus False Positive Rates. Notice that the Mission Success Rate does not change as alpha increases from 0.0 to 1.0. This shows that α does not have an effect on mission success since False Positive represents the identification of non-IED objects.

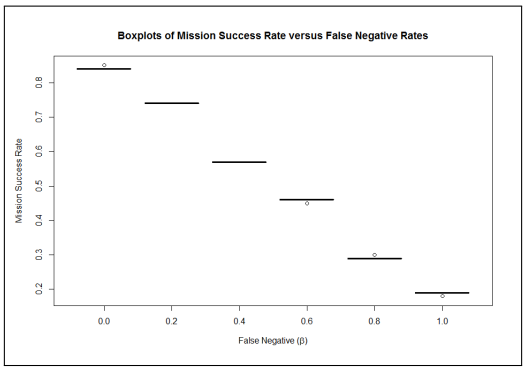
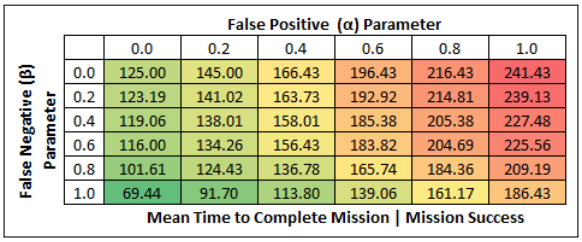


Figure 4.3: Boxplot of Mission Success Rate versus False Negative Rate (β). Notice that the Mission Success Rate decreases as β increases from 0.0 to 1.0. There is no variance in the success rate either, which is why the boxes appear as lines instead of boxes per earlier boxplots when looking at Mission Success versus False Positive Rate. This shows that β has a great effect on mission success rate versus α.

levels. The lowest average of completing mission is approximately 0.20 and 0.19 when β is 1.0, independent of α levels. The decrease in mean mission success as β increases is caused by a higher probability of incorrectly identifying the IED in NAI #2 as a non-IED. Since the IED has a probability of 0.8 of detonating, that is why the success rate is 0.20 when β equals 1.0. As the False Positive value increases from left to right the success rate generally remains constant. It is only as we increase β that there is a difference in mission success rate, concluding that β has a strong influence on the likelihood of completing the mission. Looking at the first boxplot (see Figure 4.2), one can see that the False Positive (α) does not have an effect on the mission success rate since the boxplots share the same dimensions, respectively. The Mission Success

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False Negative (β) Parameter	0.0	0.2	0.4	0.6	0.8	1.0
0.0	125.00	145.00	166.43	196.43	216.43	241.43
0.2	123.19	141.02	163.73	192.92	214.81	239.13
0.4	119.06	138.01	158.01	185.38	205.38	227.48
0.6	116.00	134.26	156.43	183.82	204.69	225.56
0.8	101.61	124.43	136.78	165.74	184.36	209.19
1.0	69.44	91.70	113.80	139.06	161.17	186.43

Figure 4.4: Heat Map of Mean Time to Complete Mission | Mission Success for different values of False Positive (α) and False Negative (β). Mean time to complete the mission takes the longest when α is 1.0 and β equals 0.0. Mean time for a successful mission increases as α increases and decreases as β increases.

Rate is very close or right above 50% as α increases from 0.0 to 1.0. Continuing on with the second boxplot, the False Negative Rate (β), mission success decreases as β increases from 0.0 to 1.0 (see Figure 4.3).
This visual helps to show that in the model that False Negative Rate (β) has a strong effect on mission success.

4.2.2 Mean Time To Complete | Mission Success

Now the study will look at the mean time to complete the mission given mission success occurs. Looking at the heat map in Figure 4.4 it appears that the mean time to complete mission given mission success is influenced more on α than β. Mean time to complete mission is highest at 241.43 minutes when $\alpha = 1.0$ and $\beta = 0.0$. This makes sense; the operator will always identify a non-IED as an IED when $\alpha = 1.0$. The lowest mean time to complete mission of 69.44 minutes is at the opposite corner when $\alpha = 0.0$ and $\beta = 1.0$. This number can be misleading because in this case, the UAV operator will always identify a piece of trash as trash ($\alpha = 0.0$), but when β is equal to 1.0, the operator will always incorrectly identify an IED as a non-IED. Therefore in this case the convoy will never stop to handle a potential threat. The only reason there is any success in this case is because there is a 0.20 chance the IED will not detonate and it is in these "lucky" cases that the mission is completed. Now examining the Mission Complete Time boxplots (see Figure 4.5) it appears that the average time to complete the mission does increase as False Positive Rate (α) increases from 0.0 to 1.0.; this makes sense in our model given that we stated earlier that if α is 0.0 it would always identify a non-IED object as a non-IED. Also when α is 1.0 the UAS operator always identifies non-IED as an IED, leading to additional time spent on a mission and exposing onself to more harm. Examining Figure 4.6 it appears that mission completion time does not vary as much and remains constant (at β value increases), proving that in the model, the False Negative Rate (β) does not have as much influence for mean

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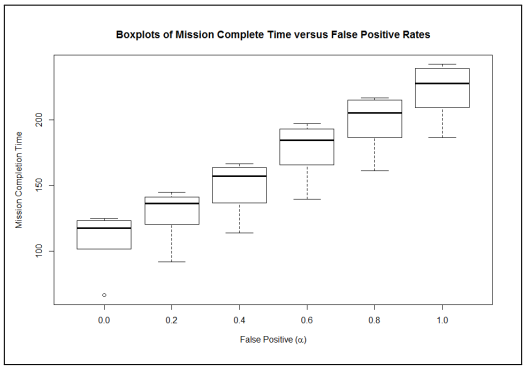


Figure 4.5: Boxplot of Mission Completion Time versus False Positive Rates. Notice that median time to complete mission increases as the False Postive Rate (α) increases. There appears to be a linear relationship; the variance for each value of α appears to be equal to one another as well. This means that α will always have an effect on amount of time it completes the mission.

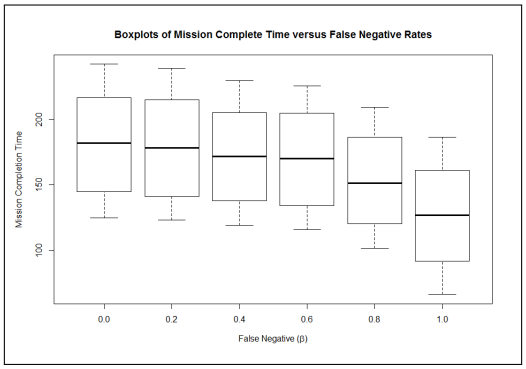


Figure 4.6: Boxplot of Mission Complete Time versus False Negative Rate (β). The False Negative parameter β does not have as much of an effect on average time it takes the convoy to complete the mission. Notice that the Mission Completion Time is not heavily influenced on the change in β from 0.0 to 1.0. A time of 150 minutes could be found for each β value. Only when the value of 0.8 is reached is there a drop in median time of completing the mission. This is because the observer has a higher probability of incorrectly identifying the IED as a non-IED, resulting in fewer times to successfully complete the mission and have an observed time.

mission completion time as the False Positive Rate (α).

4.2.3 Measuring Risk

Risk is something all commanders must take when utilizing the U.S. Army's most valuable asset: soldiers. As a means to assess risk, we can combine the considerations of mission success rate and completion time. We task risk to be:

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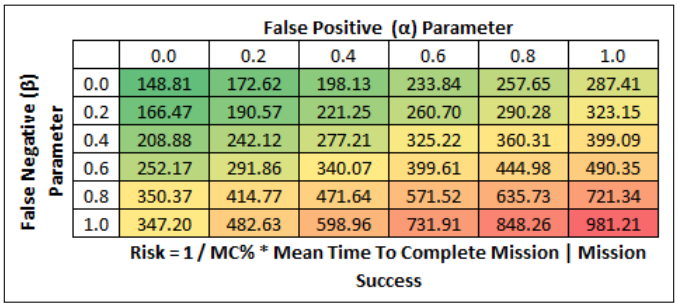


Figure 4.7: Heat Map of Risk for different values of False Positive (α) and False Negative (β). Lowest risk takes place at α and β being 0.0, 0.0. Given the IED is detected, the user has capability to correctly identify the IED and does not waste time clearing non-IEDs. When α, β is 1.0, 1.0, risk is highest (less likely to correctly identify IED and more likely to incorrectly identify non IEDs as being IEDs).

$$Risk = 1/MC\%x(MeanTimetoCompleteMission|MissionComplete) \tag{4.1}$$

Figure 4.7 shows risk as a function of α and β. It is the most interesting of the three heat maps. This measure of risk attempts to combine the risk of not identifying the IED with the inherent risk associated with being out in the open for an extended amount of time. Figure 4.7 confirms that this characterization of risk captures both aspects of the risk encountered by convoys. We expected the most dangerous situation to be when α is 1.0 and β is 1.0, when the operator always misidentifies objects as being real IEDs and never identifies the real IEDs as a real IED, this is what we can see in the heat map. At the opposite corner when α and β are 0, respectively, risk measures at 148.81. This is the best case scenario because an IED is always classified as an IED and non-IEDs (trash) are always identified as trash, minimizing the amount of time a convoy must spend on the route outside of "friendly" territory while still reducing the vulnerability to damage from IEDs.

4.3 SUMMARY

The results above show that it is possible that a UAS (like the Raven) may improve deployable force protection capabilities if the assumptions hold true in the real world. It is possible to measure success and time to complete a mission with different combinations of α and β. The heat maps provided valuable insight on the ramifications of each α and β level. The boxplots gave reassurance in the validity of the heat maps by showing differences the parameters do or do not have. Risk gave further understanding into the importance of correct versus incorrect identification of objects, and the effects of wasting time clearing non-IED threats. Next, the study will give a conclusion of using the new STA model and the idea of combining KR through

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an ontology made using special software.

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CHAPTER 5:
CONCLUSION

5.1 OUTCOMES

We demonstrated the application of the new STA model in a tactical convoy scenario in COMBATXXI. We showed the ability to model a UAS in a working environment is fundamental to a study concerning tactical convoy operations. A design of experiments and post analysis quantifies the sensitivity of the measures of effectiveness of success to conditions contributing to variability in UAS performance.

5.1.1 What Does This Mean?

Behaviors for UASs can be designed and developed using Behavior Studio Interactive Design Environment. HTNs were created to replicate the thought and action process of a convoy as it travels down a path wary of threats such as IEDs, with respect to the use of UAVs. The simulation allows for some analysis to determine if tactical convoy operations using a deployable force protection asset (Raven UAS) could be studied in COMBATXXI using the UAV sensor model, and associated dynamic behaviors without the reliance of nonadaptive scripting and compound orders currently in use. Factors such as False Positive and False Negative allows us to see how an operator's skill level can affect the outcome of a tactical convoy operations in SWA. It was found that a convoy experienced less risk and obtained a higher frequency of completing the mission when they could increase the likelihood of identifying an IED object as an IED and decreasing the likelihood of misidentifying non-IEDs.

5.1.2 Are There Any Advantages to UAS?

Given the constraints, conditions, and limitations of the sensor model and COMBATXXI, it was shown that utilizing the UAS gave a higher likelihood of success. We also showed that qualitative factors such as risk could be be controlled with the use of a UAS.

5.1.3 Have We Modeled UAS properly?

Due to the dynamics of electro-optics (EO) sensors, the human eye and thought process, it is naive to say the Raven UAS was modeled properly, in this study. This study demonstrates that it is possible to model the complexities of a UAS in a complex simulation such as COMBATXXI.

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5.1.4 Ontology Pros and Cons for Knowledge Representation with COMBATXXI

The ontology showed that it is possible to express knowledge semantically and have a reasoner classify a threat based on the clues (IED indicators) that a human would detect using a UAV such as the Raven. It is important to note that the cues used in the ontology can be represented in a model like COMBATXXI.

5.1.5 Future Work

The work presented in this thesis is an initial look at possible uses of combat models such as COMBATXXI. This work can be continued in many ways. Below are some possible areas that merit further investigation.

Develop extensions and support structures to allow COMBATXXI to be more amenable for use in studies that use the DOE methodology. This would allow it to be used in studies to look at complex parameter spaces that are not possible with the current structures.

Investigate the integration of ontology based KR systems into combat models such as COMBATXXI. By adding such structures, a wide range of investigation is made possible. These can range from identification of threats that take into consideration both observations and other information, such as past activity, to being able to reason about motives of opposing entities. The use of ontologies could also support more robust behaviors that can be used in a wider set of circumstances, which would facilitate building general purpose behaviors that can be reused in many scenarios.

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APPENDIX A: JOHNSON CRITERIA

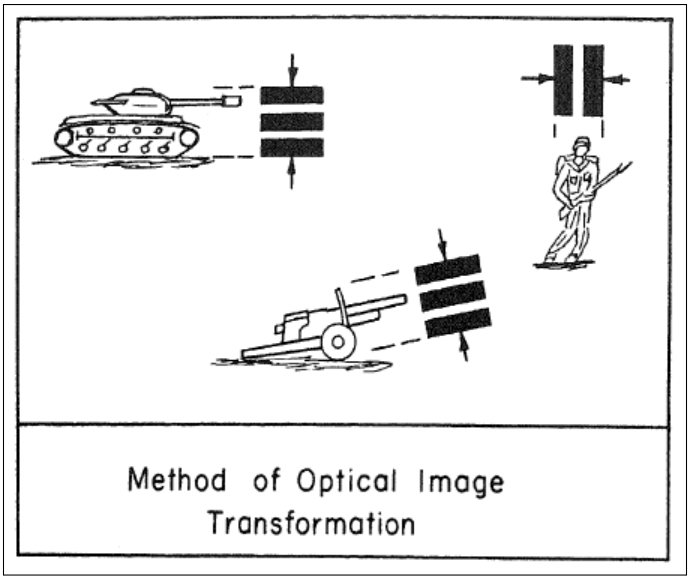


Figure A.1: Normalizing resolved line pairs for critical target dimension. After [44, p. 264]

TARGET	RESOLUTION PER MINIMUM DIMENSION			
Broadside View	Detection	Orientation	Recognition	Identification
Truck	.90	1.25	4.5	8.0
M-48 Tank	.75	1.2	3.5	7.0
Stalin Tank	.75	1.2	3.3	6.0
Centurion Tank	.75	1.2	3.5	6.0
Half-track	1.0	1.50	4.0	5.0
Jeep	1.2	1.50	4.5	5.5
Command Car	1.2	1.5	4.3	5.5
Soldier (Standing)	1.5	1.8	3.8	8.0
105 Howitzer	1.0	1.5	4.8	6.0
Average	$1.0 \pm .25$	$1.4 \pm .35$	$4.0 \pm .8$	6.4 ± 1.5

Figure A.2: Number of minimum line pairs required for the four detection, orientation, recognition, identification. From [44, p. 264]

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APPENDIX B:
CONCEPT OF OPERATIONS

Mission

In support of 2nd Platoon (PLT), Alpha Company (Co.), 2-37 IN (Infantry), 4th squad provides security and logistic runs in partnership with the 3rd LNA Battalion to support operations for the local populace while protecting the Dam.

Situation

2nd Platoon, A CO, 2-37 IN, conducted a relief in place (RIP) of the combat outpost (COP) three months ago. 2nd Platoon is scheduled to RIP with 1st Platoon within the next week and will assume FOB security at the CO HQ and serve as the CO reserve. Besides working and training the LNA troops, the platoon is also responsible for protecting the Dam workers that live on the COP. The missions are broken down into equal parts and each squad will rotate responsibilities to reduce complacency. The four task are (1) Entry Control Point [3 personnel x 3 eight hour. shifts = 1 squad], (2) Force Protection [3 Towers /OP points x 3 eight hour shifts = 1 squad], (3) Dam Observation Post [3 personnel x 3 eight hour shifts = 1 squad], and (4) local security patrols and quick reaction force = 1 squad. For each squad there is one LNA platoon supporting to be the immediate face to the community. 4th squad is equipped with 1 x Raven 11Q B UAS. Four of the 11 soldiers in the squad are qualified Raven operators.

Commander's Intent

2nd Platoon partnered with 3rd Battalion LNA will protect the population from insurgents, mentor the LNA partners, and protect the LNA partners in contact with insurgents. This partnership will maintain force protection at all times and provide over watch to the Dam to safeguard the area's power supply. 4th Squad will perform logistic runs in support of (ISO) 2nd Platoon, A CO, 2-37 IN.

Enemy

Threat forces consist of 300 insurgents equipped with RPG, PKM, AK-47, HMG, AT-3, SPG-9, SA-16 and 82mm mortar. The main threat consists of 3 x PLTs with two supporting efforts. Each PLT has the ability to emplace 2 x IEDs. There are reports of 8 to 10-man insurgent teams

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equipped with RPG, AK-47. There are also reports of possible IED emplacements along MSR WEST VIRGINIA.

B.0.6 Terrain

Open desert to desert mountains with adjacent urban structures.

B.0.7 Troops Available

Coalition and Host Nation Forces: 1 x U.S. Infantry squad equipped with organic direct fire weapons, with support from 120mm mortars. 21 soldiers from the LNA company and 16 from the LNP.

B.0.8 Time

0800, day, clear.

B.0.9 Civilian

Civilian populace is either controlled or intimidated by enemy operating within the area of operations (AO).

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APPENDIX C:
CONVOY MOVE IN FORMATION

```
1 ================================
2 Name: ConvoyMoveInFormation
3 AllowMsg: true
4 Node Type: DEFAULT
5 Is Code File: false
6 Import:
7 Datamap:
8     formation=>java.lang.String
9     route=>cxxi.model.objects.features.CMPolyline
10    NAI_phaseLines=>java.util.ArrayList
11    UAS_routes=>java.util.ArrayList
12    falseNegativeRate=>[Ljava.lang.String;@7b449b1d
13    falsePositiveRate=>[Ljava.lang.String;@5523cc24
14 Metadata:
15 Code:
16  ================================
17  Name: initInfo
18  AllowMsg: true
19  Node Type: DEFAULT
20  Is Code File: false
21  Import:
22  Datamap:
23  Metadata:
24  Code:
25      if _gt_activeNode.getVar("isInited") == None:
26       _gt_activeNode.putVar("isInited", 1)
27       _htn_precon_ret=1
28   ================================
29   Name: isCommander
30   AllowMsg: true
31   Node Type: DEFAULT
32   Is Code File: false
33   Import:
34   Datamap:
35   Metadata:
36   Code:
```


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```
37      if state.isCommander():
38       _htn_precon_ret=1
39    ================================
40    Name: setup
41    AllowMsg: true
42    Node Type: DEFAULT
43    Is Code File: false
44    Import:
45    Datamap:
46    Metadata:
47    Code:
48       from cxxi.model import CombatXXIModel
49       from os import access
50       from os import F_OK
51       from os import W_OK
52       from sys import stderr
53       try:
54        logfile
55        writeOK
56       except NameError:
57        # open the log file in the same place CXXI puts the other log files
58        logfilePathName = str(CombatXXIModel.getOutputDirectory()) + "/DFP.
    log"
59        writeOK = True
60        try:
61         logfile =  open(logfilePathName,"w")
62        except IOError:
63         print >>stderr,"\n\nWarning␣!!!!␣Could␣not␣open␣log␣file␣to␣write␣-
    ␣log␣will␣not␣be␣output.\n\n"
64         print >>stderr,"␣␣␣␣␣␣␣␣␣␣␣␣Log␣file␣may␣be␣open␣in␣another␣
    application.\n\n"
65         writeOK = False
66        if writeOK:
67         _gt_activeNode.putVar("logfile", logfile)
68       # get the rep number for this run
69       repNum = CombatXXIModel.getReplicationNumber()
70       _gt_activeNode.putVar("repNum", repNum)
71       # set up the holder in the borg to hold the non-ied names
72       name = "notIED"
73       notIED = []
74       borg.addAttribute(name, notIED, _gt_activeNode)
```


3807 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
75  ================================
76  Name: initCommander
77  AllowMsg: true
78  Node Type: DEFAULT
79  Is Code File: false
80  Import:
81  Datamap:
82  Metadata:
83  Code:
84      from HTN import UtilityFuncsExp
85      #state.addControlMeasure(nai) #adds control measure for CXXI to pay
    attention to.
86      for cm in _gt_activeNode.getParam("NAI_phaseLines"):
87       state.addControlMeasure(cm.getName())
88      speed = 2
89      # scehdule the event to get us going
90      UtilityFuncsExp.scheduleEvent(
91          info.getMyAssignedName(),
92          "GoalTracker_MoveOut",
93          0.001,
94          speed)
95  ================================
96  Name: addReplanTriggers
97  AllowMsg: true
98  Node Type: INTERRUPT
99  Is Code File: false
100 Import:
101 Datamap:
102 Metadata:
103 Code:
104     goalContainer.getCurrentExecutingStack().addReplanTrigger("
    AtAControlMeasure")
105     goalContainer.getCurrentExecutingStack().addReplanTrigger("
    GoalTracker_MoveOut")
106     goalContainer.getCurrentExecutingStack().addReplanTrigger("
    GoalTracker_UASPickedUp")
107     goalContainer.getCurrentExecutingStack().addReplanTrigger("
    EmbarkComplete")
108     goalContainer.getCurrentExecutingStack().addReplanTrigger("
    DamageOccurredInMyUnit")
```


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```
109         goalContainer.getCurrentExecutingStack().addReplanTrigger("
        GoalTracker_ResumeMovingAtSpeed")
110         goalContainer.getCurrentExecutingStack().addReplanTrigger("
        StoppedMovement")
111     ================================
112     Name: doNothing
113     AllowMsg: true
114     Node Type: GOAL
115     Is Code File: false
116     Import:
117     Datamap:
118     Metadata:
119     Code:
120         '''
121 ␣␣␣␣␣At␣this␣point␣only␣the␣commander␣does␣anything␣so␣if␣the␣tree␣is␣
        assigned␣to␣someone␣who␣is
122 ␣␣␣␣␣not␣the␣commander,␣just␣end␣the␣tree.
123 ␣␣␣␣␣NOTE␣-␣if␣this␣tree␣is␣to␣be␣used␣if␣there␣is␣attrition␣this␣should␣
        not␣be
124 ␣␣␣␣␣done␣this␣way␣and␣there␣should␣be␣a␣way␣to␣keep␣the␣tree␣around␣in␣
        case␣the␣current
125 ␣␣␣␣␣"non-commander"␣is␣promoted␣to␣command␣via␣attrition.
126 ␣␣␣␣␣'''
127     ================================
128     Name: events
129     AllowMsg: true
130     Node Type: DEFAULT
131     Is Code File: false
132     Import:
133     Datamap:
134     Metadata:
135     Code:
136         ================================
137         Name: isGoalTrackerEvent
138         AllowMsg: true
139         Node Type: DEFAULT
140         Is Code File: false
141         Import:
142         Datamap:
143         Metadata:
144         Code:
```


3809 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
145     if state.getLastTrigger().startswith("doGoalTracker_"):
146      _htn_precon_ret=1
147   ================================
148   Name: isMoveOut
149   AllowMsg: true
150   Node Type: DEFAULT
151   Is Code File: false
152   Import:
153   Datamap:
154   Metadata:
155   Code:
156      if state.getLastTrigger() == "doGoalTracker_MoveOut":
157       _htn_precon_ret=1
158       printMessage("GOAL␣TRACKER␣EVENT"+state.getLastTrigger(), True)
159    ================================
160    Name: moveOut
161    AllowMsg: true
162    Node Type: INTERRUPT
163    Is Code File: false
164    Import:
165    Datamap:
166    Metadata:
167    Code:
168       from cxxi.model.behavior import OrderUtilities
169       from java.util import Vector
170       from mtry.cxxi.model.HierarchicalTaskNetwork import HTNUtilities
171       formation = _gt_activeNode.getParam("formation")
172       route = _gt_activeNode.getParam("route")
173       printMessage("formation␣is␣" + formation, True)
174       params = state.getLastTriggerParams()
175       speed = float(params[0])
176       ord = HTNUtilities._py_getMoveOrderFromRoute(route, speed, formation
      )
177       orders.addOrder(ord)
178       startTime = state.getSimTime()
179       _gt_activeNode.putVar("startTime", startTime)
180   ================================
181   Name: isGoalTracker_UASPickedUp
182   AllowMsg: true
183   Node Type: DEFAULT
184   Is Code File: false
```


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```
185  Import:
186  Datamap:
187  Metadata:
188  Code:
189      if state.getLastTrigger() == "doGoalTracker_UASPickedUp":
190       _htn_precon_ret=1
191   ================================
192   Name: pickedUpUAS
193   AllowMsg: true
194   Node Type: INTERRUPT
195   Is Code File: false
196   Import:
197   Datamap:
198   Metadata:
199   Code:
200       from HTN import UtilityFuncsExp
201       # we have picked up the UAS, so we should continue
202       observations = state.getLastTriggerParams()[0]
203       if observations.isEmpty():
204        UtilityFuncsExp.scheduleEvent(
205            info.getMyAssignedName(),
206            "GoalTracker_ResumeMovingAtSpeed",
207            0.001,
208            None)
209       else:
210        # look at what the UAV sent us
211        # this is where the processing of the knowledge could go.  If the
     info the UAS
212        # sent back not clear other info could be used
213        # for now we kill the IED and delay while it is destroyed
214        whoToKill = observations.get(0).getAssignedName()
215        #whoToKill= str((UtilityFuncs.getEntityById(IDofWhoToKill)).
     getAssignedName())
216        state.killEntity(whoToKill,"CATASTROPHIC_KILL")
217        UtilityFuncsExp.scheduleEvent(
218            info.getMyAssignedName(),
219            "GoalTracker_ResumeMovingAtSpeed",
220            600.0,
221            None)
222  ================================
223  Name: isResumeMovingAtSpeed
```


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```
224    AllowMsg: true
225    Node Type: DEFAULT
226    Is Code File: false
227    Import:
228    Datamap:
229    Metadata:
230    Code:
231        if state.getLastTrigger() == "doGoalTracker_ResumeMovingAtSpeed":
232         _htn_precon_ret=1
233     ================================
234     Name: resumeMoving
235     AllowMsg: true
236     Node Type: INTERRUPT
237     Is Code File: false
238     Import:
239     Datamap:
240     Metadata:
241     Code:
242         speedToResume = _gt_activeNode.getVar("speedToResume")
243         UtilityFuncsExp.changeOrderSpeed(info.getMySelf(),speedToResume)
244  ================================
245  Name: modelEvents
246  AllowMsg: true
247  Node Type: DEFAULT
248  Is Code File: false
249  Import:
250  Datamap:
251  Metadata:
252  Code:
253   ================================
254   Name: isAtControlMeasure
255   AllowMsg: true
256   Node Type: DEFAULT
257   Is Code File: false
258   Import:
259   Datamap:
260   Metadata:
261   Code:
262       if state.getLastTrigger()== "doAtAControlMeasure":
263        _htn_precon_ret=1
264    ================================
```


3812 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
Name: isAtPhaseLine
AllowMsg: true
Node Type: INTERRUPT
Is Code File: false
Import:
Datamap:
Metadata:
Code:
    from cxxi.model.objects.holders import CMHolder
    from java.util import Vector
    from cxxi.model.behavior import OrderUtilities
    cm = state.getLastTriggerParams()[0]
    NAI_phaseLines = _gt_activeNode.getParam("NAI_phaseLines")
    for i in range(NAI_phaseLines.size()):
     aCMName = NAI_phaseLines.get(i).getName()
     if aCMName == cm.getName():
      printMessage("AT" + str(cm.getName()), True)
      uasRouteToUse = _gt_activeNode.getParam("UAS_routes")[i]
      _gt_activeNode.putVar("uasRouteToUse", uasRouteToUse)
      _htn_precon_ret=1
==============================
Name: stopAndWait
AllowMsg: true
Node Type: DEFAULT
Is Code File: false
Import:
Datamap:
Metadata:
Code:
    speedToResume = state.getCurrentSpeed()
    _gt_activeNode.putVar("speedToResume", speedToResume)
    UtilityFuncsExp.changeOrderSpeed(info.getMySelf(),0.0001)
==============================
Name: dispatchUAS
AllowMsg: true
Node Type: INTERRUPT
Is Code File: false
Import:
Datamap:
Metadata:
Code:
```


3813 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
306         from HTN import UtilityFuncsExp
307         printMessage("Start UAS Tree", True)
308         #airRoute  =
                                                CMHolder.
    retrieveControlMeasureByName(
309         "AIR_CORRIDOR_UAS_NAI_I_ROUTE")
310         uasRouteToUse = _gt_activeNode.getVar("uasRouteToUse")
311         # set the path to the goal
312         goalPath = "HTN/Trees/OperateUAS.xml"
313         UtilityFuncsExp.addGoal(
314             "B0000c01A1",
315             1.0,
316             goalPath,
317             [uasRouteToUse,
318             _gt_activeNode.getParam("falsePositiveRate"),
319             _gt_activeNode.getParam("falseNegativeRate")],
320             None)
321    ==============================
322    Name: isDamageOccured
323    AllowMsg: true
324    Node Type: DEFAULT
325    Is Code File: false
326    Import:
327    Datamap:
328    Metadata:
329    Code:
330       if state.getLastTrigger() == "doDamageOccurredInMyUnit":
331        _htn_precon_ret=1
332     ==============================
333     Name: stopConvoy
334     AllowMsg: true
335     Node Type: GOAL
336     Is Code File: false
337     Import:
338     Datamap:
339     Metadata:
340     Code:
341        from cxxi.model.behavior import OrderUtilities
342        from java.util import Vector
343        #if damage has occured in this unit we need to stop and for this
    scenario we are done
```


3814 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
344         if state.isCommander():
345          _htn_precon_ret=1
346          prims=Vector()
347          prims.add(OrderUtilities.createStopPrimitive())
348          ord=orders.createOrder("HTN Plan Auto Generated", 0.0, prims)
349          orders.preemptAllOrders(ord)
350          simtime = state.getSimTime()
351          elapsedTime = (simtime - _gt_activeNode.getVar("startTime"))/60.0
352          printMessage("mission ended after " + str(elapsedTime) + " minutes"
     , True)
353          # log this run
354          logfile = _gt_activeNode.getVar("logfile")
355          fnr = _gt_activeNode.getParam("falseNegativeRate")
356          fpr = _gt_activeNode.getParam("falsePositiveRate")
357          repNum = _gt_activeNode.getVar("repNum")
358          logfile.write('%d\t%.2f\t'%(repNum,simtime))
359          logfile.write('Fail\t')
360          logfile.write('%.2f\t%.2f\t%.2f\n'%(elapsedTime,fnr,fpr))
361          logfile.close()
362     ================================
363     Name: isStoppedMoving
364     AllowMsg: true
365     Node Type: DEFAULT
366     Is Code File: false
367     Import:
368     Datamap:
369     Metadata:
370     Code:
371        if state.getLastTrigger() == "doStoppedMovement":
372         _htn_precon_ret=1
373      ================================
374      Name: doneWithMission
375      AllowMsg: true
376      Node Type: GOAL
377      Is Code File: false
378      Import:
379      Datamap:
380      Metadata:
381      Code:
382         from cxxi.model import CombatXXIModel
383         simtime = state.getSimTime()
```


3815 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
384         elapsedTime = (simtime - _gt_activeNode.getVar("startTime"))/60.0
385         printMessage("finished mission at " + str(elapsedTime), True)
386         # log this run
387         logfile = _gt_activeNode.getVar("logfile")
388         fnr = _gt_activeNode.getParam("falseNegativeRate")
389         fpr = _gt_activeNode.getParam("falsePositiveRate")
390         repNum = _gt_activeNode.getVar("repNum")
391         logfile.write('%d\t%.2f\t'%(repNum,simtime))
392         logfile.write('Success\t')
393         logfile.write('%.2f\t%.2f\t%.2f\n'%(elapsedTime,fnr,fpr))
394         #CombatXXIModel.stopModel("run complete", 0)
395         logfile.close()
```


3816 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

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3817 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

APPENDIX D:
OPERATE THE IED HTN

```
1 ================================
2 Name: OperateIED
3 AllowMsg: true
4 Node Type: DEFAULT
5 Is Code File: false
6 Import:
7 Datamap:
8     sensor=>[Ljava.lang.String;@66ba60c7
9     sensorRange=>[Ljava.lang.String;@5627dd81
10    targetCount=>[Ljava.lang.String;@533f6c57
11    P_K_KIll=>[Ljava.lang.String;@68e1ee73
12 Metadata:
13 Code:
14    ''' Notes
15 ␣␣␣This␣is␣a␣tree␣to␣operate␣a␣simple␣IED.
16 ␣␣␣'''
17  ================================
18  Name: initInfo
19  AllowMsg: true
20  Node Type: DEFAULT
21  Is Code File: false
22  Import:
23  Datamap:
24  Metadata:
25  Code:
26     if _gt_activeNode.getVar("isInited") == None:
27      _gt_activeNode.putVar("isInited", 1)
28      _htn_precon_ret=1
29   ================================
30   Name: isRealIED
31   AllowMsg: true
32   Node Type: DEFAULT
33   Is Code File: false
34   Import:
35   Datamap:
36   Metadata:
```


3818 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
Code:
    if _gt_activeNode.getParam("P_K_KIll") > 0.0:
     _htn_precon_ret=1
 ================================
 Name: startObservation
 AllowMsg: true
 Node Type: DEFAULT
 Is Code File: false
 Import:
 Datamap:
 Metadata:
 Code:
    # set the the number of entities that have entered the AOI to zero
    _gt_activeNode.putVar("entitiesEnteredSensorAOI", 0)
    sensor = _gt_activeNode.getParam("sensor")
    sensorRange = _gt_activeNode.getParam("sensorRange")
    sensorObj = obs.getSensorByName(sensor)
    sensorObj.setEffectiveRange(sensorRange)
    printMessage("  Turning on area sensor!", True)
    if obs.startAOISensor(sensor):
     sensorObj = obs.getSensorByName(sensor)
     printMessage("  AOI sensor turned on", True)
    else:
     print info.getMyAssignedName(),":  Cannot start AOI Sensor "
 ================================
 Name: addReplanTriggers
 AllowMsg: false
 Node Type: INTERRUPT
 Is Code File: false
 Import:
 Datamap:
 Metadata:
 Code:
    # model events
    goalContainer.getCurrentExecutingStack().addReplanTrigger("EnteredAOI
  ")
    goalContainer.getCurrentExecutingStack().addReplanTrigger("
  GoalTracker_DetonateNow")
================================
Name: setIsNotIEDInfo
AllowMsg: true
```


3819 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
76  Node Type: GOAL
77  Is Code File: false
78  Import:
79  Datamap:
80  Metadata:
81  Code:
82      '''
83      Since this is not an actual IED - only something that could be
        confused as an
84      an IED, it does not need any behavior so this tree can finish.
85      '''
86      borg.notIED.append(str(info.getMyAssignedName()))
87      printMessage(" is not and IED", True)
88 ================================
89 Name: events
90 AllowMsg: true
91 Node Type: DEFAULT
92 Is Code File: false
93 Import:
94 Datamap:
95 Metadata:
96 Code:
97  ================================
98  Name: isGoalTrackerEvent
99  AllowMsg: true
100 Node Type: DEFAULT
101 Is Code File: false
102 Import:
103 Datamap:
104 Metadata:
105 Code:
106     if state.getLastTrigger().startswith("doGoalTracker_"):
107      _htn_precon_ret=1
108  ================================
109  Name: isDetonateNow
110  AllowMsg: true
111  Node Type: INTERRUPT
112  Is Code File: false
113  Import:
114  Datamap:
115  Metadata:
```


3820 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
116   Code:
117       printMessage("GOAL TRACKER EVENT"+state.getLastTrigger(), True)
118       if state.getLastTrigger() == "doGoalTracker_DetonateNow":
119        _htn_precon_ret=1
120    ================================
121    Name: detonate
122    AllowMsg: true
123    Node Type: GOAL
124    Is Code File: false
125    Import:
126    Datamap:
127    Metadata:
128    Code:
129       from UtilityFuncs import getUniformRandomNumber
130       # check to see if we need to kill an entity
131       rn = getUniformRandomNumber(0,1.0)
132       if rn <= _gt_activeNode.getParam("P_K_KIll"):
133        # the most recent to enter the area is the entity that will be
      killed.
134        IDofWhoToKill = state.getLastTriggerParams()[0]
135        whoToKill= str((UtilityFuncs.getEntityById(IDofWhoToKill)).
      getAssignedName())
136        state.killEntity(whoToKill,"CATASTROPHIC_KILL")
137       # have the IED destroy itself
138       printMessage("IED self destruct RND = " + str(rn), True)
139       state.killEntity(str(info.getMyAssignedName()),"CATASTROPHIC_KILL")
140 ================================
141 Name: modelEvents
142 AllowMsg: true
143 Node Type: DEFAULT
144 Is Code File: false
145 Import:
146 Datamap:
147 Metadata:
148 Code:
149  ================================
150  Name: isEnteredAOI
151  AllowMsg: true
152  Node Type: DEFAULT
153  Is Code File: false
154  Import:
```


3821 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
155 Datamap:
156 Metadata:
157 Code:
158     if state.getLastTrigger() == "doEnteredAOI" :
159      _htn_precon_ret=1
160  ==============================
161  Name: entityEnteredAOI
162  AllowMsg: false
163  Node Type: INTERRUPT
164  Is Code File: false
165  Import:
166  Datamap:
167  Metadata:
168  Code:
169     from HTN import UtilityFuncsExp
170     import UtilityFuncs
171     entitiesEnteredSensorAOI = _gt_activeNode.getVar("
    entitiesEnteredSensorAOI")
172     entitiesEnteredSensorAOI += 1
173     if  entitiesEnteredSensorAOI >= _gt_activeNode.getParam("targetCount
    "):
174      printMessage("Hello, I am executing the isEnteredAOI node and the
    sim time is:  "      +str(state.getSimTime()), True)
175      entityID = state.getLastTriggerParams()[1]
176      UtilityFuncsExp.scheduleEvent(
177          info.getMyAssignedName(),
178          "GoalTracker_DetonateNow",
179          0.001,
180          entityID) # pass the id of the entity that my be killed
181     else:
182      printMessage("Not enough entities im my AOI yet", True)
183      _gt_activeNode.putVar("entitiesEnteredSensorAOI",
    entitiesEnteredSensorAOI)
```


3822 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

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3823 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

APPENDIX E:
OPERATE UAS HTN

```
1==============================
2Name: OperateUAS
3AllowMsg: true
4Node Type: DEFAULT
5Is Code File: false
6Import:
7Datamap:
8    route=>cxxi.model.objects.features.CMPolyline
9    falsePositiveRate=>java.lang.Double
10   falseNegativeRate=>java.lang.Double
11Metadata:
12Code:
13 ==============================
14 Name: initInfo
15 AllowMsg: true
16 Node Type: DEFAULT
17 Is Code File: false
18 Import:
19 Datamap:
20 Metadata:
21 Code:
22    if _gt_activeNode.getVar("isInited") == None:
23     _gt_activeNode.putVar("isInited", 1)
24     _htn_precon_ret=1
25  ==============================
26  Name: addReplanTriggers
27  AllowMsg: true
28  Node Type: DEFAULT
29  Is Code File: false
30  Import:
31  Datamap:
32  Metadata:
33  Code:
34     #goalContainer.getCurrentExecutingStack().addReplanTrigger("
    TakeoffDone")
```


3824 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
35      goalContainer.getCurrentExecutingStack().addReplanTrigger("HaveLanded"
    )
36      goalContainer.getCurrentExecutingStack().addReplanTrigger("
    EmbarkComplete")
37      goalContainer.getCurrentExecutingStack().addReplanTrigger("
    GoalTracker_CompletedFOVScan")
38  ==============================
39  Name: createUASRoutes
40  AllowMsg: true
41  Node Type: INTERRUPT
42  Is Code File: false
43  Import:
44  Datamap:
45  Metadata:
46  Code:
47      from HTN import UtilityFuncsExp
48      from cxxi.model.behavior import OrderUtilities
49      from java.util import Vector
50      from java.util import LinkedHashSet
51      from mtry.cxxi.model.HierarchicalTaskNetwork import HTNUtilities
52      from cxxi.model.physics.geometry import Direction
53      from HTN.Scripts.general import SensorHelpers
54      myTransporter = myTransport.getTransporter()
55      _gt_activeNode.putVar("myTransporter", myTransporter)
56      allObs = LinkedHashSet()
57      _gt_activeNode.putVar("allObs", allObs)
58      # get off the transporter so we can fly our mission
59      myTransport.debark()
60      route = _gt_activeNode.getParam("route")
61      startPoint = state.getCurrentLocation()
62      _gt_activeNode.putVar("startPoint", startPoint)
63      prims = Vector()
64      prims.addAll(HTNUtilities._py_createMovePOsFromRoutes(route, 10.0))
65      prims.add(OrderUtilities.createMovePrimitive(startPoint, 10.0))
66      prims.add(OrderUtilities.createStopPrimitive())
67      ord = orders.createOrder("HTN␣Plan␣Auto␣Generated", 0.0, prims)
68      orders.addOrder(ord)
69      printMessage("Ready␣to␣turn␣on␣UAS␣sensor", True)
70      UtilityFuncsExp.addGoal(
71          info.getMyAssignedName(),
72          2.0,
```


3825 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
73          "HTN/Trees/UAVSensor.xml",
74          [0.0,-45.0,20.0,1000.0,3.5,1.0],
75          None)
76      outbound = True
77      _gt_activeNode.putVar("outbound", outbound)
78      lastDistToEndPoint = 0.0
79      _gt_activeNode.putVar("lastDistToEndPoint", lastDistToEndPoint)
80 ================================
81 Name: events
82 AllowMsg: true
83 Node Type: DEFAULT
84 Is Code File: false
85 Import:
86 Datamap:
87 Metadata:
88 Code:
89  ================================
90  Name: isGoalTrackerEvent
91  AllowMsg: true
92  Node Type: DEFAULT
93  Is Code File: false
94  Import:
95  Datamap:
96  Metadata:
97  Code:
98      if state.getLastTrigger().startswith("doGoalTracker_"):
99       _htn_precon_ret=1
100   ================================
101   Name: isCompletedFOVScan
102   AllowMsg: true
103   Node Type: INTERRUPT
104   Is Code File: false
105   Import:
106   Datamap:
107   Metadata:
108   Code:
109       if state.getLastTrigger() == "doGoalTracker_CompletedFOVScan":
110        _htn_precon_ret=1
111    ================================
112    Name: checkSensor
113    AllowMsg: true
```


3826 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
114     Node Type: INTERRUPT
115     Is Code File: false
116     Import:
117     Datamap:
118     Metadata:
119     Code:
120         #
121         # check to see if we are close to the start point in which case we
        do not continue scanning
122         currentLoc = state.getCurrentLocation()
123         dist = currentLoc.distanceTo(_gt_activeNode.getVar("startPoint"))
124         outbound = _gt_activeNode.getVar("outbound")
125         lastDistToEndPoint = _gt_activeNode.getVar("lastDistToEndPoint")
126         # test if we are still outbound
127         if outbound and dist < lastDistToEndPoint:
128          # we have started back to the landing point
129          outbound = False
130          _gt_activeNode.putVar("outbound", outbound)
131         else:
132          lastDistToEndPoint = dist
133          _gt_activeNode.putVar("lastDistToEndPoint", lastDistToEndPoint)
134         if dist > 100.0 or outbound:
135          UtilityFuncsExp.addGoal(
136              info.getMyAssignedName(),
137              0.0001,
138              "HTN/Trees/UAVSensor.xml",
139              [0.0,-45.0,30.0,1000.0,3.5,1.0],
140              None)
141         observations = state.getLastTriggerParams()[0]
142         allObs = _gt_activeNode.getVar("allObs")
143         allObs.addAll(observations)
144 ================================
145 Name: modelEvents
146 AllowMsg: true
147 Node Type: DEFAULT
148 Is Code File: false
149 Import:
150 Datamap:
151 Metadata:
152 Code:
153  ================================
```


3827 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
154  Name: isHaveLanded
155  AllowMsg: true
156  Node Type: DEFAULT
157  Is Code File: false
158  Import:
159  Datamap:
160  Metadata:
161  Code:
162      if state.getLastTrigger() == "doHaveLanded":
163       _htn_precon_ret=1
164   ================================
165   Name: UASLanded
166   AllowMsg: true
167   Node Type: INTERRUPT
168   Is Code File: false
169   Import:
170   Datamap:
171   Metadata:
172   Code:
173      from cxxi.model.behavior import OrderUtilities
174      from java.util import Vector
175      printMessage("I␣have␣landed", True)
176      myTransporter = _gt_activeNode.getVar("myTransporter")
177      prims=Vector()
178      prims.add(
179     OrderUtilities.createBoardEntityPrimitiveByName(
180     myTransporter.getAssignedName()))
181      ord=orders.createOrder("HTN␣Plan␣Auto␣Generated", 0.0, prims)
182      orders.addOrder(ord)
183  ================================
184  Name: isHaveEmbarked
185  AllowMsg: true
186  Node Type: DEFAULT
187  Is Code File: false
188  Import:
189  Datamap:
190  Metadata:
191  Code:
192      if state.getLastTrigger() == "doEmbarkComplete":
193       _htn_precon_ret=1
194   ================================
```


3828 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
195     Name: doneWithMission
196     AllowMsg: false
197     Node Type: GOAL
198     Is Code File: false
199     Import:
200     Datamap:
201     Metadata:
202     Code:
203         from HTN import UtilityFuncsExp
204         from java.util import ArrayList
205         printMessage("embarked␣on␣transport", True)
206         allObs = _gt_activeNode.getVar("allObs")
207         obsList = ArrayList()
208         # now process the observations and see if we have anything to report
209         for something in allObs:
210          aname = something.getAssignedName()
211          rn = getUniformRandomNumber(0,1.0)
212          printMessage("checking␣obs␣of␣" + str(aname) + "␣rnd␣num␣is␣" + str
    (rn), True)
213          # check to see ground truth if this is an IED
214          if borg.notIED.count(aname) == 0:
215           # this is not in the non-IED list
216           if rn > _gt_activeNode.getParam("falseNegativeRate"):
217            # we have correctly identified this as an IED
218         # so add it to the observations
219            obsList.add(something)
220          else:
221           if rn < _gt_activeNode.getParam("falsePositiveRate"):
222            # we think this is an IED so add it to the observations
223            obsList.add(something)
224         # tell our transported that we have been loaded
225         UtilityFuncsExp.scheduleEvent(
226            _gt_activeNode.getVar("myTransporter").getAssignedName(),
227            "GoalTracker_UASPickedUp",
228            0.001,
229            obsList)
```


3829 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

APPENDIX F:
UAV SENSING HTN

```
1==============================
2Name: UAVSensor
3AllowMsg: false
4Node Type: DEFAULT
5Is Code File: false
6Import:
7Datamap:
8    sensorAzimuth=>[Ljava.lang.String;@2831300d
9    sensorPitch=>[Ljava.lang.String;@3549ba18
10   FOVWidth=>[Ljava.lang.String;@7b5898fc
11   maxRange=>[Ljava.lang.String;@75a407a7
12   meanFOVTime=>[Ljava.lang.String;@63f2a147
13   standDevFOVTime=>[Ljava.lang.String;@4e3a6f94
14Metadata:
15Code:
16   ''' Notes
17    This is a simple model for a sensor observing a single Field of View.
18    '''
19 ==============================
20 Name: initInfo
21 AllowMsg: false
22 Node Type: DEFAULT
23 Is Code File: false
24 Import:
25 Datamap:
26 Metadata:
27 Code:
28    if _gt_activeNode.getVar("isInited") == None:
29     _gt_activeNode.putVar("isInited", 1)
30     _htn_precon_ret=1
31  ==============================
32  Name: initsearch
33  AllowMsg: false
34  Node Type: DEFAULT
35  Is Code File: false
36  Import:
```


3830 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
37  Datamap:
38  Metadata:
39  Code:
40      from HTN import UtilityFuncsExp
41      from UtilityFuncs import getNormalRandomNumber
42      #
43      # compute a time to scan this FOR
44      #
45      scanTime = getNormalRandomNumber(_gt_activeNode.getParam("meanFOVTime"
        ),
46          _gt_activeNode.getParam("standDevFOVTime"))
47      if scanTime < 1.0:
48       scanTime = 0.0
49      _gt_activeNode.putVar("scanTime", scanTime)
50      printMessage("scan␣time␣is␣" + str(scanTime), True)
51      UtilityFuncsExp.scheduleEvent(
52          info.getMyAssignedName(),
53          "GoalTracker_StartFOVScan",
54          0.001,
55          None)
56  ================================
57  Name: addReplanTriggers
58  AllowMsg: false
59  Node Type: INTERRUPT
60  Is Code File: false
61  Import:
62  Datamap:
63  Metadata:
64  Code:
65      goalContainer.getCurrentExecutingStack().addReplanTrigger("
      GoalTracker_StartFOVScan")
66      goalContainer.getCurrentExecutingStack().addReplanTrigger("
      GoalTracker_FOVScanDone")
67  ================================
68  Name: events
69  AllowMsg: false
70  Node Type: DEFAULT
71  Is Code File: false
72  Import:
73  Datamap:
74  Metadata:
```


3831 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
Code:
 ================================
 Name: isGoalTrackerEvent
 AllowMsg: false
 Node Type: DEFAULT
 Is Code File: false
 Import:
 Datamap:
 Metadata:
 Code:
    if state.getLastTrigger().startswith("doGoalTracker_"):
     _htn_precon_ret=1
  ================================
  Name: isStartFOVScan
  AllowMsg: false
  Node Type: DEFAULT
  Is Code File: false
  Import:
  Datamap:
  Metadata:
  Code:
     if state.getLastTrigger() == "doGoalTracker_StartFOVScan":
      _htn_precon_ret=1
   ================================
   Name: scanFOV
   AllowMsg: false
   Node Type: INTERRUPT
   Is Code File: false
   Import:
   Datamap:
   Metadata:
   Code:
      from HTN import UtilityFuncsExp
      from HTN.Scripts.general.SensorHelpers import isInFOV
      from UtilityFuncs import getUniformRandomNumber
      # collect what we can see in this FOV
      from java.util import ArrayList
      observations = ArrayList()
      _gt_activeNode.putVar("observations", observations)
      maxRange = _gt_activeNode.getParam("maxRange")
      thingsCloseBy =myIntel.getLiveEntitiesInRadius(maxRange * 1.1)
```


3832 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
116         myLocation = state.getCurrentLocation()
117         # get the actual sensor orientation
118         sensorOrientation = state.getCurrentHeading()
119         sensorOrientation.addDegreesToHeading(_gt_activeNode.getParam("
    sensorAzimuth"))
120         sensorOrientation.setPitchInDegrees(_gt_activeNode.getParam("
    sensorPitch"))
121         for something in thingsCloseBy:
122          tgtLoc = something.getPhysicalState().getSynchedLocation(False)
123          side = something.getSide()
124          if str(side) == "BLUE":
125           continue
126          if isInFOV(tgtLoc, myLocation, sensorOrientation,
127           _gt_activeNode.getParam("FOVWidth"), maxRange):
128           # compute probability of seeing
129           distToTgt = myLocation.distanceTo(tgtLoc)
130           pObs = 1.0 - (distToTgt/(220))
131           rn = getUniformRandomNumber(0,1.0)
132           printMessage("In␣FOV␣" + str(something.getAssignedName()) +
133          "␣␣Prob␣␣detect␣is␣" + str(pObs), True)
134           if rn < pObs:
135            observations.add(something)
136            printMessage("I␣saw␣" + str(something.getAssignedName()) +
137           "␣␣rn␣is␣" + str(rn), True)
138         UtilityFuncsExp.scheduleEvent(
139            info.getMyAssignedName(),
140            "GoalTracker_FOVScanDone",
141            _gt_activeNode.getVar("scanTime"),
142            None)
143    ==============================
144    Name: isFOVScanDone
145    AllowMsg: false
146    Node Type: DEFAULT
147    Is Code File: false
148    Import:
149    Datamap:
150    Metadata:
151    Code:
152       if state.getLastTrigger() == "doGoalTracker_FOVScanDone":
153        _htn_precon_ret=1
154     ==============================
```


3833 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
155     Name: scanDone
156     AllowMsg: false
157     Node Type: GOAL
158     Is Code File: false
159     Import:
160     Datamap:
161     Metadata:
162     Code:
163         from HTN import UtilityFuncsExp
164         UtilityFuncsExp.scheduleEvent(
165             info.getMyAssignedName(),
166             "GoalTracker_CompletedFOVScan",
167             0.001,
168             _gt_activeNode.getVar("observations"))
169 ================================
170 Name: modelEvents
171 AllowMsg: false
172 Node Type: DEFAULT
173 Is Code File: false
174 Import:
175 Datamap:
176 Metadata:
177 Code:
178  ================================
179  Name: printEvent
180  AllowMsg: false
181  Node Type: INTERRUPT
182  Is Code File: false
183  Import:
184  Datamap:
185  Metadata:
186  Code:
187      printMessage("EVENT"+state.getLastTrigger(), True)
```


3834 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

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3835 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

APPENDIX G:
IED ONTOLOGY

```
1<?xml version="1.0"?>
2
3
4<!DOCTYPE Ontology [
5     <!ENTITY xsd "http://www.w3.org/2001/XMLSchema#" >
6     <!ENTITY xml "http://www.w3.org/XML/1998/namespace" >
7     <!ENTITY rdfs "http://www.w3.org/2000/01/rdf-schema#" >
8     <!ENTITY rdf "http://www.w3.org/1999/02/22-rdf-syntax-ns#" >
9]>
10
11
12<Ontology xmlns="http://www.w3.org/2002/07/owl#"
13      xml:base="http://www.ied.com/ontologies/ied.owl"
14      xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
15      xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
16      xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
17      xmlns:xml="http://www.w3.org/XML/1998/namespace"
18      ontologyIRI="http://www.ied.com/ontologies/ied.owl">
19     <Prefix name="" IRI="http://www.w3.org/2002/07/owl#"/>
20     <Prefix name="owl" IRI="http://www.w3.org/2002/07/owl#"/>
21     <Prefix name="rdf" IRI="http://www.w3.org/1999/02/22-rdf-syntax-ns#"/>
22     <Prefix name="xsd" IRI="http://www.w3.org/2001/XMLSchema#"/>
23     <Prefix name="rdfs" IRI="http://www.w3.org/2000/01/rdf-schema#"/>
24     <Annotation>
25         <AnnotationProperty abbreviatedIRI="rdfs:comment"/>
26         <Literal datatypeIRI="&rdf;PlainLiteral">An IED ontology that
       describes various IEDs based on different properties that make up an IED
       .</Literal>
27     </Annotation>
28     <Declaration>
29         <Class IRI="#Abandoned"/>
30     </Declaration>
31     <Declaration>
32         <Class IRI="#Batteries"/>
33     </Declaration>
34     <Declaration>
```


3836 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
35          <Class IRI="#BelowGround"/>
36      </Declaration>
37      <Declaration>
38          <Class IRI="#Cable"/>
39      </Declaration>
40      <Declaration>
41          <Class IRI="#CellPhone"/>
42      </Declaration>
43      <Declaration>
44          <Class IRI="#Child"/>
45      </Declaration>
46      <Declaration>
47          <Class IRI="#ChildSBIED"/>
48      </Declaration>
49      <Declaration>
50          <Class IRI="#ConfirmedIED"/>
51      </Declaration>
52      <Declaration>
53          <Class IRI="#DeliveryMethod"/>
54      </Declaration>
55      <Declaration>
56          <Class IRI="#DetectionMeans"/>
57      </Declaration>
58      <Declaration>
59          <Class IRI="#DisturbedSoil"/>
60      </Declaration>
61      <Declaration>
62          <Class IRI="#Electric"/>
63      </Declaration>
64      <Declaration>
65          <Class IRI="#ElectricCurrent"/>
66      </Declaration>
67      <Declaration>
68          <Class IRI="#FemaleSBIED"/>
69      </Declaration>
70      <Declaration>
71          <Class IRI="#Grenade"/>
72      </Declaration>
73      <Declaration>
74          <Class IRI="#Human"/>
75      </Declaration>
```


3837 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
76      <Declaration>
77          <Class IRI="#IED"/>
78      </Declaration>
79      <Declaration>
80          <Class IRI="#IEDIndicators"/>
81      </Declaration>
82      <Declaration>
83          <Class IRI="#IsolatedBox"/>
84      </Declaration>
85      <Declaration>
86          <Class IRI="#Location"/>
87      </Declaration>
88      <Declaration>
89          <Class IRI="#Magnetic"/>
90      </Declaration>
91      <Declaration>
92          <Class IRI="#MaleSBIED"/>
93      </Declaration>
94      <Declaration>
95          <Class IRI="#Man"/>
96      </Declaration>
97      <Declaration>
98          <Class IRI="#ManWithCellPhone"/>
99      </Declaration>
100     <Declaration>
101         <Class IRI="#MetalPlate"/>
102     </Declaration>
103     <Declaration>
104         <Class IRI="#MiltaryVehicle"/>
105     </Declaration>
106     <Declaration>
107         <Class IRI="#MouseTrap"/>
108     </Declaration>
109     <Declaration>
110         <Class IRI="#Munitions"/>
111     </Declaration>
112     <Declaration>
113         <Class IRI="#NonMilitaryVehicle"/>
114     </Declaration>
115     <Declaration>
116         <Class IRI="#NonShellMilitary"/>
```


3838 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
117     </Declaration>
118     <Declaration>
119         <Class IRI="#Occupied"/>
120     </Declaration>
121     <Declaration>
122         <Class IRI="#OnGround"/>
123     </Declaration>
124     <Declaration>
125         <Class IRI="#Package"/>
126     </Declaration>
127     <Declaration>
128         <Class IRI="#PackageIED"/>
129     </Declaration>
130     <Declaration>
131         <Class IRI="#Physical"/>
132     </Declaration>
133     <Declaration>
134         <Class IRI="#PossibleIED"/>
135     </Declaration>
136     <Declaration>
137         <Class IRI="#PressurePlate"/>
138     </Declaration>
139     <Declaration>
140         <Class IRI="#RoundRPG"/>
141     </Declaration>
142     <Declaration>
143         <Class IRI="#RoundSmallArms"/>
144     </Declaration>
145     <Declaration>
146         <Class IRI="#SBIED"/>
147     </Declaration>
148     <Declaration>
149         <Class IRI="#ShellArtillery"/>
150     </Declaration>
151     <Declaration>
152         <Class IRI="#ShellMilitary"/>
153     </Declaration>
154     <Declaration>
155         <Class IRI="#ShellMortar"/>
156     </Declaration>
157     <Declaration>
```


3839 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
158         <Class IRI="#SodaCan"/>
159     </Declaration>
160     <Declaration>
161         <Class IRI="#Springs"/>
162     </Declaration>
163     <Declaration>
164         <Class IRI="#SteelTubes"/>
165     </Declaration>
166     <Declaration>
167         <Class IRI="#StrongBeliefIED"/>
168     </Declaration>
169     <Declaration>
170         <Class IRI="#Touch"/>
171     </Declaration>
172     <Declaration>
173         <Class IRI="#Trigger"/>
174     </Declaration>
175     <Declaration>
176         <Class IRI="#Trip"/>
177     </Declaration>
178     <Declaration>
179         <Class IRI="#VBIED"/>
180     </Declaration>
181     <Declaration>
182         <Class IRI="#Vehicle"/>
183     </Declaration>
184     <Declaration>
185         <Class IRI="#Vehicles"/>
186     </Declaration>
187     <Declaration>
188         <Class IRI="#Visual"/>
189     </Declaration>
190     <Declaration>
191         <Class IRI="#WeakBeliefIED"/>
192     </Declaration>
193     <Declaration>
194         <Class IRI="#Wires"/>
195     </Declaration>
196     <Declaration>
197         <Class IRI="#Woman"/>
198     </Declaration>
```


3840 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
    <Declaration>
        <ObjectProperty IRI="#hasDeliveryMethod"/>
    </Declaration>
    <Declaration>
        <ObjectProperty IRI="#hasHumanDeliveryMethod"/>
    </Declaration>
    <Declaration>
        <ObjectProperty IRI="#hasIEDIndicators"/>
    </Declaration>
    <Declaration>
        <ObjectProperty IRI="#hasLocation"/>
    </Declaration>
    <Declaration>
        <ObjectProperty IRI="#hasPackageDeliveryMethod"/>
    </Declaration>
    <Declaration>
        <ObjectProperty IRI="#hasPossibleBelief"/>
    </Declaration>
    <Declaration>
        <ObjectProperty IRI="#hasTrigger"/>
    </Declaration>
    <Declaration>
        <ObjectProperty IRI="#hasVehicleDeliveryMethod"/>
    </Declaration>
    <Declaration>
        <DataProperty IRI="#hasIEDIndicatorName"/>
    </Declaration>
    <Declaration>
        <DataProperty IRI="#isConfirmed"/>
    </Declaration>
    <Declaration>
        <NamedIndividual IRI="#disturbedsoil_1"/>
    </Declaration>
    <Declaration>
        <NamedIndividual IRI="#ied_0"/>
    </Declaration>
    <Declaration>
        <NamedIndividual IRI="#ied_1"/>
    </Declaration>
    <Declaration>
        <NamedIndividual IRI="#ied_2"/>
```


3841 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
240     </Declaration>
241     <Declaration>
242         <NamedIndividual IRI="#ied_3"/>
243     </Declaration>
244     <Declaration>
245         <NamedIndividual IRI="#isolatedbox_1"/>
246     </Declaration>
247     <Declaration>
248         <NamedIndividual IRI="#wires_1"/>
249     </Declaration>
250     <EquivalentClasses>
251         <Class IRI="#ConfirmedIED"/>
252         <ObjectIntersectionOf>
253             <Class IRI="#IED"/>
254             <DataHasValue>
255                 <DataProperty IRI="#isConfirmed"/>
256                 <Literal datatypeIRI="&xsd;boolean">true</Literal>
257             </DataHasValue>
258         </ObjectIntersectionOf>
259     </EquivalentClasses>
260     <EquivalentClasses>
261         <Class IRI="#IED"/>
262         <ObjectIntersectionOf>
263             <ObjectSomeValuesFrom>
264                 <ObjectProperty IRI="#hasDeliveryMethod"/>
265                 <Class IRI="#DeliveryMethod"/>
266             </ObjectSomeValuesFrom>
267             <ObjectSomeValuesFrom>
268                 <ObjectProperty IRI="#hasIEDIndicators"/>
269                 <Class IRI="#IEDIndicators"/>
270             </ObjectSomeValuesFrom>
271             <ObjectSomeValuesFrom>
272                 <ObjectProperty IRI="#hasLocation"/>
273                 <Class IRI="#Location"/>
274             </ObjectSomeValuesFrom>
275             <ObjectSomeValuesFrom>
276                 <ObjectProperty IRI="#hasTrigger"/>
277                 <Class IRI="#Trigger"/>
278             </ObjectSomeValuesFrom>
279         </ObjectIntersectionOf>
280     </EquivalentClasses>
```


3842 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
<EquivalentClasses>
    <Class IRI="#IEDIndicators"/>
    <DataSomeValuesFrom>
        <DataProperty IRI="#hasIEDIndicatorName"/>
        <Datatype abbreviatedIRI="xsd:string"/>
    </DataSomeValuesFrom>
</EquivalentClasses>
<EquivalentClasses>
    <Class IRI="#PossibleIED"/>
    <ObjectIntersectionOf>
        <Class IRI="#IED"/>
        <DataHasValue>
            <DataProperty IRI="#isConfirmed"/>
            <Literal datatypeIRI="&xsd;boolean">false</Literal>
        </DataHasValue>
    </ObjectIntersectionOf>
</EquivalentClasses>
<EquivalentClasses>
    <Class IRI="#StrongBeliefIED"/>
    <ObjectIntersectionOf>
        <Class IRI="#PossibleIED"/>
        <ObjectMinCardinality cardinality="3">
            <ObjectProperty IRI="#hasIEDIndicators"/>
            <Class IRI="#IEDIndicators"/>
        </ObjectMinCardinality>
    </ObjectIntersectionOf>
</EquivalentClasses>
<EquivalentClasses>
    <Class IRI="#WeakBeliefIED"/>
    <ObjectIntersectionOf>
        <Class IRI="#PossibleIED"/>
        <ObjectMinCardinality cardinality="1">
            <ObjectProperty IRI="#hasIEDIndicators"/>
            <Class IRI="#IEDIndicators"/>
        </ObjectMinCardinality>
        <ObjectMaxCardinality cardinality="2">
            <ObjectProperty IRI="#hasIEDIndicators"/>
            <Class IRI="#IEDIndicators"/>
        </ObjectMaxCardinality>
    </ObjectIntersectionOf>
</EquivalentClasses>
```


3843 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
322     <SubClassOf>
323         <Class IRI="#Abandoned"/>
324         <Class IRI="#Vehicles"/>
325     </SubClassOf>
326     <SubClassOf>
327         <Class IRI="#Batteries"/>
328         <Class IRI="#IEDIndicators"/>
329     </SubClassOf>
330     <SubClassOf>
331         <Class IRI="#BelowGround"/>
332         <Class IRI="#Location"/>
333     </SubClassOf>
334     <SubClassOf>
335         <Class IRI="#Cable"/>
336         <Class IRI="#Wires"/>
337     </SubClassOf>
338     <SubClassOf>
339         <Class IRI="#CellPhone"/>
340         <Class IRI="#Trigger"/>
341     </SubClassOf>
342     <SubClassOf>
343         <Class IRI="#Child"/>
344         <Class IRI="#Human"/>
345     </SubClassOf>
346     <SubClassOf>
347         <Class IRI="#ChildSBIED"/>
348         <Class IRI="#SBIED"/>
349     </SubClassOf>
350     <SubClassOf>
351         <Class IRI="#ChildSBIED"/>
352         <ObjectSomeValuesFrom>
353             <ObjectProperty IRI="#hasHumanDeliveryMethod"/>
354             <Class IRI="#Child"/>
355         </ObjectSomeValuesFrom>
356     </SubClassOf>
357     <SubClassOf>
358         <Class IRI="#DisturbedSoil"/>
359         <Class IRI="#IEDIndicators"/>
360     </SubClassOf>
361     <SubClassOf>
362         <Class IRI="#Electric"/>
```


3844 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
363         <Class IRI="#Wires"/>
364     </SubClassOf>
365     <SubClassOf>
366         <Class IRI="#ElectricCurrent"/>
367         <Class IRI="#Trigger"/>
368     </SubClassOf>
369     <SubClassOf>
370         <Class IRI="#FemaleSBIED"/>
371         <Class IRI="#SBIED"/>
372     </SubClassOf>
373     <SubClassOf>
374         <Class IRI="#FemaleSBIED"/>
375         <ObjectSomeValuesFrom>
376             <ObjectProperty IRI="#hasHumanDeliveryMethod"/>
377             <Class IRI="#Woman"/>
378         </ObjectSomeValuesFrom>
379     </SubClassOf>
380     <SubClassOf>
381         <Class IRI="#Grenade"/>
382         <Class IRI="#NonShellMilitary"/>
383     </SubClassOf>
384     <SubClassOf>
385         <Class IRI="#Human"/>
386         <Class IRI="#DeliveryMethod"/>
387     </SubClassOf>
388     <SubClassOf>
389         <Class IRI="#IsolatedBox"/>
390         <Class IRI="#IEDIndicators"/>
391     </SubClassOf>
392     <SubClassOf>
393         <Class IRI="#Magnetic"/>
394         <Class IRI="#DetectionMeans"/>
395     </SubClassOf>
396     <SubClassOf>
397         <Class IRI="#MaleSBIED"/>
398         <Class IRI="#SBIED"/>
399     </SubClassOf>
400     <SubClassOf>
401         <Class IRI="#MaleSBIED"/>
402         <ObjectSomeValuesFrom>
403             <ObjectProperty IRI="#hasHumanDeliveryMethod"/>
```


3845 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
404             <Class IRI="#Man"/>
405         </ObjectSomeValuesFrom>
406     </SubClassOf>
407     <SubClassOf>
408         <Class IRI="#Man"/>
409         <Class IRI="#Human"/>
410     </SubClassOf>
411     <SubClassOf>
412         <Class IRI="#ManWithCellPhone"/>
413         <Class IRI="#IEDIndicators"/>
414     </SubClassOf>
415     <SubClassOf>
416         <Class IRI="#MetalPlate"/>
417         <Class IRI="#IEDIndicators"/>
418     </SubClassOf>
419     <SubClassOf>
420         <Class IRI="#MiltaryVehicle"/>
421         <Class IRI="#Vehicle"/>
422     </SubClassOf>
423     <SubClassOf>
424         <Class IRI="#MouseTrap"/>
425         <Class IRI="#IEDIndicators"/>
426     </SubClassOf>
427     <SubClassOf>
428         <Class IRI="#Munitions"/>
429         <Class IRI="#IEDIndicators"/>
430     </SubClassOf>
431     <SubClassOf>
432         <Class IRI="#NonMilitaryVehicle"/>
433         <Class IRI="#Vehicle"/>
434     </SubClassOf>
435     <SubClassOf>
436         <Class IRI="#NonShellMilitary"/>
437         <Class IRI="#Munitions"/>
438     </SubClassOf>
439     <SubClassOf>
440         <Class IRI="#Occupied"/>
441         <Class IRI="#Vehicles"/>
442     </SubClassOf>
443     <SubClassOf>
444         <Class IRI="#OnGround"/>
```


3846 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
445         <Class IRI="#Location"/>
446     </SubClassOf>
447     <SubClassOf>
448         <Class IRI="#Package"/>
449         <Class IRI="#DeliveryMethod"/>
450     </SubClassOf>
451     <SubClassOf>
452         <Class IRI="#PackageIED"/>
453         <Class IRI="#PossibleIED"/>
454     </SubClassOf>
455     <SubClassOf>
456         <Class IRI="#PackageIED"/>
457         <ObjectSomeValuesFrom>
458             <ObjectProperty IRI="#hasPackageDeliveryMethod"/>
459             <Class IRI="#Package"/>
460         </ObjectSomeValuesFrom>
461     </SubClassOf>
462     <SubClassOf>
463         <Class IRI="#Physical"/>
464         <Class IRI="#DetectionMeans"/>
465     </SubClassOf>
466     <SubClassOf>
467         <Class IRI="#PressurePlate"/>
468         <Class IRI="#Trigger"/>
469     </SubClassOf>
470     <SubClassOf>
471         <Class IRI="#RoundRPG"/>
472         <Class IRI="#NonShellMilitary"/>
473     </SubClassOf>
474     <SubClassOf>
475         <Class IRI="#RoundSmallArms"/>
476         <Class IRI="#NonShellMilitary"/>
477     </SubClassOf>
478     <SubClassOf>
479         <Class IRI="#SBIED"/>
480         <Class IRI="#IED"/>
481     </SubClassOf>
482     <SubClassOf>
483         <Class IRI="#SBIED"/>
484         <ObjectSomeValuesFrom>
485             <ObjectProperty IRI="#hasHumanDeliveryMethod"/>
```


3847 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
486             <Class IRI="#Human"/>
487         </ObjectSomeValuesFrom>
488     </SubClassOf>
489     <SubClassOf>
490         <Class IRI="#ShellArtillery"/>
491         <Class IRI="#ShellMilitary"/>
492     </SubClassOf>
493     <SubClassOf>
494         <Class IRI="#ShellMilitary"/>
495         <Class IRI="#Munitions"/>
496     </SubClassOf>
497     <SubClassOf>
498         <Class IRI="#ShellMortar"/>
499         <Class IRI="#ShellMilitary"/>
500     </SubClassOf>
501     <SubClassOf>
502         <Class IRI="#SodaCan"/>
503         <Class IRI="#IEDIndicators"/>
504     </SubClassOf>
505     <SubClassOf>
506         <Class IRI="#Springs"/>
507         <Class IRI="#IEDIndicators"/>
508     </SubClassOf>
509     <SubClassOf>
510         <Class IRI="#SteelTubes"/>
511         <Class IRI="#IEDIndicators"/>
512     </SubClassOf>
513     <SubClassOf>
514         <Class IRI="#Touch"/>
515         <Class IRI="#Trigger"/>
516     </SubClassOf>
517     <SubClassOf>
518         <Class IRI="#Trip"/>
519         <Class IRI="#Wires"/>
520     </SubClassOf>
521     <SubClassOf>
522         <Class IRI="#VBIED"/>
523         <Class IRI="#IED"/>
524     </SubClassOf>
525     <SubClassOf>
526         <Class IRI="#VBIED"/>
```


3848 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
527         <ObjectSomeValuesFrom>
528             <ObjectProperty IRI="#hasVehicleDeliveryMethod"/>
529             <Class IRI="#Vehicle"/>
530         </ObjectSomeValuesFrom>
531     </SubClassOf>
532     <SubClassOf>
533         <Class IRI="#Vehicle"/>
534         <Class IRI="#DeliveryMethod"/>
535     </SubClassOf>
536     <SubClassOf>
537         <Class IRI="#Vehicles"/>
538         <Class IRI="#IEDIndicators"/>
539     </SubClassOf>
540     <SubClassOf>
541         <Class IRI="#Visual"/>
542         <Class IRI="#DetectionMeans"/>
543     </SubClassOf>
544     <SubClassOf>
545         <Class IRI="#Wires"/>
546         <Class IRI="#IEDIndicators"/>
547     </SubClassOf>
548     <SubClassOf>
549         <Class IRI="#Woman"/>
550         <Class IRI="#Human"/>
551     </SubClassOf>
552     <DisjointClasses>
553         <Class IRI="#Abandoned"/>
554         <Class IRI="#Occupied"/>
555     </DisjointClasses>
556     <DisjointClasses>
557         <Class IRI="#Batteries"/>
558         <Class IRI="#DisturbedSoil"/>
559         <Class IRI="#IsolatedBox"/>
560         <Class IRI="#ManWithCellPhone"/>
561         <Class IRI="#MetalPlate"/>
562         <Class IRI="#MouseTrap"/>
563         <Class IRI="#Munitions"/>
564         <Class IRI="#SodaCan"/>
565         <Class IRI="#Springs"/>
566         <Class IRI="#SteelTubes"/>
567         <Class IRI="#Vehicles"/>
```


3849 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
568         <Class IRI="#Wires"/>
569     </DisjointClasses>
570     <DisjointClasses>
571         <Class IRI="#BelowGround"/>
572         <Class IRI="#OnGround"/>
573     </DisjointClasses>
574     <DisjointClasses>
575         <Class IRI="#Cable"/>
576         <Class IRI="#Electric"/>
577         <Class IRI="#Trip"/>
578     </DisjointClasses>
579     <DisjointClasses>
580         <Class IRI="#CellPhone"/>
581         <Class IRI="#ElectricCurrent"/>
582         <Class IRI="#PressurePlate"/>
583         <Class IRI="#Touch"/>
584     </DisjointClasses>
585     <DisjointClasses>
586         <Class IRI="#Child"/>
587         <Class IRI="#Man"/>
588         <Class IRI="#Woman"/>
589     </DisjointClasses>
590     <DisjointClasses>
591         <Class IRI="#ChildSBIED"/>
592         <Class IRI="#FemaleSBIED"/>
593         <Class IRI="#MaleSBIED"/>
594     </DisjointClasses>
595     <DisjointClasses>
596         <Class IRI="#ConfirmedIED"/>
597         <Class IRI="#PossibleIED"/>
598         <Class IRI="#SBIED"/>
599         <Class IRI="#VBIED"/>
600     </DisjointClasses>
601     <DisjointClasses>
602         <Class IRI="#DeliveryMethod"/>
603         <Class IRI="#DetectionMeans"/>
604         <Class IRI="#IED"/>
605         <Class IRI="#IEDIndicators"/>
606         <Class IRI="#Location"/>
607         <Class IRI="#Trigger"/>
608     </DisjointClasses>
```


3850 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
609     <DisjointClasses>
610         <Class IRI="#Grenade"/>
611         <Class IRI="#RoundRPG"/>
612         <Class IRI="#RoundSmallArms"/>
613     </DisjointClasses>
614     <DisjointClasses>
615         <Class IRI="#Human"/>
616         <Class IRI="#Package"/>
617         <Class IRI="#Vehicle"/>
618     </DisjointClasses>
619     <DisjointClasses>
620         <Class IRI="#Magnetic"/>
621         <Class IRI="#Physical"/>
622         <Class IRI="#Visual"/>
623     </DisjointClasses>
624     <DisjointClasses>
625         <Class IRI="#MiltaryVehicle"/>
626         <Class IRI="#NonMilitaryVehicle"/>
627     </DisjointClasses>
628     <DisjointClasses>
629         <Class IRI="#NonShellMilitary"/>
630         <Class IRI="#ShellMilitary"/>
631     </DisjointClasses>
632     <DisjointClasses>
633         <Class IRI="#PackageIED"/>
634         <Class IRI="#SBIED"/>
635         <Class IRI="#VBIED"/>
636     </DisjointClasses>
637     <DisjointClasses>
638         <Class IRI="#ShellArtillery"/>
639         <Class IRI="#ShellMortar"/>
640     </DisjointClasses>
641     <DisjointClasses>
642         <Class IRI="#StrongBeliefIED"/>
643         <Class IRI="#WeakBeliefIED"/>
644     </DisjointClasses>
645     <ClassAssertion>
646         <Class IRI="#DisturbedSoil"/>
647         <NamedIndividual IRI="#disturbedsoil_1"/>
648     </ClassAssertion>
649     <ClassAssertion>
```


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```
650         <Class IRI="#IED"/>
651         <NamedIndividual IRI="#ied_0"/>
652     </ClassAssertion>
653     <ClassAssertion>
654         <Class IRI="#IED"/>
655         <NamedIndividual IRI="#ied_1"/>
656     </ClassAssertion>
657     <ClassAssertion>
658         <Class IRI="#IED"/>
659         <NamedIndividual IRI="#ied_2"/>
660     </ClassAssertion>
661     <ClassAssertion>
662         <Class IRI="#IED"/>
663         <NamedIndividual IRI="#ied_3"/>
664     </ClassAssertion>
665     <ClassAssertion>
666         <Class IRI="#IsolatedBox"/>
667         <NamedIndividual IRI="#isolatedbox_1"/>
668     </ClassAssertion>
669     <ClassAssertion>
670         <Class IRI="#Wires"/>
671         <NamedIndividual IRI="#wires_1"/>
672     </ClassAssertion>
673     <ObjectPropertyAssertion>
674         <ObjectProperty IRI="#hasIEDIndicators"/>
675         <NamedIndividual IRI="#ied_1"/>
676         <NamedIndividual IRI="#disturbedsoil_1"/>
677     </ObjectPropertyAssertion>
678     <ObjectPropertyAssertion>
679         <ObjectProperty IRI="#hasIEDIndicators"/>
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681         <NamedIndividual IRI="#wires_1"/>
682     </ObjectPropertyAssertion>
683     <ObjectPropertyAssertion>
684         <ObjectProperty IRI="#hasIEDIndicators"/>
685         <NamedIndividual IRI="#ied_2"/>
686         <NamedIndividual IRI="#isolatedbox_1"/>
687     </ObjectPropertyAssertion>
688     <ObjectPropertyAssertion>
689         <ObjectProperty IRI="#hasIEDIndicators"/>
690         <NamedIndividual IRI="#ied_2"/>
```


3852 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

```
691         <NamedIndividual IRI="#wires_1"/>
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693     <ObjectPropertyAssertion>
694         <ObjectProperty IRI="#hasIEDIndicators"/>
695         <NamedIndividual IRI="#ied_2"/>
696         <NamedIndividual IRI="#disturbedsoil_1"/>
697     </ObjectPropertyAssertion>
698     <ObjectPropertyAssertion>
699         <ObjectProperty IRI="#hasIEDIndicators"/>
700         <NamedIndividual IRI="#ied_3"/>
701         <NamedIndividual IRI="#wires_1"/>
702     </ObjectPropertyAssertion>
703     <ObjectPropertyAssertion>
704         <ObjectProperty IRI="#hasIEDIndicators"/>
705         <NamedIndividual IRI="#ied_3"/>
706         <NamedIndividual IRI="#isolatedbox_1"/>
707     </ObjectPropertyAssertion>
708     <ObjectPropertyAssertion>
709         <ObjectProperty IRI="#hasIEDIndicators"/>
710         <NamedIndividual IRI="#ied_3"/>
711         <NamedIndividual IRI="#disturbedsoil_1"/>
712     </ObjectPropertyAssertion>
713     <DataPropertyAssertion>
714         <DataProperty IRI="#hasIEDIndicatorName"/>
715         <NamedIndividual IRI="#disturbedsoil_1"/>
716         <Literal datatypeIRI="&xsd;string">dirt</Literal>
717     </DataPropertyAssertion>
718     <DataPropertyAssertion>
719         <DataProperty IRI="#isConfirmed"/>
720         <NamedIndividual IRI="#ied_0"/>
721         <Literal datatypeIRI="&xsd;boolean">false</Literal>
722     </DataPropertyAssertion>
723     <DataPropertyAssertion>
724         <DataProperty IRI="#isConfirmed"/>
725         <NamedIndividual IRI="#ied_1"/>
726         <Literal datatypeIRI="&xsd;boolean">false</Literal>
727     </DataPropertyAssertion>
728     <DataPropertyAssertion>
729         <DataProperty IRI="#isConfirmed"/>
730         <NamedIndividual IRI="#ied_2"/>
731         <Literal datatypeIRI="&xsd;boolean">false</Literal>
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3853 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

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    <DataProperty IRI="#isConfirmed"/>
    <NamedIndividual IRI="#ied_3"/>
    <Literal datatypeIRI="&xsd;boolean">true</Literal>
</DataPropertyAssertion>
<DataPropertyAssertion>
    <DataProperty IRI="#hasIEDIndicatorName"/>
    <NamedIndividual IRI="#isolatedbox_1"/>
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</DataPropertyAssertion>
<DataPropertyAssertion>
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    <NamedIndividual IRI="#wires_1"/>
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</DataPropertyAssertion>
<SubObjectPropertyOf>
    <ObjectProperty IRI="#hasHumanDeliveryMethod"/>
    <ObjectProperty IRI="#hasDeliveryMethod"/>
</SubObjectPropertyOf>
<SubObjectPropertyOf>
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    <ObjectProperty abbreviatedIRI="owl:topObjectProperty"/>
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<SubObjectPropertyOf>
    <ObjectProperty IRI="#hasPackageDeliveryMethod"/>
    <ObjectProperty IRI="#hasDeliveryMethod"/>
</SubObjectPropertyOf>
<SubObjectPropertyOf>
    <ObjectProperty IRI="#hasVehicleDeliveryMethod"/>
    <ObjectProperty IRI="#hasDeliveryMethod"/>
</SubObjectPropertyOf>
<FunctionalObjectProperty>
    <ObjectProperty IRI="#hasLocation"/>
</FunctionalObjectProperty>
<ObjectPropertyDomain>
    <ObjectProperty IRI="#hasDeliveryMethod"/>
    <Class IRI="#IED"/>
</ObjectPropertyDomain>
<ObjectPropertyDomain>
    <ObjectProperty IRI="#hasHumanDeliveryMethod"/>
```


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```
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774     </ObjectPropertyDomain>
775     <ObjectPropertyDomain>
776         <ObjectProperty IRI="#hasIEDIndicators"/>
777         <Class IRI="#IED"/>
778     </ObjectPropertyDomain>
779     <ObjectPropertyDomain>
780         <ObjectProperty IRI="#hasLocation"/>
781         <Class IRI="#IED"/>
782     </ObjectPropertyDomain>
783     <ObjectPropertyDomain>
784         <ObjectProperty IRI="#hasPackageDeliveryMethod"/>
785         <Class IRI="#IED"/>
786     </ObjectPropertyDomain>
787     <ObjectPropertyDomain>
788         <ObjectProperty IRI="#hasPossibleBelief"/>
789         <Class IRI="#IED"/>
790     </ObjectPropertyDomain>
791     <ObjectPropertyDomain>
792         <ObjectProperty IRI="#hasTrigger"/>
793         <Class IRI="#IED"/>
794     </ObjectPropertyDomain>
795     <ObjectPropertyDomain>
796         <ObjectProperty IRI="#hasVehicleDeliveryMethod"/>
797         <Class IRI="#IED"/>
798     </ObjectPropertyDomain>
799     <ObjectPropertyRange>
800         <ObjectProperty IRI="#hasDeliveryMethod"/>
801         <Class IRI="#DeliveryMethod"/>
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806     </ObjectPropertyRange>
807     <ObjectPropertyRange>
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810     </ObjectPropertyRange>
811     <ObjectPropertyRange>
812         <ObjectProperty IRI="#hasPackageDeliveryMethod"/>
813         <Class IRI="#Package"/>
```


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```
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815     <ObjectPropertyRange>
816         <ObjectProperty IRI="#hasPossibleBelief"/>
817         <Class IRI="#PossibleIED"/>
818     </ObjectPropertyRange>
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820         <ObjectProperty IRI="#hasTrigger"/>
821         <Class IRI="#Trigger"/>
822     </ObjectPropertyRange>
823     <ObjectPropertyRange>
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825         <Class IRI="#Vehicle"/>
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838         <DataProperty IRI="#isConfirmed"/>
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840     </DataPropertyDomain>
841     <DataPropertyRange>
842         <DataProperty IRI="#hasIEDIndicatorName"/>
843         <Datatype abbreviatedIRI="xsd:string"/>
844     </DataPropertyRange>
845     <DataPropertyRange>
846         <DataProperty IRI="#isConfirmed"/>
847         <Datatype abbreviatedIRI="xsd:boolean"/>
848     </DataPropertyRange>
849</Ontology>
850
851
852
853<!-- Generated by the OWL API (version 3.4.2) http://owlapi.sourceforge.net
        -->
```


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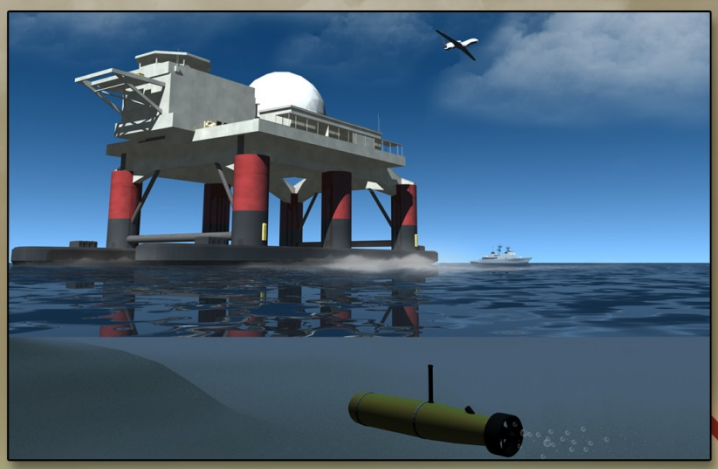
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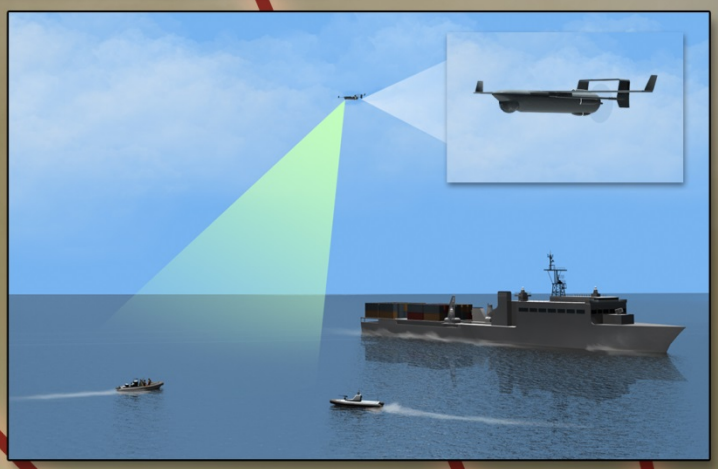
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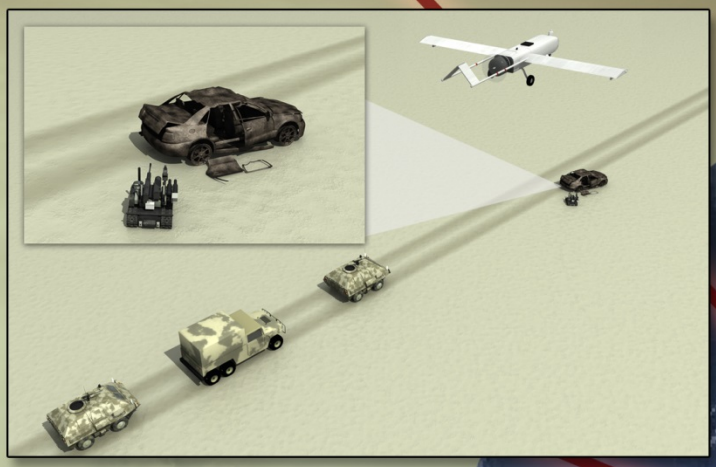
Unmanned Systems Integrated Roadmap

FY2013-2038













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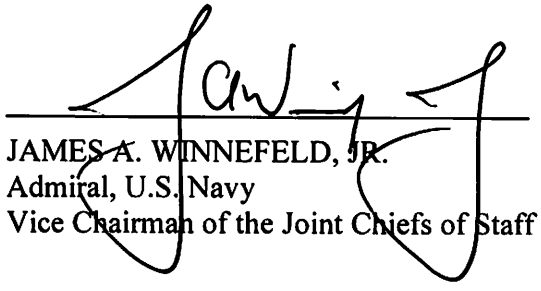
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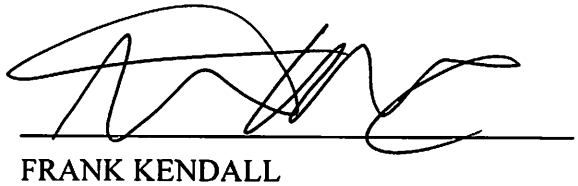
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Vice Chairman of the Joint Chiefs of Staff



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Under Secretary of Defense (AT&L)

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Executive Summary

Unmanned systems continue to deliver new and enhanced battlefield capabilities to the warfighter. While the demand for unmanned systems continues unabated today, a number of factors will influence unmanned program development in the future. Three primary forces are driving the Department of Defense's (DoD) approach in planning for and developing unmanned systems.

1. Combat operations in Southwest Asia have demonstrated the military utility of unmanned systems on today's battlefields and have resulted in the expeditious integration of unmanned technologies into the joint force structure. However, the systems and technologies currently fielded to fulfill today's urgent operational needs must be further expanded (as described in this Roadmap) and appropriately integrated into Military Department programs of record (POR) to achieve the levels of effectiveness, efficiency, affordability, commonality, interoperability, integration, and other key parameters needed to meet future operational requirements.
2. Downward economic forces will continue to constrain Military Department budgets for the foreseeable future. Achieving affordable and cost-effective technical solutions is imperative in this fiscally constrained environment.
3. The changing national security environment poses unique challenges. A strategic shift in national security to the Asia-Pacific Theater presents different operational considerations based on environment and potential adversary capabilities that may require unmanned systems to operate in anti-access/area denial (A2/AD) areas where freedom to operate is contested. Similarly, any reallocation of unmanned assets to support other combatant commanders (CCDRs) entails its own set of unique challenges, which will likely require unmanned systems to operate in more complex environments involving weather, terrain, distance, and airspace while necessitating extensive coordination with allies and host nations.

The combination of these primary forces requires further innovative technical solutions that are effective yet affordable for program development.

The purpose of this Roadmap is to articulate a vision and strategy for the continued development, production, test, training, operation, and sustainment of unmanned systems technology across DoD. This "Unmanned Systems Integrated Roadmap" establishes a technological vision for the next 25 years and outlines actions and technologies for DoD and industry to pursue to intelligently and affordably align with this vision. The Roadmap articulates this vision and strategy in eight chapters:

Chapter 1: Introduction — This chapter explains the Roadmap's purpose and scope. It examines the current unmanned environment from an inventory and budget perspective while also surveying the potential future environment. The chapter includes an operational vignette to show potential future capabilities using some of the technologies described later in this Roadmap. Also, the chapter explains the reduction in budget over the next five years beginning with the President's Budget request for $5.6 billion in unmanned systems in Fiscal Year 2013. In fact, the unmanned air domain as described in the 2014 President's Budget released to the U.S.

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Congress shows a 33.4% reduction in research, development, test, and evaluation and procurement funding from the previous year.

Chapter 2: Strategic Planning and Policy — This chapter expounds on the structure, direction, and established guidance from DoD leadership toward planning and developing unmanned systems. It briefly discusses some of the prevailing unmanned issues of the day and expresses departmental direction in their resolution.

Chapter 3: CCDR Mission and Capability Needs — A joint perspective emerges in this chapter through a discussion of mission capabilities unique to unmanned systems and an explanation of the requirements process used to deliberately develop those capabilities to achieve improved efficiency, effectiveness, and survivability and to reduce the burden on manpower at lower costs while still meeting future operational requirements. The perspective establishes that future unmanned systems must

- Provide capabilities more efficiently through such attributes as modularity, interoperability, integration with manned systems, and use of advanced technologies.
- Be more effective through features such as greater automation, improved performance, and flexible use of capabilities.
- Be more survivable in contested environments through improved and resilient communications, increased security from tampering, and system design.
- Reduce manpower requirements to operate and support unmanned systems.

Chapter 4: Technologies for Unmanned Systems — Certain key areas of interest for improving technology reflect DoD's shift in strategic priorities and address the requirement to continue to reduce lifecycle costs across all systems, including unmanned systems. The six areas of interest highlighted in this chapter are interoperability and modularity; communication systems, spectrum, and resilience; security (research and intelligence/technology protection (RITP)); persistent resilience; autonomy and cognitive behavior; and weaponry. This chapter also describes how limited science and technology funding will potentially impact such emerging technology solutions.

Chapter 5: Operating Environment — This chapter describes the operating environments of unmanned systems, which are critical in determining system performance flexibilities (e.g., appropriate levels of automation, maneuverability, communication options) needed to accomplish the mission. The chapter emphasizes that every aspect of the operating environment, including the physical and regulatory, should be incorporated in all acquisition lifecycle stages. Guidance is currently available from each Military Department although requirements and standards must still be developed to support new capabilities.

Chapter 6: Logistics and Sustainment — The rapid development and fielding of large numbers and types of unmanned systems present DoD with a significant sustainment challenge. This chapter discusses the necessary transition from supporting immediate warfighter capability requirements to creating an affordable, long-term sustainment environment utilizing a flexible blend of original equipment manufacturers (OEM), other contractors, and organic support to meet logistics support objectives.

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Chapter 7: Training — The current state and forces shaping the training environment are similar to those that have shaped the logistics environment. As DoD transitions to a peacetime environment, the proper mix among the live, virtual, and constructive domains must be put into place to ensure that the asymmetric advantages offered by unmanned systems can be employed in future operations and at a reduced cost. This chapter describes the current state of training for unmanned systems, related challenges, and the way ahead.

Chapter 8: International Cooperation — This chapter reflects DoD's efforts to include cooperative research, development, test and evaluation, and regulatory/standard agreements of defense technologies and systems with foreign partners as well as the procurement of defense articles, systems, and services from foreign partners. DoD objectives and methods are explained.

While DoD unmanned systems development funding will likely be constrained over the early part of this decade, unmanned systems (air, maritime, and ground) continue to hold much promise for the warfighting tasks ahead. If the technical, logistics and sustainment, training, and cooperation challenges are addressed by accomplishing the projects and tasks described in this Roadmap, advances in capability and affordability can readily address the needs dictated by the plans, policies, and operating environments. These advances will achieve well beyond what is attainable today.

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1 Introduction

The purpose of this Roadmap is to articulate a vision and strategy for the continued development, production, test, training, operation, and sustainment of unmanned systems technology across the Department of Defense (DoD). Recent combat operations in Southwest Asia have demonstrated the military utility of unmanned systems in today's combat environment and have resulted in the rapid integration of unmanned technologies into the joint force structure. This Roadmap establishes a vision for the next 25 years and outlines actions and technologies for DoD, industry, universities, and others to pursue to achieve the sustained, affordable, rapid integration and application of unmanned systems.

This Roadmap is required by goals within the Unmanned Aircraft Systems (UAS) Task Force charter. Specifically, Goal 5 of the charter refers to the roadmap task:[1]

> ***Goal 5. Serve as the Department's lead activity for the development and promulgation of the Unmanned Systems Roadmap.***

1.1 DoD Vision

DoD will develop and field affordable, flexible, interoperable, integrated, and technologically advanced unmanned capabilities that will

- Prevail in the full range of contingencies and in all operating domains, including cyberspace (Defense Strategic Guidance 2012);[2]
- Enable decisive force effectiveness in Joint and coalition operations;
- Be critical to future success;
- Emphasize missions according to strategic guidance from intelligence, surveillance, and reconnaissance (ISR); counterterrorism; counter-weapons of mass destruction (WMD); and operations required to operate across all environments, including anti-access and area denial (A2/AD);
- Protect the homeland; and
- Be able to surge and regenerate forces and capabilities.

1.2 Scope

This Roadmap continues the path outlined in the 2011 edition of the Roadmap and addresses three unmanned operating domains: air, ground, and maritime. It leverages the existing roadmaps produced by the individual military departments and agencies and focuses on the common technical, training, and policy challenges that each Armed Service faces in achieving the full potential of unmanned systems technology. A list of the applicable Service documents that form the foundation of these conclusions can be found in Appendix A.

[1] The full charter is available on the Unmanned Warfare Information Repository (Figure 1).
[2] "Sustaining U.S. Global Leadership: Priorities for 21st Century Leadership," Defense Strategic Guidance, January 2012.

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This document serves a diverse stakeholder community with one of the primary target audiences being DoD. By providing a common vision toward overcoming unmanned challenges, this Roadmap can shape military department investments in unmanned innovations. The plans outlined in this document also shape the efforts of Service requirements developers, budget planners, program managers, laboratories, warfighters, and other key DoD stakeholders. In addition, this document serves the defense industry by providing insight into DoD priorities and helping to shape industry investments, particularly for independent research and development investment strategies. Finally, this Roadmap informs key stakeholders outside DoD, including Congressional staffs, the Government Accountability Office, advocacy groups, and academic institutions.

The traditional unmanned catalog, historically contained in this document, now resides in a separate, online tool. This tool has been in place since 2010 and provides greater functionality than a hard-copy document. The online approach also facilitates more frequent updates to the catalog than the biennial publication of this Roadmap. Readers can find the common access card–protected catalog on the Unmanned Warfare Information Repository (Figure 1) at https://extranet.acq.osd.mil/uwir/.[3]

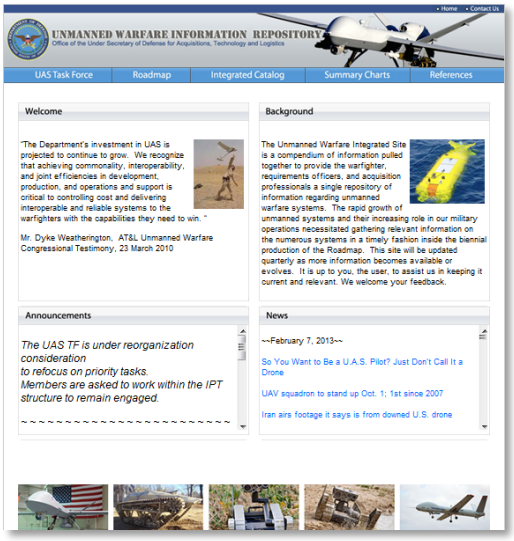


Figure 1. Unmanned Warfare Information Repository

1.3 Current Environment

Urgency resulting from the swiftly changing international environment is deeply felt within DoD's acquisition programs. Specifically, three forces are driving this sense of urgency: department budgetary challenges, evolving security requirements, and a changing military environment. Budgets for unmanned systems are discussed in this section while the other two forces are addressed in the future environment section (see Section 1.4).

> ***As we turn the page on more than a decade of grinding conflict, we must broaden our attention to future threats and challenges. That means continuing to increase our focus on the Asia-Pacific region, reinvigorating historic alliances like NATO, and making new investments in critical capabilities like cyber.***
>
> ***In order to accomplish our mission, we also must make wise budget decisions prioritizing our interests and requirements.***
>
> ***— Chuck Hagel, Secretary of Defense[4]***

[3] Common access card protection is required on the OUSD(AT&L) network infrastructure. Inquiries can be made to OUSD(AT&L)S&TS-UW&ISR. See page 149 of Appendix G for contact information.
[4] Source: http://www.defense.gov/Speeches/Speech.aspx?SpeechID=1754.

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The 2013 Presidential Budget (PB13) reduced the overall DoD budget by $259 billion over the next Future Years Defense Plan (FYDP), with a total reduction of $487 billion over the next 10 years. The 2014 Presidential Budget, with the potential effects of sequestration, further reduces the budget by about $55 billion across the FYDP.[5] Some defense programs were bolstered with additional funds while others required adjustments downward. The budget focuses on developing A2/AD technologies to ensure dominance in A2/AD scenarios and will fund the next-generation bomber and other modernizations. Table 1 explains the unmanned systems portion of PB14.

Table 1. DoD Unmanned Systems Funding ($ mil/PB14)

FYDP		2014	2015	2016	2017	2018	Total
Air	RDTE	1189.4	1674.0	1521.4	1189.4	1087.9	6662.2
	Proc	1505.5	2010.2	1843.5	1870.7	2152.8	9382.7
	OM	1080.9	1135.2	1102.7	1156.9	1178.5	5654.1
Domain Total		3775.9	4819.4	4467.6	4217.0	4419.3	21699.1
FYDP		2014	2015	2016	2017	2018	Total
Ground	RDTE	6.5	19.1	13.6	11.1	10.6	60.9
	Proc	6.5	27.9	30.7	42.6	55.4	163.1
	OM	0.0	0.0	0.0	0.0	0.0	0.0
Domain Total		13.0	47.0	44.3	53.7	66.0	223.9
FYDP		2014	2015	2016	2017	2018	Total
Maritime	RDTE	62.8	54.8	66.1	81.0	87.2	351.9
	Proc	104.0	184.8	160.1	158.1	101.1	708.2
	OM	163.4	170.3	182.4	190.5	193.6	900.2
Domain Total		330.2	409.8	408.6	429.7	381.8	1960.2
FYDP		2014	2015	2016	2017	2018	Total
All Unmanned Systems	RDTE	1,258.7	1,747.9	1,601.1	1,281.5	1,185.7	7,075.0
	Proc	1,616.0	2,222.9	2,034.3	2,071.4	2,309.3	10,253.9
	OM	1,244.3	1,305.4	1,285.1	1,347.4	1,372.1	6,554.3
Domain Total		4,119.1	5,276.2	4,920.5	4,700.4	4,867.1	23,883.2

Note: Ground operations and maintenance (OM) is funded with overseas contingency operations funding.

Over the past decade, the quantities and types of unmanned systems acquired by the Military Departments have grown, and their capabilities have become integral to warfighter operations. The size, sophistication, and cost of the unmanned systems portfolio have grown to rival traditional manned systems. Unmanned systems now include both major acquisition programs to provide long-term capability and short-duration projects to meet urgent needs.

For this Roadmap, unmanned systems operating in the air domain are referred to as unmanned aircraft systems (UAS); in the ground domain, unmanned ground systems (UGS); and in the maritime domain, unmanned maritime systems (UMS). Each operating domain brings a unique set of environmental attributes affecting the warfighter. In complex mission

[5] Source: http://www.defense.gov/speeches/speech.aspx?speechid=1643.

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environments, multiple systems across several domains must cooperate and interoperate to effectively perform mission tasks.

1.3.1 Unmanned Aircraft Systems

An unmanned aircraft system (UAS) is a "system whose components include the necessary equipment, network, and personnel to control an unmanned aircraft."[6] In some cases, the UAS includes a launching element. DoD inventories and funding of UAS are expected to continue a gradual upward trend through 2015 (see Figure 2) and then trend downward in 2016 and beyond, although UAS experienced a full $1.3 billion (33.4%) reduction from fiscal year (FY) 2013 to PB2014 in combined research, development, test, and evaluation (RDT&E) and procurement funding. Outside DoD, UAS sector growth is predicted to continue to rise and was described as "the most dynamic growth sector of the world aerospace industry this decade."[7]

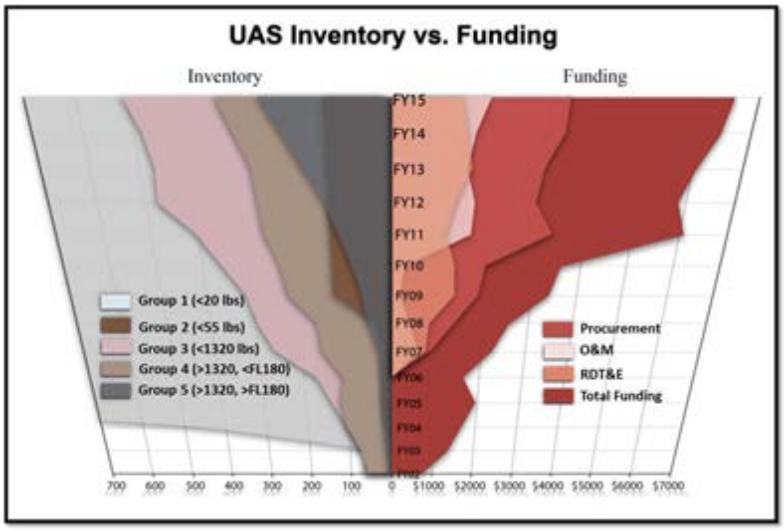


Figure 2. UAS Inventory vs. Funding

Within DoD, RDT&E funding is planned to taper off over the next five years; and depot maintenance consolidation efforts underway are expected to reduce operation and maintenance costs (O&M).

However, considering current inventory levels, overall funding demonstrates a continued commitment to invest in UAS performing predominately ISR missions. Thus, while one industry analysis and forecasting group estimates worldwide UAS spending will almost double over the next 10 years to a total of $89 billion,[8] a comparison of DoD funding plans versus industry predictions indicates DoD will not be the bulk user within that market. However, DoD does intend to be the most innovative user. From a strategic planning perspective, UAS have grown to a sizable fleet providing a variety of capabilities that DoD will need to maintain over the near term. See Figure 3.

[6] Joint Publication (JP) 3-52, Joint Airspace Control, 20 May 2010.
[7] "Teal Group Predicts Worldwide UAV Market Will Total $89 Billion in Its 2012 UAV Market Profile and Forecast," *Press Release Newswire*, United Business Media, 11 April 2012.
[8] Ibid.

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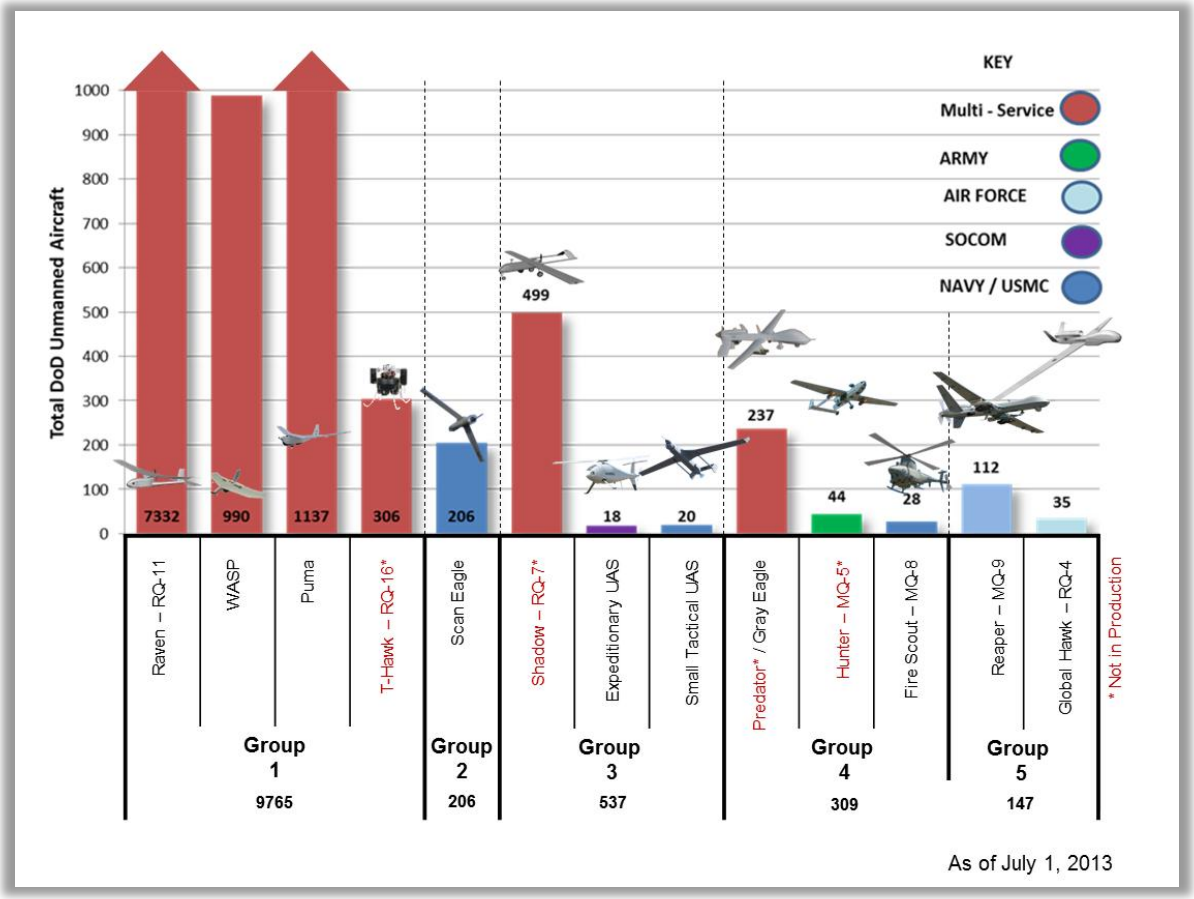


Figure 3. Inventory of DoD UAS

Looking toward the future, modernization of current capabilities will dominate, and limited development of new capabilities will likely focus on smaller numbers of higher end platforms capable of operating in more contested air environments. With fewer new systems in development and many future projects being deferred, the planning outlook toward future systems is much more conservative. See Figure 4.

Additionally, DoD seeks to improve overall interoperability over time. The latest Joint Concept of Operations (CONOPS) for UAS (approved by the Joint Requirements Oversight Council (JROC) builds on all applicable joint guidance for manned aircraft operations while describing the capabilities and complexities of employing UAS.[9] Similarly, the latest Unmanned Aircraft Systems Interoperability Initiative (UI2) Capability Based Assessment (CBA) provides an operational assessment of UAS interoperability tasks needs.[10] The CBA identifies and prioritizes DoD's ability to satisfy those needs and suggests doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy (DOTMLPF-P) solutions to close each gap.

[9] Joint CONOPS for UAS, Third Edition, November 2011: https://extranet.acq.osd.mil/uwir/docs/Joint_Concept_of_Operations_for_Unmanned_Aircraft_Systems_Third_Edition_Final_November_2011.pdf.

[10] Unmanned Aircraft Systems Interoperability Initiative (UI2) Capability Based Assessment, 14 May 2012: https://extranet.acq.osd.mil/uwir/docs/UI2%20CBA%20Report%20Final%20Signed.pdf.

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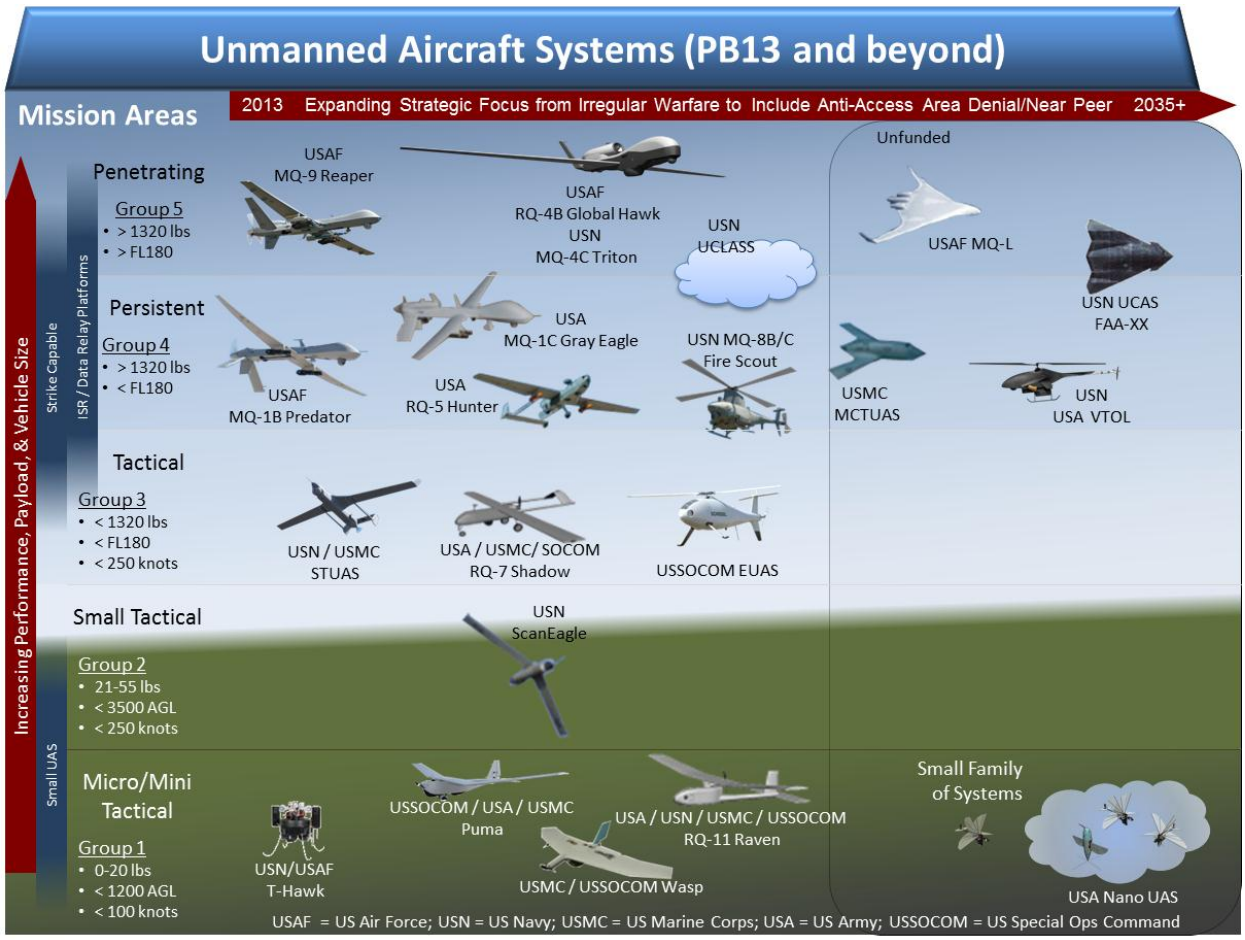


Figure 4. UAS (PB13 and Beyond)

1.3.2 Unmanned Ground Systems

UGS are a powered physical system with (optionally) no human operator aboard the principal platform, which can act remotely to accomplish assigned tasks. UGS may be mobile or stationary, can be smart learning and self-adaptive, and include all associated supporting components such as operator control units (OCU). Integration of UGS enabled by add-on mission module payloads to the other military domains is an essential part of future DoD operations, not only from a system perspective, but also from a joint-service and coalition perspective. This vision continues to be strengthened as ground-based robots have proven their worth in Iraq and Afghanistan across a spectrum of mission areas as shown in Figure 5.

As the Nation's 10 years of war wind down, DoD inventories and funding of UGS are expected to decrease in 2014, followed by a gradual upward trend in 2016 and beyond with the fielding of new programs of record (PORs) to meet expanding mission requirements. The first wave of UGS fielding resulted from rapid acquisition programs driven by urgent warfighter needs in support of Operation Iraqi Freedom. Recognizing the need to maintain the UGS capability beyond today's fight, but lacking fielded PORs, the Deputy Chief of Staff of the Army approved a directed requirement for continued support and sustainment of selected contingency systems. This directive authorizes the sustainment of specific capabilities beyond today's

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worldwide engagements to bridge the capability gap until enduring capabilities are developed and acquired using traditional Armed Service programming.

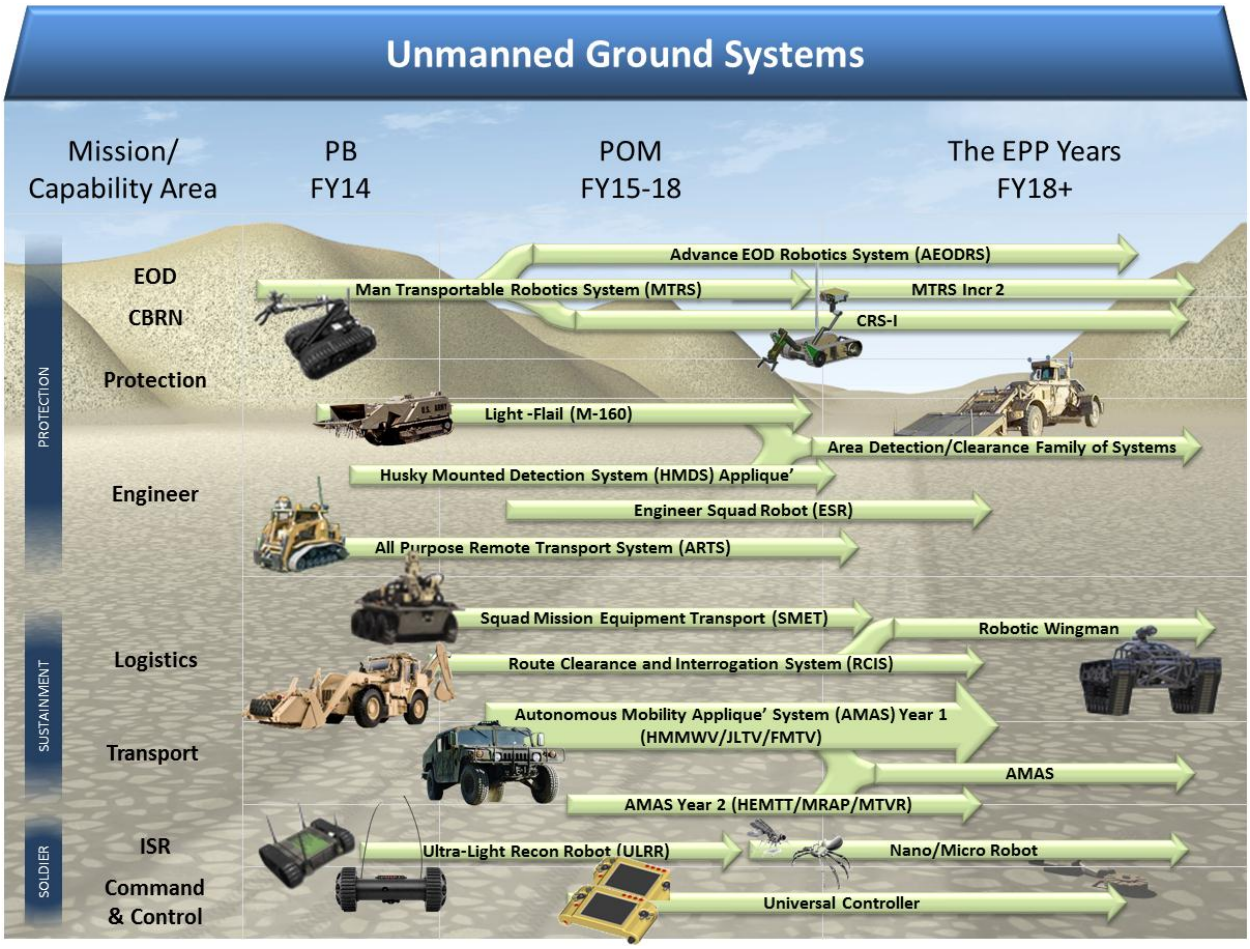


Figure 5. UGS by Mission/Capability Area

DoD has maintained an enterprise approach to UGS capability since the early 1990s. The Joint Ground Robotics Enterprise (JGRE) construct has enhanced joint-service capabilities and coordination and provided a means for focusing DoD efforts in UGS. The JGRE focus has evolved over time in response to technology advancements and warfighter needs. Today's enterprise focus is on synchronizing UGS programs across the Services to eliminate redundancy and maximize investments to ensure that future systems are affordable, mission flexible, and supportable while eliminating duplication across DoD.

In response to Congressional concerns, the U.S. Army has developed a 30-year UGS campaign plan. This campaign plan was developed as a broad avenue of approach to coordinate and synchronize UGS RDT&E efforts with Army force modernization requirements. The purpose of the resulting UGS execution order is to provide a modernized force of manned-unmanned teams with improved persistence, protection, and endurance. Realization of this goal will decrease physical and cognitive workloads on our warfighters, while increasing their combat capabilities. The end state is an affordable, modernized force as a manned-unmanned team with improved movement and maneuver, protection, intelligence, and sustainment.

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1.3.3 Unmanned Maritime Systems

UMS comprise unmanned maritime vehicles (UMVs), which include both unmanned surface vehicles (USVs) and unmanned undersea vehicles (UUVs), all necessary support components, and the fully integrated sensors and payloads necessary to accomplish the required missions. While funding for UMS is falling 45% across the FYDP, future UMS inventories continue to rise. Indeed, as new littoral combat ships arrive in service, support UMS will rise in number. Refer to Figure 6 for an overview of UMS.

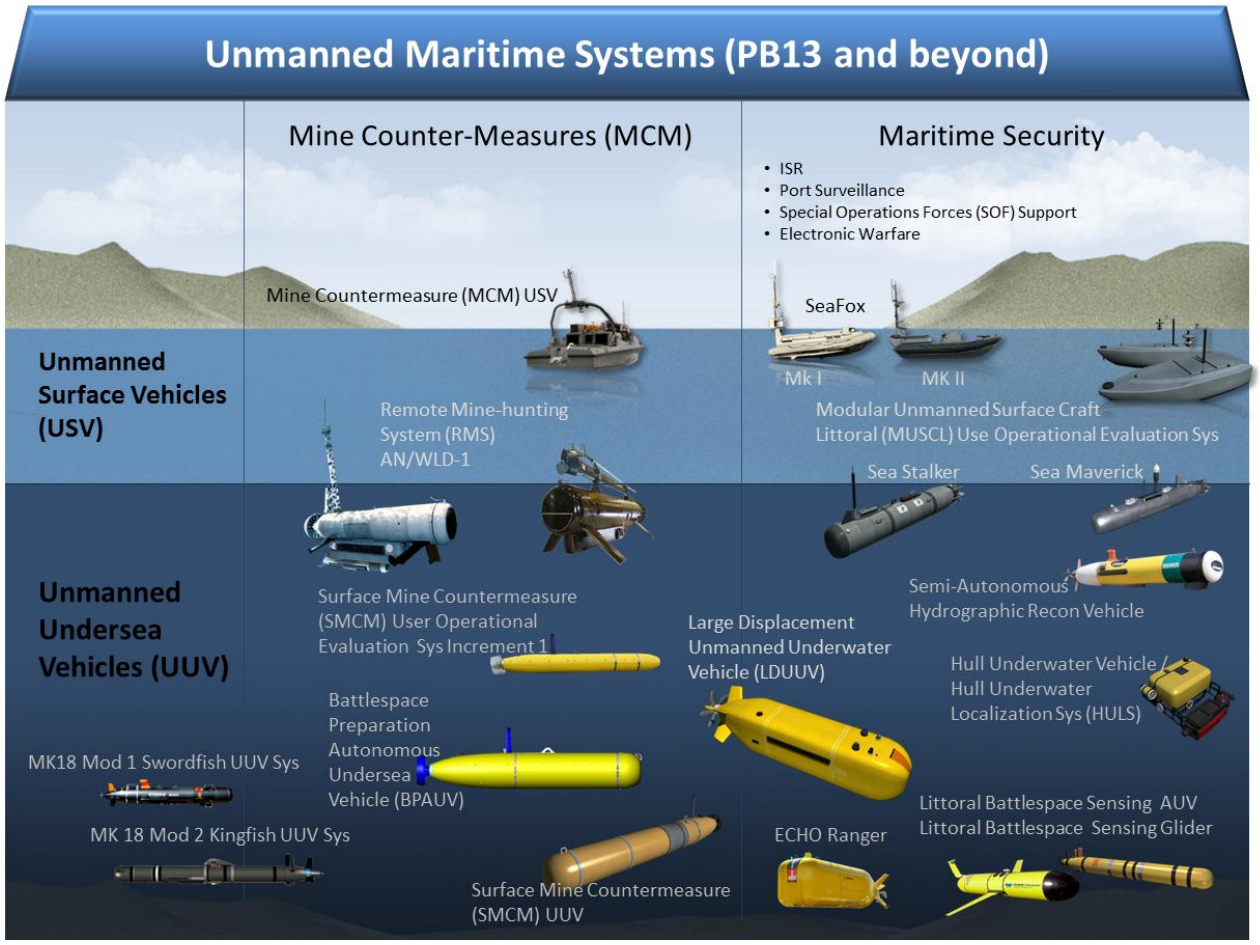


Figure 6. UMS by Mission Area

1.4 Future Environment

As stated in 1.3, the swiftly changing strategic environment is causing a sense of urgency primarily driven by three forces: department budgetary challenges, evolving security requirements, and a changed military environment. Sections 1.3.1, 1.3.2, and 1.3.3 addressed budget challenges, and 1.4.1, 1.4.2, and 1.4.3 address the security requirements and military environment and describe the future operating environments as foreseen in U.S. strategic documents.

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1.4.1 Objectives

The 2010 Quadrennial Defense Review identified two clear objectives[11] for DoD:

- Rebalance the capabilities of America's Armed Forces to prevail in today's wars while building the capabilities needed to deal with future threats.
- Continue strong support for DoD processes to better support the urgent needs of the warfighter; buy weapons that are usable, affordable, and truly needed; and ensure that taxpayer dollars are spent wisely and responsibly.

In today's conservative fiscal environment, austere military budgets must be focused on purchasing improved capabilities that responsibly support the nation's strategies while maintaining a leading edge in appropriate technology innovations. These strategies are based on potential conflicts around the world. Two strategy and budget documents that guide joint priorities, "Sustaining U.S. Global Leadership: Priorities for 21st Century Leadership" and "Defense Budget Priorities," both released in January 2012, state that U.S. military strategy will place renewed emphasis on the Asia-Pacific region.[12,13]

> ***Indeed, as we end today's wars, we will focus on a broader range of challenges and opportunities, including the security and prosperity of the Asia Pacific.***
>
> ***— Barack Obama, President of the United States[14]***

Consequently, air, land, and naval forces in the DoD planning cycle will be focused on improving operational capabilities to address current and future threats plus A2/AD security challenges analogous to the strategic state of the Asia-Pacific region as described in the "Joint Operational Access Concept."[15]

Today's problems and their solutions may not solve the problems arising 20 years from now. What possible strategic world situations should the United States prepare for to prevail militarily in conflicts 25 years in the future? What will the operational environment be like? Who are potential rivals? How should the United States invest in cutting-edge, critical unmanned capabilities to ensure success of the joint strategy while using networked cross-domain solutions?

[11] "Quadrennial Defense Review," February 2010.
[12] "Sustaining U.S. Global Leadership: Priorities for 21st Century Leadership," Defense Strategic Guidance, January 2012.
[13] "Defense Budget Priorities," January 2012.
[14] "Quadrennial Defense Review Report," February 2010.
[15] "Joint Operational Access Concept," 17 January 2012.

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1.4.2 Trends and Characteristics



Consider these environmental trends and characteristics and how they will affect DoD's operational unmanned systems:

- ***Pressure for reductions in federal budgets*** (and thus reduced military department budgets) will continue to increase; therefore, DoD cannot afford to acquire capabilities exceeding military needs. This increased pressure will further drive the need to be interoperable and better share information across the joint force.[16]
- ***Operational issues will be more complex*** as the pace of technological change accelerates.[17] Designing systems to easily accept technological improvement capabilities and support multiple mission needs will be increasingly important.
- ***U.S. military forces will be rebalanced.***
  - Tension and change will contribute to uncertainty in the Middle East.
  - Unable to compete force-on-force or globally, determined adversaries will adapt their strategies toward attempting to prevent access to certain regions or airspace and will target critical, less protected nodes (e.g., South Asia, Africa, and the Middle East). Such strategies will likely include attempts at the proliferation of nuclear weapons.
- ***Violent extremism*** will continue to threaten U.S. interests at home and around the globe.
- ***Unmanned technologies will continue to improve*** in many different capability areas.
  - Competitors are catching up in unmanned technology.
  - Increasingly data-intensive multisensor/multi-mission capabilities are evolving.
  - Unmanned technology innovations are rapidly increasing.
- ***Cyber domain will be a conflict environment*** as readily as land, sea, or air and space.[18]
- ***Enemy unmanned systems will complicate*** air, ground, and maritime operations by adding new low-altitude, ground, and amphibious threats to the force that must be countered. This concern will require the development of friendly countermeasures, including tactics, techniques, procedures, and training that enable the force to operate in the emerging environment.

1.4.3 Operational Vignette

The following futuristic storyline gives insight into the capabilities that could come about with today's emerging technologies applied on future unmanned systems.

[16] "Sustaining U.S. Global Leadership: Priorities for 21st Century Leadership," Defense Strategic Guidance, January 2012.
[17] Ibid.
[18] "Joint Operational Access Concept," 17 January 2012.

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1.4.3.1 The Setting

In the year 2020, a nuclear inspection team from the United Nations (U.N.) International Atomic Energy Agency is expelled from the (notional) country of Norachi while on its second visit in three weeks. The agency team was denied access to nuclear sites and, therefore, could not verify any "military dimension" within the country's nuclear program. A government spokesperson for Norachi insists its nuclear program does not have military applications. Meanwhile, Norachi's leader declares on state-owned TV that the country has weapons grade nuclear enrichment capability and announces new military exercises "to prevent aggressions" by Western powers. Western concern centers on a new uranium enrichment plant, which is buried deep underground and, therefore, much harder to monitor or, if necessary, attack. Additionally, the potential transport and/or selling of WMDs materiel or technology increases the threat to the Western powers.

Western officials are divided over whether Norachi is shifting toward a defensive posture or is just playing for time to pursue its nuclear program, which it says is for strictly peaceful purposes. The U.N. has responded by enacting a ban on the sale of goods to Norachi, including an embargo on oil sales. Neighboring nations that are friendly to Norachi do not share this view.

The U.N. is requesting the support of the United States and allied powers in surveillance and enforcement of the export bans to Norachi. Norachi is situated on the coast with mountainous areas inland. See Figure 7. Many ports have active commercial shipping enterprises in addition to their military facilities and berths. Additionally, Norachi has a modern road network and mature air transportation network for transport of goods to and from the country.

1.4.3.2 U.S. Forces

- Traditional manned air, sea, and land forces
- Land-based unmanned aircraft
- Sea-based unmanned aircraft operated from aircraft carriers and support ships
- Unmanned ground systems
- Vertical lift unmanned systems
- UUVs
- Small tactical UAS and UGS

1.4.3.3 Norachi Forces

- Homeland Defense ground forces
- Surface ships (patrol boats and frigates)
- Kilo-class submersibles
- Integrated air defenses with anti-aircraft artillery and surface-to-air missile systems
- Late-model fourth-generation fighters
- Sophisticated jammers
- Sensor intelligence

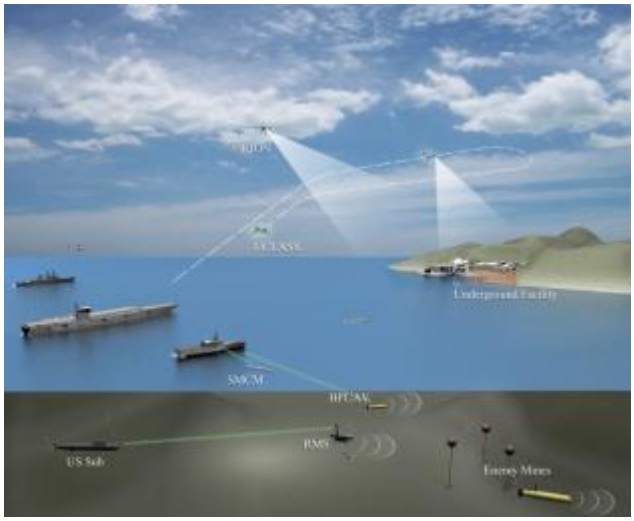


Figure 7. Operational Battlespace

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1.4.3.4 Air, Maritime, and Ground Intelligence

The National Command Authority (NCA) tasks the Combatant Commander (CCDR) to support the U.N. resolution and assist in enforcing the ban on Norachi. NCA also requests increased surveillance and reconnaissance efforts on Norachi for indications and warnings of potential escalation of threats.

To enforce the ban, the CCDR employs a variety of land-based and sea-based systems to conduct ISR and interdiction. Unmanned systems provide a critical enabler to this mission. To survey the land and sea approaches to the country, the Air Force's and Navy's unmanned systems, including the high-altitude long-endurance (HALE) UAS with its multiday ISR and communication relays, provide extended persistence with a wide variety of sensors. Also, the aircraft carrier *USS Abraham Lincoln* and its supporting carrier strike group ships are tasked to help enforce the maritime portion of the ban on exports to Norachi. Using the Unmanned Carrier Launched Airborne Surveillance and Strike System (UCLASS), persistent ISR and strike capabilities are available to the CCDR. Using ship-based and land-based UAS and UMS with sophisticated sensor suites, maritime movement to and from Norachi is effectively tracked and identified. UUVs provide an effective network that detect underwater traffic and track identified submersibles in detail. Some of these underwater systems have extreme endurance and can patrol enemy coastlines.

After a few days, unmanned reconnaissance flights and UMS intelligence establish pattern of life in the region and at the WMD facilities, including maritime traffic in the region. Activity-based algorithms exploit the incoming intelligence data and conclude anomalies exist in the Norachi nuclear facility network. Additional unmanned assets are employed to further investigate these anomalies. Special Operations Forces deploy inexpensive, small, low-power unmanned sensor systems. One bird-like vehicle is deployed to conduct an overwatch of one noted facility. It perches on an electrical power line where it derives its power to gather and transmit images. Rugged UGS are deployed; they navigate over difficult terrain autonomously and provide closer video surveillance. These electrically powered vehicles accept power from solar/moon panel converters and a low-power laser light received from overhead assets in the

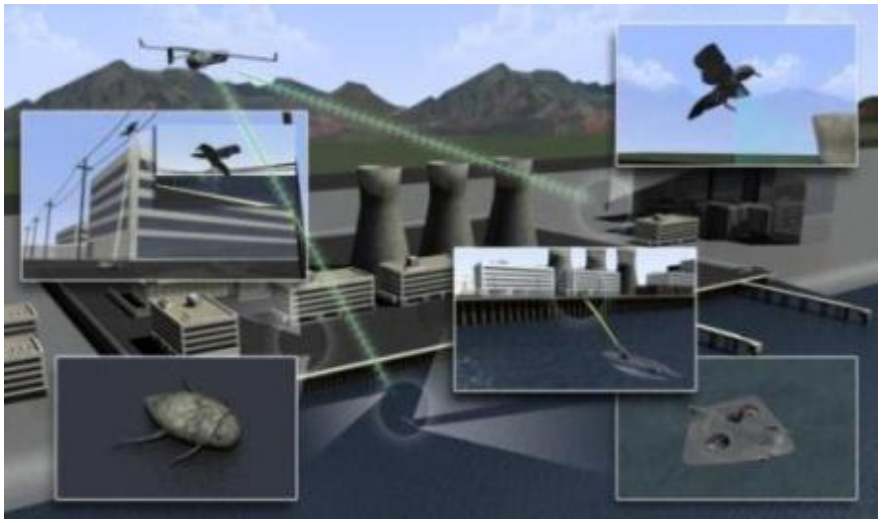


Figure 8. Array of Future Unmanned Systems (Notional)

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vicinity, such as the perched bird-like vehicle. See Figure 8. When these unmanned assets are applied and the resulting intelligence data are analyzed, U.S. leadership concludes Norachi has reached a critical stage in development at the nuclear site. Human intelligence correlates and confirms this conclusion.

1.4.3.5 Escalation of Tension

Norachi determines the international community is aware of the maturity of its nuclear program. To garner support, Norachi reaches out to another like-minded nation and negotiates a sale of WMD material. Through human intelligence, the international community becomes aware of the sale, yet does not know how or when the WMD will be moved. The threat of WMD proliferation, plus the potential of interception and stealing by non-state actors, escalates the tension with Norachi.

The United States maintains a heightened level of surveillance to detect any shipments from the WMD facilities. The integrated network of air and ground sensors, with automated processing and exploitation algorithms, monitors activity and cues sensors based on activities. The sensors detect abnormal movements of vehicles from a key WMD storage site. The U.N. authorizes interception of the WMD because proliferation and potential terrorist use of the WMD are greater risks than a likely response from Norachi. Penetrating, high-altitude airborne systems track the vehicle and provide cueing information to incoming strike aircraft. Launched from the off-shore aircraft carrier, the strike package comprises of manned tactical aircraft with numerous combat support UAS providing tactical intelligence communication relay, jamming support, and strike support. The joint strike fighter operates as a command ship and works in concert with its supporting unmanned systems as a seamless network of strike and jamming aircraft. The strike package penetrates Norachi airspace and intercepts, strikes, and stops the convoy. An extraction team follows shortly behind, secures the area, and locates the WMD. The extraction team loads the cargo on unmanned vertical-lift transports and departs the area. The operation stands down while maintaining a continuing presence of air, sea, and land systems to maintain situational awareness as the Norachi situation evolves.

As illustrated by this vignette, many new capabilities might be possible utilizing today's emerging technologies and applying those technologies on unmanned systems.

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2 Strategic Planning and Policy

2.1 Strategic Guidance

DoD uses a vast array of unmanned systems to complete its mission, from ground and undersea to aircraft flying in the upper regions of the atmosphere. In the past, those systems were such an enhancement to ongoing operations that some systems were fielded before they were completely ready for production and without adequate training plans while others were being rapidly developed in limited numbers to satisfy an immediate warfighter need.

Unmanned systems continue to prove their value in combat operations in Afghanistan, where military operations are planned and executed in extremely challenging environments. Indeed, adversaries are fighting using increasingly unconventional means, taking cover in the surrounding populations, and employing asymmetric tactics to achieve their objectives. In future conflicts, we must be prepared for these tactics as well as for a range of other novel methods of opposition, including so-called "hybrid" and A2/AD approaches to blunting U.S. power projection. Unmanned systems will be critical to U.S. operations in all domains across a range of conflicts, both because of their capability and performance advantages and because of their ability to take greater risk than manned systems.

As unmanned systems have proven their worth on the battlefield, DoD has allocated an increasing percentage of its budget to developing and acquiring these systems. With the transition from a handful of innovative experimental systems to normalized program developments, unmanned systems have received their share of inclusion in Congressional direction and are influenced by many acquisition initiatives and departmental policies.

2.2 Congressional Direction

Legislation requiring

- Creation of an executive committee (ExCom) for UAS airspace integration
- Federal Aviation Administration (FAA) plan integration of UAS into the National Airspace System (NAS) by 2015



2.3 Acquisition Initiatives

- Should Cost/Would Cost[19]
- Affordability[20]
- Better Buying Power[21]
- Roadmap Guidance — Mandate Affordability as a Requirement[22]



[19] Carter, Ashton B., Under Secretary of Defense, Acquisition, Technology, and Logistics, "Should-cost and Affordability Memorandum": http://www.acq.osd.mil/docs/Should-cost%20and%20Affordability.pdf.
[20] Ibid.
[21] Better Buying Power (Public Site): https://acc.dau.mil/bbp.
[22] Carter, Ashton B., Under Secretary of Defense, Acquisition, Technology, and Logistics, "Implementation Directive for Better Buying Power — Obtaining Greater Efficiency and Productivity in Defense Spending": http://www.acq.osd.mil/docs/USD(AT&L)_Implementation_Directive_Better_Buying_Power_110310.pdf.

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2.4 Departmental Policy Consideration

Of the many issues arising over the use of unmanned systems in today's world environment, several have become questions of departmental policy and required active direction from leadership. Five of the many unmanned issues that required departmental consideration over the past two years include autonomy, data protection, data exploitation, selective innovation, and Manned-Unmanned System Teaming (MUM-T).

2.4.1 Autonomy

DoD defines unmanned aircraft as "an aircraft or balloon that does not carry a human operator and is capable of flight under remote control or autonomous programming."[23] Therefore, when the aircraft is under remote control, it is not autonomous. And when it is autonomous, it is not under remote control. While these two conditions could exist (controlled and uncontrolled), current DoD UAS are remotely operated and capitalize on automation in extreme circumstances, such as a lost link condition, to automatically perform a preprogrammed set of instructions. This distinction is important because our community vernacular often uses the term "autonomy" to incorrectly describe automated operations. Chapter 4 contains a detailed discussion on autonomy and cognitive behavior and notes that research and development in automation are advancing from a state of automatic systems requiring human control toward a state of autonomous systems able to make decisions and react without human interaction. DoD will continue to carefully consider the implications of these advancements.



The potential for improving capability and reducing cost through the use of technology to decrease or eliminate specific human activities, otherwise known as automation, presents great promise for a variety of DoD improvements. However, it also raises challenging questions when applying automation to specific actions or functions. The question, "When will systems be fielded with capabilities that will enable them to operate without the man in the loop?" is often followed by questions that extend quickly beyond mere engineering challenges into legal, policy, or ethical issues. How will systems that autonomously perform tasks without direct human involvement be designed to ensure that they function within their intended parameters? More broadly, autonomous capabilities give rise to questions about what overarching guiding principles should be used to help discern where more oversight and direct human control should be retained.

The relevant question is, "Which activities or functions are appropriate for what level of automation?" DoD carefully considers how systems that automatically perform tasks with limited direct human involvement are designed to ensure they function within their intended parameters. Most of the current inventory of DoD unmanned aircraft land themselves with very

[23] JP 1-02, *Department of Defense Dictionary of Military and Associated Terms*, 8 November 2010 (as amended through15 April 2013): http://www.dtic.mil/doctrine/new_pubs/jp1_02.pdf.

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limited human interaction while still operating under the control of a human and perform this function with greater accuracy, fewer accidents, and less training than a human-intensive process; as a result, both a capability improvement and reduced costs are realized. This specific automatic process still retains human oversight to cancel the action or initial a go-around, but substantially reduces the direct human input to one of supervision. Human-systems engineering is being rigorously applied to decompose, identify, and implement effective interfaces to support responsive command and control (C2) for safe and effective operations.

Systems are designed and tested so that they perform their tasks in a safe and reliable manner, and their automated operation must be seamless to human operators controlling the system. This automation does not mean operators are not monitoring the control of the system. Currently, automated functions in unmanned systems include critical flight operations, navigation, takeoff and landing of unmanned aircraft, and recognition of lost communications requiring implementation of return-to-base procedures. As technology matures and additional automated features are thoughtfully introduced, DoD will continue to carefully consider the implications of autonomy. For armed platforms, DoD Directive (DoDD) 3000.09 establishes policy for the development and use of autonomous capabilities.[24]

2.4.2 Data Protection – Near, Middle, and Long Terms

Near Term (0–4 years). Encryption of UAS C2 and data links is critical for protecting UAS operations, ISR, and other communicated information. Presently, DoD specifies encryption and key management for UAS C2 communications and both still and motion imagery. Type 1 validated encryption is required for processing classified communications, and FIPS 140-2 validated encryption at a minimum must be used for processing unclassified communications.[25] DoD Instruction (DoDI) S-4660.04 also specifies further encryption and key management methods, such as the use of encryption keys provided by the National Security Agency (NSA), to enable interoperability.



Middle Term (4–8 years). Future encryption solutions will contain products that have a quicker time to market, greater coalition interoperability, and improved key management. The use of software Suite B[26] cryptography, which enables the protection of classified information,[27] is the primary driver behind faster product certification, which allows faster approval for coalition partner use. The development of UAS noncontrolled cryptographic products in the near term is expected to aid in coalition interoperability and lower lifecycle and logistics costs. Key management improvements will provide greater scalability, efficiency, and standardization for dynamic group keying techniques in UAS airborne networking with dynamic joining and leaving.

[24] DoDD 3000.09, Autonomy in Weapons Systems, November 2012.
[25] Details of these requirements, which apply to groups 2 through 5 UAS, can be found in DoDI S-4660.04, Encryption of Imagery Transmitted by Airborne Systems and Unmanned Aircraft Control Communications (U), 27 July 2011.
[26] Suite B cryptography is defined by NSA: http://www.nsa.gov/ia/programs/suiteb_cryptography/index.shtml.
[27] For additional information, see Committee on National Security Systems (CNSS) Policy (CNSSP) 15.

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Long Term (more than 8 years). In the longer term, advancements in component consolidation, higher data rate cryptography, and open standards will enhance UAS encryption. Hardware consolidation yielding single chip and coprocessor encryption modules will make routine cryptography both faster and feasible for smaller, group 1 UAS.[28] Improvements in hardware will also lead to higher data rate cryptography. Further standardization in common radio and cryptographic interfaces will enable improved remote UAS management and lower lifecycle costs.

2.4.3 Data Exploitation

Data are increasing in volume and availability as is the number of sensors with increased resolution and time-dominant requirements that present significant challenges and opportunities for DoD. As more and more sensors arrive on the battlefield and those sensors' capabilities increase, more data are delivered to warfighters, but the warfighters' ability to process and exploit such a large volume of data in a timely fashion is increasingly challenged. The problem is also exacerbated on both ends of the transmission link. Either huge volumes of data must be downsized before their transmission, or the data highway on which they travel must be increased in size and speed. Many gaps identified and prioritized in the UI2 CBA describe this in detail.

Further, after reception, the data must be used by analysts to draw conclusions for the decision makers. If the data are already formatted and arrive prioritized, fewer analysts are required to take advantage of the intelligence. Similarly, if the various databases are archived in a standard way, the various warfighter intelligence cells will use far fewer analysts to exploit databases and draw conclusions. Data must be immediately accessible by both anticipated analysts/consumers and unanticipated analysts/consumers.

Automated exploitation techniques are improving in ground-based intelligence production systems in the distributed common ground station (DCGS) families, the attack and Joint Architecture for Unmanned Systems (JAUS) programs, and other elements of the unmanned systems family. Current sensor resource management commands must be extended to include preset data resolution and reporting criteria. These current capabilities must be addressed for use as a requirements base and prototyping for UAS onboard applications. Onboard exploitation is further discussed in Section 4.6.4.

Strategic Studies Quarterly[29] recognized that DoD improvements to the warfighters' situational awareness are necessary and a metamorphosis is needed to develop into a tightly organized and dynamic ISR force. The Air Force report makes the following recommendations:

1. Overhead capabilities must be planned and executed in coordination with the National Reconnaissance Office because surveillance is increasingly becoming a standoff capability.

[28] In commercial industry, Intel implemented instructions, named Advanced Encryption Standard (AES) New Instructions (AES-NI), for Core processors in 2010 that can conduct several steps of AES encryption and decryption into a single instruction.
[29] "Air Force Strategic Vision for 2020–2030," *Strategic Studies Quarterly*, Spring 2011.

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2. Planning for a postwar (Afghanistan and Iraq) transition surveillance and reconnaissance structure must address the DCGS (a prime user of raw, unmanned-system-derived intelligence) and shift focus to processing and disseminating national and allied intelligence products.

3. Automated technologies must be exploited to improve data analysis so that human analysts are employed in the highest order tasks. Accelerated development of translation software, artificial intelligence, and electronic means to process raw data — signals and electronic intelligence — is the most practical approach to managing this glut of data and should become an Air Force funding priority. Additionally, collaborative tools could transform traditional data exploitation, including addressing high-value target intelligence mission exploitation. This activity traditionally consumes large amounts of human resources; therefore, a tool for this priority would reduce analyst requirements.

2.4.4 Selective Innovation

Both national military strategy and joint concept documents describe a vision of utilizing technical innovation for future capability improvements. Given the aforementioned budgets constraints, future mission needs will have to be met by funding capability improvements that exploit existing systems with innovative improvements to their indigenous technologies. This approach might be as simple as modifying a sensor to improve data flow or applying standard message set architectures to improve interoperability.

> ***…even at a time of increasing budget constraints, the Army has been good about finding money for UAS improvements…. Advances in technology have taken sensors, cameras and other gear from the analog to the digital age, making them ever smaller, lighter, more energy-efficient and useful.***
>
> ***— COL. Tim Baxter, Army UAS Project Manager in the Program Executive Office for Aviation[30]***

Innovation must continue, especially under the current fiscal environment, and must include not only improvements to existing CONOPS but also the development of entirely new CONOPS. More emphasis on innovative approaches must be given to all future unmanned systems development. Unmanned systems open up new avenues for pursuing systems that are smaller, lighter, faster, and more maneuverable and that take more risk than equivalent manned platforms. In particular, the ability of unmanned assets to take risks that would not be taken with manned assets opens up new CONOPS, such as low-cost, expendable systems that trade armor and stealth for quantity. In other words, a fleet of low-cost, disposable platforms could survive through attrition rather than through expensive, exquisite capabilities.

[30] Source: http://blog.al.com/huntsville-times-business/2012/04/armysunmanned_aircraft_systems.html.

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2.4.5 Manned-Unmanned System Teaming (MUM-T)

Technological advances and military adaptation will result in merging unmanned systems from air, ground, and sea domains into teams of unmanned and manned systems. MUM-T will be essential as DoD makes a shift in geographical priorities toward the Asia-Pacific region while retaining emphasis on the Middle East. A force of the smaller, more agile manned-unmanned systems of the near future will enable DoD to mobilize quickly to deter and defeat aggression by projecting power despite A2/AD challenges. MUM-T will provide the following key capabilities:

- Defeating explosive ground surface, sub-surface (tunnel), and sea hazards from greater standoff distances.
- Assuring mobility to support multiple points of entry.
- Enabling movement and maneuver for projecting offensive operations.
- Establishing and sustaining the shore lines of communications required to follow forces and logistics.
- Protecting austere combat outposts.
- Providing persistent surveillance to detect and neutralize threats and hazards within single- to triple-canopy and urban terrain.

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3 Combatant Commander Mission and Capability Needs

3.1 Why Unmanned?

The prevalence and uses of unmanned systems continue to grow at a dramatic pace. The past decade of conflict has seen the greatest increase in unmanned aircraft systems, primarily performing ISR missions. Use of unmanned systems in the other domains is growing as well. The growth of unmanned systems use is expected to continue across most domains. Unmanned systems have proven they can enhance situational awareness, reduce human workload, improve mission performance, and minimize overall risk to both civilian and military personnel, and all at a reduce cost.

The capabilities of unmanned systems are not unique over manned systems. Weapon systems produce effects in nearly all domains, independent of being manned or unmanned. It is important to highlight that there are no requirements for unmanned systems within the Joint force, but some capabilities are better fulfilled by unmanned systems. Unmanned systems provide persistence, versatility, survivability, and reduced risk to human life, and *in many cases are the preferred alternatives especially for missions that are characterized as dull, dirty, or dangerous*. With that mindset, unmanned systems are being optimized for these dull, dirty, or dangerous missions:

- Dull missions are ideal for unmanned systems because they involve long-duration undertakings with mundane tasks that are ill suited for manned systems. Good examples are surveillance missions that involve prolonged observation. Unmanned systems currently fulfill a wide variety of “dull” mission sets, and the number will increase in all domains as unmanned systems capabilities improve.
- Dirty missions have the potential to unnecessarily expose personnel to hazardous conditions. A primary example is chemical, biological, and nuclear detection missions. Unmanned systems can perform these dirty missions with less risk exposure to the operators.
- Dangerous missions involve high risk. With advances in capabilities in performance and automation, unmanned systems will reduce the risk exposure to personnel by increasingly fulfilling capabilities that are inherently dangerous.

3.2 Requirements Processes

Growth in unmanned platforms of all sizes and shapes has been substantial, with a corresponding increase in payload numbers and capability. Several of these systems were developed using the deliberative requirements and acquisitions processes. Policies have reflected a shift to support the integration of unmanned systems into the joint force and use across the battlefield when the capability is required by the CCDR. Many systems were rapidly acquired and immediately fielded using the Joint Urgent Operational Needs (JUONs) process. JUONs have successfully added significant capability to joint warfighting. While those unmanned systems were rapidly developed to meet the immediate needs of the warfighter in the near term, they have not undergone rigorous requirements review and joint coordination through the normal Joint Capabilities Integration and Development System (JCIDS) process, including, for example, review for systems interdependencies and interoperability. Further, their long-term enterprise-wide capability portfolios have not been fully considered. Consequently, they have not received

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due consideration in the context of broader joint capability areas (JCAs), which provide structure and organization to requirements development. In the future, consideration of such factors as the recently required JCIDS Training Key Performance Parameter (KPP) will more fully allow operators, maintainers, and leaders to realize full design capability sooner in the requirements process.

A formal review and approval process has been implemented for delineating which programs should transition to enduring programs (and eventually PORs) and/or which program sensors or other components need to be maintained via other programs. During this process, the JUONs and CCDR's integrated priority list (IPL) requirements were considered as well as the capabilities adjudicated against the Joint Direct Support Aerial ISR JROC-approved initial capabilities document that outlines the tactical commander's needs.

DoD recently revised the JCIDS requirements process to streamline urgent and deliberate capability development and enable requisite timeliness in meeting warfighter needs while giving important consideration to long-term affordability and sustainability. JCIDS is a key supporting process for DoD acquisition and Planning, Programming, Budgeting, and Execution (PPBE) processes. It ensures the capabilities required by the warfighter are identified with their associated operational performance criteria to successfully execute the assigned missions. This coordination ensures a better understanding of the warfighting needs early in capability development and provides a more comprehensive set of valid, prioritized requirements. DoD's acquisition arm can then focus on choosing options to meet well-defined requirement capabilities. Figure 9 shows the linked and streamlined process.

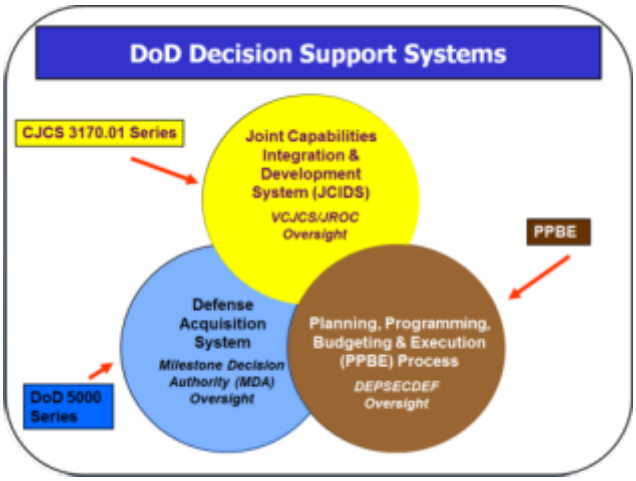


Figure 9. Linked JCIDS Process

The key decision body in the JCIDS process is the JROC, chaired by the Vice Chairman, Joint Chiefs of Staff. JROC has the responsibilities under Title 10 of the United States Code to consider input from CCDRs on joint requirements as well as to consider cost, schedule, and performance tradeoffs in establishing requirements. Currently, JROC is shaping the force with a more robust requirements review process. The Council is addressing the complex issues earlier and iteratively, using better upfront fidelity on cost, schedule, and performance tradeoffs and more analytic rigor in risk analysis. JROC constantly assesses joint capabilities by comparing risk and affordability against current defense strategies. Unmanned systems must provide capabilities with superior cost, schedule, and performance metrics to compete against other systems within JROC or other DoD forums.

Given today's highly constrained fiscal environment, it is imperative that DoD look at areas where efficiencies can be gained to create unmanned systems that are both effective and affordable. DoD will look at capitalizing on commonality, standardization, and joint acquisition strategies, among other strategies. Unmanned systems must become more efficient in addressing

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capability gaps, including increases in interoperability, autonomy, modularity, effectiveness, and teaming with manned systems. In addition, DoD demands these unmanned systems be affordable at the outset, experience little or no cost growth in their development and production evolution, and control lifecycle costs. To achieve these objectives, the full range of DOTMLPF-P options must be considered in the earliest development activities.

Capability requirements, validated by the JCIDS process, inform prioritization activities in the competition for funding during the PPBE process. The objective of the PPBE process is to provide the best mix of forces, equipment, training and support attainable within fiscal constraints according to DoDD 7045.14.[31] To meet this objective, the PPBE process aims to meet goals established by the President and the Secretary of Defense (SECDEF) in the Strategic Planning and Joint Planning Guidance. In the PPBE process, the Military Departments match available resources (e.g., fiscal, manpower, material) against validated requirements to achieve the strategic plan. A key task is to develop a balanced, affordable capabilities-based Service Program Objective Memorandum (POM). The POM position for the capability to meet a given requirement is assessed and revised when necessary to fit with Joint and coalition capabilities, and the final position becomes part of the President's budget.

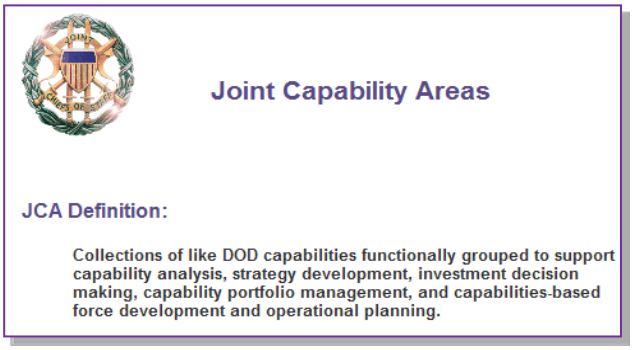
An important input to the POM position is each CCDR's IPLs. These lists are communicated annually by the CCDRs to SECDEF, the U.S. Congress, and the Joint Staff. IPLs can be specific or cross-cut capability gaps. The Joint Staff develops recommended solutions to the gaps. These gaps can span from programmatic changes of current programs, initiation of a new capability documents via JCIDS, and investment in science and technology (S&T) solutions to the initiation of new studies and experiments. JROC decides which gaps are most important to mitigate based on risk assessments and the adequacy of DoD's ongoing efforts. This prioritization of gaps is part of the capability gap analysis (CGA) process and results in a key input to the PPBE process. While specific capability gaps are classified, they typically include a range of needed capabilities. Within the CGA process, the Joint Staff determines whether any system could best satisfy the capability gap. Unmanned systems do not get special consideration. Systems must demonstrate a superior ability to satisfy the capability to garner support.

Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 6212.01F provides another JCIDS consideration.[32] It further defines responsibilities and establishes policy and procedures to develop the Net Ready Key Performance Parameter (NR KPP) and its certification requirement for all information technology (IT) and national security systems (NSS) that contain joint interfaces or joint information exchanges. The DoD Chief Information Officer (CIO) is also in the final stages of issuing DoDI 8330 to address IT and NSS.[33] This issuance will supersede DoDD 4630 issuances and the DoD CIO's Interim Guidance Memorandum. DoDI 8330 employs a new concept of "tiered accountability" to meet interoperability requirements internal to DoD and external mission partners.

[31] DoDD 7045.14, Planning, Programming, Budgeting System (PPBS).
[32] CJCSI 6212.01F, Net Ready Key Performance Parameter (NR KPP), March 2012.
[33] DoDI 8330 (DRAFT), Interoperability of Information Technology (IT), including National Security Systems (NSS).

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3.3 Joint Capability Areas (JCAs)



The JCAs[34] are currently the preferred method DoD uses for reviewing and managing capabilities. The JCA framework provides the structure around which capabilities and capability gaps can be aligned across DoD and across the various portfolios to correlate similar needs, leverage effective solutions, and synchronize related activities. Also, various frameworks, such as the Universal Joint Task List, are readily available to aid in identifying and organizing the tasks, conditions, and required capabilities.

Mapping current and projected unmanned systems against the JCAs provides a sense of what the product line portfolio is for unmanned systems and how it currently contributes, and could contribute in the future, to the missions of DoD. Each JCA represents a collection of related missions and tasks that are typically conducted to bring about the desired effects associated with that capability. Nine Tier One JCAs are defined, and unmanned systems are key contributors in the Battlespace Awareness, Force Application, Protection, and Logistics JCAs. Each area is assigned to a Functional Capability Board (FCB) on the Joint Staff (JS). FCB contact information is available on Intellipedia through the Secure Internet Protocol Router Network (SIPRNet).[35]

Current technology and future advancements can and will enable single platforms to perform a variety of missions across multiple capability areas. This versatility represents an opportunity for DoD to achieve a greater return on investment. Furthermore, the projections show that there will be opportunities for joint systems to conduct missions for each Service, just as there will be situations in which domain conditions or Service missions will dictate unique solutions.

3.3.1 Battlespace Awareness JCA – JS/J-28, BA FCB

Battlespace Awareness is a capability area where unmanned systems in all domains have the ability to contribute significantly into the future to conduct ISR and environment collection-related tasks. Applications in this JCA include aerial, ground, surface sea, and undersea surveillance and reconnaissance. Today, these functions are performed by several systems across all domains and mission sets. In the future, technology will enable mission endurance to extend from hours to days and allow for long-endurance persistent reconnaissance and surveillance in all domains. Unmanned systems are expected to integrate a greater range of C2 options from soldier-to-platform direct control to increased CONOPS options for operations that can be independent of C2. Therefore, onboard sensors that provide the systems with their own organic perception will contribute to Battlespace Awareness regardless of their intended primary mission. To achieve this goal, unmanned systems development and fielding must include the tasking, collection, processing, exploitation, and dissemination (TCPED) processes required to translate vast quantities of sensor data into a shared understanding of the environment. Many ongoing efforts are streamlining these

[34] Source: http://www.dtic.mil/futurejointwarfare.
[35] Source: http://www.intelink.sgov.gov/wiki/jroc.

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processes. This capability area lends itself to tasks and missions being conducted collaboratively across domains as well as teaming within a single domain.

3.3.2 Force Application JCA – JS/J-8, FA FCB

Force Application is another JCA that includes a proliferation of unmanned systems contributing to maneuver and engagement. Today, Predator, Reaper, and Gray Eagle UAS are weaponized to conduct offensive operations, irregular warfare, and high-value target and high-value individual prosecution; this trend will likely continue in all domains. In the air domain, projected mission areas for UAS include air-to-air combat, electronic warfare (EW), and suppression and defeat of enemy air defense. On the ground, UGS are projected to conduct missions such as remotely conducted, nonlethal crowd control; dismounted offensive operations; and armed reconnaissance and assault operations. In the maritime domain, both UUVs and USVs are projected to be particularly suited for mine laying and mine neutralization missions.

DoD personnel must comply with the law of war, including when using autonomous or unmanned weapon systems. For example, paragraph 4.1 of DoDD 2311.01E requires that "[m]embers of the DoD Components comply with the law of war during all armed conflicts, however such conflicts are characterized, and in all other military operations."[36]

Current armed unmanned systems deploy lethal force only in a fully human-operated context for engagement decisions. For these systems, the decisions both to employ force and to choose which specific target to engage are made by a human. The United States operates defensive systems for manned ships and installations that have human-supervised autonomous modes and has operated these systems for decades. As technology advances and more automatic features are introduced, DoD will continue to carefully consider the implications of autonomy in weapon systems to ensure safe and reliable operations and minimize the probability and consequences of failures that could lead to unintended engagements. For this reason, DoDD 3000.09, Autonomy in Weapon Systems, mandates a policy review before entering formal development for proposed weapon systems that would use autonomous capabilities in a novel manner.

3.3.3 Protection JCA – JS/J-8, Protection FCB

Protection has particular applicability for unmanned systems to assist in attack prevention or effects mitigation. Unmanned systems are ideally suited for many protection tasks that are deemed dull, dirty, or dangerous. As the future enables greater automation with respect to both navigation and manipulation, unmanned systems will be able to perform tasks such as firefighting, decontamination, contingency base and base camp security, installation security, obstacle construction and breaching, vehicle and personnel search and inspection, mine clearance and neutralization, sophisticated explosive ordnance disposal (EOD), casualty extraction and evacuation, and maritime interdiction. In the Protection JCA, teaming within domains and collaboration across domains will likely prevail.

3.3.4 Logistics JCA – JS/J-4, Logistics FCB

Logistics is ideally suited for employing unmanned systems in all domains to deploy, distribute, and supply joint forces. Unmanned systems will perform logistics tasks at home and

[36] DoDD 2311.01E, DoD Law of War Program, 9 May 2006.

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with the forward deployed. The purpose of the capability is to enable unmanned cargo systems in full-spectrum operations to perform the dull, dirty, and dangerous missions by capitalizing on the persistence of unmanned systems to free up manned assets for more difficult missions within an area of operation. The following tasks are particularly well suited for unmanned systems:

- Transportation of routine supplies (e.g., food, water, ammunition, and medical supplies) to the forward units in all types of ground terrain.
- The resupply from sea-based assets located offshore.
- Support for special operations forces.
- An alternative delivery option to widely dispersed operating forces for routine (around the clock) and immediate (time-sensitive) logistics support.
- Routine maintenance-related tasks such as inspections, decontamination, and refueling.
- Material handling and combat engineering.

Although currently prohibited by policy, future capabilities by unmanned systems could include casualty evacuation and care, human remains evacuation, and urban rescue. The unmanned vehicles are intended to mitigate risk to the maximum extent by reducing the requirement to operate manned vehicles when the weather, terrain, availability, and enemy pose an unsuitable level of risk.

3.4 A Look to the Future

This Roadmap provides a DoD vision for the continuing development, fielding, and employment of unmanned systems. Chapter 4 discusses the investments in technology to enhance capability and reduce cost. Warfighters value the inherent benefits of unmanned systems, especially their persistence, versatility, and reduced risk to human life. The Joint Staff will continue to support unmanned systems when they fulfill joint requirements and are effective and affordable. Unmanned systems must

- Provide capabilities more efficiently through modularity and interoperability.
- Be more effective through greater automation and greater performance.
- Be more survivable with improved and resilient communications, development for antipermissive environments, and more security from tampering.
- Take the “man” out of unmanned. Currently personnel costs are the greatest single cost in DoD, and unmanned systems must strive to reduce the number of personnel required to operate and maintain the systems. Great strides in autonomy, teaming, multi-platform control, tipping, and cueing have reduced the number of personnel required, but much more work needs to occur.

JROC supports a Joint Doctrine and Planning Conference review of the approved November 2011 Joint CONOPS for UAS to determine whether it has matured enough to transition to joint doctrine and become integrated into existing Joint Publications.

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4 Technologies for Unmanned Systems

4.1 Introduction

The pace of technological advances across the broad spectrum of unmanned systems applications has allowed what were once rather cumbersome vehicles and systems outside the "circle of warfare trust" (systems trusted by the warfighter) to shoulder burdens in warfare mission areas unforeseen only a few years ago. With dramatic increases in battery life and computer processing; reduction in size and complexity of sensors; and improvements in reliability, maintainability, automation, and operator interfaces, unmanned systems are now vital components of an operational commander's tool kit.

While commanders have become more accustomed to the capabilities (and limitations) of unmanned systems from operations during the first decade of the 21st century, the next decades are already presenting a two-sided challenge that represents stark differences from recent operations. First, a strategic shift in national security to the Asia-Pacific Theater presents different operational considerations based on environment and potential adversary capabilities. Second, a shrinking fiscal environment (without overseas contingency operations (OCO) funding) and base budget levels that are likely to be flat at best will challenge both unmanned systems operators and suppliers to seek efficiencies in total cost of unmanned systems ownership, from cost of manufacture, avionics, and deployment to manpower savings and logistics. This challenge is two-sided because one side cannot be considered without the other: meeting operational demands must be accomplished in the context of budgetary constraints — in the near, middle, and long term. See Figure 10 for an example of the President's 2012 S&T budget request for DoD.[37]

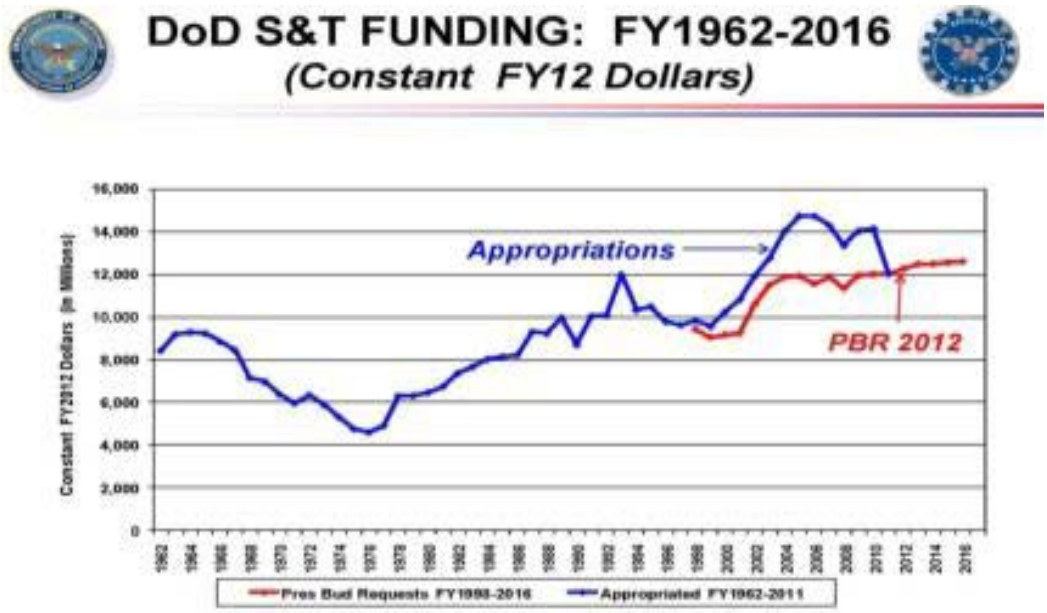


Figure 10. DoD S&T Funding: FY1962–2016

[37] Slide #15 extract from Mr. Bob Baker, Deputy Director, Plans & Programs, Assistant Secretary of Defense & Engineering, FY2012 President's Budget Request (PBR) for the DoD S&T Program Briefing, 21 June 2011.

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> ***When I announced the new guidance, I highlighted five key elements of the strategy and five key elements of the vision that we have for a military force of the future. And let me just summarize each of those…First, the military will be smaller and leaner, but it will be agile, flexible, rapidly deployable and technologically advanced. It will be a cutting-edge force…[F]ifth, we will protect and prioritize some very important and key investments in technology and new capabilities as well as our capacity to grow, adapt, to mobilize, to surge as needed.***
>
> ***— Leon E. Panetta, Former Secretary of Defense[38]***

As a result of DoD's new warfighting strategy and in recognition of new budgetary constraints, the Under Secretary of Defense (USD) for Acquisition, Technology, and Logistics (USD(AT&L)) is sponsoring a Defense Science Board study with the following charter:

"The Defense Science Board (DSB) is requested to conduct a study of emerging technologies that will enable the next generation of dominant military capabilities to be in development or fielded by 2030. Some of the products of the study will be:

1. A set of recommendations intended to guide the DoD research and development investments in applied technology and technology demonstrations over the period of 2014 to 2020;
2. Mapping of the identified technologies to applications and capabilities that may be enabled; and
3. For a select set of promising technologies, recommended experiments or concept demonstrations that foster innovation and provide entry ramps to enhance operational capabilities via block upgrades to existing systems or as entry ramps to new systems and operational concepts."

The study is guided in part by the January 2012 military strategy guidance, "Sustaining U.S. Global Leadership: Priorities for 21st Century Defense."[39]

The study will include surveying and assessing the potential for significant advances in technology outside DoD that could contribute to future military capabilities. These advances could augment DoD investments in areas such as quantum computing, microelectronics, robotics, nanomaterials, genetics, "big data," alternative energy sources, advanced materials, and modeling and simulation. Technologies that have the potential to significantly enhance or transform the nature of warfare in the sea, land, air and space, and cyber regimes will be the focus of this study.

[38] Source: http://www.defense.gov/transcripts/transcript.aspx?transcriptid=4962.
[39] USD(AT&L) Memorandum, "Terms of Reference-Defense Science Board Study on Technology and Innovation Enablers for Superiority in 2030," 15 March 2012.

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This chapter highlights six areas of interest for the technological advancement of unmanned systems. The areas are reflective of DoD's shift in strategic priorities and also address the *requirement* to continue to reduce lifecycle costs across all systems, including unmanned systems. In each section, near-, middle-, and long-term goals, as defined in Figure 11, are discussed.

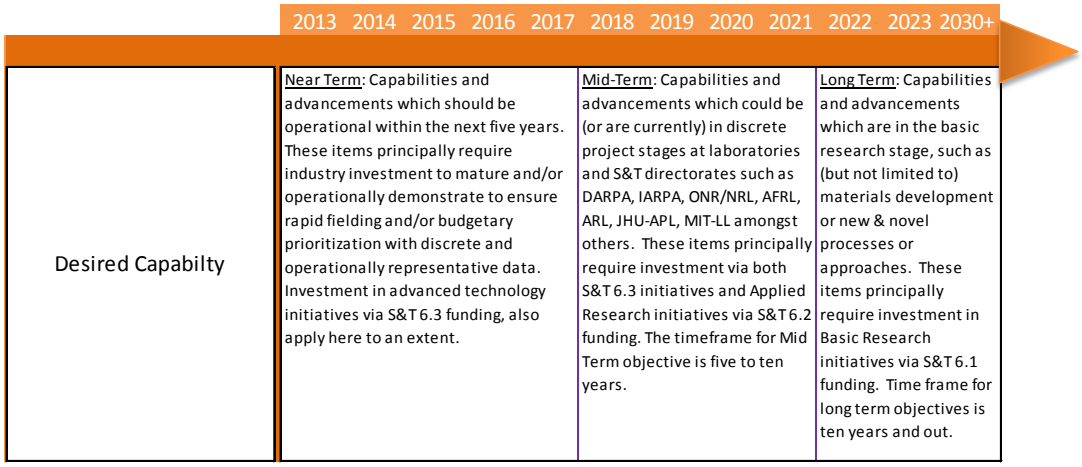


Figure 11. Near-, Middle-, and Long-Term Goals

The six areas of technology key for DoD to enhance capability and reduce cost are interoperability and modularity; communication systems, spectrum, and resilience; security (research and intelligence/technology protection (RITP)); persistent resilience; autonomy and cognitive behavior; and weaponry. Other important areas include sensor air drop, weather sensing, and high-performance computing (HPC).

4.1.1 Interoperability and Modularity

Sensor and weapon technology is rapidly maturing, as is processing and algorithm development, often outpacing DoD's ability to transition upgraded capability and material improvements to fielded platforms. The current myriad of sensors, communications, and weapons systems is continually evolving due to leveraged commercial processes and electronic standards technology. Coupled with DoD's major systems inventory designed to last several years, technology refresh presents both an intra-platform challenge (modularity) and an inter-platform challenge (interoperability). Interoperable interfaces for enhanced modularity and cross-domain data sharing present an opportunity to minimize future lifecycle costs, reduced force structure requirements, and adapt rapidly to changing threats or new available technologies. See 4.2 for more details.

4.1.2 Communication Systems, Spectrum, and Resilience

The challenges that all unmanned systems face include the availability of communication links, the amount of data that the communication links support, certification of the communication spectrum, and the resilience of all radio frequency (RF) subsystems against interference (e.g., electromagnetic). See 4.3 for more details.

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4.1.3 Security: Research and Intelligence/Technology Protection (RITP)

Unmanned systems are often employed with critical program information and sensitive, classified data to complete the assigned mission and, therefore, require RITP. Unmanned systems must include appropriate security measures not only to prevent unauthorized access/control, unauthorized or unintentional disclosure of data, and preservation of technological superiority, but also to enable more rapid adaptation of new sensors, weapons, and processing software. See 4.4 for more details.

4.1.4 Persistent Resilience

While unmanned systems are inherently more persistent based on significantly better fuel/weight ratios, unmanned systems' design schema can be better optimized to provide overall, more effective on-station time. Additionally, further miniaturization of avionics, power and propulsion, and stores management enables smaller systems, which, when combined with more persistence, can minimize investment. Increased persistence calls for improvements in reliability, maintainability, and survivability. Therefore, while further size, weight, power, and cooling (SWaP-C) improvements are hallmarks of all systems, including unmanned, they must be accomplished while enhancing reliability, maintainability, and survivability to ensure broad-spectrum warfighting effectiveness. See 4.5 for more details.

4.1.5 Autonomy and Cognitive Behavior

Nearly all unmanned systems require active control of basic vehicle operations and behavior that affects communications, manpower, and system effectiveness. One of the largest cost drivers in the budget of DoD is manpower. A significant amount of that manpower, when it comes to operations, is spent directing unmanned systems during mission performance, data collection and analysis, and planning and replanning. Therefore, of utmost importance for DoD is increased system, sensor, and analytical automation that can not only capture significant information and events, but can also develop, record, playback, project, and parse out those data and then actually deliver "actionable" intelligence instead of just raw information. As with other facets of unmanned systems, the need for greater autonomy is subject to fiscal pressures, i.e., operating within budget constraints while reducing manpower needs and U.S. exposure to dangerous risks and increasing operational effectiveness. See 4.6 for more details.

4.1.6 Weaponry

Expanding options for weapons delivery from unmanned systems includes new munition options where some capability is now integrated and adding additional weaponized platforms to the unmanned force structure. To fully integrate the use of weapons and unmanned systems, it will be critical to leverage the key technology areas in the preceding paragraphs (4.1.1 to 4.1.5) as well as in specific, weapons-related areas. See 4.7 for more details.

4.1.7 Sensor Air Drop

Unattended sensors were used extensively during the Vietnam War and were influential in reducing the rate of arrival of personnel and equipment into the south. Emplacement of multiple types of unattended ground sensors can provide indications and warning, communications relay, weather reports, activity identification, high-value individual/target

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detections, kinetic weapon cueing, and near-real-time alarms and can support predictive movements via array lay-downs. Using UMS for placing sensors provides a method for increasing persistence and determining/identifying activity and targets without dedicating personnel or multiple high-demand sorties to provide both area and/or point coverage.

Many unmanned platforms are already equipped to externally carry equipment, and all have mission plans that provide their controlled, overwatch and/or autonomous covert movement. Unattended ground sensor technologies are increasing and are able to collect and report unique information and to use coordinates-seeking location capabilities for accurate covert emplacements. The unmanned family of vehicles typically has complementary sensors that can provide exact emplacement location along with imagery information and that can support mission planning and route following. However, the need to improve persistence and situational awareness continues to increase beyond the expected numbers and capabilities of unmanned assets. In the future, UAS platforms and profiles may be ideal for penetrating denied battlespace to accurately dispense sensors and nonkinetic capabilities, etc. Future capabilities may also include deploying "attach bots" that would allow tracking/identification of personnel who pass through an area.

4.1.8 Weather Sensing

UAS platforms fly throughout areas of operations on a near-all-weather 24/7 basis at multiple altitudes. These missions require accurate and timely weather forecasts to improve sensors planning and data collection in support of the CCDR and to avoid potential weather-related accidents. Accurate weather reporting also supports complementary ground and flight planning synchronization. Future weather reporting will be ingested in near real time in the DCGS weather application and CONUS weather central and will be correlated with other weather information to improve accurate predictions for the tactical commander. Weather sensing information will be automatically formatted and reported via multiplexing on the platform's data link with automated routing to the DCGS and other appropriate weather prediction and reporting positions. As UAS endurance dramatically increases, weather predictions will be more imperative to ensure launch, recovery, and ranging limitations are accurate so that potential weather-related incidents can be avoided and coordinated flight and ground operations can be improved.

4.1.9 High-Performance Computing (HPC)

Very high capacity and high-definition sensors are causing bandwidth issues. Each sensor and communications have independent components to process disparate information. This individualism creates a wide breadth of nonstandard airframe kits, component interfaces, and SWaP-C configurations. Future technologies will provide the capability for a standard HPC (family) for most unmanned systems. HPC allows a common hardware-defined architecture to correspond with a common software-defined architecture to form a consolidated plug-and-play standard performance and applications architecture that would host the processing in one miniaturized chassis. The common architecture would be available to UAS vendors for compliance to make integration less costly. Using a member of the HPC family and/or use of a common hardware would also support technology insertions as one of several possible component interchanges within processor boards, memory, or other electronics. It would also further enable improved software downloads. HPC can be applied in multiple subsystems within

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unmanned systems to address challenges in cloud computing and multilayer security, communications, open standards, data storage, cost, ease of technology insertion, SWaP-C, etc.

4.2 Interoperability and Modularity

4.2.1 Background

Warfare has become increasingly complex, and U.S. military operations often require cost-effective integration of disparate assets from across the Services and other joint, interagency, intergovernmental, and multinational (JIIM) partners. Furthermore, unmanned systems are playing an increasingly vital role in these operations. For this reason, it is imperative for DoD, in cooperation with JIIM partners, to not just develop standard information exchange requirements (IERs), but also to stabilize them. Stable IERs that address joint and Service needs, interoperability profiles (IOPs), middleware (which can translate multiple system inputs and outputs), and other areas are needed to reach the necessary level of interoperability across manned and unmanned systems.

It is DoD policy[40] (based on federal laws) that IT and NSS employed by DoD components shall, where required, be interoperable with existing and planned systems and equipment of joint, combined, and coalition forces, other U.S. Government departments and agencies, and nongovernmental organizations, as appropriate. DoDD 5000.01 requires that "Systems, units, and forces shall be able to provide and accept data, information, materiel, and services to and from other systems, units, and forces and shall effectively interoperate with other U.S. Forces and coalition partners."[41] CJCSI 6212.01F requires DoD components to develop, acquire, test, deploy, and maintain ITs that are interoperable and supportable with existing, developing, and proposed (pre-Milestone A) ITs through architecture, standards, defined interfaces, modular design, and reuse of existing IT solutions and are interoperable with host nation, multinational coalition, and federal, state, local, and tribal agency partners.

DoD unmanned systems have historically been developed for Service-specific needs driven by the rapid fielding timelines in support of immediate operational requirements. While fielding these systems rapidly has been valuable, fully stable IERs have often been, of necessity, sacrificed to battlefield urgency, and fielded systems can generally demonstrate only limited interoperability with other manned and unmanned platforms across Services. As more and more unmanned systems are fielded, open architectures (OAs), nonproprietary interfaces, government-owned data rights, and standard IOPs will be required to further enable a broader net-centric environment that is truly interoperable, open, and scalable.

As a result, DoD is adopting and exploiting open system design principles and architectures to increase competition, foster reuse across systems, and increase interoperability. This new acquisition model requires access to multivendor solutions to enable rapid insertion of new technologies to counter emerging threats, avoid technology obsolescence, and decrease time to field new capabilities. For example, DoD is adopting an open business model to support the implementation of an OA for UAS ground control stations (GCSs) to drive greater acquisition

[40] CJCSI 6212.01F, Net Ready Key Performance Parameter (NR KPP), 21 March 2012.
[41] DoDD 5000.01, The Defense Acquisition System, 12 May 2003.

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efficiencies and reduce the total ownership costs. This effort will also include application of a common UAS Control Segment (UCS) architecture as described in 4.2.4.3.

4.2.2 Interoperability Functional Description

The USD's vision for interoperability spans the JIIM domains. Successful definition and implementation of proper interoperability will enable the warfighter to add capability, encourage innovation, and support program cost control.

> ***The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to make use of the services, units, or forces; and to use the services so exchanged to enable them to operate effectively together. An example for the use of this policy would be the condition achieved among communications-electronics systems or items of communications electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users.***[42]

Interoperability is integral to the continued success of missions using unmanned systems and represents a long-term objective of the Services and their stakeholders. The urgent needs in theater and corresponding rapid acquisition approach during recent years have resulted in the current fleet of unmanned systems that generally do not interoperate with each other or with external systems. The combat development community is calling for interoperability as a critical element to the future unmanned systems fleet. The ability for manned and unmanned systems to share information will increase combat capability, enhance situational awareness, and improve flexibility of resources. Interoperability will improve the ability for unmanned systems to operate in synergy in the execution of assigned tasks.[43] Properly stabilized, implemented, and maintained, interoperability can serve as a force multiplier, improve warfighter capabilities, decrease integration timelines, simplify logistics, and reduce total ownership costs.

New rules in acquisition establish the requirement to acquire systems and families of systems (FoSs) that are interoperable.[44] Once mature and stable IERs and other key interoperability areas are defined in support of this overall objective, DoD's unmanned systems must demonstrate interoperability in a number of realms that will challenge current systems:

- Among different systems of the same domain, i.e., using a common GCS or OCU for multiple, heterogeneous unmanned vehicles.
- Among systems of different domains, i.e., allowing ground, aircraft, and maritime vehicles to work cooperatively.
- Among systems operated by different military departments under various CONOPS and tactics, techniques, and procedures (TTPs), i.e., allowing joint Service systems to work in concert to execute a common task or mission.

[42] Unmanned Interoperability Initiative (UI2) Capability Based Assessment, 1 March 2012.
[43] JP 1-02, Department of Defense Dictionary of Military and Associated Terms, 12 April 2001 (as amended through 17 March 2009).
[44] DoDD 5000.1, Enclosure 1, paragraph E1.10.

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- Among systems operated and employed by coalition and allied militaries under the governance of various Concepts of Employment (CONEMPs) and TTPs in multinational combined operations or North Atlantic Treaty Organization (NATO) standardization agreements, i.e., allowing coalition and allied systems to work in concert to execute a common task or mission based on predefined roles and responsibilities.
- Among military systems and systems operated by other entities in a common environment, i.e., allowing military UAS to share the NAS and international airspace with commercial airliners and general aviation or allowing military UGS to operate safely in the civilian roadway environment.

4.2.3 Modularity Functional Description

Concurrently, subsystem modularity and interoperability of components are essential to affordable improvements, maintenance and sustainment, and increased capability. As payloads, sensors, software, and computing algorithms and devices are anticipated to evolve much faster than the vehicle platforms, creating interoperable component/subsystem interfaces for enhanced modularity represents an opportunity to minimize future lifecycle costs and adapt rapidly to changing threats or new available technologies. Upgrading existing proprietary components may be both expensive and logistically unfeasible because whole platforms may need to be taken out of service and/or replaced. Such a closed development approach has resulted in a number of unfavorable characteristics that impede applications of technical progress and the adoption of new capabilities. In addition to the interoperability characteristics mentioned in 4.2.2, unmanned systems must be modular so the same or at least similar components can be used in the same or different types of systems, e.g., plug-and-play use of different sensors on unmanned systems (the vehicle and its supporting systems).

4.2.4 DoD Initiatives to Increase Interoperability and Modularity

The following subsections summarize the DoD initiatives that will require technological advances and cooperation among DoD, governmental agencies, and industry. Each initiative is also described in more detail in Appendix C.

4.2.4.1 Unmanned Interoperability Initiative (UI2) Capability Based Assessment (CBA)

This CBA is the culmination of a joint working group (WG) effort to conduct an operational assessment of unmanned systems interoperability task needs, identify and prioritize gaps in the ability to satisfy these needs, and identify potential DOTMLPF-P priorities to mitigate the identified capability gaps. Appendix G of the CBA provides the prioritized listing and description for each of the 29 joint interoperability gaps. Each military department and agency will find aspects of the CBA relevant to its mission responsibilities. The Interoperability Integrated Product Team (I-IPT) under the UAS Task Force will continue to work with the military departments and agencies to close gaps identified within the CBA to ultimately improve capability to the warfighter.

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4.2.4.2 Standards and Governance Efforts

DoD is working to accomplish unmanned systems interoperability by standardizing critical interfaces within the overall UAS architecture by implementing standard IOPs. Since "standards are ever evolving," key enablers in this effort will be to clearly and consistently define the communication protocols, message formats, and implementation methods across these interfaces for new start efforts and system upgrades. In addition, development of middleware that can translate the multiple system inputs and outputs will be a key enabler. This effort will facilitate the mandated acquisition, technology, and logistics lifecycle management efficiencies across current and future unmanned programs.

4.2.4.3 UAS Control Segment (UCS) Architecture

The UCS Architecture is a framework representing the software-intensive capabilities of current and emerging UAS programs in the Army, Navy, and Air Force inventories. The goal is to develop an architecture based on Service-oriented architecture (SOA) principles, which will be adopted by each Service as a common business model for acquiring, integrating, and extending the capabilities of the control systems for UAS.[45]

4.2.4.4 Unmanned Systems Interoperability Profiles (USIPs)

USIPs are the implementation of the mandate by the Deputy Secretary of Defense's "Unmanned Aircraft System (UAS) Memorandum 14667-07" (13 September 2007) to develop standard IOPs linked to JCIDS documents. They help drive the implementation of approved DoD and/or joint interoperability priorities at the Service level and may even require a new Service IOP or revision to an existing IOP.

USIPs also support the CJCSI interoperability requirement by creating specific points of "capability-based interoperability." The purpose of a USIP is to define profiles of standards sufficient to guarantee interoperability in support of a specific mission capability. A USIP may reference DoD standards, Intelligence Community standards, Service-specific IOPs, and commercial standards to achieve capability-based interoperability. All approved USIP standards can be found on the DoD IT Standards and Profile Registry (DISR).

4.2.4.5 Service Interface Control Working Groups (ICWGs)

The intent of a Service-level ICWG is to ensure UAS program/product managers, developers, Services, and end users actively participate in the development and implementation of Service-specific interoperability solutions. This collaborative organization (Government-industry partnerships) serves as the standards recommendation body chartered within each Service to promote interoperability across various product lines.

4.2.4.6 Service IOPs

Historically, unmanned systems have used very deterministic point-to-point interfaces; however, provisions of network-centric warfare require UAS programs to implement common standards in support of a FoS type of architecture. Widely accepted or approved standards are

[45] Source: https://ucsarchitecture.org/.

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often too broadly defined with varying options and inadvertently allow compliance but not necessarily interoperability (e.g., common data link (CDL) standards and Motion Imagery Standards Board (MISB) standards). Interface "standards" vary and allow for diverse implementation strategies and interpretations. To be truly interoperable, a FoS requires the Service-level development of IOPs, and eventually those IOPs must be interoperable with IOPs of the other Services.

4.2.4.7 DoD CIO Interoperability Steering Group

Due to the SECDEF's efficiency initiatives, the DoD CIO and Director for Force Structure, Resources, and Assessment of the Joint Staff (J-8) formally agreed to transfer all Interoperability Certification Panel (ICP) responsibilities to the DoD CIO in a memorandum of understanding (MOU) dated 26 August 2011. The DoD CIO subsequently renamed the ICP to the Interoperability Steering Group. The DoD CIO will designate the chairperson of the Interoperability WG and direct its associated activities to review interoperability policy, program, testing, and certification matters in coordination with the Defense Information Systems Agency (DISA) and Joint Interoperability Test Command (JITC).

4.2.4.8 Joint Interoperability Test Command (JITC)

JITC is an organizational element of the DISA Test & Evaluation Directorate and has responsibility (per DoDI 4630) for certifying joint and combined interoperability of all DoD IT and NSS. It works closely with the Services, Joint Staff, Office of the Secretary of Defense (OSD), and DoD CIO to provide recommendations to the Interoperability Steering Group for waivers, extensions, and ultimately full interoperability certification and compliance status reporting to defense acquisition executives (DAEs) and service acquisition executives (SAEs).

4.2.4.9 Joint Technology Center/Systems Integration Laboratory (JSIL)

JSIL supports the assessment of system integration readiness during the product development process, prior to actual flight testing. JSIL provides for distributed hardware-in-the-loop testing of payloads, air vehicles, ground system components, and joint interfaces using the Multiple Unified Simulation Environment (MUSE) in globally distributed command exercises and experiments. The purpose of JSIL is to provide simulation, integration, and a full range of test support to the joint unmanned systems family.

4.2.4.10 DoD IT Standards and Profile Registry (DISR)

DISR is an online repository of DoD IT and NSS standards and related information, formerly captured in the Joint Technical Architecture (JTA), version 6.0. DISR replaces JTA. All approved USIPs are submitted to DISR. The Navy intends to use the DISR to formalize its approved Service IOPs.[46]

4.2.4.11 Future Airborne Capability Environment (FACE)

The Army common operating environment (COE) is an approved set of computing technologies and standards that enable secure and interoperable applications to be rapidly

[46] Source: https://gtg.csd.disa.mil/uam/homepage.html?timestamp= .

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developed and executed across a variety of computing environments. Within the COE initiative, FACE is Army Aviation's implementation. The objective of FACE is to establish a standard COE to support portable, capability-based applications across DoD avionics systems.

4.2.4.12 Sensor/Platform Interface & Engineering Standardization (SPIES) Initiative

The goal of the SPIES initiative is to develop electro-optical/infrared (EO/IR) sensor-platform interface standards that reduce acquisition, integration, and lifecycle costs; improve agility; promote OA and interoperability objectives via Navy/DoD standardization; and maintain system performance, reliability, maintenance, and availability.

4.2.4.13 IOPs Defined for UGS

As payloads, sensors, software, and computing devices are anticipated to evolve much faster than base platforms, creating interoperable interfaces for enhanced modularity represents an opportunity to minimize future lifecycle costs and adapt rapidly to changing threats or new available technologies. The Robotic Systems Joint Project Office (RS-JPO) I-IPT, formed in 2009, is working to establish, adopt, and apply interoperability standards for UGS by working with the combat developers, the S&T community, and private industry. The effort is focused around utilization of the Society of Automotive Engineers (SAE) AS-4 standard for Joint Architecture for Unmanned Systems (JAUS) with implementation guidance defined by the UGS IOPs.

4.2.4.14 Advanced Explosive Ordnance Disposal Robotic Systems (AEODRS) Common Architecture

Currently, fielded EOD robotic systems are modified commercial products with different OCUs, limited autonomy, different architectures and designs, and company proprietary software. AEODRS is being executed by the Naval Explosive Ordnance Disposal Technology Division via the Navy Program Office for Explosive Ordnance Disposal (PMS 408) to provide joint forces with an improved and modular EOD capability to respond to unexploded ordnance, counter-improvised explosive devices, and WMD missions. AEODRS comprises three system variants, utilizing Government-owned common system architecture and interfaces, which will be fielded in an incremental approach. The common architecture is present at the physical, electrical, and logical interface levels for the UGS FoS to enable modular plug-and-play components and interoperability.

4.2.4.15 Test & Evaluation – Architecture and Bench Testing

The AEODRS program utilizes an architecture test bed and simulation environment to verify logical interfaces that are defined by architecture definition documents and interface control documents. Capability module evaluation is accomplished by utilizing a test bed to verify compliance with AEODRS common architecture. Each capability module is plugged into the test bed separately to ensure individual capability modules adhere to architecture and performance requirements.

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4.2.4.16 GEOINT Functional Manager Seal of Approval (GFMSA)

The Director of the National Geospatial-Intelligence Agency (NGA), serving in the dual roles of the DoD Geospatial Intelligence (GEOINT) Manager and the Intelligence Community GEOINT Functional Manager, has established a GEOINT Functional Manager Seal of Approval (GFMSA) endorsement process. The GFMSA is recognition that an IT component has been tested and/or evaluated by a credible independent party and has been found to meet the standards conformance and interoperability qualification criteria set by the National System for Geospatial-Intelligence (NSG) community. GFMSA addresses NGA's responsibility to develop interoperability test and evaluation (T&E) criteria, measures, and requirements related to GEOINT per CJCSI 6212.01F. GFMSA increases visibility of GEOINT test criteria, measures, and requirements by offering recognition for entities that follow existing statutory and regulatory T&E processes while giving due diligence to GEOINT.

The GFMSA objective is to promote a standards-based interoperable working environment throughout the NSG enterprise. The GFMSA process enables program and project managers to confirm that the required GEOINT capability is delivered. One of the greatest challenges for a program/project manager is to extend high-level capability requirements sufficiently into manageable functional, operational, and technical components to accommodate acquisition development. The key questions are 1) "What do I want to have happen as a result of my program activities?" and 2) "How will I know it when it happens?" For the GEOINT functional aspect of a program/project, the GFMSA recognition program adds significant fidelity to answer these questions and minimizes the research needed to understand the application of GEOINT standards and the interoperability objectives and operational capabilities that must be realized across the NSG enterprise.

A group within NGA, the NSG Interoperability Action Team (NIAT), is an assistance and outreach body composed of subject matter experts in the field of GEOINT (and associated metadata) standardization and architecture deployment. The GFMSA is tightly connected with the NIAT functions to promote GEOINT interoperability across the NSG enterprise. The NIAT aids program offices with expertise in the area of GEOINT implementations for a given sensor/platform pairing in support of the system's capability. The NIAT supports acquisition category (ACAT) programs throughout the requirements and acquisition processes, joint capability technology demonstrations, and quick reaction capabilities. GFMSA ensures the adequacy of those implementations within the system in support of its data and metadata interoperability across the enterprise. This effort also encompasses the appropriate provisions of the standards needed to meet regulatory, architectural, operational, and functional requirements for integration of GEOINT functions and capabilities across the NSG enterprise.

4.2.5 Interoperability and Modularity Key Technologies

IER performance today is driven by a number of factors, including proprietary interfaces, data, bandwidths, communication waveforms, frequencies and settings, the type of data being shared (e.g., imagery, detections, voice), and the metadata tagging required (which varies widely depending primarily on end users, their processing needs/capabilities, and types of data). The ability of platforms to share data among a variety of users depends primarily on the characteristics described above, and in most instances, system engineering tradeoffs must be

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made in each of those characteristics so that a system's development, production, maintenance, and performance are optimized.

Two primary challenges related to improving and maintaining IER performance go hand in hand: 1) the ability to modify platforms for different IERs rapidly while avoiding broken IERs and safety degradation (particularly airborne platforms) and 2) the ability to rapidly modify platforms for different sensor capabilities while concurrently ensuring new sensing capabilities are distributed via the appropriate IERs.

Attempting to keep pace with these evolving needs with "core" platform systems is likely unattainable; however, maturation of a few key technologies could address these evolving needs while minimizing platform impact:

- ***Middleware.*** The ability to easily adjust data tagging and formatting to keep pace with evolving analytical and processing needs. If "raw" sensor data can be retagged or formatted without affecting core platform sensors or computers, IER performance could be more easily maintained while realizing the benefits of technology advances and minimizing platform impacts.
- ***Multiformat discovery and processing.*** The ability to ingest and process different data types simultaneously. This key enabler for continued performance can minimize platform impact. If data formats, tags, and content are known for fielded systems and if processing and analytical algorithms and computing can interact with different data formats and types at the same time, then analyst workload can be reduced in discovery and reallocated to analysis while platforms can more synergistically update their products via middleware and in concert with other improvements possibly driven by obsolescence issues or related emerging performance needs.
- ***Federated mission computing.*** The ability to plug and play payloads while needing only to address SWaP-C constraints. Adding new payloads to older platforms, which do not rely on centralized mission computers, is typically much easier to do than adding new payloads to newer platforms with their centralized computing. The move about 20 years ago to centralized mission computing meant that while payloads could physically be added, the cost and time to recertify the mission computing made those modifications more lengthy and difficult. Either changing mission computing philosophy or federating mission computing down to the payload (or possibly GCS) level could greatly improve rapid integration of new technologies.
- ***Universal payload adapters.*** The ability to install and uninstall different payloads given a platform's allocated SWaP-C. When combined with federated mission computing and defined platform SWaP-C, a standard hardware and interface installation point is critical to rapidly reconfiguring platforms for emerging needs. Today, platform weapons stations are typically used for this function because their SWaP-C and data interfaces are defined and controlled by the weapons that must be carried. A similar approach for sensing payloads would be a key enabler.

4.2.6 Summary

While the initiatives summarized in 4.2.4.1 to 4.2.4.16 are by no means all inclusive, they serve to illustrate the vast amount and diversity of effort and attention being given to

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interoperability and modularity concerns and the pursuit of mature and stable IERs. The battle lines in the maneuver space of the battlefield are blurring, and the need to share information, sensors, payloads, and platforms is real. The fiscal battlespace is also blurring, and vendors must shift strategies to adhere to open standards to the maximum extent practical by utilizing tools such as universal payload adapters, different mission computing philosophy, and key open subsystems (KOSS); developing middleware solutions to manage the input and output from legacy systems and manned systems; migrating toward OAs; reusing software; and developing robust repositories. As unmanned systems are relied on more and more heavily, their ability to communicate data with Service and joint systems along with their ability to adapt internally and externally will be critical to maintaining warfighting effectiveness against emerging threats while taking advantage of more capable technology. Figure 12 summarizes the goals for interoperability and modularity for unmanned systems.

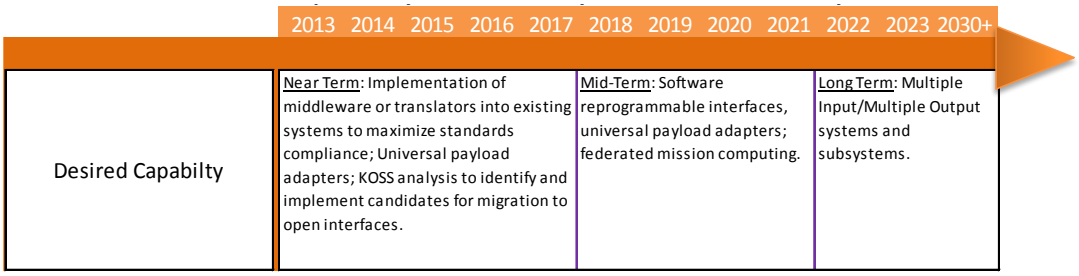


Figure 12. Interoperability and Modularity Goals for Unmanned Systems

4.3 Communication Systems, Spectrum, and Resilience

4.3.1 Introduction

Key challenges all unmanned systems (other than pure autonomous systems) face are the availability of communication links, the amount of data that the communication links support, the assignment of spectrum allocations, and the resilience of all RF subsystems against interference (e.g., electromagnetic). There is a continued need for the Services and agencies to match and improve interoperability requirements to meet mission needs for CCDRs. DoD unmanned systems need a process for operational control and mission data distribution, especially for nonautonomous systems. For some UGS and UMS, these types of information exchanges can use a cable for the transmission path, but for highly mobile unmanned operations, the exchange is more likely to use signals sent across the electromagnetic spectrum (EMS) or by other means (e.g., acoustical or optical).

Figure 13 illustrates the communication network operational architecture (OV-1) required to support unmanned systems. Manned systems are included in this architecture to illustrate the need for a common communication support infrastructure between manned and unmanned sensor and other C2 systems — the supporting command, control, communications, and computers (C4) infrastructure should be platform agnostic (manned or unmanned). The operational architecture employs various EMS frequency bands, communication gateways and relay sites, data centers and data dissemination nodes, and terrestrial radio and network services. The communication links within this architecture support the C2 of unmanned platforms and their respective payloads and support the backhaul of information from those payloads to tactical, operational, and strategic consumers. Wherever possible, payload mission data should

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instantly reside on globally accessible data centers that enable users worldwide to find, obtain, and consume real-time and non-real-time ISR and other mission data quickly and easily. Sections 4.3.2 through 4.3.17 address needed and planned developments within the unmanned communication systems architecture and identify applicable standards and system guidance for each area.

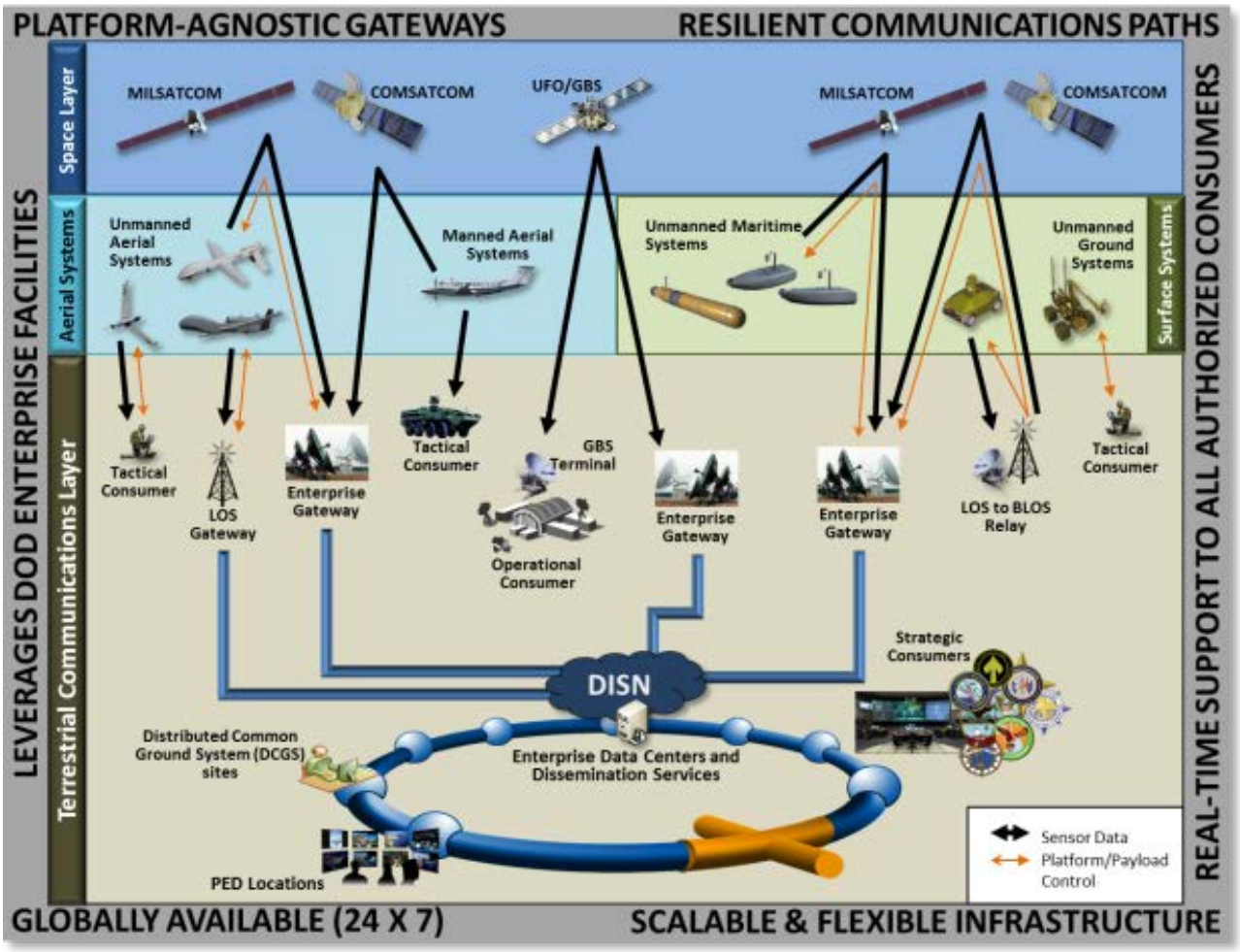


Figure 13. High-Level C4 Infrastructure Operational Concept Graphic (OV-1)

4.3.2 Issues with Current Unmanned Systems Communication Infrastructure

Operational lessons learned, detailed analytical studies, after action reviews, JUONs, and combat mission need statements over the past 10 years of global combat operations have repeatedly shown C4 infrastructure shortfalls in our ability to support unmanned platforms. Specific issues include

- ***Poor Global Connectivity.*** Insufficient ability and capacity to globally distribute high-bandwidth data from unmanned platforms (e.g., full-motion video (FMV)) to strategic, operational, and tactical users. A majority of the current unmanned infrastructure is focused on the Middle East and unable to support operations in other parts of the globe.

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- ***Costly Satellite/Network Contracts.*** Much of our satellite communication bandwidth for each system is procured separately through commercial leases, often at a premium over the traditional DISA commercial satellite communications (SATCOM) portfolio. Many systems also rely on separate platform-centric terrestrial network infrastructures to provide connectivity with tactical, operational, and strategic consumers. Because this connectivity is often provided by leased commercial networks, the overhead cost of each system is further increased.
- ***Stovepipe Infrastructures.*** Many unmanned systems programs established vendor proprietary communication solutions, including gateways for beyond-line-of-site (BLOS) communication and access to terrestrial network infrastructures. This approach prevents the sharing of resources across platforms, significantly increases infrastructure overhead costs (e.g., facilities, program management), and inhibits system interoperability.
- ***Poor Information Sharing.*** Many systems employ dedicated processing, exploitation, and dissemination (PED) and mission data infrastructures that prevent effective data sharing among systems, services, and organizations.

In short, the current unmanned systems communication infrastructure is prone to wasteful redundancy of efforts, lacks interoperability, and inhibits the distribution of system data to potential consumers.

To better understand the best ways of addressing the challenges facing future unmanned systems operations, it is helpful to make several key assumptions:

- ***Programmed Resources Will Be Limited.*** OCO funding has been sustaining most unmanned systems operations in recent years. This funding will disappear in the coming years as troops draw down. Without program resources, the limited leased C4 infrastructure in place today will atrophy.
- ***C4 Infrastructure Demand Is Growing.*** Unmanned systems capacity requirements will grow with improvements in sensor technology and greater global distribution and will require a robust and flexible communication infrastructure, which in turn will require growth in the transport of multiplexed and multilevel classified disparate information. UAS data link capacities are expected to be capable of consolidating several high-bandwidth ingests and be network capable. Advanced airborne routers should be able to sort single-data-link disparate data and route to the appropriate consumer with assured classification transport. Onboard processing should also provide applications to provide appropriate bandwidth, compression, imagery frames per second, and resolutions in accordance with user capabilities.
- ***Operating Environment Will Be Challenged.*** Future unmanned missions are expected to occur in both benign and contested C4 operating environments. The C4 infrastructure must be resilient and able to perform the mission even in hostile electromagnetic and cyber environments.
- ***Open Standards Improve Interoperability.*** Future development of unmanned system platforms and their associated communication infrastructure must be guided by open standards and interfaces to enable interoperability and efficiently utilize limited resources.

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- ***Enterprise Capabilities Improve Efficiency.*** Establishing a sensor-agnostic communication infrastructure that is shared by multiple unmanned programs will provide cost reductions and improve information sharing and interoperability.

4.3.3 Communication Gateways and Relay Sites

DoD and commercial gateways provide access to military and nonmilitary satellites and to the Defense Information Systems Network (DISN) transport and Internet Protocol (IP) net-centric services, which in turn provide global distribution of mission data and enable long-range C2 of unmanned systems. Likewise, relay sites connect line-of-sight (LOS) communications with BLOS radio systems for mission data and C2 connection to DISN.

Numerous platform-centric and proprietary gateways are provided today to support operations in the Middle East. To reduce long-term expenditures on gateways and to more efficiently and effectively process information from unmanned systems, DoD will transition to platform-agnostic gateways utilizing existing global enterprise SATCOM gateway facilities (e.g., teleport standard tactical entry point (STEP) sites). Existing enterprise gateways can provide common, secure facilities; operators and maintainers; and rack space. They can also provide centralized management of floor space; power; and heating, ventilation, and air conditioning (HVAC). As a result, they can reduce the duplication of efforts among the various unmanned system program offices. Leveraging these Government assets greatly improves the affordability over a communication infrastructure based on dedicated, proprietary gateways currently used for some unmanned systems. Near-term efforts are already underway to establish manned and unmanned ISR connectivity at the Lago Patria Gateway, Italy, and Pope Air Force Base (AFB), North Carolina, STEP sites. These facilities will be configured to support a wide variety of airborne platforms utilizing commercial Ku band SATCOM.

Each gateway site will host multiple IP SATCOM systems including frequency division multiple access (FDMA) (e.g., enhanced bandwidth efficient modem) and multiple frequency time division multiple access (MF-TDMA) (e.g., Joint IP Modem, iDirect, Linkway, Linkstar, and Advantech) modems. The gateways provide intermediate frequency (IF) routing of signals between modems and earth terminals. All IP-enabled modems are connected to the converged IP transport and routing network to provide dynamic routing of IP packets and access to DISN services. Each gateway site will provide cooperative technologies to enable and/or support automated bandwidth leveling, di-plexing and further IP dissemination (routing) of multilevel security information, alternate routing, and recovery and data backup.

SATCOM gateways alone will not satisfy all deployed warfighter requirements for satellite coverage. Certain operating environments will fall outside the coverage area of these gateways and their associated SATCOM assets or may require service from satellites with which the SATCOM gateways are currently unable to communicate. In such scenarios, a dedicated BLOS gateway will still be required to support unmanned systems. DISA is developing cooperative research and development agreements (CRADAs) with industry to look at expanding the SATCOM gateway enterprise to include commercial satellite gateways. DISA's SATCOM gateway vision includes leveraging commercial satellite gateways as black (encrypted) packet entry points into DISN. This capability could provide a lower cost alternative to coverage shortfalls and preclude the need to hire dedicated vendors to establish all new entry facilities, baseband and encryption equipment, and associated terrestrial connectivity to DoD networks. To

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support this CRADA effort, DISA is also exploring improvements in gateway transport technology, in particular, the development of digital IF technology for interfacility transport of a modem IF output. This capability would facilitate connectivity from any modem to any antenna in the world, through the DISN fiber core. Digital IF will enable collapse of modem assets into centralized enterprise sites and transform SATCOM gateways into simplified radio access facilities. Additionally, digital IF would also allow the option of using commercial gateways as radio access facilities to provide black packet transport in areas where DoD SATCOM gateways do not provide sufficient coverage.

Unmanned systems require standard relay system architectures to facilitate connection of LOS systems to potential global consumers. To support operations in Afghanistan, a JUON drove the development of relay systems to support delivery of high-volume sensor traffic. The corresponding C4 infrastructure took more than a year to build and deploy. To provide support for operations outside the Afghanistan area of operation and to ensure this capability is available at the start of a contingency operation, DoD might consider a designated lead agent to manage and develop future relay systems. The lead agent could leverage existing radio systems wherever possible. For example, linking state-of-the-art transceivers used for LOS transmission of FMV and C2 data with two-way Global Broadcast Service (GBS) systems can provide a standard relay component for the unmanned systems architecture.

4.3.4 Enterprise Data Centers and Distribution Nodes

The Intelligence Community and Under Secretary of Defense for Intelligence (USD(I)) are responsible for ensuring that data are accessible, and they have made great strides in increasing accessibility to the warfighter. Ultimately, NGA and NSA are the functional combat support agencies for imagery and signals intelligence and maintain the authority and responsibility for data storage and dissemination. The stovepipe nature inherent in current unmanned systems extends to the data storage, handling, and dissemination functions of these systems. To reduce overhead costs, optimize manpower requirements, and improve data sharing among various services, organizations, and allied partners, unmanned systems data should be consolidated into cloud-enabled enterprise data centers with a standard infrastructure established to distribute the data to all authorized consumers. This approach falls in line with overall federal and DoD mandates to consolidate and reduce data centers and establish a select number of facilities to support all platforms and joint consumers. Recent efforts to accomplish this goal include the Intelligence Community's "big data" cloud computing efforts and DISA's Unified Video Dissemination Service (UVDS) established to support real-time distribution of FMV data to consumers around the globe. See Figure 14.

DISA's UVDS provides DoD-wide FMV consolidation, enterprise-wide FMV situational awareness, metadata transformation and dissemination services, and a robust routing capability for worldwide dissemination of FMV. Installed in DISA's Defense Enterprise Computing Centers, UVDS supports various FMV sources and user communities by providing for the dissemination of black (encrypted) and red (unencrypted) FMV streams via multicast streaming and near-real-time web-based streaming. UVDS implements DoD and industry standards, protocols, and profiles (e.g., SD, HD, H.264, MPEG-2, FLASH) to ensure the greatest level of interoperability among existing systems while taking advantage of existing computing infrastructures associated with DoD's Global Information Grid (GIG) terrestrial connectivity. The robust routing architecture connects CONUS and OCONUS locations and takes advantage

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of DoD gateways for efficient and real-time dissemination of FMV across SATCOM networks (e.g., GBS, Joint IP Modem, and USCENTCOM Digital Video Broadcast with Return Channel via Satellite). UVDS replaces the need for dedicated point-to-point communication circuits supporting Predator and Reaper operations. See Figure 15.

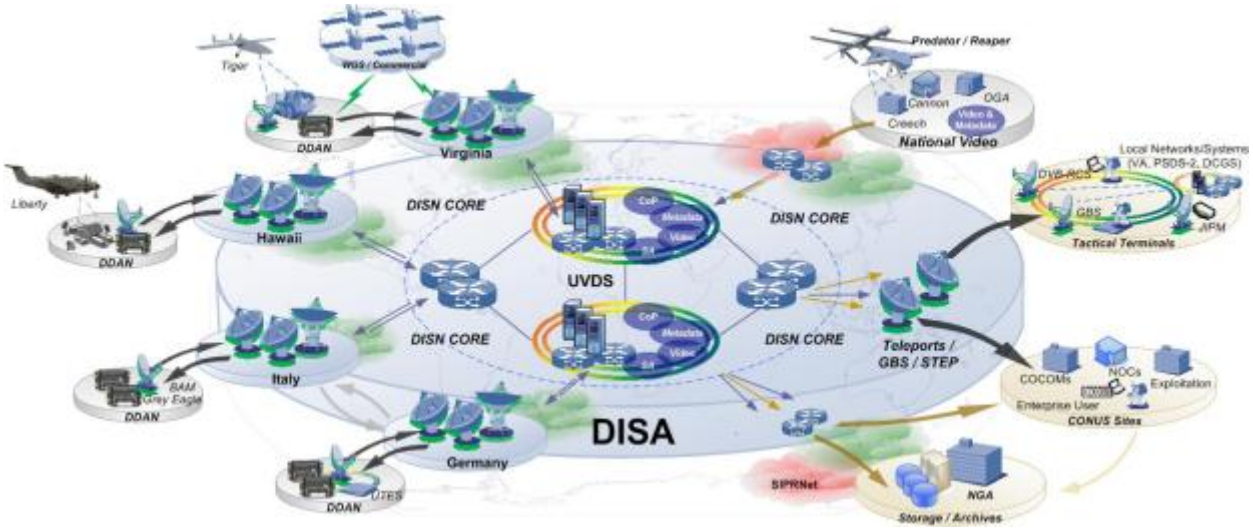


Figure 14. DISA Proposed UVDS Functional Architecture

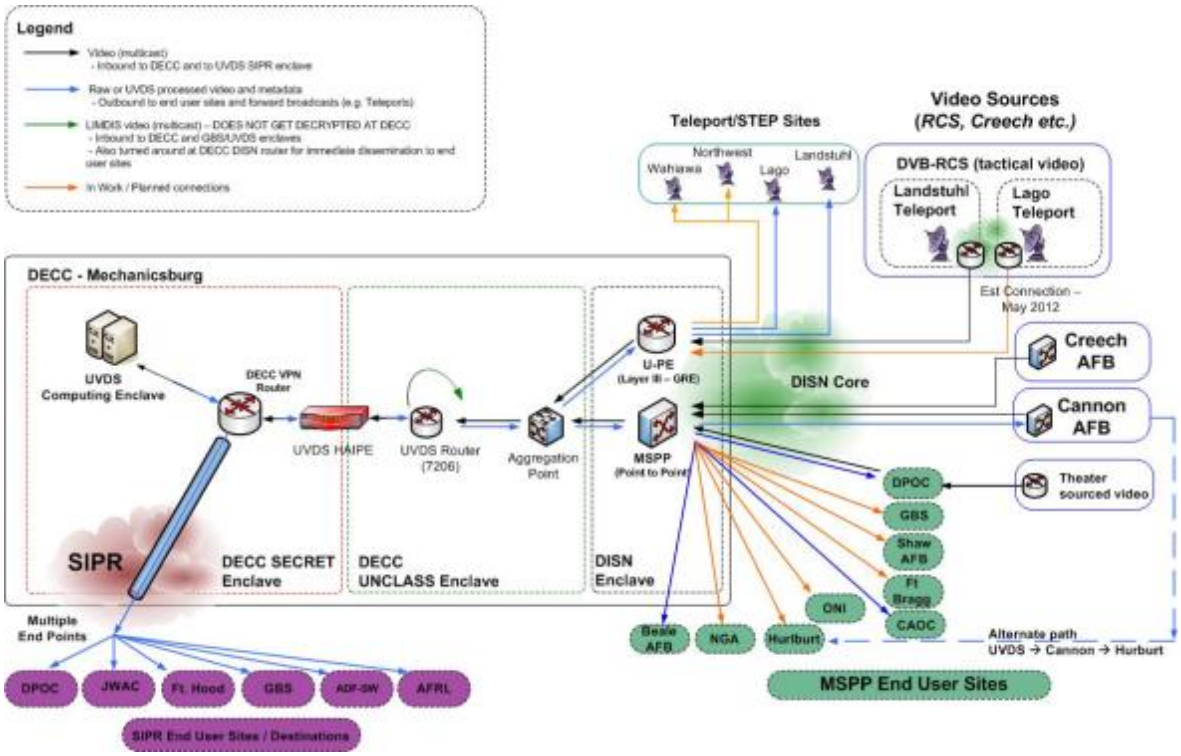


Figure 15. Current UVDS Operational Architecture (February 2012)

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4.3.5 Satellite Communications

A significant cost of current unmanned systems architectures is the procurement of satellite bandwidth through commercial leases. Most bandwidth used in support of deployed unmanned systems missions was procured individually, under unfavorable terms. By aggregating commercial SATCOM leases across multiple unmanned systems, DoD could significantly reduce costs in the future. To do so, future lease arrangements should be investigated through the DISA commercial SATCOM portfolio, utilizing the Future COMSATCOM Services Acquisition (FCSA) contract structure. Additionally, DoD should pursue innovative, alternative contractual opportunities and arrangements with industry that minimize the necessity for annual or multi-year leasing. These approaches allow more competitive pricing and increased buying power for Government customers. Using a common infrastructure, including compatible waveforms, will make possible the sharing of satellite bandwidth and potentially reduce the aggregate demand below the sum of the individual requirements of each system. Furthermore, the FCSA contract structure will provide the flexibility for "surges" in capabilities in response to changing mission environments.

In addition to more efficient commercial leases, the overall cost of satellite bandwidth can be further reduced by leveraging more DoD SATCOM assets. Wideband global satellite (WGS) can be used in conjunction with DoD enterprise gateways to offload unmanned systems data traffic from commercial transponders. However, this strategy is not feasible today due to a lack of installed Ka band terminals on unmanned platforms. All unmanned systems programs requiring BLOS connectivity must develop plans to establish Ka band capability to leverage military SATCOM resources and avoid costly annual commercial leases. Wherever possible, unmanned systems BLOS transceivers should consider support of both commercial and military satellite bands to provide operational flexibility and use available DoD resources.

These benefits should be carefully weighed against the potential operational risks if military units use commercial SATCOM services. UAS programs must consider a strategy and/or provisions to manage the potential risks of using the non-U.S. military SATCOM services. The major components of an implementation strategy should include need, potential operational risks identified in all related operational scenarios, and the optimal balance between cost effectiveness (benefits) and operational risks.

4.3.6 Networking Infrastructure and Systems

Wherever possible, unmanned systems programs should leverage the DISN core as their baseline terrestrial networking infrastructure for global connectivity. Connection points to the DISN core are already available at DoD gateway sites. Additionally, DISA is further developing its DISN core and enterprise wide area network IP service offering to complement the unmanned systems relay solution set.

The IP networking component of enterprise gateways provides routing and encryption/ decryption to multiple security enclaves for access to DISN. Encrypted unmanned systems traffic would be routed through the DoD gateway net-centric convergence router, which provides connectivity between IP modem hubs and DISN. The convergence router is currently connected to both the Layer 3 unclassified provider edge and Layer 2 multiservice provisioning platform and supports multiple traffic types, virtual private network tunnels, and circuit connections.

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Unmanned system design configurations and DISN must ensure that proper IP address and ports and services assignments are planned into the design before the systems are fielded and that the systems' network configurations are modifiable in the field to quickly respond to network intrusion events.

However, unmanned systems design configurations and DISN will need to provide technology that rectifies jitter and latency inherent within an all-IP-based system for the most sensitive type sensors or other critically high reliability mission functions. Buffering issues discovered on legacy unmanned systems can cause loss of sensitive data due to dropped packets if transferring on an all-IP-based environment. In the past, deterministic technologies, such as asynchronous transfer mode, would provide the precise timing and buffer resilient capability to ensure complete data transfers with effectively no jitter or latency. Unmanned systems and DISN will need to develop and provide a similar network that ensures no packets are lost end to end between the most sensitive sensors from the unmanned vehicle, through the respective unmanned controlling segment, to various networking, to end user mission partners.

DISN core connectivity will not be readily available in all potential operating environments. Networking of multiple deployed unmanned systems may be necessary to better ensure connectivity of the systems in non-line-of-sight (NLOS), urban, hostile, and/or noisy EMS environments to relay or transfer the collected information onto GIG. Currently, envisioned network concepts include employing topology control algorithms for sparsely connected directional networks in response to jamming detection; developing cognitive algorithms for jammer detection; utilizing resilient topology control for directional networks, using IP-based, autonomous, self-organizing, nonhomogeneous networks; and providing LOS control to UAS from within an isolated network (i.e., no reach back). In 2012, the Air Force demonstrated a network with UAS and several ground nodes under the Net-T demonstration. Another concept is within the Defense Advanced Research Projects Agency's (DARPA's) LANdroids program,[47] which calls for the deployment of small, inexpensive, smart robotic radio network relay nodes that can leverage their mobility to coordinate and move autonomously. The program seeks to demonstrate the capabilities of self-configuration, self-optimization, self-healing, tethering, and power management. There is interest in the application of SOA approaches to future network configurations and the use of multicast communication technologies to allow semiautonomous and autonomous collaborations.

4.3.7 Antennas

Communication with highly mobile systems requires high-gain, rugged, and lower cost multidirectional antennas. The larger UAS may also use highly focused beams to achieve connectivity with more distant systems.[48] Developments in phased array antennas and "smart" antennas (including combining signals from multiple antennas) could offer an alternative to traditional dish antennas; however, they require tradeoffs among SWaP-C. DoD and industry must also continue developing such techniques as multifocused and supercooled antenna systems.

[47] Source: http://www.darpa.mil/ipto/programs/ld/ld.asp.
[48] Global positioning system (GPS) could be used to aid in this connectivity.

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Future antenna systems must be able to receive signals over a broad range of frequencies, but they also must be frequency selective (see 4.3.13). Therefore, phased arrays are a viable approach. Dynamically controlled (e.g., null jammers) element (~ 9 elements) arrays are available now, but significantly larger numbers of elements that are conformal (e.g., using metamaterial) and that are molded within the vehicle surfaces are in development (2020). SWaP-C and low-profile aspects are major developmental areas. The utilization of common apertures has called for the development of new interference mitigation methodologies that minimize co-site interference effects and improve the potential for achieving simultaneous transmit/receive operations within adjacent frequency bands.

4.3.8 Transmitter/Receiver Systems

Future transmitter/receiver systems require improved interoperability, resiliency, efficiency, and operational flexibility. Wherever possible, future BLOS transceivers should support both commercial Ku band and military Ka band connectivity. Programs such as the Navy's Triton and Army's Gray Eagle efforts are already moving in this direction. Such hardware will allow maximum flexibility across operating environments and improve resiliency of the systems in contested environments. The challenge of using multiband terminals on unmanned sensor platforms is often not caused by technological limitations, but rather by budgetary constraints. Significant upfront cost is involved with upgrading or installing new multiband terminals on unmanned platforms. However, the lifecycle costs of such systems are lower than the lifecycle costs of a Ku band–only platform, which continues to rely on leased, costly commercial SATCOM bandwidth to support operations. Further, all platforms should consider employing multiband LOS transceivers. This strategy will provide an alternate means of connectivity to potentially contested satellite resources, improve link diversity/resiliency, and link to future ground and airborne (e.g., Joint Aerial Layer Network (JALN)) relay nodes. In addition to this broad guidance on transmitter/receiver systems, the following technical recommendations are provided:

- ***Transmitters.*** Current transmitter solid-state power amplifiers (SSPAs) are typically made with gallium arsenide (GaAs) substrate. Gallium nitride (GaN) SSPAs, currently in development, provide significant advantages over GaAs SSPAs. GaN SSPAs offer more than double the efficiency of GaAs amplifiers; they increase the amplifier operational bandwidth; and they may provide for a wider range of frequency of operation. The high transmit efficiency of GaN systems will also reduce the cooling requirements. To achieve some of these benefits, the amplifier designs are being enhanced with adaptive operating point controls that adjust to the instantaneous power being demanded from the amplifier. This enhancement significantly reduces the average prime power required by the transmitter's high-power amplifier (HPA) by allowing it to effectively turn itself off when not in use, yet adjusting to maintain proper conditions to ensure minimal distortion at higher instantaneous powers. The GaN technologies are currently available for selected frequency bands and will soon be available for fielding (2014). The HPAs may also utilize signal-processing-based signal predistortion techniques to compensate for the basic nonlinearity of the amplifier's transfer characteristics. To help in anti-jam and RF interference risks, developments in frequency-hopping characteristics should continue.

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- ***Receivers.*** Instantaneous bandwidth performance and analog-to-digital converter sampling speeds have continued to improve year after year.[49] In addition, improvements in integrated chip fabrication methods have allowed for significant miniaturization and reductions in part counts and for various transmit/receive and antenna functions and components to be integrated on a single chip (2013). These receivers must incorporate higher system selectivity, high spur-free dynamic range (greater than 80 dB to 90 dB from adverse adjacent and off-channel electromagnetic environmental effects (E3)), and resistance to adverse E3. Fiber optics has been used to speed up the data and signal transfers from and to the antenna and the signal processing hardware (2012).[50] Microelectromechanical systems (MEMS) developments should provide smaller size, more flexibility, and greater performance (by a factor of 100 or better) in receiver designs (2015). However, these receivers must be able to operate in the presence of adjacent high-power transmitters that can drastically desensitize their RF front end, and tunable analog preselector filtering (using innovative low-SWAP-C technology) may reduce such desensitization. Future developments are expected to provide improved reliability and fabrication yields, reduced thermal characteristics, reduced integration complexity, and lower production costs.
- ***Transmit/Receive Systems.*** Such systems will emphasize new technologies like spatial, combining, high-power, solid-state amplifiers using monolithic microwave integrated circuits (MMICs). A MMIC (sometimes pronounced "mimic") is a type of integrated circuit device that operates at microwave frequencies (300 MHz to 300 GHz) and typically performs functions such as microwave mixing, power amplification, low-noise amplification, and high-frequency switching. MMICs are smaller and cheaper than conventional integrated circuits.

Recent developments, including software-defined radios, have produced a diversity of technologies, but no formal standards have been developed yet for this technology. Recently, the VITA 49 Radio Transport (VRT) standard[51] has been proposed as a solution to the interoperability dilemma. This standard provides an interoperability framework that can be used for analysis of RF spectrum and localization of RF emissions. The framework is based on a transport protocol to convey time-stamped signal data in IF data packets and metadata in context packets. The protocol abstracts the receiver data from specific hardware implementations and thus enables a common software suite to be developed independent of the receiver architectures, manufacturers, and physical links.

4.3.9 UMS Communications

Ocean dynamics challenge underwater and surface communications and are unique to UUVs and USVs. However, there is a significant difference between UUV and USV communication requirements. An UUV is very autonomous and requires less bandwidth than an USV acting on the surface. Due to collision regulations and safety, the USV must send to a

[49] Lundberg, Kent H., *High-Speed Analog-to-Digital Converter Survey*, MIT Press, 2002.
[50] See the DARPA Optical RF Communications Adjunct and the Office of Naval Research's Enabling Capability programs. This application is more for ground-based systems than for airborne systems. This use also significantly minimizes the signal loss and allows more advantageous placement of selected components.
[51] Reference work by Robert Normoyle, DRS-Signal Solutions.

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watchstander live feedback that requires significant bandwidth. Once autonomy becomes more reliable, perhaps the bandwidth could decrease, but a USV is expected to always have a requirement for higher bandwidth due to its mission types. For example, the USV will be used generally for engagement of surface targets requiring active oversight by an operator/weapons person.

UUVs will gain efficiency and effectiveness with the development of improved real-time, two-way communications that do not undermine mission accomplishment. The Navy's *Undersea Dominance Roadmap* (published in 2012) identified current and future architectures to link UUVs, distributed netted systems, and tactical platforms. The Navy has begun initial production of a planned 150 littoral battlespace sensing UUVs, which are capable of completing up to six-month-long autonomous sensing missions. Advanced UUV sensors and clandestine and low-latency communication and networking capabilities are viewed[52] as key game changers. Future developments will come through the Office of Naval Research S&T research and development efforts.

4.3.10 Spectrum Considerations

The EMS is highly regulated at the national[53] and international[54] levels. Federal Acquisition Regulations and Office of Management and Budget policies require U.S. national spectrum approval before funds are expended on spectrum-dependent systems (SDS). DoD policy and military department regulations require submission of technical parameters to the national spectrum approval process as well as to host nation's approval processes for prior approval before spectrum operations can commence within the United States or other nations. While numerous over-the-air communication systems and active sensors, such as radar, have been designed, built, and fielded so they comply with national and host nation spectrum regulations and technical standards and have performed reasonably well, others have been fielded in a noncompliant status and have often not met final operational constraints.

U.S. military operations are now occurring in many parts of the world where adequate spectrum is not available for C2, sensor, and data link systems. There is a significant increase in the number of SDS the United States, our partners, and our coalition forces deploy to address current, and may want to deploy to address expected future, mission areas. In addition, these SDS collect more information, and missions often require greater bandwidths to send their information directly to warfighters. Also, mission areas are becoming more spectrally "noisy" because of increasingly cluttered and hostile spectrum environments. As such, a continual demand for improved spectrum efficiency and effectiveness is being placed on all DoD SDS.[55] All unmanned systems must complete, during their development process, a spectrum supportability and risk assessment (SSRA) in accordance with DoDI 4650.01. The SSRA is to identify and mitigate regulatory, technical, and operational spectrum supportability. Because

[52] Navy's updated UUV Roadmap.
[53] For the U.S. Government, see the National Telecommunications and Information Administration's *Manual of Regulations and Procedures for Federal Radio Frequency Management*. Washington, DC, January 2008 edition, September 2009 revision (incorporated by reference under 47 CFR 300.1).
[54] International Telecommunication Union (ITU), *Radio Regulations*, Geneva, Switzerland. 2007 Edition.
[55] All new and modified SDS programs now must conduct an SSRA prior to Milestone B (source: DoDI 4650.01).

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national and international spectrum rules and policies can rapidly change,[56] developers should maintain a close liaison with appropriate DoD spectrum offices before finalizing communication system designs.

There is particular interest in expanding DoD UAS operations in nonsegregated portions of the NAS; this expansion may require the use of specific types of spectrum allocations to perform C2 and sense and avoid (SAA) functions due to safety and regularity of flight requirements. The preferred allocations are those set aside for, and carefully controlled by, civil aviation authorities. Where necessary, alternative allocations may be used by Government users provided an equivalent level of protection can be demonstrated. That equivalent level may include higher performance specifications, e.g., those for reliability and data latency.

The teleoperation of UGS from a remote location requires negotiation between LOS and NLOS conditions to provide situational awareness and reconnaissance to the warfighter. Wide frequency bandwidths are needed to support the near-real-time imaging required to negotiate confined areas, doors, etc. The availability of the right spectrum is critical for the operation of UGS to support various missions. This availability is determined by a number of factors, including a host nation's allocation and assignments of spectrum within its borders, congestion, and operational requirements of the SDS. Based on the results of appropriate SSRAs, the SDS may need to be planned and designed for multiband operation and/or provide significant tuning flexibility to maximize global use.

The DARPA's Next Generation project and its follow-on Wireless Network after Next (WNaN) program demonstrated the feasibility of dynamic spectrum access (DSA). DSA offers the ability to change frequency band use based on the actual use or nonuse of certain bands by other adjacent SDS. The Army is also considering having WNaN become part of an Army POR. However, a recent Air Force Scientific Advisory Board study said that DSA is far from being proven technology. Developmental challenges include susceptibility to countermeasures, costs of integrating with existing systems, developing standards (including regulatory aspects), and co-site interference (2015).

4.3.11 Waveforms

In accordance with DoD policy, CDL is the DoD standard waveform for all airborne manned and unmanned platforms with ISR sensors. All ISR wideband terminal variants, including tactical CDL equipment, must comply with Specification 7681990 and the overarching Specification 60038365.[57] Furthermore, wideband terminal variants must comply with the latest revision of Specification 60038368.[58] Legacy ISR programs upgrading communication

[56] Relatively near-term spectrum usage changes came from ITU and its 2012 Worldwide Radiocommunication Conference (WRC); UAS spectrum use was a conference agenda item. Changes in frequency band usage for UAS may also come from the FAA and the International Civil Aeronautics Organization (ICAO) as part of the UAS operations in the NAS airspace and in other nation-states' airspace during preparations for the WRC to be held in 2015.

[57] Specification Number 7681990, Performance Specification for the Standard Common Data Link (Std-CDL) Waveform, November 2009, and Specification Number 60038365, Capstone Specification for the Network-Centric Common Data Link (CAPSTONE), November 2007.

[58] Specification Number 60038368, Performance Specification for the Bandwidth Efficient-Common Data Link (BE-CDL) Waveform, May 2011.

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capabilities must comply with the latest revision of the appropriate CDL specification, and any systems not implementing a current interoperable version of CDL must develop a migration plan for review by the DoD CIO and USD(I). Any waivers from these requirements must be approved by the USD(AT&L).

The CDL family (currently five variations) of waveform specifications permits terminals to operate in S, C, X, Ku, and Ka bands. Other bands are under consideration (see Figure 16), and they are employed in multiple aerial and ground ISR platforms. Current plans call for CDL to evolve from a point-to-point capability. Near-term added capability plans include modernized cryptographic solutions (including agile and dynamic key distribution methods to support mission retasking at the strategic and tactical level), dynamically adaptive waveform parameters and A2/AD requirements [anti-jam, and low probability of intercept/low probability of detection (LPI/LPD)]. Middle-term (2019) plans include new networking capabilities (e.g., self-healing and self-forming, ad-hoc networking, disruption-tolerant networking, and dynamic and multiple-access network management). Long-term (2020+) plans include autonomous policy-based network management and cognitive CDL. CDL waveform changes must comply with DoDI 4630.09.[59]

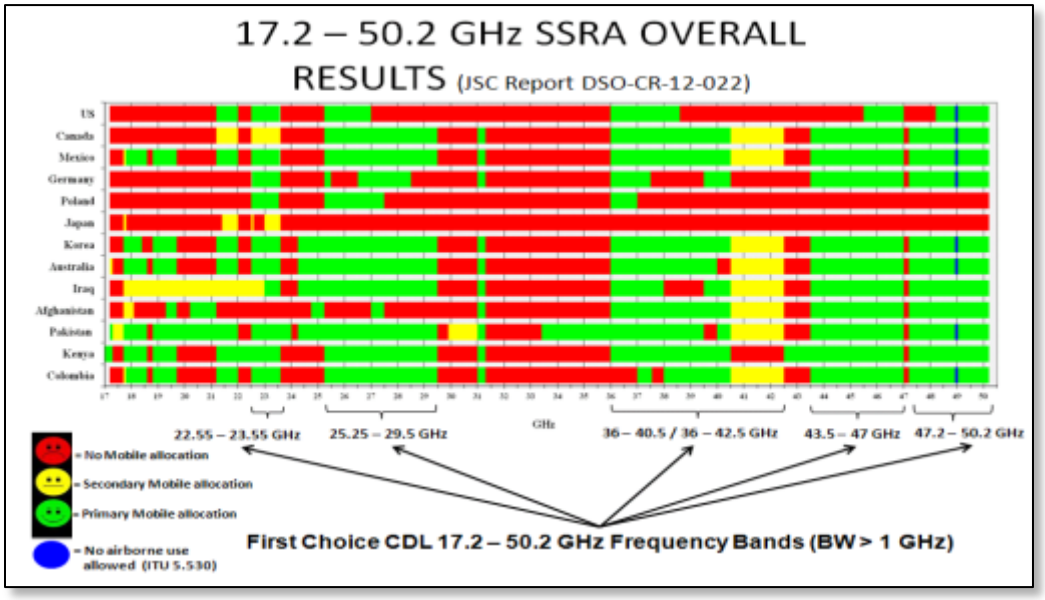


Figure 16. Possibilities of Obtaining Spectrum Support in Various Host Nations for Wider Frequency Range

Due to size, weight, and power considerations, small unmanned aircraft systems (SUAS), which require data link terminals smaller than available miniature CDL technology, may be exempted from this policy after waiver review by the OUSD(AT&L). Moreover, to ensure SUAS transition to achieve DoD net-centric policies and to support efficient spectrum use, incorporation of encryption, and interoperability requirements, the DoD CIO and USD(I) will review and approve any SUAS data link solutions prior to acquisition. The miniature CDL terminal has low enough size, weight, and power that it could be used on vehicles down to

[59] DoDI 4630.09, Wireless Communications Waveform Development and Management, 3 November 2008.

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roughly 30 lb. All CDL terminals require an approved encryption capability (DoDI S-4660.04). Any CDL terminals not compliant with encryption policy require a review by the DoD CIO and USD(I) with support of NSA.

The CDL program will promote interoperability, standardize interface implementations, promote compliance with industry-accepted standards (including USIP and other commercial development/maintenance standards), and maximize use of open standards. Future CDL technologies will promote reuse of waveforms, software, and hardware so that the amount of new development (i.e., items created from scratch) is reduced. The Services are encouraged to use competitive acquisition for procurement of CDL systems, and any new CDL developments shall include unlimited rights for technical data and software.

4.3.12 Multiple-Input, Multiple-Output (MIMO) Systems

MIMO is a proven technology and is currently being used in commercial fourth generation (4G) wireless systems moving at less than 30 knots. It has been tested at data rates up to 300 Mbps.[60] MIMO combines information theory, forward error correction coding, signal processing, and propagation theory; therefore, the mathematics behind MIMO and space-time coding is complicated. MIMO would use multiple paths (although they are not necessarily independent) with lower data rates on each path; apply space-time coding and capacity optimization to achieve a total high data rate mission; apply power saving to jammer margin; and evaluate performance in benign and stress conditions.

With further improvements in electronic discovery, interface design, and adaptive protocols, self-forming and self-healing mesh networks may enable unmanned systems to operate in multiplatform, multisensor networks.

4.3.13 Electromagnetic Environmental Effects (E3)

Electronic systems may be susceptible to damaging E3 that can arise from a variety of natural or manmade (including enemy EW and friendly counter-EW) environmental sources.[61] E3 applications include full vehicle susceptibility analysis; enclosure shielding effectiveness calculation; test rig design, assessment, and normalization to free space environments (e.g., lightning return conductor systems); cable design and shield transfer impedance extraction; prediction of induced currents and voltages in complex cable systems; and performance of electromagnetic interference (EMI) filters, ferrites, or nonlinear transient protection circuits. The DoD E3 handbook[62] describes the tasks that should be accomplished to ensure E3 control and EMC measures are incorporated into the development and operational procedures of an item to achieve the desired level of EMC during its life cycle. The joint E3 control strategy recognizes that electromagnetically interfering and susceptible equipment designs should be eliminated or avoided (via proper budgeting support) during development and in acquisition and proposes use

[60] The conditions in UAS applications are much different than those for commercial cell phones.
[61] These sources may include electromagnetic pulse (EMP), radio frequency interference, high-intensity radiated fields (HIRF), electromagnetic interference (EMI), electrostatic discharge (ESD), lightning strikes, and precipitation static (P-STATIC). Other concerns include the hazards of electromagnetic radiation to personnel, ordnance, and volatile materials (RADHAZ).
[62] MIL-STD-464, MIL-STD 461F, and MIL-HDBK-237B, Guidance for Controlling Electromagnetic Environmental Effects on Platforms, Systems, and Equipment.

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of a positive control methodology called "gating" in conjunction with established "exit criteria" to monitor the planning and application of E3 control measures.

A critical challenge is that while communication needs continue to increase, degradation from interference also tends to increase at a comparable, if not more accelerated, rate. While it is not an easy task to design a highly sensitive radio receiver that also has a wide dynamic range, communication systems transmission advances without comparable E3 resilience advances will not ensure continuous operations of unmanned systems.

4.3.14 Optical Communications

The application of lasers in unmanned systems communications could provide increased target detection capabilities, improved anti-jam performance, robust LPI/LPD, and decreased EMI within the communication subsystem. Optical routers will be more practical when we employ unmanned high-flying vehicles like the Global Hawk, Boeing's Phantom Eye, and the X-37B. Optical communication systems are hampered by atmospheric absorption challenges, yet they offer far greater bandwidth (measured in gigabits per second) capabilities. LOS optical links have successfully been demonstrated at link ranges in excess of 50 km. Applications could apply to fixed locations and in air-to-air and ship-to-ship scenarios. Theoretical estimates indicate that air-to-ground links are feasible at rates up to 100 Mbit/s for link slant ranges up to 100 km, depending on atmospheric conditions. Due to the extreme narrow beamwidth of such systems, maintaining pointing accuracy to and from a moving unmanned system will be a major challenge (>2020). A recently completed DARPA program, Free Space Optical Experimental Network Experiment, employed a hybrid optical/RF communication technology and demonstrated air-to-air (>200 km range; data rates of 3 Gb/sec to 6 Gb/sec) and air-to-ground (>130 km slant range; 3 Gb/sec to 9 Gb/sec) point-to-point communications.

4.3.15 Advanced Navigation Developments

DARPA[63] is working on two advanced navigation strategies that are kinematic (i.e., there is no force rebalance) and should offer significant improvements in effectiveness.

The Precision Inertial Navigation Systems (PINS) program seeks to use ultra-cold atom interferometers as an alternative to GPS updates. Advancements in atomic physics in the past two decades have given scientists much better control over the external quantum states of atoms, including deliberate production of matter waves from ultra-cold atoms. This advancement has allowed development of matter wave interferometry techniques to measure forces acting on matter, including high-precision atomic accelerometers and gyroscopes. Using this technology, this program seeks to develop an inertial navigation system, which should have low unprecedented drift rates yet address many scientific and technical challenges. The program is on schedule to demonstrate a high-precision atom interferometer inertial navigation system on an aircraft during 2013, with a total system volume less than 20 liters. Since this innovation is an entirely inertial system, it will require no transmissions to or from the platform, thus enabling a jam-proof, nonemanating inertial navigation system with near-GPS accuracies for future military submarines, aircraft, and missiles.

[63] The point of contact is Dr. Stefanie Tompkins.

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The program has developed improved gravity gradiometers, accelerometers, and gyroscopes where the atoms are in a nearly perfect inertial frame of reference (no sensor case) and the laser/atomic physics interactions determine the relative motion between the inertial frame and the sensor case. The sensor accuracy derives from the use of optical wave fronts to determine relative motion.

The High Dynamic Range Atom (sensors) (HiDRA) program seeks to develop the compact sensor operation used on dynamic platforms where the inertial measurement unit (IMU) would offer accuracies of a 20 m/h, 10 g, 100 º/s, <4 L sensor, <20 L system. Relative to conventional sensors, it would offer a common technology for accelerometers and gyroscopes, a high sensitivity and linearity for high-g environments, and cost-effective fabrication and maintenance. Relative to PINS II sensors, it would offer use in multiple axes, high-g operation, compact sensor heads, integrated laser system/sensor heads, field-programmable gate array timing system for high repetition rate operations, atom recapture, scattered light suppression for short modulation period, and multipulse beamsplitters (optional).

4.3.16 Improved GPS Operations

The NGA has developed the Estimation and Prediction of Orbits and Clocks to High Accuracy (EPOCHA) real-time software for GPS orbit/clock estimates, which enables the capability for potentially higher accuracy GPS positioning for many platforms. Using the NGA EPOCHA products could provide more current, higher rate information to improve position estimates. The concept has been demonstrated in post-processing, and the results confirm the improved accuracy; decisions regarding incorporating it within existing or future systems have yet to be made. Initial Operational Capability (IOC) for EPOCHA real-time support to military platforms is FY2014 (October 2013), with a 5-minute message update rate. Full Operational Capability (FOC) is scheduled by FY2016 (October 2015), with a 30-second message update rate.

Many UAS conduct Positioning, Navigation, and Timing (PNT) using GPS. Currently, DoD requires Selective Availability Anti-Spoofing Module (SAASM) GPS[64] as SAASM decreases GPS vulnerabilities by offering encrypted GPS data and satellite authentication. In the near future, a military GPS upgrade known as M-code GPS will be made available. M-code GPS is required for all new acquisitions starting in FY2017.[65] The M-code signal provides better jamming resistance and has enhanced features for authentication, confidentiality, and key distribution. Unlike prior systems that may rely on GPS for positioning, M-code GPS can calculate PNT independently using only the M-code signal.

4.3.17 Cost Effectiveness Considerations

DoD's desire is to operate unmanned systems in theaters or within the United States and its possessions so that constraints on communications and active sensor systems do not adversely affect successful mission execution. Specifically, DoD must significantly improve communication transmission efficiencies; attain better bandwidth efficiencies; increase transmitter/receiver efficiencies; acquire communication systems that are of less size and weight,

[64] Relevant SAASM GPS policies include DoD GPS Security Policy, 4 April 2006, and Chairman of the Joint Chiefs of Staff Master Positioning, Navigation and Timing Plan, 13 April 2007.
[65] The M-code GPS mandate is stated in Public Law 111-383, Sec 913.

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require less power, and need less cooling to operate satisfactorily; and acquire higher gain antennas that are able to receive signals over a broader range of frequencies while retaining frequency selectivity. Unmanned systems programs must also leverage existing DoD enterprise facilities wherever possible and avoid building separate platform-centric communication infrastructures. Current and future operational employment of unmanned systems will also require access to a range of SATCOM capabilities. Planning and budgeting for such unmanned systems operations must take into account realistic assessments of projected SATCOM bandwidth (both military and commercial) in a range of operational scenarios. Investments in unmanned systems must be matched with appropriate investments in the military and commercial SATCOM capabilities that are required to support unmanned systems operations.

4.3.18 Future Trends

Based on the force multiplier that unmanned systems have provided to our combat troops, it is expected that there will be a continued and increasing demand for capabilities to be supported by their communication systems. Those demands will include such capabilities as having a single operator conduct more real-time analysis of multiple situations, while the unmanned system performs many of its assigned functions autonomously. Future communication equipment must be simple plug-and-play payloads that are easily, quickly, and cost-effectively modified, updated and/or upgraded, and linked to globally available enterprise capabilities (e.g., gateways, data centers) to ensure rapid discovery and exploitation of mission information from any authorized DoD consumer.

4.3.19 Mobile Technologies

The mobile technologies initiative is pursuing rapid Government off-the-shelf application development; transition to tablets and smartphones for computing platforms; and a 4G cellular infrastructure to disseminate intelligence, data, and voice transmissions. By leveraging the devices developed and supported by commercial industry, significant cost advantages and infrastructure can be used to accomplish missions without requiring taxpayer investment in a large and bureaucratic network or capability.

4.3.20 Summary

Several steps can be taken to solve the challenges faced by the future unmanned systems communication infrastructure. Affordability may be improved by centralizing unmanned systems enterprise management. Centralized management of C4 transport and network infrastructures can greatly improve system availability and efficiently use scarce system resources. Common management of multiple system assets will result in network redundancy, resilience, and path diversity for sensor platforms. It will also allow flexible frequency usage for launch and recovery. Interoperability should be the key factor in considering affordability of future architecture solutions. The architecture should transition away from redundant stovepipe solutions to leveraging existing enterprise SATCOM, gateway, and terrestrial network assets. Common IP modems (e.g., JIPM) should become the standard for providing net-centric system capabilities. Future commercial services should be procured through more innovative strategies (e.g., FSCA leases, point-of-presence access to commercial gateways). Additionally, the pool of communication resources can be deepened by expanding operating spectrum usage to military

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Ka band and leveraging aerial networking capabilities such as JALN, including its GIG injection points.

Open standards and interface definitions are key to mitigating the challenge of interoperability of unmanned systems communication infrastructures. Enforced open standards and Government-owned data rights will promote the leveraging of common components and facilitate reuse among heterogeneous unmanned system platforms. Using Government-owned enterprise assets (e.g., WGS, DoD enterprise gateways, DISN core) will help unify the communication infrastructure.

Figure 17 summarizes the target unmanned systems communication architecture with the proposed solutions in place, and the new infrastructure exhibits greater interoperability among various unmanned system platforms through the use of common control and data dissemination systems. Resiliency is improved through use of multiband terminals and common interfaces, and this improved resiliency allows access to DoD and commercial SATCOM resources as well as to enterprise gateways and small points of presence at commercial radio facilities. The increased utilization of DoD assets in this architecture offsets commercial resource requirements, improves efficiency, and reduces the operating costs.

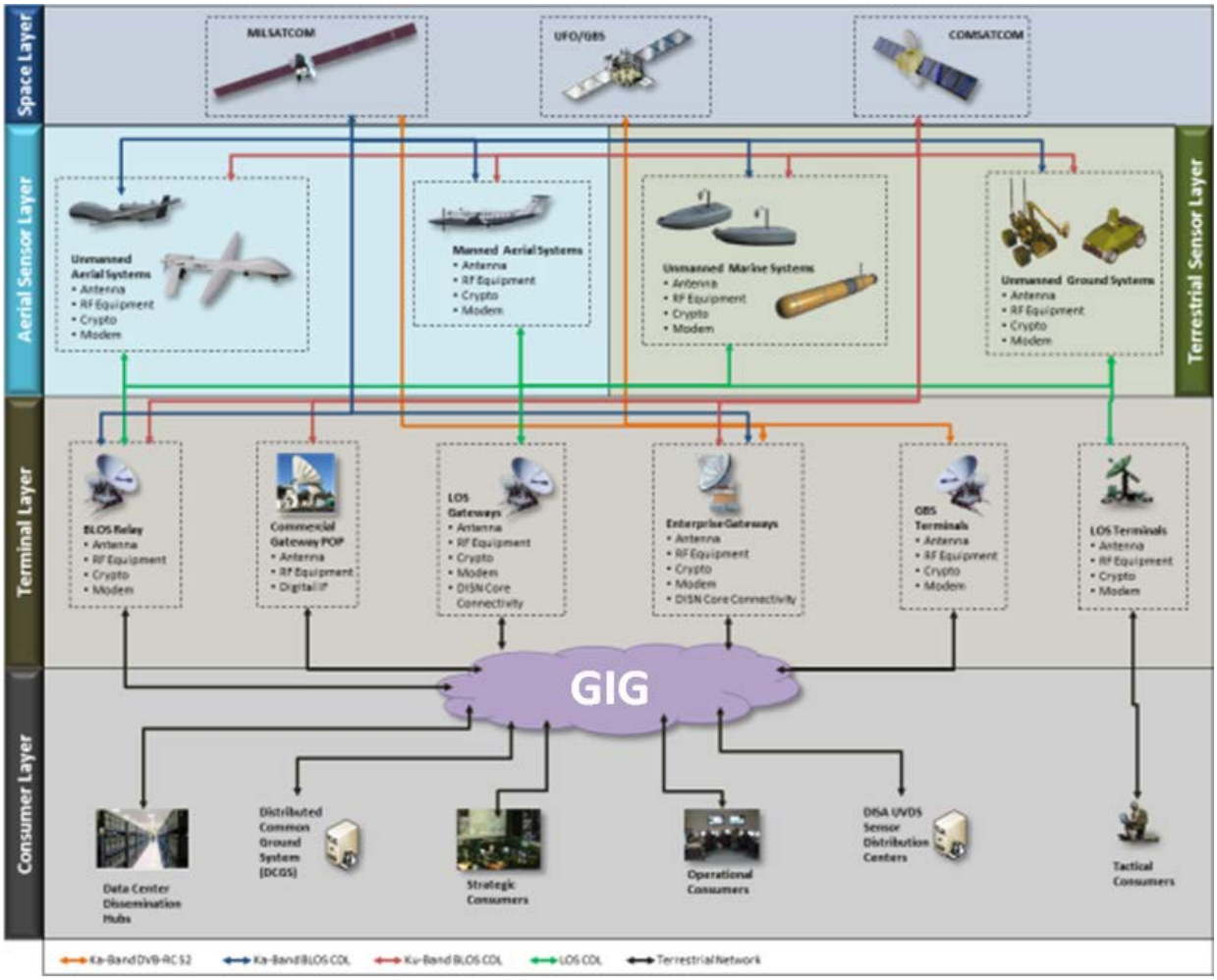


Figure 17. Unmanned Systems Target Architecture

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Figure 18 summarizes the goals for communications systems, spectrum, and resilience for unmanned systems.

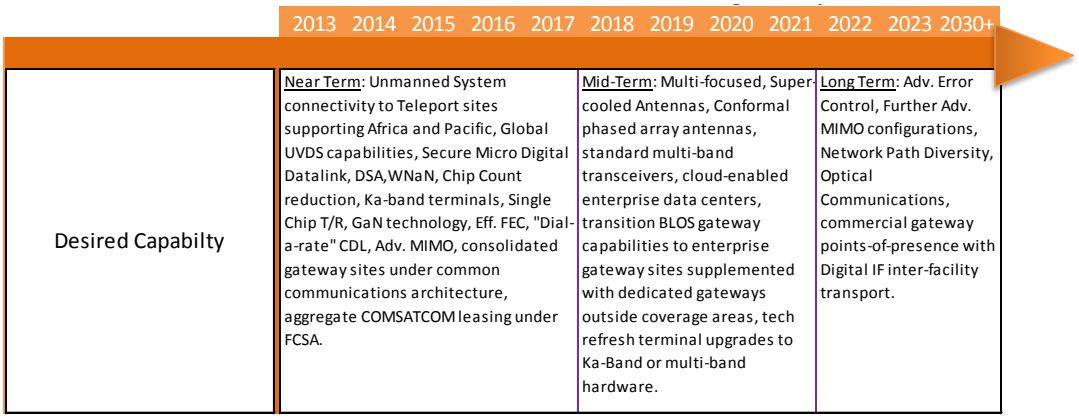


Figure 18. Communication Systems, Spectrum, and Resilience Goals for Unmanned Systems

4.4 Security: Research and Intelligence/Technology Protection (RITP)

While the challenge of incorporating security measures on unmanned systems mirrors that of manned systems, additional C2 requirements are unique to unmanned systems and expand the overall requirement for system security. This section addresses those overall requirements.

The evolution of integrated sensors across multiple systems drives the need for a modified approach to program protection. The emphasis has shifted from protecting system-organic technologies and information to a more comprehensive methodology: a platform-agnostic, sensor-specific approach to address program protection across multiple systems and platforms. This methodology seeks to ensure protection of not only the technology on which the sensors are based, but also the intelligence information collected by these sensors.

RITP includes the layered application of protective principles, techniques, and solutions to prevent compromise of critical information and/or technology to an adversary or otherwise unintended entity. This concept was developed to address the range of security elements required to carry out policies described in DoDI 5200.39.[66] RITP incorporates DoD and Navy directives, instructions, policies, and guidance concerning program protection and/or countermeasures, including anti-tamper. RITP is accomplished through the rigorous evaluation of subsystems to identify critical program information (CPI) and assessment of resulting CPI to determine which elements require additional protective measures. RITP bridges systems security engineering and other overarching security operations to ensure protection of intelligence sensors and products.

System vulnerabilities and threats are examined, as well as risk of exposure and consequence of system compromise, to proactively establish the foundation of security disciplines as early as reasonable in the developmental life cycle. Impact to the program in terms of cost, schedule, and performance is also factored into the determination of appropriate protective measures. When applicable, protective measures selected for implementation are

[66] DoDI 5200.39, Critical Program Information (CPI) within the Department of Defense.

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validated and verified as part of program systems engineering, T&E, and systems security engineering processes. With the integration of emerging technologies with critical information, it is more important than ever to evaluate appropriate layered protective measures through an integrated approach that includes complementary disciplines such as information assurance, operational security, anti-tamper, and counterintelligence and intelligence analysis. Anti-tamper is more cost effective when implemented at program onset.

4.4.1 Data at Rest (DAR) Encryption

To date, no NSA-approved, type 1–certified DAR encryption devices are suitable for U.S. military operational and/or tactical airborne platforms storing data labeled top secret and secret compartmented information (TS/SCI) and below. The manned systems community often relies on an emergency destruct plan to ensure physical destruction of classified media, including DAR stored on hard drives, should an operator believe the classified media are at risk of compromise.

As spinning hard drives are replaced by solid state drives and other media storage devices, the need for other methods of destruction becomes more critical. Other manned platforms face similar data destruction challenges. While NSA-approved data sanitization techniques are available, these techniques are either too time consuming for emergency scenarios or not approved for the sanitization of TS/SCI data. These limitations drive programs to seek other protective measures, including encryption.

For UAS, destruction of data becomes an even more challenging endeavor because aircrews are not available to carry out procedures such as an emergency destruct plan. Unmanned programs must rely on autonomous protective measures. Unmanned platforms are required to have an emergency location transmitter that transmits its GPS location to support rapid recovery and/or for coordinates-seeking NLOS weapon targeting for data/vehicle destruction.

4.4.2 Cost Effectiveness

Since the DAR encryption capability for data labeled TS/SCI and below is extremely limited, several programs have collaborated to devise a solution that can be implemented across systems in the very near term, such as within 24 months. Although some development work is still required, the cost involved with the acquisition, development, and production is relatively minimal when the overall payoff is considered. The end product would cost less than most Type 1–certified network encryptors and would help to ensure that, with a push of a button (or even with an autonomous command), DAR would be rendered unobtainable by the adversary. The overall cost savings in terms of prevention of technology or information/intelligence loss would far exceed the initial development cost.

4.4.3 Near-Term Goals

Representatives from the Navy and Air Force have identified the need to integrate more robust methods for protecting classified DAR. The proposed solution includes the identification of resources for concept development of an NSA-approved Type 1–certified DAR encryptor that will be integrated on airborne (manned and unmanned) platforms and their associated ground support and processing stations. Unmanned systems must have the ability to remotely and

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autonomously render DAR unrecoverable by the adversary through a reliable and immediate encryptor key zeroization process. The proposed solution also allows the DAR to be recovered when appropriate key recovery protocols are executed.

The proposed next-generation DAR encryptor must be installed in a manner that is as transparent to platform subsystem functionality as possible to minimize subsystem redesign requirements. Performance must not be degraded due to encryptor latency. The use of inline media encryptors (versus software-based and/or embedded encryption methods designed into each platform subsystem) may minimize the integration impact on legacy platform subsystems requiring DAR encryption. Inline media encryptors will also allow for flexibility to upgrade to media with greater storage capacity. Mission and ground support and processing CONOPS have proven to be a primary driver for DAR encryptor functional specifications. Key management processes must be conducive to interoperability across systems and GCSs. Multiple encryptor keys may be loaded through a single key fill port. The single encryptor may support multiple inputs and multiple target storage media locations, at multiple classification levels. Technical concepts for a next-generation DAR encryptor have been identified and evaluated for compatibility with the intended CONOPS. Several platforms have provided input for encryptor functionality with a focus on platform-agnostic, sensor-specific integration.

4.4.4 Middle- and Long-Term Goals

Evolving technologies for storage media will drive the need for faster, more specified encryption devices that support data in various states and blur the line between DAR and data in transit. Similarly, storage media requirements will increase, along with the need to move those media at a more efficient speed. As more data are processed and stored off the system, the need for adaptive technologies for data encryption becomes more critical. As these adaptive technologies emerge to support encryption, program protection requirements will also evolve. The complementary approach of integrating layered protective measures will likely yield the most cost-effective and robust means to prevent compromise of the data and/or technologies.

4.4.5 Unified Security Classification Guidance

As sensors are integrated across multiple platforms with similar mission requirements, the need for unified security classification guidance becomes more evident. Systems will integrate sensors from multiple classification levels and comply with guidance from various classification authorities. As conveyed by the Office of the Director of National Intelligence, Associate Director of National Intelligence, and the DoD CIO in the “Intelligence Community Classification Guidance Findings and Recommendations Report”:

> ***A critical component of effective intelligence collaboration and information sharing is a common understanding of information classification standards and policies. Inconsistent interpretation and application of the classification levels defined by Executive Order 12958, as amended, often results in uneven guidance, misunderstanding, and a lack of trust between Intelligence Community agencies and mission partners concerning the proper handling and protection of information. Agency-unique or contradictory classification guidance can slow or prevent information sharing across agency, Government, and partner lines. Therefore, we must***

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create classification guidelines that transcend organizational cultures. True information sharing and intelligence collaboration cannot occur until all participants trust that when they provide information it will be appropriately protected. A capstone Intelligence Community classification guide governing intelligence information is necessary to enable that trust.

4.4.6 Cloud Computing and Multilayer Security

With the progression of unmanned ISR platforms and the resulting surge of data, the need to disseminate this information to a broad area of users in a timely manner becomes painfully evident. On a similar note, as DoD continues to feel budgetary pressure, programs are urged to find ways to more effectively conduct their operations — the Intelligence Community is no exception. There is a tremendous push to consolidate IT systems, eliminate redundancy, and focus on a cloud solution instead of traditional desktop or network architectures. It is not surprising that the Intelligence Community embarks on this endeavor with a great deal of caution.

There is going to be a cultural shift in addition to a technology shift in the way we do business, and in the agencies recognizing that some of their individualities and their equalities are not going to be given up, but they're going to interface with them in a different way.

Cloud computing initiatives are being developed as the Intelligence Community works to transform its use of IT to a model that incorporates shared services and requires less duplicative resources.

Grant Schneider,
Deputy Director, Information Management and CIO, Defense Intelligence Agency

Some of the driving concerns about cloud computing within the Intelligence Community involve confidentiality, integrity, and availability. Stringent requirements are set to prevent unauthorized disclosure of classified data. It is critical to ensure that the implementation of a cloud computing architecture in the Intelligence Community enables the user to distribute and receive information, while maintaining the required level of security controls to protect that information. Integrity of that information must be preserved to ensure that the data are not unintentionally (or maliciously) modified or degraded. Availability to users is a primary concern. The expansive operational (and often mobile) user environment dictates the need for a robust cloud computing capability. The increasing requirement for larger volumes of data presents bandwidth, latency, and storage challenges. As the user base becomes broader and multiple classification domains are introduced, these challenges become even more difficult to manage.

Incorporating a multiple-security-level network (and the associated requirement for data tagging) presents its own inherent challenges: combining these networks into a well-defined, interoperable architecture requires extensive consideration. As agencies move to a centralized architecture, security processes, policies, and standards must be integrated into a unified,

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enforceable structure. This transition is not simple because agencies are already operating under well-established processes and governances. Initiatives are in place to incorporate cloud computing in the Intelligence Community. The residual challenges reside in how the operational platforms will be able to incorporate their mission CONOPS and platform architectures into the cloud to enable more effective information dissemination.

4.5 Persistent Resilience

By working with Service sponsors and their respective laboratories in aligning the S&T portfolios to the warfighters' needs, the Services must take a synergistic approach to provide linkages and insight to upcoming technology initiatives across the unmanned systems portfolio.

To that end, persistent resilience is a key component to all unmanned systems, regardless of whether the system is being used in air, ground, or maritime domains. The Navy is currently developing a Broad Area Maritime Surveillance (BAMS) UAS under the Persistent Maritime Unmanned Aircraft Systems program office (PMA-262). BAMS UAS, now called Triton, is being developed to provide persistent ISR, which to successfully execute will not be possible without the resilient subsystems that make up the overall UAS. In simplistic terms of a system or subsystem, without resilience, persistence is not possible. *Resilience* is the ability for an application, system, or subsystem to react to problems in one of its components and still provide the best possible service. *Persistence* is the continuance of an effect.

The areas where emerging technology enablers should focus for persistent resilience are

- Size, weight, power, and cooling (SWaP-C) (see 4.5.1)
- Reliability, availability, and maintainability (RAM) (see 4.5.2)
- Survivability (see 4.5.3)
- Structures and material degradation (see 4.5.4)
- Propulsion (see 4.5.5)

4.5.1 Size, Weight, Power, and Cooling (SWaP-C)

DoD wants to reduce the size, weight, and power consumption of military platforms, as does the consumer electronics business, because large SWaP-C impedes mobility and raises maneuvering costs. Day-to-day operations may require tradeoffs in available time on task when a payload must be added at the expense of less fuel. If the payload is too large to add into existing internal space, it may have to be added externally. External placement can add drag to a UAS and reduce time on task. Additionally, some program offices are currently being constrained by the power consumption of payloads. These programs must look at upgrading to larger, more powerful generators, which add more weight, take up space, increase heat, and cause cooling concerns.

Miniaturization generally enables smaller systems and, when combined with more persistence, often minimizes investment. Miniaturization also generally reduces weight and power consumption. Therefore, SWaP-C issues can be addressed by focusing on compact sensor operation on dynamic platforms. In development under DARPA's PINS/HiDRA programs is a six-degrees-of-freedom cold atom IMU, which is an example of a miniaturized three-axis gyro-accelerometer currently being developed to address package size, weight, and power

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consumption while still providing precision navigation. Additionally, focus is turning toward modularity of payloads, which allows plug-and-play capabilities in joint and combined architectures. Plug-and-play attachments are capable of rapid integration into existing systems, including joint systems that integrate into an OA in which the interfaces comprise open standards. As DoD envisions cost savings by reducing stovepipe development and shifting toward standardized architectures to further enable interoperability, modularity will also play a key role to ensure interoperability, ease of upgrades to systems, and synergized DOTMLPF-P. Miniaturized systems that allow multirole, multi-mission capabilities will further reduce costs by allowing Services and program offices to leverage modular systems that have already been developed. Ultimately, less continual investment is required when a smaller volume can continually accomplish the same missions. Figure 19 summarizes the goals for SWaP-C for unmanned systems.

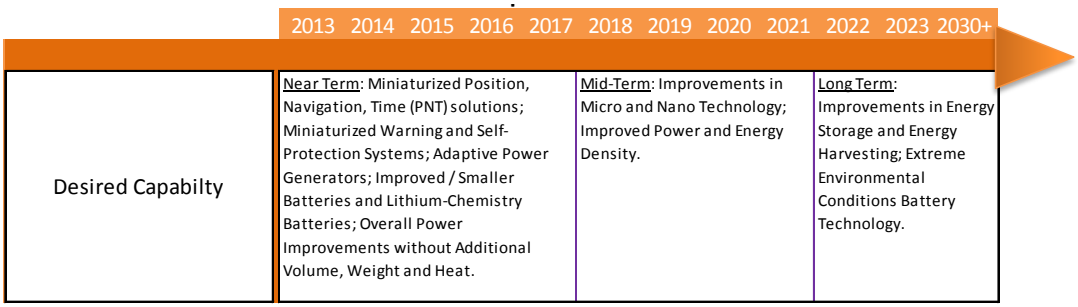


Figure 19. SWaP-C Goals for Unmanned Systems

4.5.2 Reliability, Availability, and Maintainability (RAM)

Reliability and maintainability are critical performance attributes for unmanned systems to accomplish their missions and to achieve required operational availability. With many unmanned systems being required to provide persistent support, such as ISR for periods of 24 to 30 hours (and potentially more in the future) by one vehicle, it is inherent that the systems are reliable with low failure rates. Use of failure rate will be consistent with any reliability parameter such as mean time between failure (MTBF). Systems must meet or exceed mission reliability goals to ensure that unmanned systems can reliably accomplish their missions once they have been deployed. Furthermore, when a system becomes degraded, it must be simple enough to maintain and replace, especially in the austere expeditionary environments with little infrastructure support in which these systems are being operated. These systems must remain simple and supportable by the operators and maintainers in the field. Built-in tests may be sufficient at a weapons-replaceable-assembly (WRA) level, but at a system or subsystem level, the lack of integration causes RAM issues.

The more reliable the systems, the more cost effective they become over the life cycle. As well, the simpler a system is to maintain and repair, the more cost savings it provides. However, one of the largest challenges to maximizing system RAM is the potential impact to development and production cost. Another hurdle to achieving RAM in systems is the continued pursuit of new capabilities, which often consumes program resources at the expense of RAM. To overcome this hurdle, it is important for strong RAM requirements to be developed concurrently with the system CONOPS and capability requirements. Satellite systems are designed to last without repair for years and sometimes decades by necessity, but that also comes at a significant

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development and production cost. To achieve total ownership cost effectiveness in RAM, higher reliability materials and parts must be used to reduce sparing levels, improve maintainability (including enhanced integrated diagnostics), and reduce levels of corrective/direct maintenance, etc. Figure 20 summarizes the goals for RAM for unmanned systems.



Figure 20. RAM Goals for Unmanned Systems

4.5.3 Survivability

Survivability is a function of five key elements:

- ***Detectability*** is the probability of being discovered by an enemy force.
- ***Susceptibility*** is the probability of being hit or jammed in a particular environment.
- ***Vulnerability*** is the probability of surviving if hit or jammed in a particular environment.
- ***Stability*** is the probability the vehicle will reliably operate in the manner that was intended after it has been hit or jammed in a particular environment.
- ***Crashworthiness*** is the probability the vehicle and its load will survive an impact without serious damage.

An important characteristic of unmanned systems is that to some extent their loss is acceptable if it prevents the loss of warfighters or innocent civilians. Areas of survivability that are always a challenge, particularly for UAS, are susceptibility and vulnerability. Many of the warning and self-protection systems that are found on manned platforms may seem applicable to unmanned platforms because they face the same threats. However, the vehicles typically have not been designed with the SWaP-C or, in some cases, the maneuverability of the manned platforms, which would more easily support the warning and self-protection systems currently used on manned platforms. The warning and self-protection systems found on manned platforms require high electrical power, which causes high temperatures, or heat, in the avionics compartments; because UAS (and unmanned systems in general) have smaller compartments, heat dissipation is a constant issue. Adding to the heat issues, due to bandwidth limitations in uplinks and downlinks, more and more processing is being done aboard the platforms to reduce

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the high amounts of raw data being transmitted via the C2 links. With the need for more processing power aboard the platforms come increases in temperature on the small computer chips and boards of the survivability systems. Another challenge area in susceptibility and vulnerability is jamming or spoofing. Miniaturized solutions for anti-jam antennas or SAASMs to counter threats such as GPS-denied environments are needed. Again, unmanned systems are typically smaller than manned systems; however, some unmanned systems still have large radar cross sections, IR, and acoustic signatures that make them detectable and, therefore, susceptible.

Cost effectiveness in the area of survivability is going to be achieved much the same way that it will be achieved in SWaP-C. Survivability systems require a lot of power and put out a lot of heat, which, in the smaller compartments of unmanned systems, can cause RAM issues. By miniaturizing the survivability systems and improving power consumption and heat dissipation with more reliable and durable components, cost savings can be realized. This approach will also translate into systems that can be used by both manned and unmanned platforms and thereby provide a way to leverage common systems across similar and dissimilar platforms. Additionally, improvements or new technologies, e.g., IR signature reduction or low IR paints, must be cost neutral to standard paints and equipage currently being used. These products must also remain as maintenance and cost recurring friendly as possible. Figure 21 summarizes the goals for survivability for unmanned systems.



Figure 21. Survivability Goals for Unmanned Systems

4.5.4 Structures and Material Degradation

Today's unmanned systems operate in extreme environments ranging from sandy and hot climates to humid or freezing climates and from high altitudes to fathoms beneath the oceans. Unmanned systems need optimized material properties that can endure these conditions in addition to withstanding stress, corrosion, and other structural effects of the operating environments. Today's unmanned systems are relying more and more on composite materials that provide lightweight, flexible, strong structures. While these new composites are currently difficult and expensive to repair, industry and DoD are making great strides in the design and production of advanced composite materials.

The tradeoff for a lighter yet strong material is its high cost. Cost effectiveness for structural and material durability must now be achieved by focusing on the strength and durability of materials and structures to reduce or avoid repair costs. DARPA's Defense Sciences

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Office has multiple programs with objectives to improve materials in the areas of novel materials and material processes, multifunctional materials and material systems, and biologically inspired materials. However, more industry focus must be on the near term for structures and material degradation. Figure 22 summarizes the goals for structures and material degradation for unmanned systems.

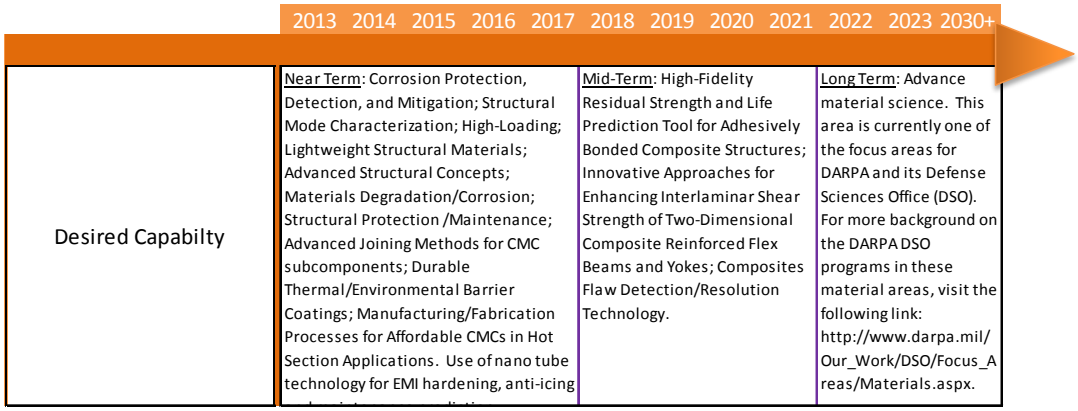


Figure 22. Structures and Material Degradation Goals for Unmanned Systems

4.5.5 Propulsion

As mentioned in 4.5.4, today's unmanned systems operate in many different and extreme environments. With these external factors, fuel-efficient propulsion and power output is needed for the many systems aboard unmanned systems. Persistence in conducting missions such as ISR is not possible without adequate propulsion and power. Unmanned systems must maintain their health, currency, and technical superiority with innovative approaches for increasing power and thermal management and improving power output and thermal loads. Many of today's persistent systems rely on efficient forms of propulsion that are sustainable for long-endurance missions. Other systems require propulsion that can be optimized for long range and endurance or optimized for high speed. Additionally, systems such as UUVs face challenges to extend endurance into months with energy technologies that are air independent. Regardless of providing propulsion for an air system or a surface system, a propulsion system must be not only efficient, but also adaptive to faults by continuing to operate in a degraded state or by stabilizing itself and returning to a normal state.

As technology for propulsion systems continues to evolve and improve, the areas of maintenance, sustainment, and lifecycle cost reduction will always remain key to achieving cost effectiveness. Smarter systems (via software and computers) should allow for diagnostics or logic-based tools to perform "virtual inspections" and thereby reduce the time to troubleshoot the system or its components. Likewise, validated propulsion health monitoring systems will allow for just-in-time maintenance. Also, biofuels that are renewable and that meet or exceed military or jet fuel performances metrics will help reduce the dependence on fossil fuels. Additionally, as mentioned above in RAM, the more resilient propulsion systems become, the more cost effective they will be, and the more cost savings they will provide. Figure 23 summarizes the goals for propulsion for unmanned systems.

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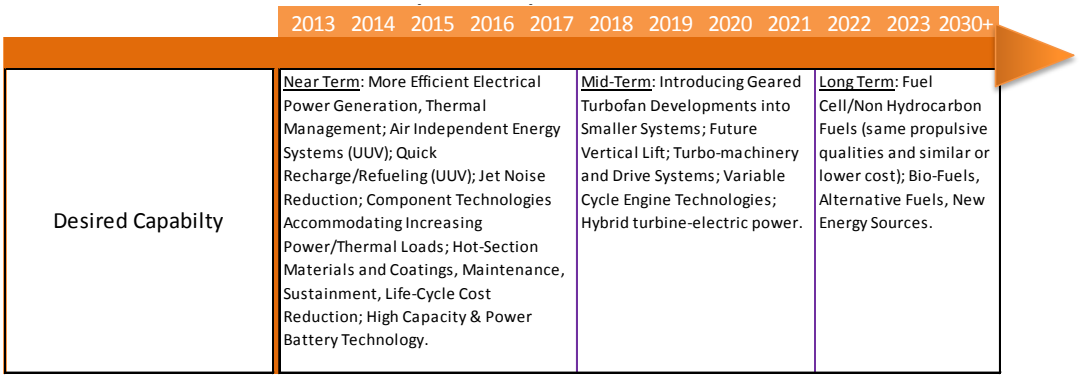


Figure 23. Propulsion Goals for Unmanned Systems

4.5.6 Summary

As stated in 4.5, the areas of focus for emerging technology enablers in persistent resilience are

- Size, weight, power, and cooling (SWaP-C)
- Reliability, availability, and maintainability (RAM)
- Survivability
- Structures and material degradation
- Propulsion

For unmanned systems in future middle- to high-intensity combat against more capable adversaries, persistent resilience must not be limited to traditional analysis of just the unmanned vehicle(s), but must also investigate the ground, communication, tactics, and manning aspects that collectively provide the unmanned systems capability. The ultimate benefit from this activity is the avoidance of significant loss of unmanned systems capability and resulting adverse combat outcomes for the total force. The objective of early analysis of persistent surveillance is to achieve early identification of system weaknesses in the context of known and projected threats; subsequent identification, analysis, and exploration of alternatives to mitigate significant weaknesses; and the development of material solutions and/or training and tactics solutions to institute before encountering such conflicts in the future.

4.6 Autonomy and Cognitive Behavior

Unmanned systems that have the option to operate autonomously today are typically fully preprogrammed to perform defined actions repeatedly and independently of external influence or control; that is not to say these systems are unmonitored. These systems can be described as self-steering or self-regulating and can follow an externally given path while compensating for small deviations caused by external disturbances. However, the automatic system is not able to initially define the path according to some given goal or to choose the goal that is dictating its path.

The future of autonomous systems is characterized as a movement beyond autonomous mission *execution* to autonomous mission *performance*. The difference between execution and performance is that the former simply executes a preprogrammed plan whereas performance is associated with mission outcomes that can vary even during a mission and require deviation from

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preprogrammed tasks. Autonomous mission performance may demand the ability to integrate sensing, perceiving, analyzing, communicating, planning, decision making, and executing to achieve mission goals versus system functions. Preprogramming is still a key part and enabler of this kind of operation, but the preprogramming goes beyond system operation and into laws and strategies that allow the system to self-decide how to operate itself. Initially, these control algorithms are created and tested by teams of human operators and software developers. However, if machine learning is employed, autonomous systems can develop modified strategies for themselves by which they select their behavior. An autonomous system is self-directed by choosing the behavior it follows to reach a human-directed goal. Various levels of autonomy, in any system, guide how much and how often humans must interact or intervene with the autonomous systems. In addition, autonomous systems may even optimize behavior in a goal-directed manner in unforeseen situations (i.e., in a given situation, the autonomous system finds the optimal solution).

It is important to note here that automation is only as good as the software writer and developer because the control algorithms are created and tested by teams of humans. In these algorithms, the "patterns of life" are critical to automation and must be observed and captured properly to ensure accuracy and correctness of a decision-making process within the software. Ensuring accuracy and correctness requires a continual process in which the observe – orient – decide – act (OODA) loops in the software are continually updated via manual analysis, training, and operator understanding of algorithm inputs and outputs. The human brain can function in dynamic environments and adapt to changes as well as predict what will happen next. In simplistic terms, the algorithms must act as the human brain does.

To take on increased autonomy in unmanned systems, the systems will require additional sensors that can provide a more accurate perspective of their surroundings as well as the capacity to interpret those inputs so that they can respond appropriately to the situation. Additionally, they will require the ability to be untethered from human interaction. A key enabler in unmanned systems autonomy will be navigation. Given the dependence UAS have on PNT, the platform will execute only as well as the accuracy of the PNT in the system. Inaccurate PNT introduces error to air vehicle navigation and sensor cueing. Mission computers are continuously updated with position, air speed, ground speed, and drifts so the UAS can intelligently pick the best route to take while maneuvering away from restricted areas or boundaries. Navigation alternatives must be researched and evaluated to overcome dependency on systems such as GPS.

Autonomy in unmanned systems will be critical to future conflicts that will be fought and won with technology. The near-term area for Air Force and Navy capability development is implementing land and carrier-based UAS to provide ISR and strike from the land and sea. Middle- and long-term naval capability will focus on A2/AD. The Air Force and Navy are investing research and development efforts and procurement programs to overcome these access threats and assure the ability of the joint force to project power in support of our allies and partners and to protect U.S. interests.

An important element of overcoming access threats and maximizing the fleet's capacity is unmanned systems. As a result, autonomy in unmanned systems has been identified by Navy and DoD leadership as a high priority. However, specific pathways for the introduction of technologies that enable greater levels of autonomy have not been identified. The special feature of an autonomous system is its ability to be goal-directed in unpredictable situations. This ability

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is a significant improvement in capability compared to the capabilities of automatic systems. An autonomous system is able to make a decision based on a set of rules and/or limitations.

To aid in the ongoing solutions for autonomy on unmanned systems, the Naval Research Advisory Committee is conducting a study to clarify the potential of autonomy to transform naval operations and eventually the operations of other Services. The study will explore the current and anticipated potential of technology to achieve various levels of autonomous operations. The study will also consider potential naval uses of autonomy, with emphasis on maritime systems, and the challenges associated with realization of these applications. The study will consider autonomy as a capability that is enabled by a set of technologies, such as sensing, intelligence, reliability, and endurance. Advances in these technologies are key to permitting an autonomous system to make decisions in the framework of an operational mission. The study will assess state-of-the-art autonomy and identify technical shortfalls or opportunities to significantly advance the capability. The goal is to identify where autonomy has high potential to enable naval missions; however, implementation of autonomous systems also introduces operational challenges, such as affordability, policy, and doctrine.

Additionally, S&T development programs are underway in the Air Force, Army, and Navy as well as at DARPA. While applications of autonomy among the Services tend to be applied to a specific domain of interest, in many cases the underlying technology is applicable across domains. For example, the Air Force is developing teaming technologies for air platforms, while the Navy and Marine Corps are applying similar technologies to ground vehicles and the Army is applying similar technology to robots. The following subsections detail efforts by the Department and show similarities where appropriate.

As the level of autonomy increases, manpower savings can be achieved and/or human resources can be redirected to other tasks. As examples, Army tactical robots could ultimately augment manning in small units, Marine Corps intelligent UGS may also conduct logistics missions, and Air Force/Army systems are envisioned to be designed so a single operator can control multiple UAS. All these systems offer the opportunity for significant manpower savings or the opportunity to use the saved manpower in other critical tasks.

As DoD advances the state of the art in autonomy, industry and academic partnerships will be critical. Investment to produce affordable systems will allow unmanned systems to become ubiquitous on the battlefield.

4.6.1 Today's State (2013–2017)

In general, research and development in automation is advancing from a state of automatic systems requiring human control toward a state of autonomous systems able to make decisions and react without human interaction.

Related to UAS, the Navy is partnering with the Air Force in advancing airborne sense and avoid (ABSAA) technologies. The Army is leading the ground-based sense and avoid (GBSAA) common requirements development coordination for the Airspace Integration IPT. In addition to technologies for airborne operation, the Navy is investing in development of autonomous deck operations. In the near term, autonomous deck operations research and

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development includes technologies to support high operating tempo (OPTEMPO) launch and recovery of small UAS and precision on-deck UAS locating and tracking.

A major goal of naval developments for Marine Corps applications is to make systems smarter and cheaper. The Navy is developing low-cost, ubiquitous, intelligent, tactical UGS that will operate as a force multiplier integrated with manned, unmanned, and optionally manned systems. The current state of autonomy for most tactical UGS requires human decision makers and LOS communications. Systems that are autonomous require highly structured and predictable environments. In the near term, Navy research focuses on transitioning from teleoperated UGS to autonomous logistics connector UGS with independent path planning functionality and doctrinally appropriate maneuvers and behaviors. Further, the Navy is developing technologies to navigate trafficable on- and off-road terrain at tactically appropriate speed. Affordability is a key requirement for all these developments, and effective operation in day, night, and GPS-denied environments is critical. In the near term, the Office of Naval Research is developing technologies that will enable a 2016 limited military utility assessment of the logistics connector Unmanned Ground Vehicle (UGV), which includes multimode perception, day and night operation, and complex terrain traversibility.

> ***We can't support small teams of Marines using robotic platforms whose sensors cost hundreds of thousands of dollars, and whose software cost millions or in some cases billions of dollars to develop.***
>
> ***— George Solhan, Director, Office of Naval Research Code 30***

The Army S&T vision is one where manned and unmanned systems work together with greatly enhanced capabilities in the following five problem domains: adaptive tactical reasoning; focused situational awareness; safe, secure, and adaptive movement; efficient proactive interaction with humans; and interaction with the physical world. The Robotic Collaborative Technology Alliance (RCTA) uses the following anthropomorphic shorthand to describe these five problem domains: think – look – move – talk – work.[67] Figure 24 summarizes the Army's vision for these five problem domains, barriers to achieving its vision, and work to be done to advance toward the vision.

In the near term, the RCTA plans a Capstone Experiment in FY2014. See Figure 25. The Capstone Experiment is centered around a notional cordon-and-search operation: during urban transit by a small unit (i.e., four to five soldiers), a fugitive is reported to have entered a building the unit is approaching. A man-transportable robot is instructed to "cover the back door" of the building by the unit commander because he cannot safely split up his limited resources. The robot must understand and acknowledge the order, associate the order with its perceived environment, move safely and securely to an appropriate vantage point, observe activity behind the building, and report any salient events to the unit commander. As needed, it enters the building and negotiates stairs or other mobility obstacles. It then returns to its unit, maintaining situational awareness, and is ready for another assignment. While this narrative occurs in the context of a cordon-and-search operation, its underlying capabilities support a broad range of

[67] Robotic Collaborative Technology Alliance (RCTA) FY2012 Annual Program Plan.

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potential operational missions. Similar to the other Services, middle- and long-term work by the RCTA will continue to evolve and improve capabilities to increase the level of autonomy in systems from the current, remotely operated systems to autonomous systems and system-of-systems (SoS) approaches.

	Barriers to Achieving our Vision ----->	Simplistic and Shallow World Model	Mobility-Focused Perception	Tele-operated or (at best) Scripted Planning	No Shared Understanding of Missions and Roles	Missing or Shallow Learning Capabilities
		World Model is either at only a metric level precluding reasoning, or at only a cognitive level without physical grounding	Objects in the world are perceived primarily only as mobility regions not as discrete objects of semantic and cognitive importance	Bots are almost always tele-operated or at best only perform sample scripted behaviors - and scripting all needed behaviors is not tractable	Bots are opaque and distributed, and cannot explain what they are doing - primarily because they don't know	Bots must be explicitly programmed to do tasks, so it is intractable to product the needed scope of behavior. Any learning capability is shallow and lacks generalization
"Think"	**Adaptive Tactical Reasoning**					
	Understand tasks, missions (METT-TC)	World model needs to represent concepts such as missions, tasks, and generally METT-TC.		Robots need to generate behaviors pertinent to achieving the mission, adapt to changing situation.	Robots need to be able to follow instructions given at a semantic or cognitive level, not just "goto (x,y)."	
	Follow semantic instructions					
	Generate behaviors to achieve mission, adapting to changing situation					
	Understand teammates and what they need to know					
"Look"	**Focused Situational Awareness**					
	Maintain SA relevant to current task/mission	World model needs to represent, maintain, monitor, and correct all info needed for SA.	Robot needs to contribute to the general SA of the unit, noting salient observations.		Robot needs to report on salient observations as needed to other elements of its unit.	Robot should learn by comparing its observations and actions to those of ts human counterparts.
	Contribute to general SA of unit					
	Look for salient unforeseen events					
	Observe and report on salient activity					
"Move"	**Safe, Secure and Adaptive Movement**					
	Move cognitively in reaction to safest route in the world (as people do) with GPS or other metric crutches	World model needs to store and operate upon all entities needed to relate movement to tactical constraints.	Robot must perceive all entities in its environment relevant to safe, secure, and adaptive movement.	Robots must move in a tactically correct manner and react to changes in mission or circumstances.		Robot needs to learn from its movement experience whether from mobility challenges or tactical behavior.
	Move in tactically and continually relevant manner					
	Adjust to mobility challenges such as terrain, weather, barriers					
"Talk"	**Efficient Interactive Communication**					
	Receive and acknowledge semantics instructions	World model needs to have shared mental models as a basis for human-robot interaction.	Robot needs to send and information relevant based on a shared perception (common ground).		Robot needs to receive and acknowledge4 cognitive-level instructions and similarly explain its own behavior.	Robot needs to be able to learn through cognitive-level interaction with human teammates.
	Explain own behavior					
	Report information relevant to mission					
	Seek guidance as needed					
"Work"	**Interaction With Physical Wold**					
	Inspect and manipulate objects	World model needs to represent wide variety of objects to be manipulated.	Robot needs to perceive well enough to interact effectively with objects in a 3D world.	Robot needs to figure out how and when to manipulate or transport objects as needed.		Robot needs to learn from interaction with the physical world, e.g. when door is locked.
	Transport objects as needed					
	Open doors, windows, hoods, trunks, etc.					
	Use tools as needed					

Figure 24. Army's Vision for Five Problem Domains (Think – Look – Move – Talk – Work)

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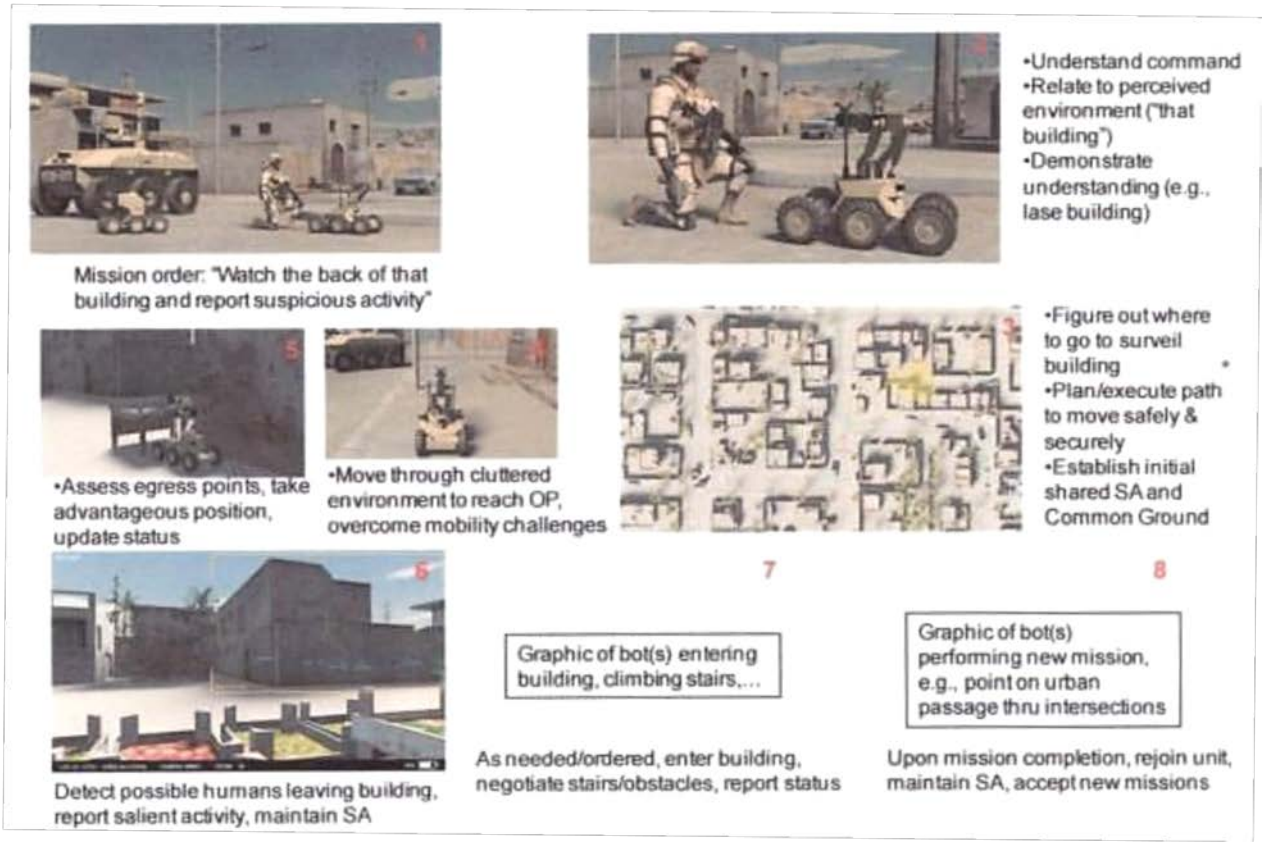


Figure 25. RCTA's Capstone Experiment in FY2014

4.6.2 Middle-Term Future State (2017–2022)

The middle-term future state in the 2017–2022 time frame will consist largely of a further maturation of near-term capabilities. Middle- and long-term goals primarily increase capability, scale technologies, move from ground-based to platform-based technologies, and move the capability further along the scale from automatic to autonomous behavior. As an example, the Air Force's multiple-aircraft manager could be matured to include management of transit operations involving multiple UAS, which could reduce crew requirements and optimize the allocation and use of crews.

The Navy's middle-term technology developments will evolve near-term technologies to greater levels of autonomy and team-oriented behaviors. In the middle term, naval autonomous deck operations research includes technologies for autonomous flight deck awareness and movement, decision aids for interactive manned/unmanned operations, and robust intelligent autonomous flight deck operations. Middle-term plans for Marine Corps UGS include transition from autonomous logistic connector to integrated operations with dismounts with follow-me/come-to/go-to capability; autonomous "wingman" capable of human-like tactical behaviors; in-stride support of Marine Corps rifle squads, including tactical decision making while in enemy contact; advanced perception of individual humans, urban environments, and effective operations

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in challenging weather conditions; and enhanced human-robot interaction that enables teaming and trust.

4.6.3 Long-Term Future State (Beyond 2020)

The long-term state for unmanned systems will bring further maturation of the middle-term capabilities. It will also bring higher levels of automation. It will allow concepts like smart teams of unmanned systems operating autonomously to conduct operations in contested environments. It will also allow concepts like "loyal wingmen," i.e., unmanned systems that operate in conjunction with manned platforms to conduct operations.

Similarly, naval research and development for both shipboard systems and marine UGS in the long term are focused on greater automation and SoS. The desired long-term capabilities for UGS include fully autonomous, multirole platforms with independent and cooperative decision making. Additionally, the Marine Corps desires self-sustaining, integrated warfighter-machine SoS approaches in the long term.

4.6.4 Key Enablers and Concerns

To fully realize the operational benefits of autonomy, certain key enablers must be available. Included among these are mission planning that is dynamically modifiable; precise navigation and timing; cross-cueing sensors; handoff capabilities and information transport to other onboard systems; and data dissemination to GCS operators, controllers, and edge warfighters. Autonomous controls are required to develop and disseminate requisite information tailored to bandwidth and user profiles. Precise PNT is critical for autonomous systems operation. PNT allows for freedom of movement, understanding of the operational area, collision avoidance, and sensor and weapons cueing. Precise PNT must be maintained even in harsh and GPS-denied environments. Ultra-high precision inertial navigation systems and other non-GPS navigation systems will be key enablers for autonomous system operations.

Additionally, cross-cueing and/or dynamically retasking of multi-intelligence sensors/modes and/or weapons capabilities are required to support onboard processing that provides aided target recognition, identification, and tracking. Filtered target information must be passed to onboard weapons systems as the onboard cueing and/or tasking of onboard sensor target information is confirmed. Change and status notification must be given to UAS operators and operations intelligence staffs so they can monitor, and override if necessary, the autonomous payload and/or weapons systems information and controls. The system must be able to operate in a continuous OODA loop. This ability will depend on well-written and tested software, coupled with sensors that allow the system to autonomously observe and react to patterns of behavior. To achieve autonomy, this OODA loop interaction must occur continuously and must not be based on a single point in time.

As autonomous systems become ubiquitous, efficient utilization of bandwidth will be a key enabler. As more autonomous systems occupy the battlefield, MIMO communication networks could be one of the crucial technologies. Further, bandwidth must be used efficiently and effectively to prevent denial of service.

Finally, several concerns are associated with full-scale operation of autonomous systems, many of which are related to the key enablers. As examples, maintaining accuracy and

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availability of PNT is a key concern. Proper training and timeline to develop the operational experience that enables the continuous OODA loop are additional concerns. Development of the ability for operators to turn processing on and off and conserving bandwidth via metadata standards are additional concerns. Lastly, development of appropriate rules of engagement for utilizing processed information and for lost links is a developmental concern. As autonomy development continues to proceed from automatic to autonomous systems, developers must address these concerns.

4.7 Weaponry

The increased use of unmanned systems as weapons delivery platforms has been a significant step in the integration of unmanned systems in the battlespace. Unmanned systems can be used in significantly different operating and threat conditions than manned platforms, come in a much wider range of classes and sizes than manned systems, can exhibit greater persistence and endurance than manned systems, and have the potential to support a large range of mission sets.

The introduction of remote video links, enabling operators to monitor the unmanned systems payload view in real time, enables users to employ weaponized unmanned systems with more flexibility and with improved confidence. Network-enabled systems employing distributed C2 elements with ISR and armed airborne assets (either separate platforms or integrated into a single unit) benefit from progress made with unmanned systems and precision-guided weapons.

Typical weapons that could be adapted for UAS use include the Laser Homing Attack or Anti-Tank Missile (LAHAT) (Figure 26). As early as 2004, this weapon was proposed for testing with U.S. Hunter UAS. LAHAT utilizes the semi-active laser homing guidance method to accurately home in on targets from a distance beyond 10 km. Fitted with a shaped charge multipurpose warhead, LAHAT can engage targets marked by a laser designator mounted on the launching platform or by an indirect designation from another unit located closer to the target. Each missile weighs about 13 kg, and a complete launcher with the four missiles weighs only 75 kg, significantly less than any alternative weapon.

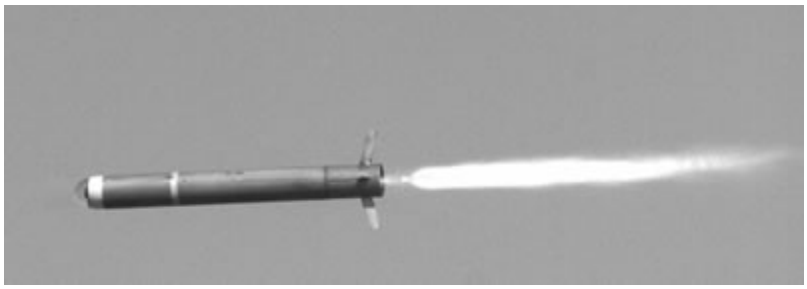


Figure 26. Laser Homing Attack or Anti-Tank Missile (LAHAT)

The laser-guided SPIKE (Figure 27) was developed by the Weapons Division of the Naval Air Warfare Center with assistance of DRS Technologies. Originally designed as a man-portable weapon for the Marines and the Navy's special operations force, SPIKE fills a critical niche for a low-cost, lightweight guided weapon for U.S. ground forces. It is also considered for tactical UAS and a force-protection weapon to defend surface ships from small-boat swarms or light aircraft. The missile uses a semi-active laser seeker to engage laser-designated targets from

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a distance of two miles. Each SPIKE missile weighs 5.3 lb (2.5 kg) and is 25 inches (63.5 cm) long. The missile performed its first controlled flights in 2005. The Spike missile is designed to be used on medium-weight and lightweight UAS. The missile has already been tested with the DRS Sentry HP drone at Eglin AFB, Florida, as part of Air Force UAS Battlelab evaluation.



Figure 27. Laser-Guided SPIKE

Another type of lightweight weapon considered for UAS is the 2.75-inch Hydra-70 rocket. In 2005, four 2.75-inch rockets were fired from Vigilante UAS test bed and demonstrated the weaponization potential of rotary-wing UAS. The tests evaluated the stability and flight control adjustments necessary to compensate for excessive loads during the weapon's firing. On these tests, the Vigilante was controlled from a nearby UH-1 manned helicopter. Such tests will provide important data for the integration of Advanced Precision Kill Weapon System (APKWS II) with future rotary-wing UAS.

APKWS II is intended to fill an aviation systems weapons gap between the Hellfire missile and unguided Hydra-70 2.75-inch rocket and introduce an affordable, lightweight, precision aerial guided rocket. APKWS II weighs about 13 kg and integrates a strap-down laser seeker (fixed in the wing roots) and guidance section onto the Hydra-70 rocket. It will be effective against soft and lightly armored targets as well as urban operations. A new design uses existing or new production rockets, fitted with a middle-body guidance approach that employs a distributed aperture semi-active laser seeker; the same element is also used in the Army's Precision-Guided Mortar Munitions program.

APKWS II will use the Hydra Universal Rail Launcher (HURL), a lightweight four-rail launcher originally developed for the Comanche attack helicopter but modified for use with UAS. Designed as a "smart rocket launcher," HURL can be linked to onboard avionics through MIL-STD-1760 and MIL-STD-1553 interfaces.

A version of a 2.75-inch laser-guided rocket called Direct Attack Guided Rocket (DAGR) is designed to be fully compatible with the Hellfire II system and 229 smart launcher system and, therefore, to increase the launcher load out by up to four times.

Switchblade (Figure 28) is a weapon designed for hand, tube, or aerial launch that could provide the warfighter with a rapid delivery to gather ISR information on BLOS targets. Designed as an expendable system, Switchblade will also have an option to carry a small explosive charge to enable rapid prosecution of selected targets with minimal collateral damage.

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The miniature, remotely piloted or automated platform can either glide or propel itself via quiet, electric propulsion and provide real-time video for information gathering, targeting, or feature or object recognition.



Figure 28. Switchblade Munition

Adapting proven weapons technology with new concepts to take advantage of unmanned systems persistence and emerging net-centric capability, manned and unmanned teaming will be critical to improving the sensor-to-shooter equation and further decreasing in the kill chain timeline. However, certain technological issues must be addressed to further enhance unmanned systems as weapons delivery platforms in the near, middle, and long term.

4.7.1 Interoperability

No current weapons system employed from unmanned systems was designed specifically for unmanned vehicles. As discussed in other sections of this chapter, the capability need to rapidly deploy weapons on unmanned systems drove design compromises in interoperability. The same rigor now being applied to systems interoperability must be used to address current concerns and design of future weapons systems for unmanned systems:

- Cross-Service, cross-platform interoperability and capability. Manned platform have settled on common armament interface units, bomb racks, and logistics. Unmanned systems should follow this lead, especially with shipboard storage and employment concerns, logistics, training, and flight certification.
- Interchangeability within classes of unmanned systems where practicable as well as with manned systems where practicable.
- CONEMPs and TTPs standardized across the services.

The OSD USIP WG initiated a Weapons USIP (USIP 5.0) based on a recommendation from the I-IPT and Services. This effort was a truly joint approach to enable efficient UAS weapon integration to significantly reduce risk with mature, standardized interfaces. USIP 5.0 helps to define the mandatory implementation of standards and specifications to achieve an interoperable mode of operation for internal and external exchanges for all weaponized UAS and applicable manned platforms. The USIP also includes an IOP to address cooperative engagement and the Joint Digitally Aided CAS (DACAS) project. Once approved by OSD(AT&L), USIP 5.0

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will be maintained on the DISR as a mandated standard and shared with the appropriate NATO Standardization Agreement (STANAG) bodies for incorporation into international standards.

4.7.2 Unmanned System–Specific Weapons

To take advantage of all classes of unmanned systems, especially UAS, technological advances in specific areas must be addressed in weaponry to arm multiple classes of unmanned systems:

- ***Weapons designed for multiple missions.*** The ability to select the yield of the weapon in advance of employment is often referred to as a "scalable effects" warhead. The ability to vary the explosive power of a warhead has clear implications for reducing risk to friendly forces and civilians and also for reducing unnecessary damage to infrastructure other than the intended target. Historically, the notion of varying the explosive power of a warhead has been primarily linked with nuclear weapons, where the term "dial-a-yield" is generally used. In this case, the amount of material that can "boost" the yield (for example, tritium) can be varied, as can the performance of "initiators," which allow a chain reaction to propagate. Achieving this scalability with conventional (i.e., chemical) explosives presents different challenges. A plausible explanation of how this may be achieved would be varying the manner in which the explosive material contained in the warhead is detonated.
- ***Weapons designed with multiple modes.*** Current multimode requirements are derived from current and future mission environments, such as frequent bad weather. In current operations for both manned and unmanned aircraft, a mix of weapons is carried to ensure the proper weapon is available for the weather and threat at the target area. Depending on the environment, often only half of the bomb load is employed. For certain classes of unmanned systems, this approach is simply not an option. A true multimode weapon will be an essential aspect of arming unmanned systems. However, multimode weapons are only part of the solution. The ability to integrate unmanned systems within the manned weapons construct, while taking advantage of the unmanned systems' inherent traits of endurance, survivability, etc., will be key. They must be able to target and track moving threats reliably and precisely and identify the target and acceptable collateral damage in bad weather and with many targets in a cluttered environment. This goal will require a common network between human observers, the unmanned system, and other delivery platforms and weapons.
- ***Weapons design for use within the unmanned systems environment.*** The potential weapons operating environment for unmanned systems will be significantly different from comparable manned platform performance envelopes and weapons engagement envelopes.
- ***Standardized weapons designs*** including modular designs, interchangeable within similar unmanned systems from different services and designed for shipboard storage and employment.

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4.7.3 Advanced Weapons Technology Areas

4.7.3.1 Nanoenergetics

Energetic materials contain chemical energy that, when released, can burn rapidly, such as in fireworks or rocket fuel, or explode, such as in a grenade or bomb. Energetic materials at the nanoscale show promise for military applications. Nanoparticles have more surface area and, therefore, have increased contact with the other chemicals that make up a propellant or explosive. After a reaction is initiated (that is, the explosion is set off), this greater surface area causes a faster reaction rate, which makes for a more powerful explosion. This work could be useful in weapons systems that would utilize greater amounts of energy, making them more lethal. By working at the nanoscale, weapons designers can also control the rate at which energy is released by changing the size of the nanoparticles; in other words, the designers could customize the explosive for each application. For example, a weapon designed to penetrate into the ground to destroy a bunker may need an explosive with a different reaction rate than a weapon designed to explode and project shrapnel above ground troops. See Figure 29.

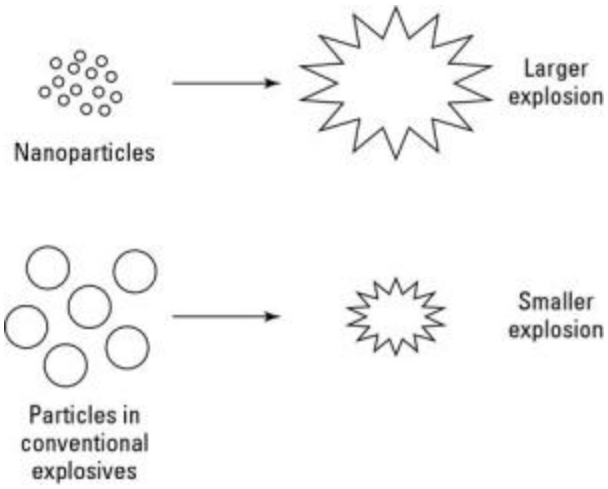


Figure 29. Nanoparticles and Explosions

An example of this technology is the use of aluminum nanoparticles in explosives that the Air Force is developing. When nano-aluminum powder is added to explosives, weapons can be made smaller and more powerful. These weapons are useful in aircraft with limited space, such as remote control drones. Researchers are developing techniques that allow weapons manufacturers to add a greater amount of nano-aluminum powder to an explosive using a solvent.

4.7.3.2 Advanced Weapons Materials

Significant research is ongoing at Service and national laboratories in areas such as polymers, metals, ceramics, composites, and bio-inspired materials. Unmanned systems are looking for opportunities to transition to these advancements to reduce SWAP-C and enhance safety and survivability, where applicable.

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4.7.3.3 Unmanned Systems as a Weapon

The theory of aerial dominating weapons is not new, but to date its implementation has remained limited by current technology to few, specific contingencies, such as the suppression of enemy air defense (SEAD), where targets could be clearly identified and pursued with radar homing weapons.

Israel pioneered this field with the Harpy loitering SEAD weapon, developed by Israel Aerospace Industries. The system has been acquired by several countries including China, Turkey, South Korea, and India. Israeli Military Industries is demonstrating a similar multipurpose warhead for its Delilah air-launched missile, yet this weapon is quite large for conventional UAS. A follow-on to Harpy, known as Cutlass, was developed under U.S.-Israeli cooperation. While the program has not been officially concluded, Israel is known to have offered advanced Harpy systems to several customers, including the United Kingdom, where it was proposed as "White Hawk," for the British Loitering Munition Capability Demonstration under cooperation with Missiles, Bombs, and Deadly Ammunitions (MBDA). Another Israeli company, RAFAEL, competed for the same program, offering the BLADE (Battlefield Loitering Artillery Direct Effect), based on a modified Sparrow M UAS designed and produced by EMIT.



A different concept developed for the Army, pursued area domination by a combination of several types of loitering NLOS missiles. The original concept included "smart" loitering weapons, which would provide area surveillance, target acquisition, and pursuit of time-critical attack, while other targets would be engaged by precision attack missiles (PAMs), fitted with imaging IR seekers. However, this concept proved too costly and complex. The Army eliminated the loitering missile-sensor element and deployed the NLOS launch system with the PAM, as a weapon repository ready to support combat units, targeted by assets available to the unit over the network.

Various types of air domination systems are being considered by the Air Force to enable a military force to dominate an area from the air for extended periods and deny enemy movements and maneuvering. Current systems under consideration are standard weaponized UAS or small expendable loitering weapons, fitted with imaging sensors, such as the Low-Cost Autonomous Attack System (LOCAAS). Operating in swarms of "intelligent munitions" weapons, the LOCAAS can autonomously search for and destroy critical mobile targets while aiming over a wide combat area. Recent enhancements of the LOCAAS concept introduced man-in-the-loop functionality to enable retargeting and the ability to abort attack by a human controller when required. Further enhancements could integrate the LOCAAS into a "Surveilling Miniature Attack Cruise Missile" (SMACM) "mothership" carrying four LOCAAS units. The mothership will be able to support the units with targeting, surveillance, and communication support and extend the range and persistence of the basic version beyond 250 nautical miles. LOCAAS and SMACM are designed to operate in open area and pursue stationary and mobile targets of opportunities as soon as they are exposed in the open.

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A tremendous amount of work has yet to be done in the area of autonomous systems as a weapon. Current systems have less than optimal loiter times and are not readily adaptable to the shipboard environment and the strike fighter mission. As well, advances in interoperability, materials technology, and fusing have not been incorporated across the unmanned systems spectrum.

Figure 30 summarizes the goals for weaponry for unmanned systems.



Figure 30. Weaponry Goals for Unmanned Systems

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5 Operating Environment

5.1 Introduction

The world's markets, technologies, and regulatory environments for unmanned systems are evolving rapidly and creating opportunities in platforms, payloads, leasing, operations, and maintenance. DoD is looking beyond Iraq and Afghanistan towards a world of rapid deployments to trouble spots where airfields may not be available. After U.S. forces begin withdrawal from Afghanistan in 2014 in accordance with presidential planning, commanders expect to focus on contingency missions where the United States may have no established presence. UAS must then operate from ships or beaches rather than from fixed bases. Airborne launch of unmanned platforms is another approach.

Unmanned systems are better suited than manned platforms in some circumstances. In anticipation of such use, every segment of unmanned systems — the deployed platform, control station(s), and control link(s) — must all be considered from the earliest stages of program development. The environment must encompass all influences on this extended system, not just focus on the platform itself. System technology program requirements must be outlined in a CONOPS that details how the system is to be used in the intended physical operating environment and provides a baseline for all system requirements.

In addition to operating unmanned systems in strenuous physical environments, programs must also account for the ability to operate within existing regulations and within socially acceptable means. There will always be regulatory uncertainty when a revolutionary technology is introduced, as is the case with unmanned systems. A prime example is the consideration of UAS flights in the NAS, where UAS must operate within the FAA Federal Aviation Regulations (FARs). Even in cases where UAS do meet all applicable FARs, users of the UAS must consider the safety of the general public and abide by applicable privacy laws. Similarly, UGS intending to operate on U.S. public roads must at a minimum comply with Department of Transportation (DoT) regulations and federal, state, and local motor vehicle laws, but should additionally show safety and traffic efficiency enhancements to gain acceptance from the general public.

The unmanned systems safety guide for DoD acquisition references DoDI 5000.1, which instructs program managers to prevent environment, safety, and occupational health (ESOH) hazards, where possible, and manage ESOH hazards where they cannot be avoided. The unmanned systems must also comply to the Army equipment spectrum certification (ESC), which allows program management offices and others to apply for new equipment frequency allocations (i.e., spectrum certifications), request changes to existing spectrum certifications, request host nation coordination, and submit questions. The system tracks these "requests" and provides real-time status updates and mechanisms to collaborate with the Spectrum Management Office, which processes the request. Currently, the ESC process manager supports only Army requests while Navy and Air Force versions of this system are under development. Also, unmanned systems must meet information assurance requirements for their complex software systems as these systems must interact with other systems and humans through networked C2 systems to share information and control these systems. The Navy and Air Force have differing versions of this same process.

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5.2 Problem Statement

The operating environment of the unmanned system is a critical factor in determining the appropriate level of autonomy and the capability to maneuver as needed to accomplish the mission.

The intended physical operating environment provided in a CONOPS and other program requirement documents will help determine the level of technology that must be applied to the unmanned system. More stressing physical environments will most notably affect the level of autonomy required, along with the capability to act on the situation at hand.

Similarly, in the regulatory environment, program plans must account for the regulatory hurdles that are typical with revolutionary technologies. Individual technologies must be carefully examined at every level in the system until the appropriate levels of technological advances are defined to be capable of overcoming such hurdles.

These concerns are especially important and apply to A2/AD scenario planning factors. These factors include technologies supporting survivability, anti-jam, all weather, and persistence capabilities as described in Chapter 4.

5.3 Physical Environment

The physical operating environment provides the basis for the unmanned systems capabilities. Ideally, unmanned systems should be able to adapt to any environment but, to constrain the problem, many state-of-the-art unmanned systems are currently designed from the ground up to operate within an assumed environment.

The UAS physical operating environment may vary greatly. Generally, UAS will operate in similar conditions as manned aircraft, i.e., in all weather, from low to high altitude, and in airspace that is congested and possibly contested. Some UAS, such as Triton, are intended to fly in maritime environments at both very high and low altitudes. Flights at lower altitudes must consider saltwater and humidity in both design and operation, while high-altitude operations must consider extreme temperatures and the lack of air pressure. Also, the altitude transitions through weather and additional stresses will require additional capability considerations.

The physical operating environment determines the basis for UGS capabilities. Operations for future UGS will vary from occurring in structured and semi-structured environments to occurring outside a defined perimeter on semi-structured to unstructured terrain in support of force protection or physical security missions in more hostile environments. UGS maneuvering must account for environmental conditions (e.g., obstacles, threats, road conditions) in addition to the system performance. Further environmental classifications, such as urban/rural, forest/open, road/non-road, indoor/outdoor, must be addressed with regard to UGS.

DARPA and the auto industry continue to pursue automated technologies that could allow UGS to operate in a variety of conditions. Current efforts allow vehicles to operate within pavement lines, operate in sequence, stop when objects are ahead, and take caution when foreign objects are near (such as deer). Many of these efforts are intended to enhance vehicular safety, but also assist unmanned systems technology through increasing automation.

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The intended physical operating environments for UMS are in and around harbors, strategically placed within major shipping routes such as the Strait of Hormuz, or possibly out in the open ocean. Although maneuvering with no roads and no "water traffic controller," USVs must be capable of avoiding ships, docks, floating debris, and navigation aids and must stay within proper navigable waters (i.e., not run aground). In addition, USVs must operate in accordance with collision regulations (COLREGS).[68] Because not all maritime traffic (including military and commercial) always follows the COLREGS, however, autonomous behavior is more difficult to develop for USVs.

On the other hand, although UUVs have the risk of running into underwater obstructions, they do not typically have to worry about other vehicles. Furthermore, there are also no navigation rules for underwater operation. For UUVs operating in a stressing environment such as open ocean, the technology must be capable of providing enough power to last long durations of time while autonomously performing their missions even when communication links are limited.

5.4 Policy and Regulatory Environment

Unmanned systems programs must consider all the policies and regulations of the appropriate authorities as program planning begins. UGS may need to operate on public roads where DoT is the regulatory authority within the United States, while UGS on foreign lands must remain within the policies of the host nations. Projects conducted by the National Highway Traffic Safety Administration will provide valuable data to develop safety standards and performance requirements, which will help ensure the safe testing and subsequent operation of autonomous vehicles on public roads. New technologies for UGS must be tested for safety and verified by the appropriate regulatory authority.

The primary regulations controlling the safe navigation of U.S. vessels are the navigation rules published by the U.S. Coast Guard.[69] These rules are applicable to international and inland waters. The international waters rules are based on the 1972 International Regulations for Prevention of Collision at Sea (72 COLREGS), as amended, a treaty that the United States adopted in 1977.

The Navigation Safety Advisory Council (NAVSAC) was established by the U.S. Congress to advise the Secretary of Transportation, via the Commandant, U.S. Coast Guard, on matters relating to the prevention of collisions, rammings, and groundings. In May 2011, NAVSAC recommended to the Coast Guard that UMS be required to comply with the navigation rules, including some amendments deemed necessary for UMS compliance.

In addition to safe navigation rules, UMS must comply with other rules and regulations, such as for RF communication equipment operation and for environmental restrictions covering the operation of sonars and underwater acoustic instruments.

Safe operation of aircraft within domestic national airspace is governed by the FARs maintained and published by the FAA. Compliance with the FARs requires a pilot in the cockpit of the aircraft to "see and avoid" other aviation traffic. Therefore, UAS by nature cannot comply

[68] International Regulations for Prevention of Collision at Sea (COLREGS), 1972.
[69] COMDTINST M16672.2D, Navigation Rules, International – Inland, 23 November 2011.

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with the FARs. DoD UAS operations outside of restricted or warning areas within the NAS are currently required to obtain a Certificate of Waiver or Authorization (COA) from the FAA in accordance with FAA Order 7610.4, Chapter 12, Section 9.[70] The order identifies information that should be included in the COA request, including a description of the intended flight operations, UAS characteristics, and lost link procedures.

Outside U.S. sovereign national airspace, foreign nations have designated civil aviation authorities (similar to the FAA) that regulate and exercise governance over their sovereign national airspace. Furthermore, when operating in international airspace (i.e., over the high seas) DoD UAS observe International Civil Aviation Organization (ICAO) flight procedures when practical and compatible with their mission. However, in accordance with DoD policy (and consistent with international law) when operational situations do not lend themselves to ICAO flight procedures, such operations may be conducted under due regard.[71] In designated combat airspace, DoD UAS operate in accordance with instructions provided by the designated airspace control authority.[72]

5.4.1 Testing and Certification

Testing of UMS is required for the Military Departments to be able to certify compliance with regulations and demonstrate safe operations.

USVs must meet the same requirements of a manned craft or boat that is intended to be put into service. Testing unmanned systems in general is a significant challenge and can be very costly. For example, if it is impossible to put a man aboard a USV, the amount of time and expense increases significantly to verify that the propulsion system is working correctly. The Navy has developed a guide for testing USVs and drafted an approach to certifying USVs. The guide and draft certification method are available from the Naval Surface Warfare Center Carderock, Detachment Norfolk.[73]

To be able to fly in any airspace, DoD UAS are required to be certified as airworthy. Airworthiness certification is a core acquisition and engineering process conducted for system safety and takes into account material, service life, and mission requirements within the intended airspace.

Level of certification depends on the mission requirements of the system. A certification allowing unlimited NAS access may be cost prohibitive and unnecessary. For systems that do not require full airspace access or are constrained by cost or other technical hurdles, military departments may impose operational restrictions when issuing airworthiness statements for UAS. Examples include flights within a shipboard environment, only in uncongested airspace, or under other certain conditions with specific safety precautions. UAS may be allowed very limited access to the NAS, such as flights limited only within restricted or warning areas or only over unpopulated areas with other restrictions if little is known about the system or the operational risks are deemed too high to permit operations within the NAS.

[70] FAA Order 7610.4P, Chapter 12, Section 9.
[71] DoDI 4540.01, Use of International Airspace by U.S. Military Aircraft and for Missile/Projectile Firings, 28 March 2007.
[72] JP 3-52, Joint Airspace Control, 20 May 2010.
[73] Scott Sampson, Naval Surface Warfare Center Carderock, Detachment Norfolk.

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5.4.2 Sense and Avoid (SAA) Capability

SAA is a technical approach that has been proposed to bridge the gap between the FAR requirement for a pilot in the cockpit to "see and avoid" and the "unmanned" nature of UAS. In general, an SAA system should include the ability to perform the eight functions listed in Figure 31. It should be noted that for DoD UAS, expanded access to the NAS based on SAA technology will require continued use of COAs until current FAA policy, guidance, or regulations can be changed.

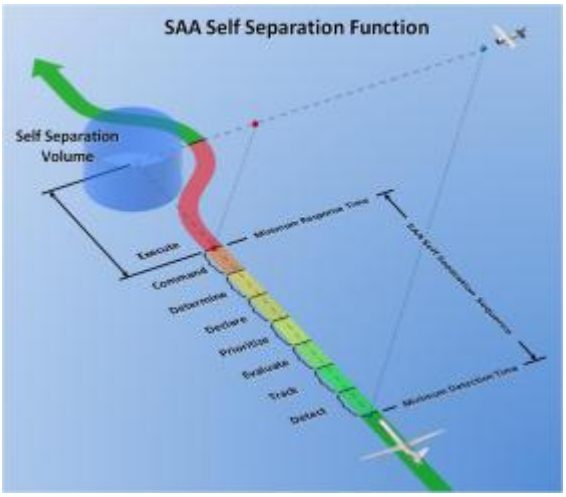


Figure 31. SAA Self-Separation Functions

5.4.3 UAS Executive Committee (ExCom)

The UAS ExCom was developed from a recommendation on conflict and dispute resolution from the 2009 National Defense Authorization Act. It is a focal point for senior leaders from DoD, FAA, the National Aeronautics and Space Administration, and the Department of Homeland Security to resolve any policy and procedural disputes and to identify solutions to enable the integration of DoD and other federal agency UAS into the NAS.

The UAS ExCom approved the UAS NAS Access Plan in October 2010, which addresses the milestones, policy recommendations, flight standards, and operating procedures necessary to provide a path for UAS integration into the NAS. The ExCom continues to work on many of the issues and recommendations identified in the plan, including continued improvements to the COA process as well as policy and procedural updates to enable significant improvement in UAS NAS access. In addition, the ExCom extended the COA expiration interval from 12 to 24 months and formalized an agreement on allowing transition from Class D airspace to adjacent Restricted or Warning areas. The ExCom is actively working to improve several other policy-related UAS issues, including

- Developing processes and procedures to allow multiple unmanned and manned operations in Class D airspace
- Simplifying the process for UAS to operate in Class D airspace from military airfields
- Simplifying the process for, and expanding the access of, SUAS to operate in Class G airspace
- Allowing UAS flights in remote operating areas with limited restrictions

5.5 Technology Application

An unmanned system may include a SoS. For example, a USV may host a UAS and UUS, or a UAS can provide inflight refueling to another UAS, or a UAS may be deployed as a communication relay station for UGS. Unmanned systems may be part of a greater system including manned elements as well. Technology developments must assess the impact each has across the rest of the system components or other systems.

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Technology will improve the performance of our systems and allow them to last longer, to use fewer people, to cost less, and to provide more relevant information, where it's needed and when it's needed.

5.5.1 Unmanned Aircraft Systems

One of the key capabilities UAS currently provide to the warfighter is persistence, for example, persistent ISR. Technology improvements can expand persistence much further, but programs must consider the operating environment while incorporating the technology. As an example, one technology application is onboard data processing. This automation technology can help minimize critical bandwidth necessary to transmit ISR data to the warfighter and may also be suitable for reducing the intelligence officer workload and decreasing the time in the kill chain.

Key technology enablers that UAS will encounter in operational environments include C2 links, SAA systems, sensors and displays, separation algorithms, and interoperability.

5.5.1.1 C2 Links

As an essential component of UAS by definition, solutions to problems associated with link spectrum availability, latency, and reliability must be developed in all operating environments. Spectrum considerations should be fully understood for UAS to operate at any given location for C2 and also for SAA (where radar is employed). For C2 within LOS, the United States and other countries have an approved spectrum allocation to globally use the Aeronautical Mobile (Route) Service 5030–5091 MHz band. For BLOS, the World Radiocommunications Conference (WRC) was unable to reach agreement at the WRC-12, but will continue studies for decision at WRC-15. The WRC-12 decided that no additional spectrum allocation was required for SAA purposes.

5.5.1.2 SAA Systems

An SAA system, whether ground, air, other, or integrated, will result from the effective use of many technologies. The SAA system will be a SoS, including sensors to detect and track, C2 subsystems to transmit information to a display providing situational awareness to a qualified pilot/operator, and algorithms to recommend or implement maneuvers depending on varying degrees of autonomy. Complex SAA systems may allow for formation flights or multiple shipboard operations in both SUAS and large UAS environments, all while preserving or enhancing flight safety.

5.5.1.2.1 Ground-Based SAA (GBSAA) Systems

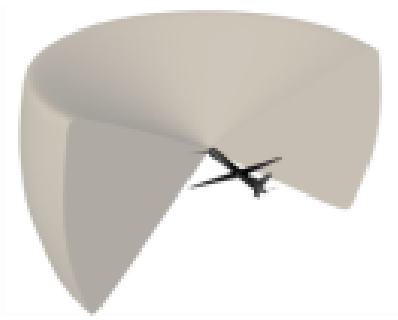
A GBSAA system is designed to provide safe separation for UAS operations within a prescribed volume of airspace using a ground-based system of sensors, displays, communications, and software. The sensors perform detect and track functions while algorithms and/or displays assist the pilot/operator with the requirement to evaluate, prioritize, declare, and determine the best course of action to avoid a hazard. The mission-critical information is provided to the pilot/operator in a GCS or at the operating station to enable the pilot/operator to

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make decisions to safely navigate the airspace. Future developments may automate maneuvers and allow more efficient use of the airspace and the easing of air traffic management tasks.

5.5.1.2.2 Airborne Sense and Avoid (ABSAA) Systems

ABSAA development efforts are focusing on an onboard capability to perform both self-separation and collision avoidance to ensure an appropriate level of safety. The capability is intended to give pilot/operators the ability to avoid conflict and collision avoidance with other aircraft in a safe and efficient manner in all classes of airspace. Early versions of this technology may function similarly to early phases of GBSAA by requiring the pilot/operator to initiate maneuvers, but work is being done to enable autonomous action by the aircraft, or pilot-on-the-loop operations, where the system can identify and react to conflicts. Current programs have phased validation schedules for flights within airspace in which DoD is authorized to operate with due regard, en-route/Class A, and divert/Class E/Class G operations as technology innovation and integration allow.



5.5.1.3 Sensors and Displays

Although developing common and interoperable sensors across multiple types of control systems and extensible to multiple platforms is best for the current fiscal environment, UAS sensors must be customized to the mission environment. Miniaturization of sensors will allow additional capabilities on smaller UAS and/or will enable the capability to collect more information aboard a single platform. Displays built for SAA functions should be common and compatible across the Services, regardless of GBSAA or ABSAA applications, as well as across air traffic services (see Figure 32). This compatibility will reduce training costs and allow the development of common terminology and understanding.



Figure 32. UAS Pilot Simulator Training

5.5.1.4 Separation Algorithms

For the foreseeable future, a pilot/operator will have direct decision authority for all UAS actions; this approach is known as “pilot in the loop.” Predicated on the failure of self-separation and approaching collision avoidance scenarios, the addition of separation algorithms will aid the pilot/operator in completing the mission. Such algorithms will also be needed for autonomous systems. This capability applies in the NAS, foreign airspace, and combat zones, but may be most applicable in open ocean and other areas where flights would be conducted under “due regard” regulations where air traffic services are not available.

5.5.1.5 Interoperability

UAS will be operating in an increasingly crowded airspace with the potential need to interact with manned assets. The UI2 CBA identified and prioritized IOP gaps in airspace

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integration and interoperability capabilities. Decision makers on the ground must be able to access sensor systems for both manned and unmanned aircraft to enhance situational awareness. Video data must be capable of transferring between aircraft to maintain ISR continuity. Therefore, interoperability standards must be in place so the right information gets to the right people. Initial stages of this type of interoperability were demonstrated during the Army's Manned Unmanned Systems Integration Capability (MUSIC) exercise in September 2011. This technology needs continued maturation across the military departments to meet DoD interoperability goals.

5.5.1.6 Other Technologies

Technology can be used to improve survivability under hostile environments and also improve overall reliability of unmanned systems. Improved reliability will make them more acceptable to a cautious public. Power systems can allow the endurance of a UAS to expand further beyond today's limited envelope. Also, as sensor payloads continue to improve and collect more data (such as FMV), data processing techniques must be able to smartly filter relevant data to pass to the ground within the limited bandwidth available.

5.5.2 Unmanned Ground Systems

The ability to maneuver effectively in a wide range of environments is a requirement that a UGS must meet. Those environments could include being thrown or launched, climbing hills or stairs, and hopping and landing upright. The technologies for advancing this capability are primarily autonomy, sensors, and avoidance algorithms.

5.5.2.1 Autonomy

The ability of the UGS to navigate autonomously is largely dependent on the accuracy and robustness of its perception system, which seeks to create an accurate model of its environment. Designing a perception system capable of dealing with all types of environments is very challenging with the current technology. To constrain the problem, current state-of-the-art UGS are designed from the ground up to operate within an assumed environment(s). If these assumptions are valid, the UGS often operate effectively. The UGS will fail to operate as intended, however, when circumstances are different from assumed. To alleviate this problem, it is desirable to have a perception system that can adapt to various environments. To be able to adapt, the UGS must understand the context of its environment and recognize when that context changes. One possible method of understanding context is through the classification of video imagery. Once an environment is classified, UGS require perception adjudication that specifically addresses the perceptual needs of the UGS at run-time. A number of factors dictate the perceptual needs of UGS, including mission awareness, environmental complexity, mobility requirements, and the sensor capabilities necessary to build contextual information from the environment. The



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enabling technology supporting these factors includes hardware and software related to autonomy, communications, power, vision, architecture, warfighter machine interfaces, manipulators, terrain mobility, and payloads.

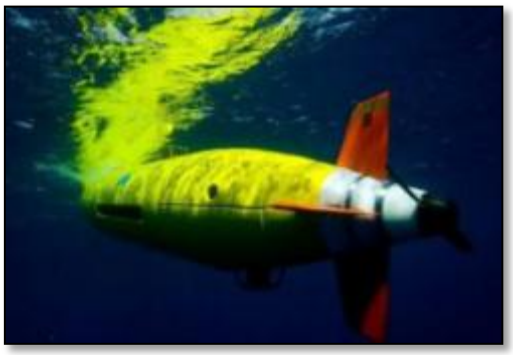
5.5.2.2 Sensors and Avoidance Algorithms

Although collision avoidance systems on unmanned systems have been tailored for UAS, there is also a great need to apply them to ground systems. Examples of this technology include collision avoidance algorithms, traffic pattern recognition, and navigation. While avoidance systems for UGS may come about from UAS technologies, a good opportunity to leverage developments comes from the auto industry. The auto industry has a much greater ability to apply research and development technology funding with the initial focus on improving safety, and many of these technological developments will apply to making UGS safer as well.

5.5.2.3 Other UGS Technologies to Consider

Other technologies may also give UGS greater flexibility within its intended environment. Interoperability may be a very important consideration to reduce costs and add efficiency, especially as the sensors become more complex. Issues such as dual-use sensors, high/low data, data storage, and secure communication links may all be very important to evaluate. Vehicle-to-vehicle communications have the potential to greatly increase safety by sending and receiving data messages across equipped vehicles and translating the data into warnings to the driver of potential collisions. Several top auto manufacturers are quickly developing prototypes with varying technologies for civil auto applications. These technologies will benefit the civil community through fuel and time savings and improved safety and will certainly have benefits to DoD as well.

5.5.3 Unmanned Maritime Systems



UMS may be used for a variety of purposes. They can ensure security within harbors, scan for problems on a ship hull, sweep an area for mines, secure critical waterways, provide ocean tracking, and more. Because of the operating environment, the technology that allows these capabilities is unique. Like UAS, persistence is a key capability that UMS can provide; however, unlike UAS, UMS allow more than just persistence. For example, the largest issue with UAS is their inability to operate in bad weather or low visibility. UUVs, on the other hand, can operate in poor weather conditions. Therefore, DoD can continuously scan for mine drops or follow an enemy threat such as a submarine. In any case, persistence requires improved power and propulsion systems, autonomy and data processing, improved communication systems, and advanced sensors.

5.5.3.1 Power Systems

Certainly powering for long-term persistence is a large challenge. Having the ability to sprint at high speeds to intercept a target is not the only power requirement. Towing also requires power; for example, the mine warfare mission typically requires a significant tow load — much

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more than a normal craft's capability. Certain supporting payloads are also very power intensive. A USV carrying other UUVs or USVs would have to recharge or refuel the other payloads, and this requirement would require more power.

5.5.3.2 Autonomy and Data Processing

Like UAS or UGS, UMS can be preprogrammed for certain missions. For example, UUVs can autonomously scan the hull of a ship for threats or other foreign objects within harbor or scan a geospatial area for mines. However, the technology gets more complex as the level of autonomy increases. The appropriate autonomy level plays a key role in persistence during clandestine missions, e.g., the ability to sense and avoid hostile forces and to detect and avoid obstacles such as approaching vessels, fishing nets, or more conventional obstacles like rock formations or coral heads. Autonomy may also play a key role in the capability to diagnose and react in a proportional manner to UMS internal failures (fault management) during long missions, especially in clandestine missions. For these types of missions, the UMS needs the capability to send important, relevant information as needed, such as relaying the track of a detected threat.

Data processing enables the transmission of a reduced amount of data like beam-formed sonar images instead of raw, stave data, without compromising quality. Not only is there a need to use preprocessing to reduce the amount of data transmitted, but also automated target recognition enables target discrimination, i.e., reporting contacts of interest instead of sending entire images for human interpretation.

5.5.3.3 Communication Systems



Communication systems on UMS drive the need for advanced data processing techniques. Undersea C2 limitations preclude teleoperated solutions, and such limitations drive UUV autonomy needs. Bandwidth is much lower with acoustic signals compared to RF signals; therefore, wireless data rates are reduced. In clandestine operations, C2 links must extend over long distances into the undersea environment to provided operators with situational awareness and supervisory control over a UUV.

5.5.3.4 Advanced Sensors

New technologies enable real-time adaptation and optimization of sensor settings and unattended tactical planning for sensor employment according to the environmental conditions. Because a human is not around to recognize that the sensor is not operating optimally, sensors need the capability to adapt to optimize their abilities. In addition, they must improve in other areas:

- ***Marinization.*** Typically most commercial sensors are built for UAS. Their environment is simpler compared to USVs and UUVs. Not only is salt water a problem, but the accelerations and shock from bumps are well above anything experienced by a UA.

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- ***Built-in test.*** Sensors must have the ability to know and report when they are not working correctly so the control system can take appropriate action.
- ***Data fusion.*** To be truly useful in the future, sensor data output must be standardized for incorporation into a fusion engine providing for a better world view (i.e., understanding of the environment around the unmanned system).
- ***Additional capability.*** Sensors must allow for faster operation (i.e., as speed of a USV increases, cameras and radars must be able to see further and clearer to determine the proper course of action so the vehicle has time to react).

Sensors must continue to be developed and improved to gain even more capability and robustness in a maritime environment.

5.6 Way Ahead

To operate within the existing regulatory environment, programs must comply with existing policy framework or get policy waivers because policies tailored to unmanned systems are still in development. Regulatory and cultural hurdles must be carefully considered early in system development. In this paradigm, technology development and tests will help shape the appropriate requirements, standards, and regulations. Industry will help frame what is possible as the "state of the art," and programs will define what is fiscally responsible. Once the standards and regulations are complete, PORs can then create requirements for their systems with a complete set of expectations.

5.7 Case Study: Air: Airworthiness and GBSAA



Services programs and CCDRs that require UAS must define the types of airspace they require for their missions. The CONOPS should define the operating environment, considering the NAS for training before deploying overseas in a foreign airspace. Two important factors, although not the only factors, for UAS flights in the NAS are the airworthiness of the vehicle and the SAA solution to comply with FAR or COA requirements. Below, we quickly examine these factors in a case study of the Army Gray Eagle at Fort Hood, Texas. The Gray Eagle currently requires a COA to transit from Joint use Class D airspace to restricted airspace a short distance away.

Like manned systems, the Gray Eagle vehicle must be certified as airworthy and properly equipped to fly in the intended airspace. The aircraft structure, propulsion system, control redundancies, software, and control links must all be certified to a certain standard defined by the Service's technical airworthiness authority (TAA). However, the Army has determined that certification costs are prohibitively expensive to certify the Gray Eagle to manned aircraft

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standards. Therefore, the Army TAA takes into account the potential risk of a failure and the population density below the intended flight path, which would cross over a road. To minimize risk to people and property on the ground, the Gray Eagle will fly perpendicular to the road and take other similar precautions.

The Army has a clear understanding of the airspace the UAS must transit, equipage requirements for that airspace, normal aircraft traffic patterns, surrounding terrain, and other potential hazards to accomplish its training mission. The Army decides that GBSAA is the chosen SAA solution based on mission requirements and costs. The GBSAA radars monitor the airspace for potential conflicting traffic, and algorithms assess the potential for conflicts and suggest heading changes to the operator to maintain separation.

The combination of these efforts allows the Army to confidently navigate the airspace safely with regard to other airspace users as well as people and property on the ground. This solution provides the capability to accomplish the training mission without incurring high costs such as transiting the entire unit to another location.

5.8 Summary

Technology is evolving rapidly, and this fast evolution is challenging regulatory authorities to keep pace with needed rules and regulations as well as challenging military departments to keep costs down when abiding by DoD acquisition and management processes. Every aspect of the operating environment, including the physical and regulatory, should be kept in mind at every stage of the acquisition life cycle. Guidance is currently available from each Military Department although the requirements and standards must still be developed.

Unmanned systems are ideally suited to increase the envelope for the physical environment. They are often built with the intent of putting them in harm's way and avoiding risk to a pilot, operator, or controller. The timeline in Figure 33 shows the technical path toward successful increases in capability across the domains for the next 25 years.

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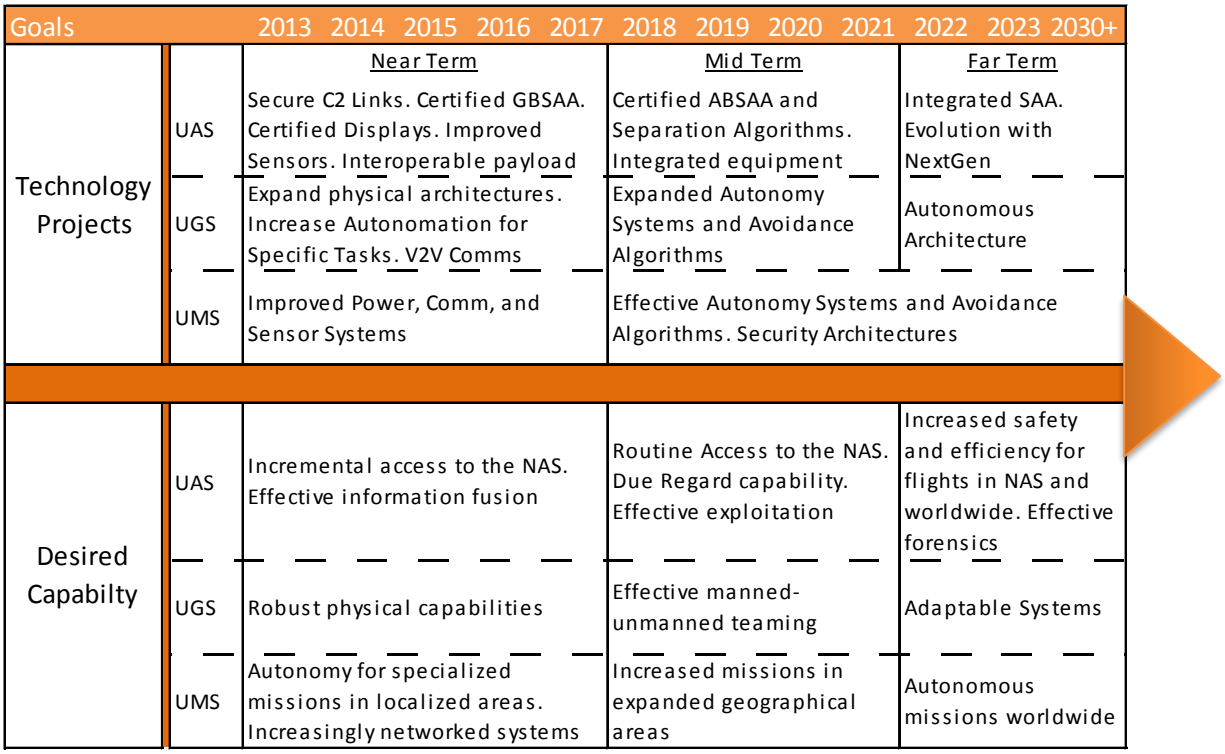


Figure 33. Operating Environment Technology Development Timeline

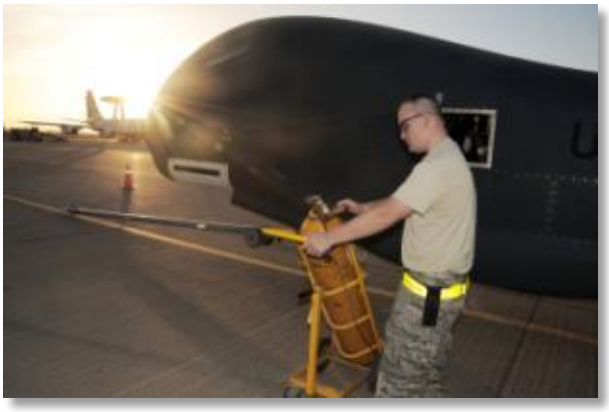
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6 Logistics and Sustainment

6.1 Current Sustainment Environment

The rapid development and fielding of large numbers and types of unmanned systems present DoD with a significant sustainment challenge. Reliance on joint operations and multinational coalitions further complicates that sustainment challenge. Joint mission requirements need matching logistics capabilities that meet the specific mission requirements of the CCDR.

Evolving requirements often force premature system redesign efforts to meet emerging warfighter needs. Rapidly evolving technology and economic conditions affect the requirement and the ability of unmanned systems to meet stated reliability, maintainability, and affordability requirements. Original equipment manufacturer (OEM) assertions of proprietary interests complicate organic support. As budget pressures increase, programs must develop more cost-effective sustainment solutions. The transition from supporting the warfighters' immediate capability requirements to creating an affordable, long-term sustainment environment will require a flexible blend of OEM and organic support to meet logistics support objectives.



6.2 Problem Statement

The first generation of fielded unmanned systems was focused on the rapid delivery of immediate capability to the warfighter. Because of the need to rapidly develop and field these initial capabilities, long-term sustainability planning has often occurred late in the development cycle. Many programs have been procured as vertically integrated, vendor-propriety solutions relying on a single prime contractor who was often held accountable to meet many criteria, including a compressed delivery schedule. These rapidly fielded programs are often immature in terms of reliability and supportability and are heavily reliant on contractor logistics support (CLS). In most cases, unmanned systems are no different from manned platforms and require investments in reliability and maintainability to provide availability at an affordable cost. However, reliability, maintainability, and lifecycle costs have been secondary considerations, and early application of reliability and maintainability engineering activities to the design has been neglected. As programs plan for long-term sustainment, they must establish lifecycle sustainment strategies that can cost-effectively meet documented warfighter requirements and comply with statutory requirements and DoD policies.



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6.3 Challenges to Logistics and Sustainment

The need to quickly field unmanned capability led to shortcomings in the area of logistics and sustainment planning and implementation. Challenges include

- Sustaining non-PORs
- Limited RAM data
- Delayed core logistics capability requirements
- Transition from CLS for Life to Organic capabilities
- Immature or lack of lifecycle sustainment planning

6.3.1 Sustaining Non-PORs

Programs initially fielded as user operational evaluation systems or as rapid acquisitions in response to JUONs have since transitioned to PORs that provide enduring warfighting capabilities. Many involve procurement quantities of hundreds of units that will be sustained for the foreseeable future. The Services have focused on "getting product out the door," rather than maturing and improving sustainability within systems because of the urgent goal to meet immediate warfighter needs with unmanned systems capabilities. The programs often have not developed the data strategies to support the system for the long term, including procuring failure and product support usage data. The Services have met the needs of the warfighter by fielding developmental versions of the PORs as quick reaction capabilities, fielding non-POR sensor and weapons capabilities on POR platforms, and fielding multiple POR low-rate production units prior to completion of the initial operational test and evaluation (IOT&E) and formal declaration of IOC.



The Services have also developed innovative, and sometimes ad hoc, logistics concepts to support near-term in-theater warfighter readiness. For instance, in 2006, the Army Materiel Command chartered the RS-JPO to provide in-theater support via the Joint Robotics Repair Facility (JRRF) and the Joint Robotic Repair Detachments (JRRDs). JRRF provides a one-stop shop for fielding, sustainment, training assessment, and asset accountability. It also provides support, e.g., operational instruction, preventative maintenance checks, services, and troubleshooting. The JRRDs, established in Kuwait and Afghanistan, fill an Army maintenance capability gap created by the acquisition and deployment of commercial off-the-shelf (COTS) robotic systems in theater. These organizations operate outside the standard Army logistics system and force structure to provide training and to issue and repair robotic equipment. The facilities are staffed with a mix of Government personnel and contractors.

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6.3.2 Limited RAM Data

Much of the unmanned systems capabilities were delivered with large numbers of developmental and low-rate production assets that were not fully matured or proven to meet the system's RAM requirements. The lack of proven reliability creates a challenge to long-term system availability and affordability because reliability is typically the single largest design-controllable driver of operations and sustainment costs. While providing a tremendous capability to the warfighter, when IOT&E does occur, systems often do not meet their operational sustainment thresholds and are deemed not suitable.

6.3.3 Delayed Core Logistics Capability Requirements

The rush to deliver these critical capabilities to the field led to a reliance on the OEM to satisfy sustainment requirements. Prime contractors have been responsible to provide CLS to ensure the operational readiness of their systems in the field. In many cases, little organic maintenance capability at the military organizational and intermediate (field) level has been established. Program offices have relied on the capacity of the prime contractors' production lines to satisfy depot maintenance requirements. The delay in the establishment of organic depot capabilities sometimes put programs at odds with statutory requirements. Several programs have begun the transition from contractor support to an organic capability. However, contractor assertions of proprietary technical data rights,[74] investment costs for support equipment and facilities, parts obsolescence, and frequent software upgrades create challenges to establishing depot capability in the near term. In an effort to create organic maintenance efficiencies and commonalities between the programs, the Services have begun to work together to identify potential synergies in establishing common sustainment concepts and capabilities. An FY2011 UAS Organic Depot Study recommended the establishment of repair capabilities at a limited number of depots based on major subsystems to take advantage of existing depot capabilities and capacity (see Figure 35 in 6.7.1). The Joint Logistics Board endorsed the workload assignment consolidations and directed that Air Force avionics, ground electronic, software, and sensor workloads be further evaluated for potential consolidation.

6.3.4 Transition from CLS for Life to Organic Capabilities

For UAS, the same FoS was often selected to meet the requirements for ISR and weapons platforms of different Services; therefore, a large degree of commonality exists among the various platforms and sensors. However, because of the initial strategy of using the prime contractor for CLS for life to sustain rapidly deployed and evolving capabilities, the various program offices are just beginning to recognize and take advantage of commonalities by establishing common logistics infrastructures to reduce investment costs as they develop plans to transition to organic support late in the development cycles.

Contracts for CLS, in many cases, have not been performance based, i.e., requiring specified levels of readiness, but rather cost-plus-award-fee arrangements providing flexibility to respond to changes in requirements and OPTEMPO. While these arrangements provide an

[74] 10 USC 2320 provides that in the case of an item developed by a contractor or subcontractor exclusively at private expense, the contractor or subcontractor may restrict the right of the United States to release or disclose technical data to persons outside the Government. The statute further states that these restrictions do not apply to technical data that are necessary for operation, maintenance, installation, or training.

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immediate advantage to quickly field warfighter operational capability, more affordable sustainment solutions are required as fleet sizes have grown.

6.3.5 Immature or Lack of Lifecycle Sustainment Planning

Fielded unmanned systems are frequently not managed or maintained as other platforms are within the inventory. For instance, with Army UGS, the operational urgency and uniqueness of these platforms required a nonstandard approach in integrating these technologies into the force. This understandable and needed deviation created, as a byproduct, a parallel management system that bypassed many established processes and procedures. The RS-JPO sustainment strategy for the family of robots includes improvements and upgrades to current platforms with the latest technologies. Due to the drawdown from theater, RS-JPO is developing a responsible drawdown strategy that includes long-term storage and future disposition of robotic systems.

The Army lacks adequate maintenance doctrine to address the technologies incorporated into robotic systems. Robotic maintenance doctrine has not been delineated in Army doctrine. Only a small group of operators and personnel within the Army working in the development, testing, and acquisition of robotic technologies is well acquainted and/or understand the impact of these technologies. RS-JPO initiated efforts to improve the maintenance strategy by improving databases and how data are analyzed, decreasing top sustainment parts cost drivers, and outsourcing repairable parts. By improving the way data are collected and analyzed in the Cataloging Ordering Logistics Tracking System, JRRF hopes to identify and increase MTBF and identify systemic parts problems to reduce the number of parts consumed. Also RS-JPO is currently working with the OEMs to analyze the repair-versus-replace cost of their top sustainment parts cost drivers to determine whether the return maintenance actions are being accomplished efficiently. Future plans also include the possible outsourcing of parts repairs to a non-OEM contractor. JRRF continues to develop and refine repair processes and serve as the center for technician support for all the detachments and training sites.

Multiple challenges exist for sustainment due to the many different configurations of nonstandard equipment (NSE). The optimum goal is to have modularity across platforms for plug-and-play adaptability. This approach will reduce the number of required repair parts and allow plug-and-play payload options to fulfill multiple capability requirements. This effort will also maximize the life of the current fleet and save a substantial amount of money in repairs and spare part purchases.

6.4 The Way Ahead

For unmanned systems to move from an environment of rapid development and fielding to an environment of long-term sustainment, programs must take a lifecycle management approach. Affordable lifecycle sustainment solutions that meet the warfighter's threshold requirements must be generated to maintain the capabilities of the first generation of unmanned systems over the foreseeable future. As new unmanned systems and capabilities are developed, new programs must apply lessons learned to ensure long-term sustainability is addressed early in the development process.

In September of 2011, USD(AT&L) directed that sustainment plans be developed for all unmanned acquisition programs and be reviewed for improved affordability and effectiveness.

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Lifecycle logistics planning and analysis execution is important from the acquisition phase through operations to the retirement phases of the weapon system life cycle. Cross-functional planning and integration are essential to ensure that supportability requirements are addressed comprehensively and consistently with cost, performance, and schedule during the life cycle. The objective is operational effectiveness through an affordable, effective support strategy that meets goals for optimum readiness and facilitates iterative technology enhancements during the weapon system life cycle. See Figure 34.

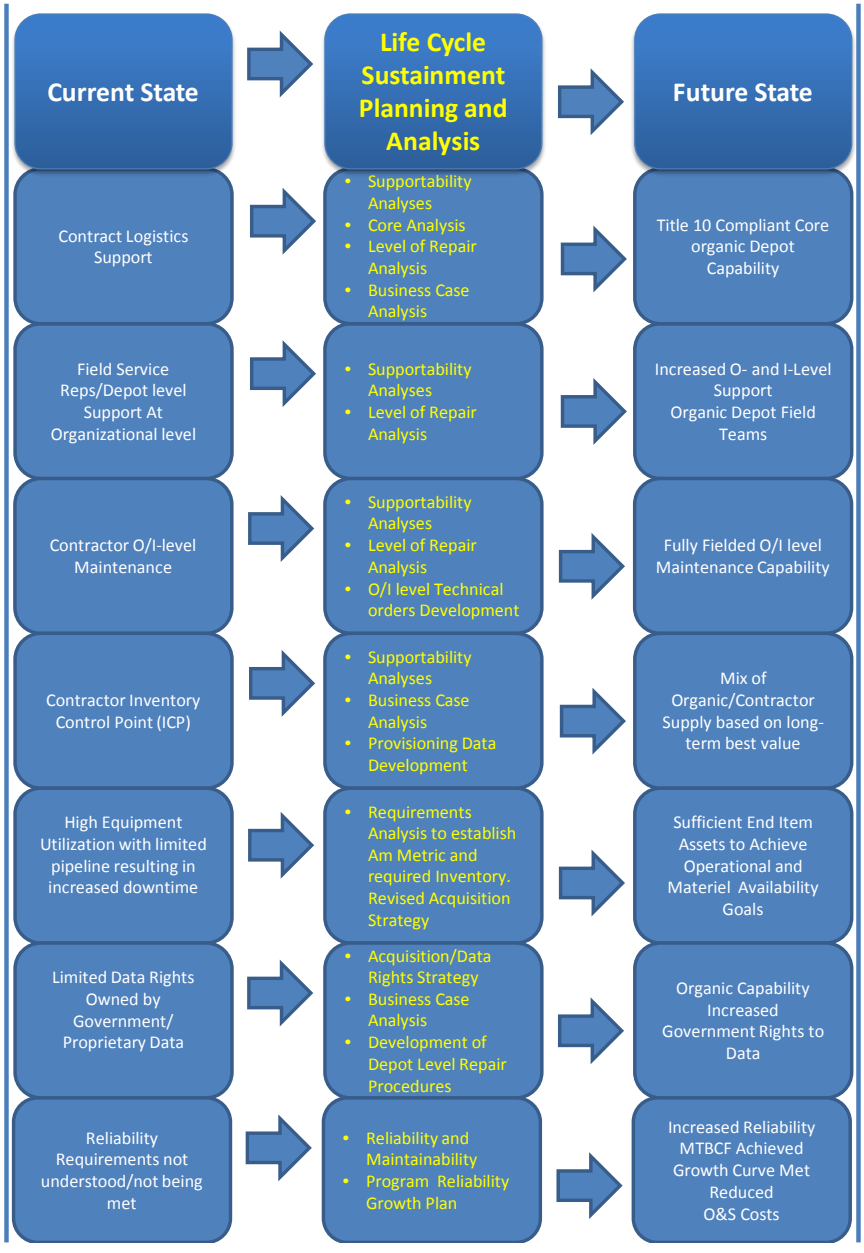


Figure 34. Lifecycle Sustainment Planning Analysis Way Ahead

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6.5 Planning for Organic Depot Maintenance

Central to sustainment planning and execution is the concept of core depot-level maintenance capabilities. First codified in 1984, the current statute[75] states, "It is essential for the national defense that the Department of Defense maintain a core logistics capability that is Government-owned and Government-operated (including Government personnel and Government-owned and Government-operated equipment and facilities) to ensure a ready and controlled source of technical competence and resources necessary to ensure effective and timely response to a mobilization, national defense contingency situations, and other emergency requirements."

The National Defense Authorization Act (NDAA) for FY2012, as further amended in the FY2013 NDAA, introduced several new provisions of law relating to the identification and implementation of core logistics capabilities that affect the sustainment of UAS. The law now specifically requires a determination of the applicability of core logistics requirements by Milestone A and an estimate of core logistics capabilities and sustaining workloads by Milestone B. The identification of core capability requirements and sustaining workloads is now a three-stage process linked to the acquisition cycle. The Milestone Decision Authority (MDA) must now certify pursuant to 10 U.S.C. 2366a(a)(4), "that a determination of applicability of core depot-level maintenance and repair capabilities requirements has been made," prior to Milestone A approval.[76] Milestone B approval may not be granted until the MDA certifies, "An estimate has been made of the requirements for core depot-level maintenance and repair capabilities…and the associated sustaining workloads to support such requirements."[77] Additionally, "Prior to entering into a contract for low-rate initial production of a major defense acquisition program, the Secretary of Defense shall ensure that the detailed requirements for core logistics capabilities…and associated workloads required to support such requirements have been defined." This three-stage process is designed to identify organic depot-level maintenance requirements early in the acquisition cycle to reduce the necessity for interim CLS and to allow for the timely establishment of organic capabilities. The determination that a function is core requires that government-owned and government-operated depot-level maintenance and repair capabilities and capacity, including the facilities, equipment, associated logistics capabilities, technical data, and trained personnel, shall be established not later than four years after a weapon system or item of military equipment achieved IOC or is fielded in support of operations.[78]

The early identification of core requirements and sustaining workloads will drive programs to identify and acquire data required to establish repair capabilities early in the acquisition process. DoD must also be ready to challenge assertions that unmanned systems were developed exclusively at private expense, or at a minimum be prepared to aggressively assert its "Government purpose rights" (under the provisions of 10 USC 2320) to the technical data required to maintain these systems.[79]

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[75] 10 USC 2464, Core depot-level maintenance and repair capabilities.
[76] 10 USC 2366a, Major defense acquisition programs: certification required before Milestone A approval.
[77] 10 USC 2366b, Major defense acquisition programs: certification required before Milestone B or key decision point B approval, section (a)(3)(F).
[78] Ibid.
[79] 10 USC 2320, Rights in technical data.

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6.6 Sustainment Metrics and Performance-Based Logistics

Recent JCIDS guidance requires the establishment of a Sustainment KPP for all ACAT 1 programs in the capability development document and Capabilities Production Documents (CPDs) for the system.[80] ACAT II and below programs with materiel solutions are required to include the Sustainment KPP or sponsor-defined sustainment metrics. The Sustainment KPP is stated as a Materiel Availability threshold and objective and is supported by key system attributes for reliability and for Operations and Support (O&S) costs. Establishing these metrics early and tracking them throughout the life cycle of the program will help ensure that the programs can meet the warfighter's requirements at an affordable price. The flowdown of these metrics into performance-based logistics strategies to achieve operational effectiveness and system affordability is the preferred approach to systems support.[81]

Establishment of rigorous *reliability growth* programs to ensure that programs are meeting reliability thresholds has great potential to enhance the long-term affordability and availability of unmanned systems. Incorporating *design* features to enhance maintainability and supportability into future UAS has the potential to greatly increase readiness and lower O&S costs. Incorporating modularity and common interfaces that can accommodate integration of new sensor, weapons, and communication capabilities without requiring major platform redesigns and retrofits can potentially improve maintainability by simplifying the fault isolation, removal, and replacement of subsystems. In-flight diagnostic and prognostic technologies have the potential to improve repair turnaround and improve readiness. As the unmanned systems portfolios mature, responsible program executive offices (PEOs) and program offices can create opportunities for efficiencies by adopting policies and processes that encourage the use of common components and configuration elements, such as batteries, fasteners, electrical distribution panels, and support equipment. Commonality creates opportunities for common supply chains, sources of repair, and other product support elements.

6.7 Joint Logistics Integration

6.7.1 Unmanned Aircraft Systems

As the sustainment of UAS becomes more institutionalized within the organic support infrastructures for maintenance, supply, and transportation, the accomplishment of much of the field- and depot-level maintenance will transition from CLS to the Government and military. Because of similar platform characteristics, subsystems, and manufacturing and repair processes, there is great potential for UAS programs to team together to reduce investments and operations and maintenance costs. The use of tools such as public/private partnerships (PPPs) and performance-based logistics contracts should be explored as methods to reduce sustainment and infrastructure costs. Agreements across different programs and Services can also reduce the costs of establishing organic repair capabilities and incentivize increases in systems reliability. As a result of these efforts, overall O&S costs can be reduced.

To facilitate the identification of opportunities to reduce overall investment and O&S costs, the UAS Task Force has established a Logistics and Sustainment IPT with the Services. In

[80] CJCSI 3170.01, Joint Capabilities Integration and Development System, 19 January 2012.
[81] DoDI 5000.02, Operation of the Defense Acquisition System, 8 December 2008, pg 29, enclosure 2.

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FY2011, a depot WG was established to recommend depot sources of repair for UAS major subsystems. The group recommended the establishment of depot repair capabilities at a limited number of depots based on major subsystems to take advantage of existing depot capabilities and capacity (see Figure 35). The Joint Logistics Board endorsed the workload assignment consolidations and directed that Air Force avionics, ground electronic, software, and sensor workloads be further evaluated for potential consolidation. The recommendations resulted in rational depot source of repair assignments for UAS core workloads and generated large cost avoidances and savings.

UAS Organic Depot Maintenance Sources of Repair
Approved Consolidations

Commodity	CCAD	LEAD	TYAD	FRC E	FRC SE	FRC SW	OC-ALC	WR-ALC	OO-ALC
Airframes/Composite	A				N	N		N, AF	A, AF
Engine/Engine Components	A			N	N		A, N, AF		
Sensors (Electro-optic)			A		A, N, AF			AF*	
Sensors (Infared)			A		A, N, AF			AF*	
Hydraulics	A			N	N	N	AF		A, N, AF
Pneumatics	A			N			A, N, AF		A
Landing Gear	A			N	N	N			A, N, AF
Ground Station	A	A	A,N, AF			N		AF	AF
Ground Data Link			A,N,AF			N		AF	AF
Avionics			A	N	N	N		A, N, AF	AF*
Environmental		A		N	N	N	A, N, AF		
Fuel System Components	A			N	N	N	A, N, AF	AF	
Flight Controls	A			N	N	N		A, N, AF	
Targeting			A		A, N, AF				
Targeting (laser)			A		A, N, AF				
Radar (ground)			A, N, AF						
Radar (air)			A*			N		N, AF	
Software			RSA		NAWC			AF	AF
Communications (Ground)			A, N, AF			N		AF	
Propellers	A							A, N, AF	

Service Workload Designations: A = Army AF = Air Force N = Navy * = workloads fall in on existing repair capability

	Sources of Repair				Highlights:
Army	CCAD = Corpus Christi Army Depot	LEAD = Letterkenny Army Depot	TYAD = Tobyhanna Army Depot	RSA = Redstone Arsenal	Green = Approved
Navy	FRC E = Fleet Readiness Center East	FRC SE = Fleet Readiness Center Southeast	FRC SW = Fleet Readiness Center Southwest	NAWC = Naval Air Warfare Center	Red Circle = Considering
Air Force	OC-ALC = Oklahoma City Air Logistics Complex	OO-ALC = Ogden Air Logistics Complex	WR-ALC = Warner Robins Air Logistics Complex	AF = Air Force Sustainment Activity	Current: 1/30/13

Figure 35. Organic Depot Maintenance Sources of Repair Approved Consolidations

In FY2012, the Logistics and Sustainment IPT met to create a forum to discuss lessons learned and to foster sustainment synergies. The IPT has identified potentially high payoff strategies of creating partnerships with industry to support families of components, such as sensors and communication links common across the Services. The UAS programs are researching opportunities to use existing manned aircraft capabilities to sustain similar UAS components. The Air Force's Reaper program and the Army's Gray Eagle program will use the Navy's Fleet Repair Center Southeast, Jacksonville, Florida, repair capability for H60 helicopter MTS-A sensors to repair their MTS-B sensors.

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6.7.2 Unmanned Maritime Systems

The Navy is currently supporting UMS through a combination of OEM and organic support. In the next few years, the sustainment strategy and infrastructure for UMS must be formalized and standardized to gain better control of the supportability resources and become more responsive and effective. The quantities of USVs and UUVs being developed and fielded in the next decade demand that attention be given to effective system sustainment. An organic support infrastructure for configuration control, supply support, maintenance, storage, and transportation is essential to bring efficiencies and cost effectiveness to these critically important systems. A planning yard should be established for UMS.

6.7.3 Unmanned Ground Systems

For UGS, due to the tremendous amount of dollars invested into NSE to meet the warfighter capability gap for the current conflict, the Army's Capabilities Development for Rapid Transition process categorized NSE robots into three categories: 1) recommend POR, 2) retain to support in theater, and 3) terminate. The majority of the NSE robots fall into category 2. A significant quantity of NSE robotic systems has been purchased and is being maintained using other contingency operations dollars. These NSE robots have proven to provide a needed capability to the warfighter and have saved lives. Also, these NSE robotic systems provide some of the capabilities outlined in the documents of developing PORs that meet current and future operational commander's capability requirements, but these PORs are not scheduled to be fielded until FY2015 and beyond. The strategy is to utilize some of the NSE robots as a bridging capability to the PORs until the PORs are fielded, store them for future contingencies, or utilize them as training aids. Nevertheless, these NSE robots still require a sustainment package that can be provided by JRRF or the OEM.

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7 Training

7.1 The Need to Train

Training is a critical link in delivering warfighter capability. DoD can acquire and deliver the most technologically advanced equipment, but if the operators, maintainers, leaders, planners, users, and support personnel are not properly trained on the equipment or do not have a thorough understanding of its CONEMP, the advantages offered by this warfighting capability will be lost through its misapplication. A study by the Defense Science Board found that "U.S. armed forces have a training superiority that complements their technological superiority."[82] The report points out, however, that this superiority can be eroded if the acquisition process does not properly integrate training into equipment development, testing, and fielding. The criticality of acquisition and training integration is emphasized by the requirement for acquisition program managers to "work with the training community to develop options for individual, collective, and Joint training" as part of the acquisition process.[83] The report also emphasizes that failure to deliver adequate training venues, where needed, will negate technical superiorities of hardware. Operators, maintainers, users, support personnel, and leaders must, therefore, be properly trained at the appropriate levels and intervals throughout their careers using the optimum mix of live, virtual, and constructive or blended reality training domains so they can use equipment effectively and to its full design capability. This chapter describes the current state of training for unmanned systems, some of the challenges involved, and the way ahead.

7.2 Problem Statement

Unmanned systems have been a warfighting success story, but work must still be accomplished in the institutionalized training environment. As operations in Afghanistan draw down and decisions are made about which systems transfer to a peacetime footing, the Services will have to make serious decisions about training. These decisions will not be limited to simply stating recurring training requirements. Rather, the details of how the training will be implemented must be planned and weighed so that every training opportunity is maximized to offset its incurred costs. At play will be cultural and political realities; interacting dynamics of technology, policy, and regulation; and fiscal constraints. Failure to meet the training challenges will result in a loss of combat-gained experience and an inability to effectively employ these systems in the future.

7.3 Challenges to Training

Even with the success unmanned systems demonstrated on the battlefield, DoD faces challenges in training. These challenges, as discussed in 7.4, relate not only to the types of unmanned systems (e.g., UAS, UGS, UMS), but also to acquisition, regulations, technology, manpower and other assets, and policy and documentation. This discussion is by no means exhaustive or in any particular order of precedence. Furthermore, DoD fully expects that as new generations of unmanned systems develop, the variety of missions they perform expands, and

[82] Report of the Defense Science Board Task Force on Training Superiority & Training Surprise, OUSD(AT&L), Washington, DC, January 2001.
[83] DoDI 5000.02 Operation of the Defense Acquisition System, 8 December 2008, p.61.

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priorities change based on circumstances such as wartime, OPTEMPO, NAS restrictions, new challenges will arise.

7.4 Current Training Environment

Today's training environment for unmanned systems is similar to that characterized for logistics and sustainment, i.e., one of playing catch-up, in this case, to provide training support for the rapid fielding of unmanned systems. The term "disruptive technology" was coined by Clayton Christenson in 1995 to describe a situation where a technology introduces new priorities and value structures requiring significant structural adjustments to processes, organizations, and operational paradigms. The rapid development and fielding of large numbers and types of unmanned systems to meet expanding contingency needs is an example of a disruptive technology, which has resulted in significant challenges for the training community. The challenges presented by sheer unmanned systems numbers, diversity, and rapid fielding are complicated by the imminent drawdown of forces in theater and their return to a peacetime footing with a more stringent regulatory environment.

Improvements in joint operations integration, both at the individual and unit levels, are necessary to be able to employ combat capability synergistically:

- Operators must receive tailored training specific enough to support unique Service mission sets, yet broad enough to allow operators to integrate and contribute in a coalition environment.
- Training programs must adequately encompass initial qualification and proficiency/refresher training while also providing room to accommodate growth as technology and TTPs improve and evolve.
- Training programs must be integrated into the institutional base.

These challenges include such things as availability of resources, policy, and regulation. DoD is cognizant of these challenges and is making progress toward meeting them. In the future, the use of common equipment may also significantly reduce overall program costs and time to train.

7.4.1 Unmanned Aircraft Systems

UAS are fielded by all four Services. UAS training has undoubtedly received more attention than UGS and UMS training. Service training programs are at different stages of maturity; however, as unmanned systems have matured, so too have the Service training programs. In an effort to establish minimum levels of training across the Services, the Joint Staff developed CJCSI 3255.01, which serves as the foundational crewmember training enabler with the FAA toward UAS integration into the NAS.[84] To achieve initial manning levels and arrive at a steady-state throughput, the Services have used varying mixes of organic and nonorganic UAS training, a variety of approaches for the different groups of UAS, and various personnel strategies.

[84] CJCSI 3255.01, Joint Unmanned Aircraft Systems Minimum Training Standards.

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7.4.1.1 *Army*

The Army architecture for its Group 3 and above UAS operations includes an aircraft operator and a payload operator. The Army operates and maintains its RQ-7 Shadows, MQ-5 Hunters, and MQ-1C Gray Eagles. The 2nd Battalion, 13th Aviation Regiment (2–13th Aviation), formerly Army UAS Training Battalion (UASTB), located at Fort Huachuca, Arizona, conducts initial entry and military occupational specialty (MOS) training for all operators, maintainers, and leaders on Group 3 and above UAS. Operators attend a two-phase training program (see Figure 36) and receive a 15W MOS plus an additional skill identifier (ASI) for the aircraft they are qualified to operate. Maintainers attend a 17-week common UAS repairer course graduating with a 15E MOS, which qualifies them to maintain the Shadow. Additional courses and skill identifiers are required for qualification in Hunter and Gray Eagle maintenance. Additionally, 2-13th Aviation supports the Joint community by training Marine Corps and Navy UAS personnel. In FY2012, they trained more than 2,100 UAS personnel.[85]

The Raven is the Army's primary SUAS. Ravens are lightweight, man-portable, and operated and maintained by a single soldier. The Army's Maneuver Center of Excellence at Fort Benning, Georgia, currently conducts all Army Raven UAS training. As of 1 October 2012, the Army has transitioned to a SUAS Master Trainer program to train experienced operators at Fort Benning. These Master Trainers then return to their respective units to train SUAS operators at home station; this approach reduces the impact to the unit and enhances training flexibility. Uniformed instructor mobile training teams that deploy to units to deliver the syllabus are used to supplement training needs. Training is provided primarily to enlisted soldiers, but officers are also trained. Upon completion of the course, personnel are qualified to program, launch, fly, retrieve, and maintain Ravens. Qualification does not result, however, in the award of an MOS or Specialty Identifier.

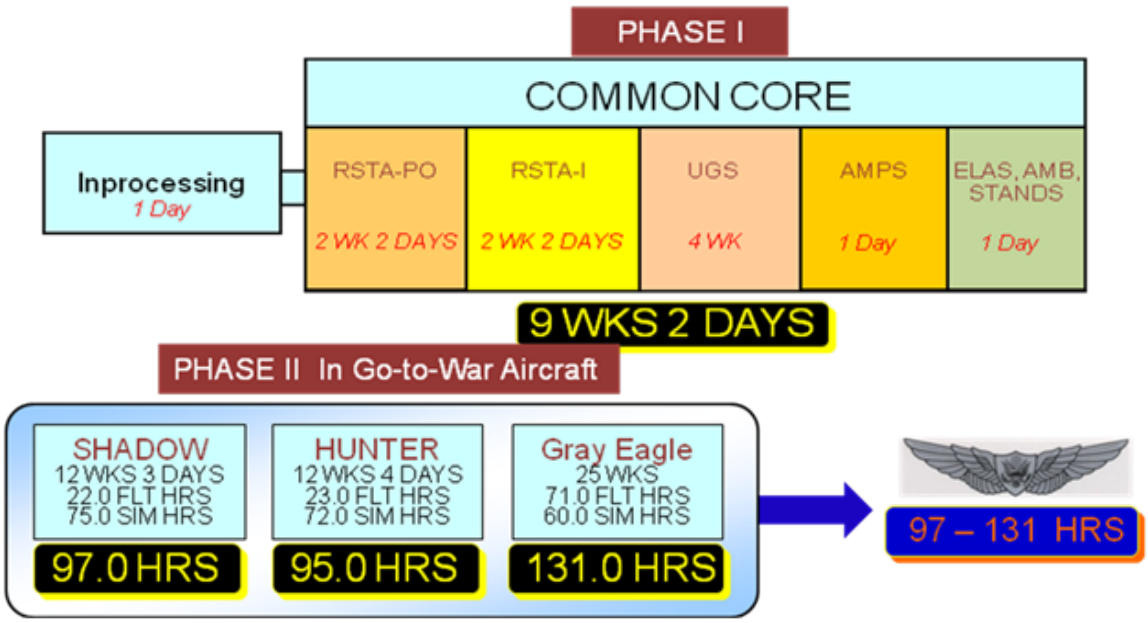


Figure 36. Army Group 3 and Above UAS Operator Training Flow

[85] Eyes of the Army, U.S. Army Unmanned Aircraft Systems Roadmap 2010-2035.

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7.4.1.2 *Marine Corps*

The Marine Corps uses a three-person crew for its RQ-7B Shadow training. The crew consists of an unmanned aircraft commander (UAC), an air vehicle operator (AVO), and a mission payload operator (MPO). RQ-21A Small Tactical Unmanned Aircraft Systems (STUAS) are crewed by a UAC and an AVO, who performs the MPO function as well. UACs are officers, while both AVOs and MPOs are enlisted positions. Currently, Marine Unmanned Aerial Vehicle Squadron (VMU) officers are sourced from the existing pool of qualified aviation officers; however, with the establishment of the VMU Officer Primary Military Occupational Specialty (PMOS), new second lieutenants will begin to be qualified as UACs. This dual sourcing strategy will continue until grade shaping of the MOS is achieved. AVOs and MPOs are sourced as entry-level positions, and each is also assigned a unique UAS MOS identifier.

The Marine Corps utilizes Army, Navy, and Air Force schools to train its VMU personnel, including maintenance personnel. The flow for Marine Corps Group 3 training is depicted in Figure 37. The Marine Corps is currently exploring the feasibility of standing up a UAS schoolhouse to standardize training for its RQ-7B and RQ-21A UACs, operators, and maintainers. This schoolhouse will build on joint training primary schools and maximize the use of simulation.

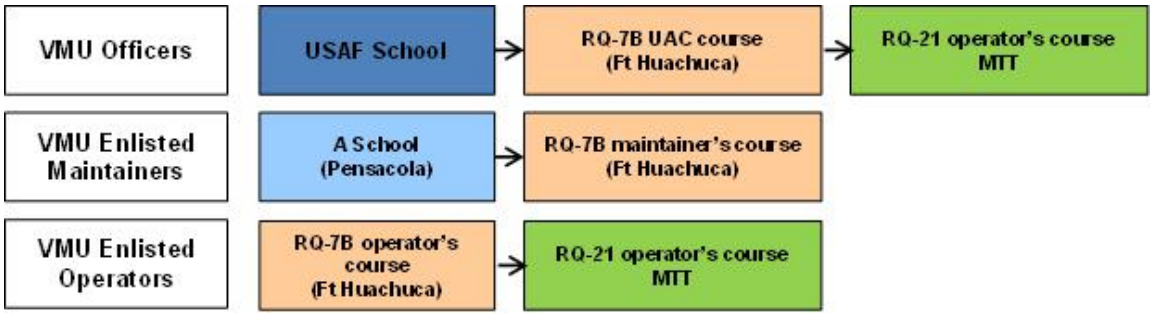


Figure 37. Current Marine Corps Group 3 UAS Operator Training Flow

In July 2012, the Marine Corps stood up a Group 1 SUAS training activity at Camp Lejeune, North Carolina, to provide standardized non-MOS training for enlisted Marine Corps operators of SUAS. One of the goals of this schoolhouse is to relieve the line units from the burdens of providing initial SUAS training for their operators. By providing a centralized schoolhouse co-located with 2nd Marine Division, efficiencies in training and logistics have been achieved. A similar SUAS training activity is planned for Camp Pendleton, California, in support of 1st Marine Division.

7.4.1.3 *Air Force*

The Air Force classifies its Groups 4 and 5 UAS (MQ-1 Predator, MQ-9 Reaper, and RQ-4 Global Hawk) as Remotely Piloted Aircraft (RPA). RPA pilot and sensor operator aircrews are formally trained to operate the aircraft. Officer RPA pilots are sourced from the current rated pilot community or through the newly established Undergraduate RPA Training (URT) program, similar to Specialized Undergraduate Pilot Training (SUPT) program for manned aircraft. URT is another dual accession strategy to reach initial USAF RPA manning requirements. Sensor operators are enlisted airmen sourced similarly to pilots, some from current intelligence career

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fields and others through the newly created RPA sensor operator career field. The Air Force created new career fields and associated specialty codes for both its new rated RPA pilots and sensor operators. The training flow for these positions is depicted in Figure 38 (NOTE: The formal training unit for the Global Hawk is at Beale AFB, California.)

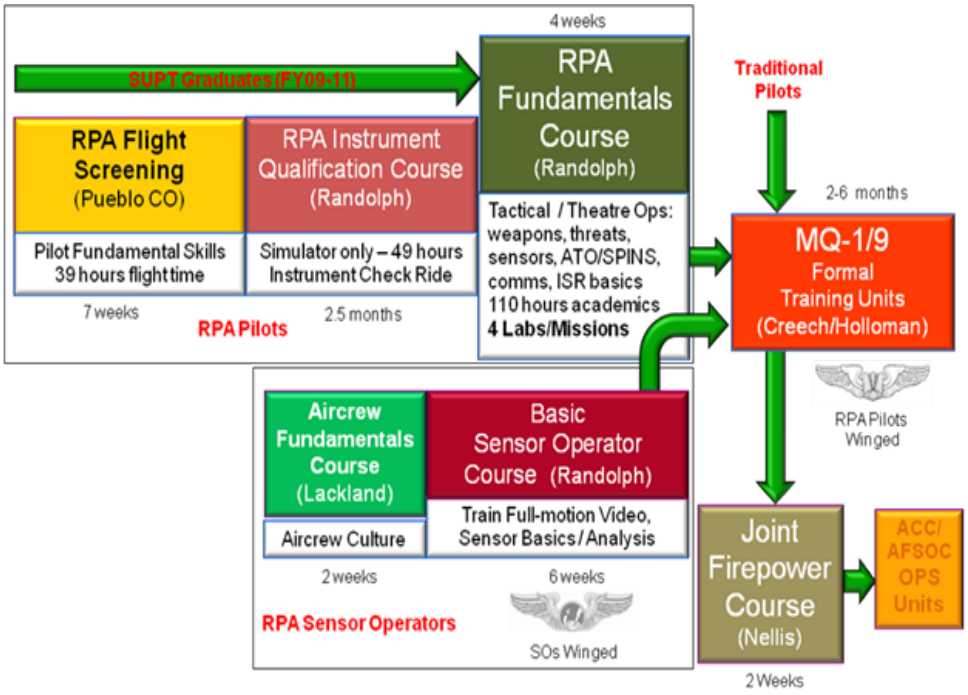


Figure 38. Air Force MQ-1/9 Pilot & Sensor Operator Training Flow

The Air Force has also created a Mission Intelligence Coordinator position to manage real-time/near-real-time intelligence information available to MQ-1/9 RPA pilots and/or sensor operators. Mission intelligence coordinators are sourced primarily from existing squadron intelligence positions and intelligence officer positions. Candidates undergo an initial qualification training course at either Creech AFB, Nevada, or March Air Reserve Base, California, and further mission qualification training at a squadron to attain mission-ready status.

Air Force RPA maintenance training is accomplished at three Air Force skill levels. RPA maintenance fundamentals are taught at the maintenance school at Sheppard AFB, Texas. Following RPA training at Sheppard AFB, initial and advanced skills maintenance training occurs at the operational RPA squadron.

The Air Force classifies its Groups 1 to 3 UAS, such as the Raven, Scan Eagle, and Shadow, as SUAS. They are operated by qualified SUAS operators, primarily enlisted airmen. These SUAS operators attend a formal, 10-day training course approved by Air Force Special Operations Command and conducted by Det 1, 371 SOCTS at the Eglin Range Complex in Florida. Curriculum has been developed and approved for the RQ-11B and is in development for the RQ-20A. SUAS operators are interchangeably qualified as vehicle operators and mission operators, the two crew positions required to operate the system. Qualification as an SUAS operator does not result, however, in the award of an Air Force Specialty Code or Special Experience Identifier.

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7.4.1.4 *Navy*

While the formal deliberative process for developing training to support emerging large-scale Navy PORs is in the infancy stage, the Navy has the advantage of drawing on lessons learned from the other Services. Current training during system development for PORs and rapid deployment capability efforts is being supported and provided by the associated program offices through contractor arrangements.

The Navy recently opened up a MQ-8 Fire Scout operator and maintainer training center at Naval Air Station Jacksonville. The aircraft and personnel are dual qualified in SH-60 Seahawks and assigned to mixed aviation squadrons containing both Seahawks and Fire Scouts. A similar organizational and basing construct is being examined for the MQ-4 Triton, the UAS complement for the Navy's fleet of P-3/8 aircraft to conduct ISR missions. Triton is currently operated at a demonstration level with training of initial operational evaluation crews slotted for late FY2014 followed a year later by initial cadre training. In June 2010, the Navy and Air Force signed a Triton and Global Hawk synergy memoranda of agreement (MOA) that specifies Navy and Air Force WGs to "Identify and incorporate every appropriate synergy in basing, maintenance, aircraft C2, training, logistics, and data requirements for processing, exploitation, and dissemination (PED) functions."[86]

Viable long-term training solutions for Navy systems are currently being developed within the framework of the basic UAS qualification standards outlined in the CJCSI 3255.01 and the Naval Education and Training Command Course Development and Revision Process.

7.4.1.5 *Continuation and Joint Training*

The focus of Service training efforts and strategy thus far has centered on developing initial skill sets and qualifying personnel to man a rapidly increasing UAS fleet. How to maintain and advance these skill sets through continuation training and education at the individual, crew, and collective levels has been largely overshadowed by the contingency environment. While Services have established currency requirements for their operators, currency is typically maintained through real-world operations rather than in a training environment. Furthermore, additional challenges impact domestic training. These challenges are being mitigated largely by the use of simulators and surrogates, but the full mix and balance of the live, virtual, and constructive domains and blended reality must be identified for the future.

Given that individual, crew, and collective continuation training constitutes the majority of training requirements and activity, the Services will need to continue efforts in these areas. These training programs are necessary to prepare operators for joint training and pre-deployment exercises.

While surrogates and virtual substitutes do address some challenges, the lack of home station UAS training opportunities and codified TTPs can limit the training experience of units preparing for deployment into theater. For example, combat training centers have observed units that were not adequately trained in UAS operations at home station prior to capstone training

[86] Memorandum of Agreement between Broad Area Maritime Surveillance (BAMS) and the RQ-4 Global Hawk system, signed 12 June 2010

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exercises. Such units routinely receive UAS hands-on immersion training following deployment into theater during mission execution.

Attempts are being made to incorporate unmanned systems into joint and multinational exercises at every level. As a high-demand/low-density asset, live unmanned systems are often unavailable for exercises and pre-deployment training. The use of manned surrogate platforms to replicate aspects of unmanned platform behavior, such as FMV feeds, is common and useful in ensuring the exercise participants are trained and familiar with unmanned systems capabilities when deployed. Additionally, exercise and pre-deployment training scenarios use computer-generated, simulated video feeds to support joint exercises and to ensure warfighters are able to incorporate unmanned systems into their training even when actual systems are not available.

7.4.2 Unmanned Ground Systems

The Army provides UGS training through the RS JPO. Headquartered in Warren, Michigan, the RS JPO's training mission is twofold: 1) to develop, integrate, and manage UGS training operations, requirements, plans, and products through partnerships with organizations and entities internal and external to the RS JPO and 2) to execute joint functional operator and technical training for COTS and POR systems to support force capability generation and unit resetting through mobile training teams and resident courses. Since its inception, RS JPO has been tasked as the equipment support activity manager for supporting the "in theater" and "training center" sustainment operations for UGS for the Army, Navy, Air Force, and Marine Corps. Currently, training is from neither a systems approach nor a MOS organizational construct identified or designated to perform the training function.

In 2004, the RS JPO established the JRRF in response to urgent operational needs and in support of the joint forces engaged in the theatre of operations for all Joint Service NSE robotic systems. The JRRF's support areas include in-theater sustainment support and individual and unit operations training of robotic systems. RS JPO conducts operator certification courses on all robotic systems currently fielded and intended for users in the theater of operations. Training is currently conducted at Fort Leonard Wood, Missouri; Selfridge Air National Guard Base (SANGB), Michigan; and unit home stations through mobile training teams.

The small robot certification course is a two-day course that provides the operator system uses, characteristics, capabilities, limitations, component identification, pre-mission mechanical and functions checks, and hands-on practical application. Personnel are required to successfully complete a practical exercise performance evaluation to obtain certification. The M160 operator course is six days long and currently conducted at Fort Leonard Wood.

All robot technicians are trained on tasks that are required for the repair and maintenance of robotic systems supported by RS JPO. This training is achieved via a 10-week robot maintenance and repair course currently taught at SANGB. The course totals 400 hours of training in which the technicians are certified to work on RS JPO-supported robotic systems. Technicians receive operator training and hands-on training in troubleshooting; removing and replacing line replaceable units on currently deployed robotic systems; and using maintainer tools, special tools, and test equipment to maintain robotic platforms.

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Due to increasing robotic sustainment and training demands, RS JPO opened the Robotic University at Fort Leonard Wood on 4 April 2012. This detachment consists of technician bays and classrooms, warehouse space, and office space. Robotic University is truly a one-stop-shop with the ability to repair, supply, and train robotic systems. The Robotics University and SANGB training sites, with their equipment, materials, technicians, and instructors, give service members the required skills and confidence in the robotics.

7.4.3 Unmanned Maritime Systems

The Navy currently has a number of UMS consisting of USVs and UUVs that perform a variety of missions including mine warfare, mine neutralization, reconnaissance, surveillance, hydrographic surveying, environmental analysis, special operations, and oceanographic research. These systems vary in size and displacement and run from man-portable systems to systems 40 feet in length and several thousand pounds in displacement. These systems are predominately launched from submarines or surface ships and recovered and maintained aboard those vessels. The new Littoral Combat Ship (LCS) employs the largest inventory of unmanned systems for a variety of missions including surface warfare (SUW), anti-submarine warfare (ASW), and mine countermeasures (MCM).

UMS training consists of an assortment of methodologies that provide an optimal learning environment and include classroom as well as hands-on training. Classroom instruction consists of the fundamentals of operation and maintenance while the hands-on training covers the practical application of that knowledge. Follow-on and refresher training is provided by computer-based training (CBT) that includes online simulations of actual operations. Training is conducted at the appropriate training center, such as the Mine Warfare Training Center in San Diego, California, or at the Warfare Center that is the core support center for the specific system.

LCS Detachments consisting of up to 15 officers and technicians are assigned to LCS for each of the respective Mission Modules (i.e., SUW, ASW, MCM) and undergo classroom and hands-on training before boarding LCS for a deployment. As the personnel rotate on and off one LCS to other assignments and then back again, refresher training is provided at the Shore Based Trainer in San Diego. It includes individual CBT consoles and team training consoles to help sharpen previously learned skills. There are also CBT modules that can be downloaded for continuous training while aboard the LCS. Additional training centers will be established in Fort Lauderdale, Florida, and at various overseas locations as warranted to maintain detachment proficiency.

7.4.4 The Acquisition Process

Much has already been said in this document about the challenges created by the rapid acquisition of unmanned systems in response to urgent operational needs. As the immediacy of urgent operational needs begins to slow, the unmanned systems acquisition process will begin to normalize. As requirements for new generations of unmanned systems are generated, training must be developed concurrently with the new systems. Associated costs should be appropriately addressed across the program life cycle. The training KPP is required to eliminate ad hoc training systems at delivery.

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7.4.5 The Regulatory Environment

The regulatory environment is a unique challenge to unmanned systems operations, particularly in peacetime. While all systems are governed by regulatory requirements of one sort or another, unmanned systems bring with them an additional set of procedural and safety concerns because they are *unmanned*. These concerns are further increased with discussions of system autonomy. Much attention is being given to UAS autonomy, but it is not unique to UAS. How to train with an unmanned truck, for example, designed to move along roadways in a combat environment presents challenges when trying to traverse the U.S. interstate system and local county roads. Regulatory oversight may have the most significant impact on basing decisions and training operations, especially for UAS.

7.4.6 Technology

Technology challenges for training can be grouped into two categories: 1) the need to train to new missions and affiliated technologies and 2) technology impacts on training. New missions, hardware developments, and software integration appear to be endless. Each has to be accompanied by associated training. For example, access to airspace may be enhanced by SAA technologies that open up more opportunities for live training. Conversely, high-fidelity simulators and the availability of surrogate platforms could lessen the dependence on live training. Some technology impacts may not be so direct, but may be important none the less. For instance, a common control system not only has a training component, but could also lessen manpower requirements by leveraging the ability of a single operator to control multiple systems simultaneously. As a result, training throughput requirements and manpower resources could be decreased.

7.4.7 Manpower

Training faces several manpower challenges. First is the need for a sufficient instructor cadre. With ongoing contingency operations, qualified and potential instructors are often unavailable. Second, the Services have to address personnel qualifications and requirements, to adjust force structure, and to revise personnel processes to accommodate the new technologies. These actions affect the training audience. The coordination and integration of operators, force structure, and data analysts impact how training is accomplished and how training affects human resources. Manpower considerations for training must be fully explored to attain mission efficiencies and readiness.

7.4.8 Asset Availability

Adequate training resources are another challenge. First, similar to unavailability of instructors because of real-world operations, actual unmanned system platforms are often not available for training. This lack of platforms can be mitigated by leveraging the use of simulation and surrogates. Second, programs need training capability assets, such as realistic target sets in representative terrain, runways, scoring and feedback systems for crewmember after action reviews, access to airspace and frequency spectrum, simulators and surrogates, communications infrastructure, and C2 organizations and processes at ranges. Low-cost training munitions that replicate the service munitions of weaponized platforms will also need to be developed to facilitate realistic training within budgetary constraints and installation range limitations. These

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assets can be integrated into training requirements and plans. Moreover, the assets can influence basing decisions, operations, and funding strategies.

7.4.9 Policy and Documentation

Processes for capturing lessons learned and developing Service and joint doctrine and TTPs must be established and institutionalized through policy and documentation. Policy and documentation serve as the basis from which the Services develop training CONOPS, requirements, and plans. DoD, Service, and Joint plans identify and describe how the populations will be exposed to unmanned systems through professional military education and training. Training strategies for weaponized unmanned systems must identify the types and quantities of munitions required to maintain operator, crew, or unit proficiency in a training environment. Additionally, policy, documentation, and plans codify career paths and expectations for unmanned systems leaders, operators, planners, maintainers, and users.

7.5 The Way Ahead

Despite the challenges introduced by the rapid acquisition and fielding of unmanned systems, these systems are providing valuable capabilities to CCDRs today. Introduction of new systems and processes are traditionally fraught with growing pains, including in training. It is through their perseverance, ingenuity, and professionalism that our soldiers, sailors, airmen, and marines can adjust to ever-changing circumstances to maintain mission readiness and combat effectiveness. As DoD moves toward an environment where unmanned systems needs are more mature and the acquisition process normalizes, training processes and systems will also mature. While the real-world environment flexes with real-world contingencies and the realities of domestic unmanned systems training become more imminent, DoD is addressing training challenges as follows:

- The requirement and acquisition processes will continue to be reviewed for inclusion of training plans throughout a program's development to help improve the rapid acquisition process. Current policy requires a draft training plan at each acquisition milestone. Additionally, new policy is being developed to strengthen those requirements and provide guidance for developing training for rapid acquisition programs. The policy will also offer a training plan template for the Services to support an appropriate training strategy.
- Organizations within DoD are working with regulators, other government organizations, and industry on how to safely incorporate these new technologies into today's world on an ongoing basis. For example, the Airspace Integration IPT and UAS ExCom, discussed in Chapter 5, will continue to implement products and activities to incrementally gain access to the NAS with the goal of attaining the level of UAS access to the NAS necessary to complete training and readiness requirements.
- Training plans will be developed and updated to reflect modifications to legacy systems and introduction of new systems. DoD will continue to develop SAA technologies to gain access to the NAS, increase commonality across control systems, increase autonomy of systems, and align fidelity of simulators for appropriate phases of training. Additionally, long-term success can be economically achieved with increased commonality of hardware to reduce unnecessary unique systems training.

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- As forces redeploy, the availability of instructors to fill training positions at all levels is expected to increase. As initial manning quotas are met, cross-flow accessions will be curtailed, and schoolhouses will transition to steady-state throughputs. As newly established career fields grow, season, and develop, experience levels will increase and normalize, similar to other career fields across the forces. Personnel systems will continue to align to the new technologies and mature.
- As forces return to home station from the current operational contingencies, decisions will be made about which systems become enduring PORs and transition back with the forces. It is envisioned that the redeployment will increase the availability of assets for training. Service and Joint training plans will need to mature and add the specificity needed to make prudent basing and resourcing decisions that enable effective training.
- Service roadmaps will continue to evolve and mature along with the doctrine, training plans, and documentation needed to support robust training systems. Emphasis will be put on fostering jointness and incorporating cross-service participation during exercises. A comprehensive training strategy will be developed to guide the myriad of efforts across DoD and help ensure effective and efficient training. The strategy will leverage work already completed or underway within the Services and Joint Staff. Its scope will be broad to address the totality of UAS training, from the smallest to the largest systems, at all echelons, for all appropriate personnel, and across the training continuum.

A notional timeline for UAS training objectives is presented in Figure 39 and will be further refined upon completion of the UAS training strategy in FY2013. By overcoming these training challenges and developing a DoD-wide training strategy, future unmanned systems will deliver more effective warfighting capabilities to the battlefields of tomorrow.

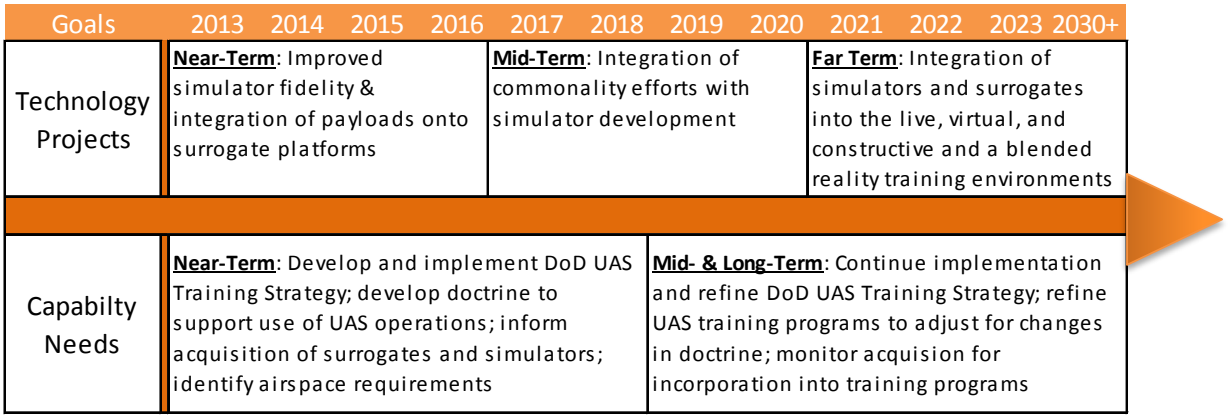


Figure 39. UAS Training Objectives

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8 International Cooperation

8.1 Introduction

DoD international cooperation efforts include the cooperative research, development, test, and evaluation of defense technologies and systems with foreign partners as well as the procurement of defense articles, systems, and services from foreign partners. It also includes participation in NATO capability groups. The objectives of international cooperation are

- ***Operational.*** To increase military effectiveness through interoperability and partnership with allies and coalition partners.
- ***Economic.*** To reduce weapons acquisition cost and achieve better buying power by sharing costs and economies of scale, avoiding duplication of development efforts, and cooperatively producing or selling more weapons systems to our allies and friends.
- ***Technical.*** To access the best defense technology worldwide and minimize the capabilities gap with allies and coalition partners.
- ***Political.*** To strengthen alliances and relationships with other friendly countries.
- ***Industrial.*** To bolster domestic and allied defense industrial bases.

8.2 Methods of International Cooperation

Three primary methods are used for international cooperation:

- International agreements such as memoranda of agreement/understanding (MOAs/MOUs) aimed at joint research, development, and/or procurement of, or investment in, new defense technologies and systems
- Foreign military sales (FMS)
- Direct commercial sales (DCS)

8.2.1 MOAs and MOUs

DoD has entered into bilateral and multilateral agreements with a variety of international partners for the joint development of defense technologies and systems. Under such agreements, DoD works with its foreign counterparts and shares existing technology, expertise, and resources to develop new technical information; develop new technology, defense systems, or platforms; or improve existing products. DoD has entered into several such international cooperative agreements with foreign partners to advance UAS. For example, The Technical Cooperation Program (TTCP), a collaborative defense S&T program involving the United States, Great Britain, Canada, Australia, and New Zealand, was established to familiarize all partners with each other's national defense S&T programs and to cooperate in a broad range of defense S&T activities and projects. The results of TTCP activities assist each participant in meeting defense requirements, while avoiding unnecessary duplication of effort. The participants of TTCP have an active UAS program to share and conduct joint experiments in areas such as autonomous C2, novel aircraft configurations and systems, UAS self-protection, and counter-UAS. This activity has spawned an International Operators' Group, which includes both operators and researchers to identify and address pervasive issues, as well as a number of bilateral agreements with individual nations.

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8.2.2 Foreign Military Sales (FMS)

The FMS program is the U.S. Government's program for transferring defense articles, services, and training to other sovereign nations and international organizations. Under FMS, DoD procures defense articles and services on behalf of the foreign customer using the same acquisition process DoD uses for its own military needs. Countries approved to participate in this program may obtain defense articles, services, or training by paying with their own national funds or with funds provided through U.S. Government-sponsored assistance programs. In certain cases, defense articles, services, and training may be obtained on a grant basis. The Defense Security Cooperation Agency administers the FMS program for DoD. FMS cases must be reviewed/approved through the Department of State (DoS), and, in some cases, the U.S. Congress must be notified through the Congressional Notification process. In general, these government-to-government purchase agreements tend to ensure standardization with U.S. forces, provide contract administration services that may not be available through the private sector, and help lower unit costs by consolidating purchases for FMS customers with purchases for DoD.

8.2.3 Direct Commercial Sales (DCS)

Under DCS, U.S. companies obtain commercial export licenses from either DoS (for munition items) or the Department of Commerce (DoC) (for dual-use items). These licenses allow the companies to negotiate sales directly with foreign customers. All DCS are subject to the approval of DoS or DoC and, in some cases, the U.S. Congress and must comply with applicable U.S. exports laws and regulations. DCS allows the foreign customer more direct involvement during contract negotiation, may allow firm-fixed pricing, and may be better suited to fulfilling nonstandard requirements.

8.2.4 NATO

The military alliance promotes cooperation and interoperability through information exchange and the development of standards (see http://nsa.nato.int/nsa). For example, airworthiness standards have been developed and adopted by member nations and are being incorporated in MIL-HDBK-516B.[87] Additionally, the alliance is acquiring (under DCS) the NATO Alliance Ground Surveillance (AGS) System, a derivative of the U.S. Global Hawk system. Five Europe-based AGS aircraft will serve alliance missions and, in turn, reduce demand for U.S. ISR systems to meet NATO requirements. See Appendices B and C of this roadmap for additional information on alliance standards, and see the publication AAP-03[88] for established procedures for the production, maintenance, and management of NATO standardization documents in accordance with NATO regulations.

8.3 International Cooperation Authority, Jurisdiction, Approval, and Disclosure

The U.S. Government has split export licensing authority for FMS and DCS among multiple organizations. The two primary Government regulations are the International Traffic in

[87] MIL-HDBK-516B, Airworthiness Certification Criteria.
[88] AAP-03, Production, Maintenance and Management of NATO Standardization Documents, Edition J, Version 2, November 2011 (http://nsa.nato.int/nsa).

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Arms Regulation (ITAR), which controls defense articles and services under the jurisdiction of DoS, and the Export Administration Regulation (EAR), which controls dual-use items under the jurisdiction of DoC.

8.3.1 Authority and Jurisdiction

8.3.1.1 International Traffic in Arms Regulation (ITAR)

The Arms Export Control Act (22 U.S.C. 2778) authorizes the President to control the export and import of defense articles and services. Pursuant to Executive Order 11958, this statutory authority was delegated to the DoS. ITAR implements that authority and is the governing regulation controlling the export of defense articles and services. ITAR includes the U.S. Munitions List, a list of defense articles controlled by ITAR. It further defines the export licensing requirements and procedures needed to export a defense article or perform a defense service as well as the process to determine the jurisdiction of a commodity (i.e., whether an item is controlled under ITAR or EAR).

ITAR provides a number of exemptions to the licensing requirements for defense articles and services. Many of these exemptions are country specific (e.g., through implementation of UK and Australian defense trade treaties, the Canadian exemption) while others are transaction specific (e.g., shipments by or for U.S. Government agencies). Most ITAR exemptions have rigorous procedures, documentation, and record-keeping requirements associated with their implementation. Each of the U.S. military services, as well as other select DoD organizations, has been delegated limited export authority by the DoS.

8.3.1.2 Export Administration Regulation (EAR)

EAR implements the Export Administration Act (EAA) of 1979. DoC has statutory authority for implementing EAA, which governs the export of the dual-use items identified in EAR's Commodity Control List (CCL). "Dual use" refers to EAR-controlled items that can be used both in military and other strategic uses and in civil applications and are distinguished from items with weapon and military-related use or design that are subject to DoS control or the Department of Energy's nuclear-related controls. EAR delineates license requirements for dual-use controls and, similar to the ITAR, provides for licensing exemptions. Note that not all items on the CCL require a license for release to all countries, and some commodities not specifically listed on the CCL could require an export license for select end uses and end users.

8.3.1.3 Foreign Disclosure

Decisions to disclose classified military information are often tied to security assistance and arms cooperation programs or to the transfer of defense articles; therefore, the National Disclosure Policy (NDP-1) must be in compliance with the provisions of the Arms Export Control Act and the Conventional Arms Transfer Policy. The release of classified military information for all U.S. Government disclosure activities must support U.S. foreign policy and military objectives. The basis for the release or denial of classified military information is twofold: a judgment by designated disclosure authorities that 1) the foreign recipient has the capacity and intent to provide adequate security protection to the information and 2) the national interest (foreign policy or military) will benefit.

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The policy provides for operation by exception. Exceptions to the policy may be decided by the Secretaries of State and Defense, their principal deputies, or the National Disclosure Policy Committee (NDPC). In most instances, the NDPC grants exceptions to policy. After deliberation by the NDPC, disclosure authority is delegated to the heads of departments and agencies responsible for the information within certain security classification limits (e.g., top secret, secret, or confidential) for specified categories of classified military information. Considered in establishing these limits for each country or international organization are the following factors:

- Evaluation of the capability to protect the information based on a favorable NDPC security survey and/or a Central Intelligence Agency assessment of the risk to the information
- Existence of a formal government-to-government security agreement providing for the protection of the information
- Existence of a mutual defense or similar arrangement
- Frequency of disclosure

8.3.2 Approval and Disclosure

8.3.2.1 Technology Security

DoD has created 12 technology security review processes. Each process has responsibility for select technologies. For example, these processes include low-observable and counter-low-observable technology, GEOINT, communications security (COMSEC) devices, intelligence data, GPS, data links and waveforms, and night vision devices. Prior to the export (or implied export) of any item or technology controlled by the various technology security processes, the responsible process must be engaged and provide its concurrence with the proposed transfer.

8.3.2.2 Conventional Arms Transfer (CAT) Policy

The CAT policy is the standing Presidential policy guidance on arms transfers.[89] It is intended to promote restraint in the transfer of U.S. weapons systems, while supporting U.S. national security and foreign policy objectives and meeting the legitimate defense requirements of allied and friendly nations. DoS is responsible for articulating this policy and plays a major role in any proposed changes to it. DoS action officers use the CAT policy in case-by-case reviews of proposed transfers to determine whether a particular transfer of military equipment and/or services meets the 12 criteria established by the policy. This list of criteria can be found at http://www.state.gov/t/pm/rsat/c14023.htm.

8.3.2.3 Congressional Notifications

Pursuant to Section 36(b) of the Arms Export Control Act, the Executive Branch is required to formally notify the Senate Foreign Relations Committee and the House Foreign Affairs Committee when a potential FMS meets or exceeds specified dollar thresholds. Bureau of Political-Military Affairs Office of Regional Security and Arms Transfer (PM/RSAT) officers

[89] Presidential Decision Directive 34 (PDD-34), Conventional Arms Transfer Policy, 17 February 1995.

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work with Bureau leadership and DoD to make the required notifications, including briefing Congressional staff on the potential arms sale and how it will serve U.S. interests.

8.4 Special UAS-Related Considerations

In addition to the above general constraints, certain considerations are unique to UAS, i.e., they normally do not apply to other unmanned systems.

8.4.1 Missile Technology Control Regime (MTCR)

MTCR is an informal and voluntary association of countries that share the goals of nonproliferation of unmanned delivery systems capable of delivering WMDs and that seek to coordinate national export licensing efforts aimed at preventing WMD proliferation. MTCR rests on adherence to common export policy guidelines that are applied to an integral common list of controlled items. The greatest restraint (i.e., "a strong presumption of denial") is applied to what are known as "Category I items." These items include UAS with capabilities exceeding a 300 km/500 kg range/payload threshold, the production facilities for such systems, and any major subsystems.

8.4.2 Armed UAS

DoD and DoS both place a high level of scrutiny on the export of armed UAS. In addition, the U.S. Congress has previously expressed reservations over the release of armed UAS to any but our closest allies.

8.5 Reform Efforts

The U.S. Government and DoD have initiated a wide variety of reform efforts that will affect the DoD processes and procedures involved in international cooperation. Although not an exhaustive list, 8.5.1 through 8.5.4 highlight some of the current major reform efforts that will likely affect international cooperation related to unmanned systems.

8.5.1 Security Cooperation Reform

The FY12–16 Defense Planning and Programming Guidance[90] called for establishing a task force to conduct a comprehensive review of DoD's security cooperation processes. Specific requirements included the development of options for adjusting the operational direction, control, and authority of agencies implementing security assistance; options for aligning and streamlining security assistance and technology transfer processes, organizations, and regulations; a plan to implement a certification curriculum for security cooperation professionals similar to that for the defense acquisition workforce; and a plan to consider authorities, alignment of planning and resources, organizational change, and key processes. After analysis and outreach, the Security Cooperation Reform Task Force (SCRTF) revealed a series of findings and took a two-pronged approach to build an "anticipatory" system with a "fast-track" capability for urgent partner needs.

[90] FY12–16 Defense Planning and Programming Guidance, para. 6.3, Reform Security Cooperation (U), pg. 30, 20 May 2010.

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SCRTF identified a set of 58 recommendations across five focus areas: planning, FMS process (i.e., contracting, procurement, transportation, and distribution) improvement, accelerated delivery, workforce development (training and education), and technology security and foreign disclosure.

In July 2011, SECDEF directed that the SCRTF recommendations be implemented and that SCRTF — under the direction of the Chairman of the Joint Chiefs of Staff and the USD(Policy) — oversee implementation of the recommendations in the report.

8.5.2 Defense Exportability Features (DEF)

The DEF program is intended to ensure that the design and engineering of export variants of U.S. systems are initiated early in the acquisition process to increase the security of sensitive U.S. technology, avoid the high cost of developing an export variant from a fully engineered and implemented U.S. system, and achieve better buying power through the economies of scales realized through increased international procurement. The DEF pilot program was authorized in the FY2011 National Defense Authorization Act. In FY2012, four programs, including a Navy UAS, conducted DEF feasibility studies. These assessments identify the potential benefits and costs of providing protection to critical program information for the export variants in the design.

8.5.3 Export Control Reform (ECR) Initiative

In August 2009, the President directed a broad-based interagency review of the U.S. export control system, with the goal of strengthening national security and the competitiveness of key U.S. manufacturing and technology sectors by focusing on current threats and adapting to the changing economic and technological landscape. This review determined that the current export control system is overly complicated, contains too many redundancies, and, in trying to protect too much, diminishes our ability to focus our efforts on the most critical national security priorities. The Administration has determined that fundamental reform of the current system is necessary to overcome the inefficiencies and redundancies of a set of systems within a system.

As a result, the Administration launched the ECR Initiative, which is a common sense approach to overhauling the nation’s export control system. The ECR Initiative, which is not related to the President’s National Export Initiative, is designed to enhance U.S. national security and strengthen the ability of the United States to counter threats such as the proliferation of WMDs. The purpose of export controls is to ensure that items do not end up in the hands of someone who intends to harm the United States or its allies. It is a risk-based system, where items are generally authorized for export to low-risk destinations, while other items may be allowed to other destinations after closer scrutiny and some items may be denied.

The Administration is implementing the reform in three phases. Phases I and II reconcile various definitions, regulations, and policies for export controls, while building toward Phase III, which will create a single control list, single licensing agency, unified IT system, and enforcement coordination center. This implementation plan is designed to resolve core problems first, before focusing on Government reorganization. The consolidation plan in the final phase would eliminate the need to keep the systems within a system fully synchronized, by eliminating these separate systems. This common sense approach is good government, especially in this era of tightening budgets.

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8.5.4 Technology Security and Foreign Disclosure (TS&FD)

The Export Control Reform Task Force Report (issued 29 January 2010) recommended the initiation of an effort "to streamline and harmonize" U.S. Government TS&FD processes. As a result, the Deputy Secretary of Defense tasked USD(AT&L) and USD(Policy) to conduct a review of DoD-led TS&FD processes and provide alternative TS&FD system concepts to enhance transparency, predictability, and timeliness while maintaining the overall high quality of U.S. Government decision making in this key area.

The U.S. Government currently has 13 separate, internal TS&FD processes in which DoD either leads or is a key participant. These processes are generally reactive in nature and do not anticipate building partner nation capacity requirements. Since these processes are neither integrated nor harmonized with each other, the lack of transparency and predictability in the U.S. Government TS&FD decision-making processes makes it difficult to synchronize U.S. Government activities to build partner nation capacity, which includes Washington arena, country team, CCDR, partner nation, and U.S. and foreign industry involvement.

DoD's current TS&FD activities are focused on three areas:

- Establishing a TS&FD office to serve as the central processing organization of DoD decisions that affect DoD aspects of TS&FD release requests.
- Developing and issuing revised DoD and U.S. Government policy guidance to consolidate and restructure current U.S. Government TS&FD decision-making processes to enhance the quality, timeliness, and efficiency of DoD's overall TS&FD decision making.
- Implementing overarching improvements in DoD for building partner nation capacity, defense exportability features, industry and partner outreach, and DoD workforce initiatives oriented toward proactive — rather that purely reactive — TS&FD decision making.

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9 Summary

While DoD unmanned systems development funding may taper off over the early part of this decade, unmanned capabilities hold much promise for domestic commercial applications and personal consumer use. This trend could indeed reduce the price point of these systems for the military, which is good news for the U.S. taxpayer. However, if the technical challenges to unmanned systems development and operations are addressed by accomplishing the technical projects and tasks described in this roadmap, advances in capability can be readily achieved by the Services well beyond what is achievable today. See Figure 40.

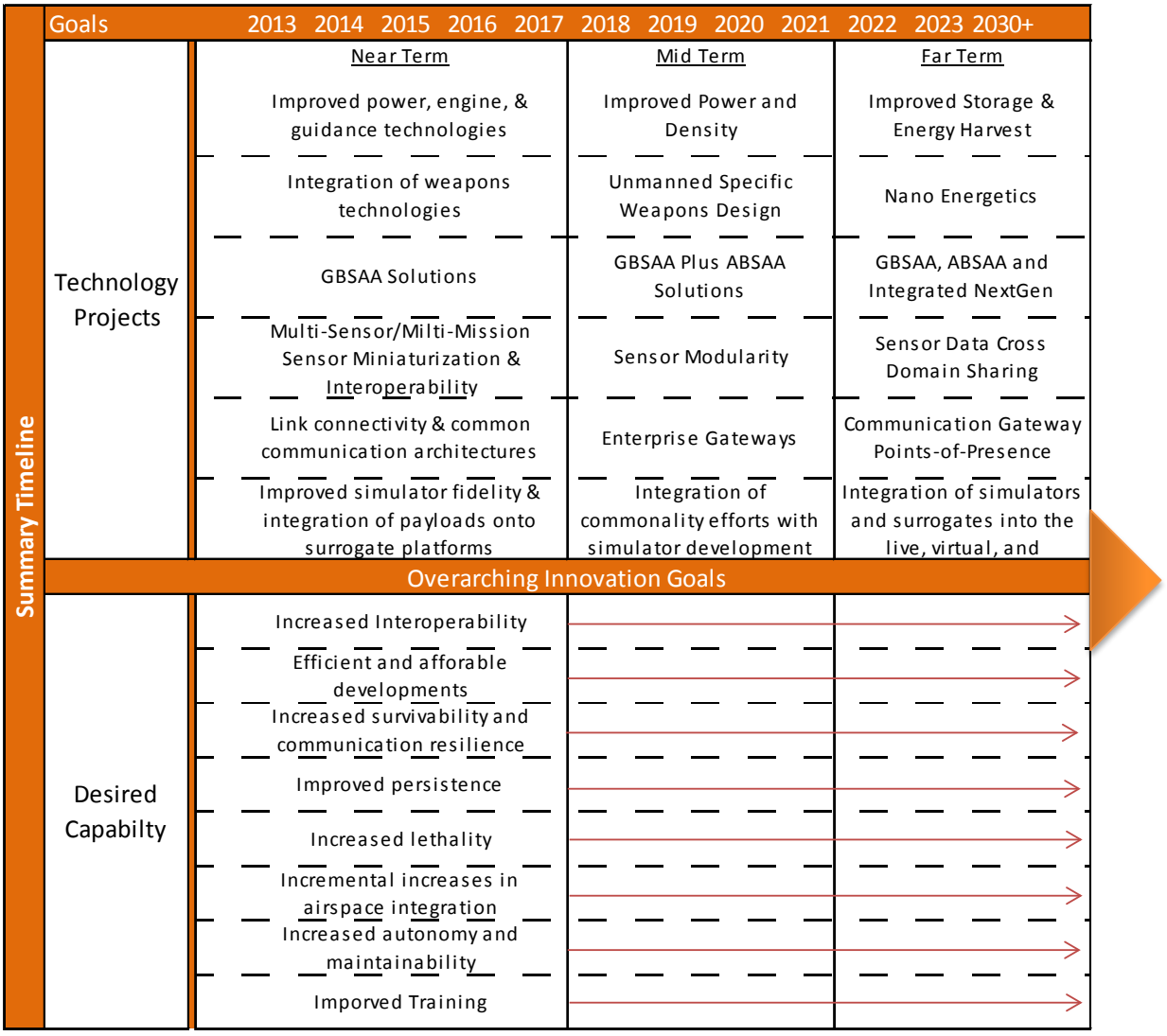


Figure 40. Overarching Innovation Goals Timeline

As the unmanned industry moves toward more deliberate and traditional program developments, it is imperative these future capabilities be addressed by the Service requirements managers as new programs are initiated. Working together with industry, academia, and other agencies, DoD will continue to map an affordable path using emerging technologies as a basis for future warfighter capabilities.

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Committee on National Security Systems (CNSS) Policy (CNSSP) 15.

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"Fiscal Year 2012 President's Budget Request (PBR) for the DoD S&T Program," briefing, Mr. Bob Baker, Deputy Director, Plans & Programs, Assistant Secretary of Defense & Engineering, 21 June 2011.

"FY12–16 Defense Planning and Programming Guidance," 20 May 2010.

International Telecommunication Union (ITU), *Radio Regulations*, Geneva, Switzerland. 2007 Edition.

Joint CONOPS for UAS, Third Edition, November 2011.

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Lundberg, Kent H., *High-Speed Analog-to-Digital Converter Survey*, MIT Press, 2002.

Naval Science and Technology Strategic Plan, Office of Naval Research, September 2011.

National Telecommunications and Information Administration (NTIA), *Manual of Regulations and Procedures for Federal Radio Frequency Management*, Washington, DC, January 2008 edition, September 2009 revision.

Presidential Decision Directive 34 (PDD-34), Conventional Arms Transfer Policy, 17 February 1995.

"Quadrennial Defense Review Report," Department of Defense, February 2010.

Report of the Defense Science Board Task Force on Training Superiority & Training Surprise, OUSD(AT&L), Washington, DC, January 2001.

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"Teal Group Predicts Worldwide UAV Market Will Total $89 Billion in Its 2012 UAV Market Profile and Forecast," *Press Release Newswire,* United Business Media, 11 April 2012.

"Terms of Reference-Defense Science Board Study on Technology and Innovation Enablers for Superiority in 2030," USD(AT&L) Memorandum, 15 March 2012.

Unmanned ground systems roadmap, Robotic Systems Joint Program Office, July 2011.

Unmanned Interoperability Initiative (UI2) Capability Based Assessment, 1 March 2012 and 14 May 2012.

Unmanned Systems Integrated Roadmap FY2011-2036.

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Appendix B PRIORITY INTEROPERABILITY STANDARDS

The list of standards below is not all-inclusive; rather the list focuses on priority standards for joint interoperability and UI2 CBA gaps. To be effective, policy and standards require DAE and SAE commitment, oversight, and enforcement prior to approving applicable JCIDS milestones (and DoD architecture framework products), Interoperability Certification and Information Support Plans (ISP). These priorities will be updated during biannual reviews of this Roadmap (or sooner by exception).

- **USIP 1.1 Line of Sight Transmission of Motion Imagery for Battlespace Awareness Using Standard Common Data Link.** Mandated standard available on DISR, 30 November 2010. Interoperability Profiles (IOPs):

  IP 1.1: Motion Imagery for Situational Awareness Governing Standards. These standards are the basis for the implementation and take precedence.
  - ✓ MISP 5.1, Motion Imagery Standards Profile, December 2008
  - ✓ Motion Imagery Standards Board (MISB) Standard 0601.2 UAS Datalink Local Metadata Set, October 2008
  - ✓ MISB EG 0902, MISB Minimum Metadata Set, May 2009
  - ✓ IETF RFC 0768, User Datagram Protocol, August 1980
  - ✓ IETF RFC 0791, Internet Protocol (IPv4), September 1981

  Other Applicable Standards. These references are cited by the governing standards and provide further specification detail to completely define the implementation.

  - ✓ MISB Standard 0807, DoD/I/NSG Motion Imagery Metadata Registry
  - ✓ MISB Standard 0604, Time Stamping Compressed Motion Imagery
  - ✓ MISB Standard 0102.5, Security Metadata Universal and Local Data Sets for Digital Motion Imagery
  - ✓ MISB RP 0603, Common Time Reference for Digital Motion Imagery Using Coordinated Universal Time
  - ✓ MISP RP 0903, Video Moving Target Indicator Local Data Set
  - ✓ ISO/IEC 13818-1:2007, Information Technology — Generic Coding of Moving Pictures and Associated Audio Information: Systems
  - ✓ SMPTE 335M-2001, Metadata Dictionary Structure
  - ✓ SMPTE 336M-2007, Data Encoding Protocol Using Key-Length Value
  - ✓ SMPTE RP210.10-2007, Metadata Dictionary Registry of Metadata Element Descriptions
  - ✓ NGA.STND.0024-2_1.0, Sensor Independent Complex Data (SICD) for complex SAR imagery
  - ✓ NATO STANAG 4676, NATO Intelligence, Surveillance, Reconnaissance Tracking Standard (NITS)—Key enabler for UAS information fusion, currently used to “make sense” of GMTI “dots”
  - ✓ NATO STANAG 4607, Ground Moving Target Indication Format (GMTIF)
  - ✓ NATO STANAG 4559, NATO Standard Image Library Interface (NSILI)—currently edition 3, the next edition will be XML capable—used to share and expose data between systems

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- ✓ NATO STANAG 3277, Joint ISR Task and Request Data Format—cross-cue and sensor task request implementation
- ✓ Theater Net-centric Geo-location (TNG) Joint Interface Control Document (JICD)—SIGINT interoperability
- ✓ JPEG 2000, Interactive Protocol (JPIP)—useful in large format sensor applications like wide area surveillance sensors
- ✓ SMPTE 296M-2001, 1280 x 720 Progressive Image Sample Structure — Analogue and Digital Representation and Analogue Interface
- ✓ SMPTE 274M-2008, 1920 x 1080 Image Sample Structure, Digital Representation and Digital Timing Reference Sequences for Multiple Picture Rates
- ✓ SMPTE 295M-1997, 1920 x 1080 50-Hz — Scanning and Interface
- ✓ NATO STANAG 4609, AIR (Edition 2) — NATO Digital Motion Imagery Standard
- ✓ AEDP-8 (Edition 2), NATO Motion Imagery (MI) STANAG 4609 (Edition 2) Implementation Guide
- ✓ MIL-STD-2500C, National Imagery Transmission Format (NITF) Version 2.1 for the National Imagery Transmission Format Standard

IP 2.1: Managed Configuration of STD-CDL Terminals Governing Standards:

- ✓ Specification Number 7681990, Rev H, Performance Specification for the Standard Common Data Link Waveform
- ✓ Specification Number 60038365, Capstone Specification for the Network -Centric Common Data Links
- ✓ NATO STANAG 7085, Interoperable Data Links for Intelligence, Surveillance, and Reconnaissance (ISR) Systems, Edition 3, pending promulgation https://gtg.csd.disa.mil/uam/marketing.jsp

- **UAS Control Segment (UCS) Architecture Release 3.1** https://ucsarchitecture.org

- **National Geospatial-Intelligence Agency (NGA) GEOINT Metadata Standards** (OUSD-I Memo 31 AUG 2011) for MIL STD 2500C, MISP and STANAG 4607.
  - ✓ DoD IT Standards and Profile Registry (DISR) Online https://gtg.csd.disa.mil/uam/marketing.jsp

- **DoD Common Data Link (CDL) Policy** 7 August 2009.

- **Joint Fire Support Executive Steering Committee (JFS ESC) Digitally Aided Close Air Support (DACAS) Engineering Change Proposals (ECPs).** ECP # 8 Unmanned Aircraft System (UAS) Integration as a Strike Platform. https://community.apan.org/joint_close_air_support_jcas/dacas_ci_usc/default.aspx

- **CJCSI 6212.01F** NET READY KEY PERFORMANCE PARAMETER (NR KPP), 21 March 2012.

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- **NATO STANAG 4586, Standard Interface of the Unmanned Control System (UCS) for NATO UAS Interoperability**
- **DoD Architecture Framework (DoDAF), Version 2.0**
  http://dodcio.defense.gov/dodaf20.aspx

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Appendix C DOD INITIATIVES TO INCREASE INTEROPERABILITY AND MODULARITY

UI2 CBA

This CBA is the culmination of a joint WG effort to conduct an operational assessment of unmanned systems interoperability task needs, identify and prioritize gaps in the ability to satisfy these needs, and identify potential DOTMLPF-P priorities to mitigate the identified capability gaps. Each military department and agency will find aspects of the CBA relevant to its mission responsibilities. The I-IPT under the UAS Task Force will continue to work with the military departments and agencies to close gaps identified within the CBA to ultimately improve capability to the warfighter.

The CBA effort derived the 29 prioritized joint UAS interoperability gaps, which are listed below. The complete approved CBA is available on the USD(AT&L) restricted Unmanned Warfare Information Repository website.

- Detect or sense and avoid other airspace users in accordance with NAS standards and tactical requirements for deconfliction and collision avoidance.
- Provide selectable ISR data in joint approved network formats and waveforms.
- Provide ISR, tracking data, and location information in common, discoverable, retrievable, selectable formats to authorized subscribers across domains, including C2 interfaces such as Blue Force Tracker.
- Provide accurate position reporting sufficient for joint common operational picture and joint common air picture applications.
- Provide location information from all sensors for ISR contacts of interest from UAS to authorized subscribers, including the transfer of targets in different domains, e.g., for the transfer of a subsurface maritime contact by a UA. (Authorized subscribers include direct machine-to-machine data exchange.)
- Provide accurate UA position reporting sufficient for safe and effective operation in NAS airspace and theater airspace.
- Enable vehicle/payload control by all authorized joint users with approved control mechanisms.
- Provide UAS sensor point and area of interest location information to authorized subscribers in the specified format.
- Enable multiple authorized controllers (subscribers/requests) to control and transfer control of the vehicle (and/or payloads) and to accept transfer of control between approved control nodes (including when payloads are able to support multiple users simultaneously) (will require the capability to assess and prioritize requests).
- Provide communication gateway and aerial network or network node services compatible with appropriate joint networks.
- For appropriately equipped UAS, provide target designation in accordance with requirements of precision joint munitions (such as JAGM, Hellfire, and small diameter bomb).
- Provide and/or exchange payload and mission information to authorized subscribers in the specified format.

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- Transmit, relay, or retransmit required voice transmissions or sensor data in accordance with joint standards to authorized DoD and non-DoD subscribers.
- Provide fire support functions that are compatible with joint targeting control systems and procedures.
- For both manned and unmanned platforms, provide airborne handoff of missions or services between platforms.
- Enable authorized users to access data archive and retrieval systems.
- Integrate with the unmanned systems environment to C2 sensor fields using other unmanned sensors and platforms.
- Provide and enable joint information operations and information warfare effects including electronic attack, electronic protection, and EW support that is compatible with joint EW attack systems and appropriate requirements for "hardening" against EW threats.
- Deliver lethal or nonlethal effects in accordance with joint TTPs.
- Provide battle damage assessment input data in joint approved formats to authorized subscribers and assessment teams.
- Provide meteorological and oceanographic data in common, discoverable, retrievable format to authorized subscribers.
- Provide chemical, biological, radiological, nuclear, and high-yield explosive data in prescribed format to authorized subscribers.
- Simultaneously control multiple air vehicles of either similar or dissimilar types from a single control station.
- Provide multiple authorized users (GCS or manned aircraft) with the capability to control target designation and weapon launch in accordance with joint TTP.
- Provide nonmilitary data compatible with federal and state agencies in support of a range of disaster, wildfire, and rescue operations.
- Provide platform-operating status by UAS class sufficient to facilitate transfer of control (handover) of the air vehicle or systems within the joint force to facilitate safe operation.
- Provide platform health indicator information to authorized controllers in the specified format.
- Perform launch and recovery under the control of multiple authorized and capable joint users and facilities (terminal phase of operations).
- In situations involving a loss of control link or loss of communications, comply with DoD contingency procedures.

Standards and Governance Efforts

DoD can accomplish unmanned systems interoperability by standardizing critical interfaces within the overall UAS architecture and implementing standard IOPs. DoD must clearly and consistently define the communication protocols, message formats, and implementation methods across these interfaces. The I-IPT will work with DoD partners, the Services, and the Joint Staff to define and enforce the standard IOPs through the USIP WG and the UCS WG for incorporation into the JCIDS processes. This effort will facilitate the mandated acquisition, technology, and logistics lifecycle management efficiencies across current and future UAS programs.

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The OSD defines OA as follows:[91]

A multifaceted strategy providing a framework for developing joint interoperable systems that adapt and exploit open-system design principles and architectures. This framework includes a set of principles, processes, and best practices that:

- ✓ Provide more opportunities for competition and innovation
- ✓ Rapidly field affordable, interoperable systems
- ✓ Minimize total ownership cost
- ✓ Optimize total system performance
- ✓ Yield systems that are easily developed and upgradeable
- ✓ Achieve component software reuse

UCS OA is the business model foundation on which all USIPs and Service IOPs should be based. In some instances, USIPs and/or Service IOPs may be incorporated into the UCS framework; however, the overarching intent is to ensure synchronization and compatibility among UCS, USIP, and Service IOP directives.

UCS Architecture

The UCS Architecture is a framework representing the software-intensive capabilities of current and emerging UAS programs in the Army, Navy, and Air Force inventories. The goal is to develop an architecture based on SOA principles, which will be adopted by each Service as a common business model for acquiring, integrating, and extending the capabilities of the control systems for UAS. Under direction from the USD(AT&L) Acquisition Decision Memorandum (11 February 2009), the UAS Task Force chartered the UCS WG to develop and demonstrate a common, open, and scalable architecture supporting UAS Groups 2–5. The UCS WG comprises Government and industry representatives and operates collaboratively using a technical society model where all participants are encouraged to contribute in any area of interest. In this context, the UCS Architecture supports the following OSD-stated high-level business objectives:

- Acquisition flexibility for control segment subsystems and components
- Cost control
- Innovation at all levels of industry
- Reduced integration time for new capabilities
- Reuse across Service and joint UAS programs where appropriate

Upon completion of UCS Architecture version 2.1, the UCS WG is planning to transition to the Army's Aviation and Missile Research, Development and Engineering Center (AMRDEC) Joint Technology Center/Systems Integration Lab (JSIL) at Redstone Arsenal for enduring governance, oversight, management, and custodianship of the UCS business model, interfaces, web repository, and future revisions to the UCS Architecture and/or interfaces. JSIL will establish the UCS Steering Committee (SC) and continue to support OSD and the service acquisition portfolio managers. JSIL will stay synced with USIPs, ICWGs, and IOPs and will be the Government lead for both the UCS SC and USIP SC. In this capacity, JSIL will act as an

[91] Terms and Definitions, Defense Acquisition University: https://acc.dau.mil/CommunityBrowser.aspx?id=22108.

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unbiased third party to routinely advise OSD, the Joint Staff, and Service acquisition executives on all UCS issues.

The restricted website is https://fusion.dynetics.com/project/UCSWG. To request access, visit the I-IPT public website (http://ucsarchitecture.org), and follow the instructions for requesting access to the restricted website.

Unmanned Systems Interoperability Profiles (USIPs)

USIPs are the implementation of the mandate by the Deputy Secretary of Defense's "Unmanned Aircraft System (UAS) Memorandum 14667-07" (13 September 2007) to develop standard IOPs linked to JCIDS documents. They help drive the implementation of approved DoD and/or joint interoperability priorities at the Service level and may even require a new Service IOP or revision to an existing IOP.

USIPs also support the CJCSI interoperability requirement by creating specific points of "capability-based interoperability." The purpose of a USIP is to define profiles of standards sufficient to guarantee interoperability in support of a specific mission capability. A USIP may reference DoD standards, Intelligence Community standards, Service-specific IOPs, and commercial standards to achieve capability-based interoperability. All approved USIP standards can be found on DISR.

The USIP WG is currently run by the JSIL and comprises Government and industry representatives in the same enduring governance, oversight, and management role as the UCS SC. This new USIP SC will form an advisory group that is responsible to the UAS Task Force and serves in an unbiased, coordinating role for all UAS Task Force IPTs involved in USIP development, implementation, and initiation. The USIP SC shall coordinate staffing and approval of proposed USIPs with the UAS Task Force, JROC, and JCA functional capabilities boards as required. The USIP SC will remain engaged with the Service ICWG/IOP processes to ensure synchronization and foster the vertical and horizontal cooperation essential to joint interoperability.

The intent of the USIP development and management process is to leverage existing processes within both the DoD acquisition management system and the JCIDS process to develop more capable and interoperable unmanned systems.

- USIP 1 (LOS FMV), approved, in DISR release 11-1.
- USIP 2 (BLOS FMV), to be submitted for DISR release 12-1.
- USIP 3 (Bandwidth Efficient LOS), on hold pending BE-CDL Rev B outcome.
- USIP 4 (Video Control Interface for Region of Interest Delivery), in progress. This effort relates to wide area sensors.
- USIP 5 (Weaponization), in progress.

The restricted website is https://software.forge.mil/sf/go/proj1887. To request access, visit the I-IPT public website (https://software.forge.mil/sf/projects/usip_universal_systems_interoper), and follow the instructions for requesting access to the restricted website.

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Service Interface Control Working Groups (ICWGs)

The intent of a Service-level ICWG is to ensure that UAS program and product managers, developers, Services, and end users actively participate in the development and implementation of Service-specific interoperability solutions. This collaborative organization (Government-industry partnerships) serves as the standards recommendation body chartered within each Service to promote interoperability across various product lines.

The ICWG is a technical "engineering-level" body focused on identifying interoperability solutions for the respective Service's UAS FoS. These select requirements and implementation strategies are published within a set of IOPs and are for use by developers and implementers of new (and potential) UAS and related capabilities. IOP implementation across UAS products facilitates diverse levels of interoperability and is intended to provide the end user with an increased payload utility, a reduced tactical footprint, and an expanded unmanned aircraft platform availability.

The Services as a whole have made significant progress in establishing these ICWGs for unmanned systems for the end-to-end management of interface control. Each Service's ICWG has an independent process for IOP development and configuration control. To ensure horizontal and vertical integration, each Service's ICWG staff is represented within the other's ICWG consortia unmanned systems, including the I-IPT, UCS WG, and USIP WG. Members from both the UCS SC and USIP SC are also represented. The Army established the ICWG process within PEO Aviation's UAS project office. The Navy recently followed suit and is actively working to establish its program under PEO Unmanned Warfare. The Air Force is in the process of vetting approval for the same for unmanned systems and organizations.

In coordination with the USIP SC and UCS SC, ICWGs are ideal bodies to nominate and/or implement USIPs either as a bottom-up nomination or a top-down implementation directive from OSD/Joint Staff. It is envisioned that applicable Service IOPs may be candidates for DoD/joint implementation through the USIP nomination process. Conversely, USIPs and/or UCS Architecture requirements may drive the development of new Service IOPs or modification of existing IOPs. In either case, the overarching intent is to avoid duplicative or conflicting Service IOPs.

Service IOPs

Historically, unmanned systems have used very deterministic point-to-point interfaces; however, provisions of network-centric warfare require UAS programs to implement common standards in support of an FoS type of architecture. Widely accepted or approved standards are often too broadly defined and inadvertently allow compliance but not necessarily interoperability (e.g., CDL standards and MISB standards). Interface "standards" vary and allow for diverse implementation strategies and interpretations. To be truly interoperable, an FoS requires the Service-level development of IOPs.

IOPs provide implementation guidance, best common practices, and profiles of standards to help ensure interoperable systems within a Service. IOPs are tightly coupled to program offices and industry partners because each sponsoring entity (e.g., program, industry partner) typically signs off on the IOP. Service system integration laboratories test against their IOPs to

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ensure program compliance. IOPs perform a similar function to USIPs but typically have a broader scope. A single IOP may touch on several interrelated capabilities and their associated standards, profiles, practices, etc. IOPs that have support across multiple Services are good candidates for nomination as new bottom-up USIPs.

IOPs are managed by their respective Services and are developed through a collaborative process of various product offices and private industry partnerships. Within IOPs and related publications, each Service attempts to set and enforce only the standards critical to respective UAS interoperability. This approach provides the level of commonality required for interoperation while minimizing the impact on the native capabilities and design for each platform. IOPs contain interface requirements specific to interoperation capability within the various UAS. Additionally, IOP-related products (such as associated performance specifications, implementation guides, and interface control documents) support IOP implementation strategies, provide clarity of intent, and promote the use of emerging technologies expected for future standardization. In Service-specific cases, IOPs may be posted on DISR depending on the nature and approved enforcement or testing mechanisms.

Joint Interoperability Test Command (JITC)

JITC is an organizational element of the DISA Test & Evaluation Directorate and has DoDI 4630 responsibility for certifying joint and combined interoperability of all DoD IT and NSS. JITC follows the processes outlined in DoDI 4630, the DoD CIO Interim Guidance Memorandum, and the JITC Interoperability Process Guide (10 September 2012) to perform joint interoperability testing and certification. It works closely with the Services, Joint Staff, OSD, and DoD CIO to provide recommendations to the Interoperability Steering Group for waivers, extensions, and ultimately full interoperability certification and compliance status reporting to DAEs and SAEs. OSD and JITC are committed to testing reciprocity agreements with the various joint and Service testing facilities to encourage compliance testing earlier in the acquisition and product development process and to support the USIP SC, UCS SC, and ICWGs.

The restricted website (DKO) is available on the public website: (http://jitc.fhu.disa.mil/index.html).

Joint Technology Center/Systems Integration Laboratory (JSIL)

JSIL supports the assessment of system integration readiness during the product development process, prior to actual flight testing. JSIL provides for distributed hardware-in-the-loop testing of payloads, air vehicles, ground system components, and joint interfaces using MUSE in globally distributed command exercises and experiments. The purpose of JSIL is to provide simulation, integration, and a full range of test support to the joint UAS family.

More recently, JSIL was resourced in a program decision memorandum to support OSD, the UAS Task Force, and I-IPT plan of action and milestones. As the UCS WG and USIP WG transition to an enduring role, JSIL will continue to lead the UCS SC and USIP SC in direct support to OSD's acquisition oversight roles for establishing, maintaining, and reporting USIP/UCS implementation and compliance.

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The restricted website is provides more information. To request access, visit the I-IPT public website (https://software.forge.mil/sf/projects/usip_universal_systems_interoper), and follow the instructions for requesting access to the restricted website.

DoD IT Standards and Profile Registry (DISR)

DISR is an online repository of DoD IT and NSS standards and related information, formerly captured in JTA, version 6.0. DISR replaces JTA. All approved USIPs are submitted to DISR.

In addition to the definition of common capability descriptions, standards, data models, and architectures, DoD, through OSD, continues to promote the development of OA tools and implementations to aid system acquisition and development in embracing the OA concepts. These efforts extend across the technology and unmanned vehicle spectrum, from software development kits, to complete architectures, addressing UGS, UMS, and UAS, across the Services. Examples of such tools include the following ongoing efforts on the ground, in maritime spaces, and in airspaces:

1. The JAUS Tool Set (JTS) is a tool to help developers build JAUS-compliant software components without having to be intimately familiar with the details of JAUS. JTS allows an unmanned systems designer to focus on behavior, rather than on messaging, protocol, and other considerations, by providing a graphical user interface service editor, validator, internal repository, C++ code generation, and Hypertext Markup Language (HTML) document generation.

   The Navy and OSD have supported and promoted the use of JTS and have had success incorporating it into development and acquisition efforts. Use of JTS on programs accrues benefits to a number of stakeholders in the acquisition chain and research and development and T&E communities. These benefits include enabling a fair basis for competition among vendors so that true capabilities are evaluated, reducing vendor lock-in on unmanned systems, and enabling the development of a "service repository" for JAUS capabilities that have been developed and are available for reuse. JTS reduces the threshold for entry into developing JAUS-compliant systems, opens the market to small businesses, and drives competition and innovation focused on core technology. In addition, JTS provides an accepted, common validation capability, which is critical to ensure systems maintain compliance with JAUS.

2. The NATO STANAG 4586[92] Compliance Toolkit (4586CT) is an integrated set of software tools that provides passive, interactive, and automated test capability. Its core function is to verify the structure and content of data link interface (DLI) messages against both NATO STANAG 4586 and "private" messages as defined to support service-, mission-, or platform-specific requirements. This nonintrusive capability is provided either in real time or during post-run analysis. Additionally, 4586CT can be interoperable with other DLI-compatible systems in either manual mode (where an engineer monitors and injects DLI messages into the network) or automated mode (in

[92] NATO STANAG 4586, Standard Interface of the Unmanned Control System (UCS) for NATO UAS Interoperability.

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which 4586CT interacts directly with other DLI systems according to user-defined scripts and procedures).

These capabilities enable 4586CT to perform compliance testing of unmanned systems relative to NATO STANAG 4586 and other, more specific IOPs, at both the message level and the higher level protocol session levels. Complex DLI message dialogs can be monitored and system interaction sequencing verified as 4586CT follows user-defined test programs. As 4586CT can function as a proxy for other unmanned system components, it is also used during system development and task-specific integration testing and can provide insight into unmanned systems interaction and performance. Multiple instances of 4586CT can also be employed to perform rapid prototyping of interoperation protocols during profile design; as a result, 4586CT can be a useful tool during the development of interoperability standards themselves.

Future Airborne Capability Environment (FACE)

Near Term. The Army COE is an approved set of computing technologies and standards that enable secure and interoperable applications to be rapidly developed and executed across a variety of computing environments. Within the COE initiative, FACE is Army Aviation's implementation. The objective of FACE is to establish a standard COE to support portable, capability-based applications across DoD avionics systems.

FACE will reduce lifecycle costs and time to field, obtain industry and DoD program management endorsement, and facilitate conformance with standards to maximize interoperability between applications within the avionics system. The environment builds on OAs, integrated modular avionics, and a modular open systems approach (MOSA) and is designed to be portable, modular, partitioned, scalable, extended, and secure. By expanding on the MOSA and OA principles, FACE uses abstraction layers at key interfaces to diminish the need for new standards. The FACE technical strategy is to create a software environment on the installed computing hardware of DoD aircraft that enables FACE applications to be deployed on different platforms with minimal to no impact to the FACE application.

SPIES Initiative

Near Term. The goal of the SPIES initiative is to develop EO/IR sensor-platform interface standards that enable reduced acquisition, integration, and lifecycle costs; improve agility; promote OA and interoperability objectives via Navy/DoD standardization; and maintain system performance, reliability, maintenance, and availability.

SPIES will also work to enable a methodology and process for maintaining and revising the standards and adding new standards, as required. By following the computer peripheral model, the intent is for all devices and components to operate over standard buses and use standard connectors and basic database protocols. With SPIES, the expected total ownership cost savings is expected to be around 25%, with additional benefits, including reduced integration risk.

IOPs Defined for UGS

As payloads, sensors, software, and computing devices are anticipated to evolve much faster than base platforms, creating interoperable interfaces for enhanced modularity represents

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an opportunity to minimize future lifecycle costs and adapt rapidly to changing threats or new available technologies. The RS-JPO I-IPT, formed in 2009, is working to establish, adopt, and apply interoperability standards for UGS by working with the combat developers, the S&T community, and private industry. The effort is focused around utilization of the SAE AS-4 standard for JAUS with the implementation guidance being defined by the UGS IOP.

Near Term: IOP V0. In December 2011, the IOP v0 development process and content were presented to a joint executive board, consisting of Government leaders from the material developer, combat developer, and S&T communities. The joint executive board voted unanimously to approve and publish IOP V0. The IOP enables tailoring based on the use of interoperability attributes. Not every interoperability requirement will apply to every future system; therefore, the IOP provides a mechanism to independently specify these requirements in a composable manner. Interoperability attributes applicable to the specification and design of a system can be identified and used to filter applicable requirements from the IOP to support system design, development, conformance, and validation testing, IOT&E, and fielding. This approach shrinks the "design space" of future UGS interfaces from infinite to a small number of options. RS-JPO will require the use of IOPs in future requests for proposals for PORs. For industry, this interoperability approach means that companies with business models that favor closed-architecture products will ultimately either lose market share or need to adapt their business strategies. In the near term, the core interoperability team within RS-JPO and the Tank and Automotive Research, Development, and Engineering Center will be defining program- and system-specific instantiations of IOPs. Program-specific IOP instantiations will become part of future IOPs, and system-specific instantiations of IOPs will be used to determine whether there is any supporting business case to upgrade existing fielded systems to be fully or partially IOP compliant.

Middle Term: IOP V1. In addition to the capabilities already resident in widely fielded systems, IOP V1 will include interfaces for unmanned applique kits, explosive detection and marking payloads, modular controller interfaces, and a basic interface with SUAS assets. In IOP V1, the focus will be on increasing the interoperability with other domains, such as overarching networks, UAS, and manned systems.

Long Term. Future UGS are anticipated to interface with tactical and enterprise networks, such as GIG. The Army has defined a strategy for realizing a COE network into which UGS are anticipated to eventually interface. While achieving this interface would entail significant acquisition challenges in terms of information assurance planning, this interface would provide great opportunities for increasing the capabilities of UGS for warfighters. For example, a warfighter equipped with a COE-connected mobile device could search for software applications that are needed to conduct the mission, including UGS video feed and sensor-control applications. In addition, geospatial models and other data structures available in the COE could significantly enable UGVs to navigate autonomously. Autonomous operations could reduce the amount of computing power necessary on platforms and controllers and may reduce the wireless communication bandwidth required in UGS radios.

DoD will also increase coordination between ground and air domains. Although UAS and UGS are based on different standards (NATO STANAG 4586 for large UAS and SAE AS-4 (JAUS) for UGS), it is feasible for future systems to use an inward (ground) facing SAE AS-4 protocol and an outward (air) facing NATO STANAG protocol to interoperate. In addition, as

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UGS become more accepted and embedded in the force structure, interoperability with manned ground systems will be necessary. It is anticipated that the vehicular integration for C4, ISR, and EW interoperability (VICTORY) standard will provide the interoperable interfaces for communicating with manned ground systems. As a result, RS-JPO's interoperability profiles must eventually define the protocols for interfacing with VICTORY-based systems.

AEODRS Common Architecture

Currently, fielded EOD robotic systems are modified commercial products with different OCUs, limited autonomy, different architectures and designs, and company proprietary software. AEODRS is being executed by the Naval Explosive Ordnance Disposal Technology Division via the Navy Program Office for Explosive Ordnance Disposal (PMS 408) to provide joint forces with an improved and modular EOD capability to respond to unexploded ordnance, counter-improvised explosive devices, and WMD missions. AEODRS comprises three system variants, utilizing Government-owned common system architecture and interfaces, which will be fielded in an incremental approach. The common architecture is present at the physical, electrical, and logical interface levels for the UGS FoS to enable modular plug-and-play components and interoperability.

Near Term: Intraplatform Modularity. AEODRS Increment 1 is partitioned into nine separate capability modules (CMs) designed to function as standalone components across the variant platforms in the family of vehicles. Each CM is task and function specific and is designed to perform specific functions within the overarching system. Because major interfaces are defined and available to CM and subsystem competitors, the OA model aims to promote future technology infusion in a truly competitive environment. Increment 1 is broken down into three major subsystems including the OCU, the UGV, and the communication link. CMs within the UGV include CM-MOB (mobility), CM-PWR (power), CM-MAS (master), CM-MAN (manipulator), CM-VIS (vision), CM-EEF (end effector), and CM-AB (autonomous behaviors).

Middle Term: Interplatform Modularity/Interoperability. The AEODRS program consists of an FoS including three system variants that will be fielded in an incremental approach. Increment 1 (dismounted operations) will be fielded first, followed by Increment 2 (tactical operations) and Increment 3 (base/infrastructure operations). Use of common architectures and task- and function-specific capability modules will enable use of modules, software, and OCUs across platforms for all three system variants. The OA throughout the FoS allows interoperability between platforms through Government-defined and -controlled electrical, physical, and logical interfaces, in addition to the commonality of the OCU. In addition, the FoS is characterized by interchangeable modules that can be integrated in plug-and-play fashion without proprietary issues for each subsystem.

Interface Standards and IOPs

DoD has long recognized the value in fostering collaboration among Government, industry, and academia in open unmanned systems to address interoperability and common standards. To that end, a number of IPTs, WGs, and other communities have formed to address the interoperability challenge. These forums for unmanned systems have enabled the Government to engage with industry at all levels to aid in the systems and architecture design process, rather than just be customers. These collaborating communities exist within a variety of

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national and international standards bodies, span the domains of unmanned systems (air/ground/maritime), and address key cross-domain areas as well as domain-unique capabilities. DoD intends to continue to support this type of collaboration as it fosters the development of interoperability and standards WGs. Examples include the following:

- NATO Joint Capability Group Unmanned Aerial Vehicle (JCGUAV) is engaged in interoperability efforts in unmanned aviation. JCGUAV subsumed NATO's three military department UAS-related groups (i.e., PG-35, Air Group 7, and Task Group 2) in 2006. Its major accomplishments to date include NATO STANAG 4586 for UAS message formats and data protocols, NATO STANAG 4660 for interoperable C2 links, NATO STANAG 4670 for designated UAS operators training, and NATO STANAG 4671 for UAS airworthiness, and NATO STANAG 7085 for the CDL communication system, which has been mandated by OSD since 1991.[93]
- Current USIPs produced by the I-IPT define the standard interface for payload products and the data link between a control station and air vehicle for LOS and BLOS scenarios. Future USIPs will address other aspects of interoperability, including data encryption, different data link technologies such as BE-CDL, and enhanced capabilities provided by future sensors.
- JAUS began in 1995 as an effort by the Army's program office for UGS in the Aviation and Missile Research, Development and Engineering Center (AMRDEC) at Redstone Arsenal to establish a common set of message formats and data protocols for UGS made by various manufacturers. Deciding to convert JAUS to an international industry standard, the program office approached the SAE, a standards development organization (SDO) with robotics experience, which established the AS-4 Unmanned Systems Committee in August 2004. The AS-4 committee has three subcommittees focused on requirements, capabilities, and interfaces and an experimental task group to test its recommended formats and protocols before formally implementing them. The migration to the SAE has been completed, and the first set of SAE JAUS standards, focusing on the JAUS Service Interface Definition Language, core services, mobility services, manipulation services, and environmental sensing services, has been balloted and released. Although AS-4 committee members may create standards on other aspects of unmanned systems beyond message formats and data protocols for UGS, much of this broader work is now being undertaken by other UAS-related SDOs. NATO STANAG 4586 is unmanned aviation's counterpart to JAUS.

[93] NATO STANAG 4660, Standard for UAV Interoperable Command and Control Data Link (IC2DL); NATO STANAG 4670, Recommended Guidance for the Training of Designated Unmanned Aerial Vehicle Operators; NATO STANAG 4671, Unmanned Aerial Vehicle Systems Airworthiness Requirements; and NATO STANAG 7085, Interoperable Data Links for Intelligence, Surveillance, and Reconnaissance (ISR) Systems, Edition 3, pending promulgation.

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Appendix D UNMANNED SYSTEMS T&E CAPABILITIES CURRENT STATUS

Unmanned Aircraft Systems

UAS T&E activities are heavily leveraging existing manned air systems T&E capabilities to test unmanned systems. Capabilities are being added to address differences for T&E of unmanned systems for primarily Level 1 autonomy systems (e.g., JUAS–Mission Environment). The C2 of today's UAS is located both on the surface (land and water) and in manned aircraft. For example, the Army recently demonstrated control of a UAS from an Apache helicopter. Today, the air vehicle decision solutions are made with deterministic algorithms. As autonomy levels increase, for example, Autonomous Aerial Cargo Utility System (AACUS) Innovative Naval Prototype (Ref 3), the systems will incorporate an ever-increasing number of nondeterministic algorithms in the UAS. T&E of how and why decisions are reached by these algorithms is a challenge that requires new improved processes and resources. As UAS embody more Level 2 to Level 4 autonomy capabilities in the future, improved tools will be needed for efficiently and effectively testing these higher levels of autonomy.[94]

Unmanned Ground Systems

UGS T&E capabilities across the Services are primarily derived from manned vehicle test capabilities. These capabilities are environment and terrain specific and were successfully used in the past to verify the safety, performance, and effectiveness of early UGS, which were controlled remotely, teleoperated, or possessed very low levels of supervised autonomy. The sensing and perception capabilities of autonomous systems are increasing rapidly, and obstacles on the terrain are equal, if not more important, to safety, performance, and effectiveness as actual terrain types and geometries.

The challenges facing the operational test community will involve the safe use of UGS integrated with warfighters and manned systems during events as well as the ability to assess mission effectiveness based on a finite number of possible physical scenarios that can be efficiently construed. Warfighters are on the ground or mounted in formation with these vehicles. Before placing these systems in the presence of the warfighter, safety and performance must be proven under controlled conditions.

To date, traditional evaluations have yet to be performed with UGS. Evaluations of currently fielded systems have been based on documenting, verifying, and assessing system safety and performance capabilities, unlike traditional evaluations, which correlate a capability to a system or mission requirement. Existing evaluation techniques based on manned systems fail to adequately assess sensing, perception, and intelligent control.

It is imperative to test UGS to verify they are safe to operate among dismounted personnel and other moving vehicles. Each Service, as well as several public and private entities, offers some degree of T&E capability required to prove the safety, suitability, and effectiveness

[94] For a description of autonomy levels, see table 3 on page 46 of the Unmanned Systems Integrated Roadmap FY2011-2036: http://www.acq.osd.mil/sts/docs/Unmanned%20Systems%20Integrated%20Roadmap%20FY2011-2036.pdf.

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of future UGS. Existing ranges and test facilities have been adequate to test systems with very limited autonomous capabilities and systems operated through teleoperation.

Unmanned Marine Systems

Existing ranges are limited to support the testing of UMS in a fully autonomous mode. Long-endurance mission profiles and limited tracking coverage restrict the test envelope for comprehensive autonomous testing behavior.

UUV test capabilities remain largely centered on underwater T&E ranges familiar with weapon systems that have attributes in common with a number of UUVs. Many UUV T&E requirements can be accomplished on these traditional underwater tracking ranges, which provide accurate track, simulation/stimulation, and acoustic acquisition and some of the required bathymetry. Many of the ranges offer additional operational areas with challenging bathymetry and environmental conditions, which help meet the T&E needs for UUV missions.

Advances in power systems and autonomy and the need for extended missions of up to a month at a time are stretching the ability of current underwater tracking ranges. Extended power capabilities and a high degree of autonomy allow newer UUVs to operate over extended areas and increase the risk of loss of these very high value, one-of-a-kind, assets. The ability to maintain track or provide areas with low risk of surface and underwater target (SUT) loss is important in these future T&E events.

The ability to safely launch and recover UUVs as SUTs presents challenges for T&E. The Navy does not have submarine platforms dedicated to T&E, and the introduction of developmental systems into the operational platform is a daunting process. This situation, coupled with limited at-sea time, challenges the comprehensive testing evolutions to demonstrate the suitability of the integrated host/UUV platform to the mission.

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Appendix E MANNED UNMANNED TEAMING (MUM-T) AND MUSIC

Manned-Unmanned Teaming (MUM-T)

The concept of MUM-T is to combine the inherent strengths of manned platforms with the strengths of UAS, with product synergy not seen in single platforms. MUM-T combines robotics, sensors, manned/unmanned vehicles, and dismounted soldiers to achieve enhanced situational awareness, greater lethality, improved survivability, and sustainment. Properly designed, MUM-T extends sensor coverage in time and space and provides additional capability to acquire and engage targets.

The pilot can use the sensor on the UAS, just as a sensor would be used aboard an aircraft, except that the position of the UAS sensor can be up to 80 km ahead from the aircraft. The MUM-T capability provides an unprecedented standoff range from threat weapons and acquisition systems. MUM systems largely depend on mission, enemy, terrain, troops, time, and civil considerations. The transfer of sensor data between the UAS and the manned system reduces risk to both platforms and increases the mission effectiveness and survivability rates of friendly forces. Environmental conditions affect the efficiency of MUM-T employment.

Manned Unmanned Systems Integration Capability (MUSIC) Exercise

Interoperability has been a top objective of the Army and the UAS project office for years. Interoperability greatly increases efficiency in Army systems through common interfaces and shared assets. Development, integration, and testing of interoperability standards into UAS universal products, such as the universal GCS and the universal ground data terminal, are top objectives of the UAS project office in the near term. In an effort to streamline and coordinate interoperability initiatives across products, the UAS project office, under oversight of PEO Aviation, hosted its first MUSIC exercise in September 2011 with plans to continue conducting exercises every two years or as needed.

The MUSIC exercises showcase to the soldier and Army community the progress being made in unmanned interoperability and emerging technologies through common interfaces. Exercises also act as a strategic planning tool by driving integration and test of the various platforms to a common hardware and software baseline.

MUSIC I Exercise

Overview. The objective for the MUSIC I Exercise was to showcase interoperability progress and emerging technologies in accordance with the 2.x series of the Army UAS IOPs. The exercise took place in Dugway Proving Grounds, Utah, at the UAS Rapid Integration & Acceptance Center on 16 September 2011. Weeks of pre-ground and -flight checks culminated into a live two-hour demonstration to a group of media, contractors, and Army officials. The audience witnessed real-time video feeds from the unmanned and manned payloads, screen captures from the GCSs, video feeds from within the shelter, and visual aids through an operational scenario to help demonstrate the capabilities and achieve a better understanding of how they benefit the soldier. Successful execution of the MUSIC exercise provided the product office with a wide range of lessons learned across multiple areas, including system usability, reliability, integration, and configuration control.

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Capabilities. MUSIC I showcased four main capabilities as outlined in Figure 41 and Table 2.

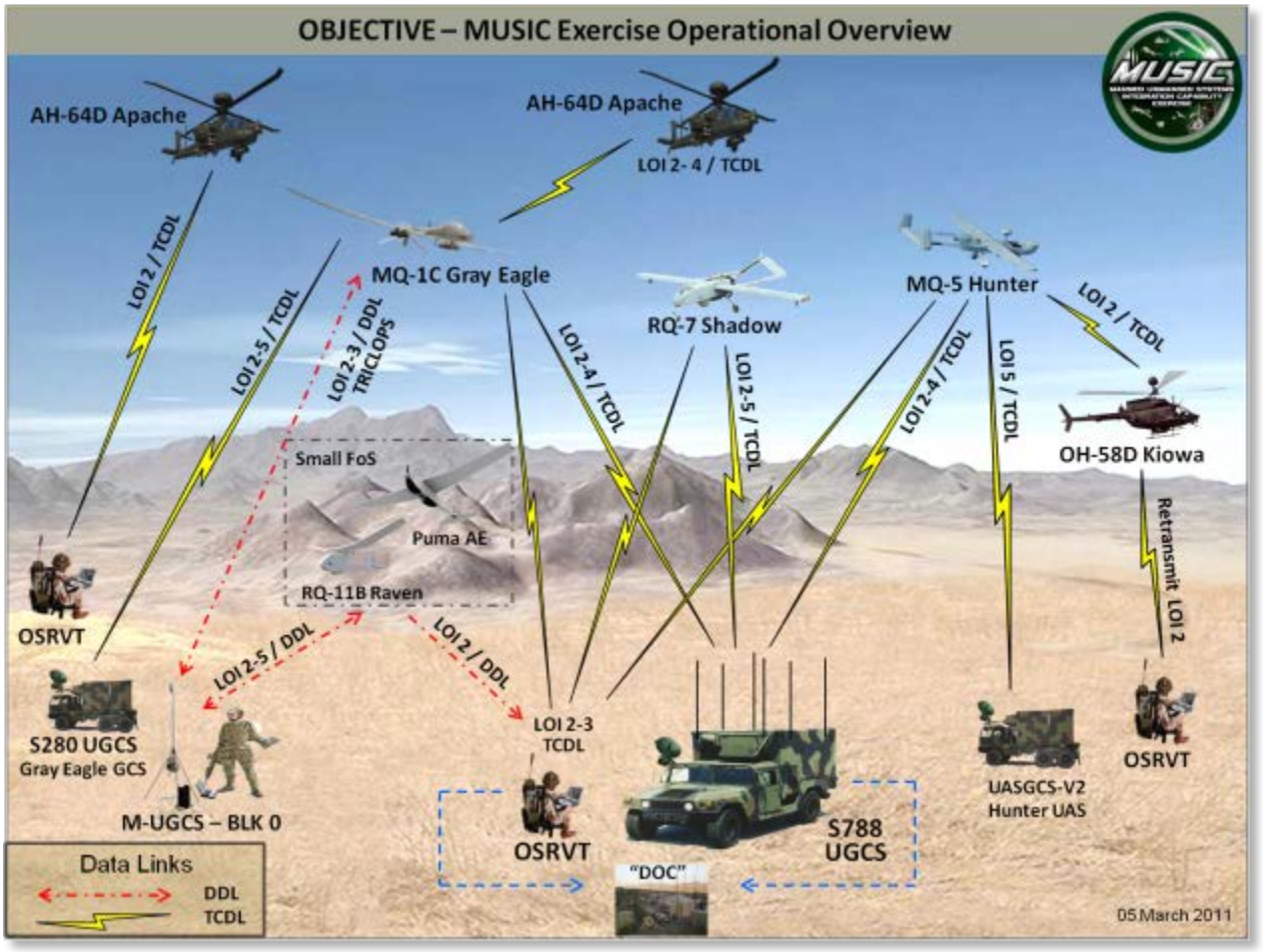


Figure 41. MUSIC I Operational View (OV-1)

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Table 2. MUSIC I Capabilities and Use Cases

Capability	Description	Use Case
Universal Ground Control Station (UGCS)	A single ground control station with common hardware and software for each of the large AV, Gray Eagle, Shadow, and Hunter with the ability to consecutively control each of the large aircraft through an IOP compliant exclusive control handover sequence	Shadow UGCS control of a Gray Eagle AV via a class B handover from a Gray Eagle native GCS
		Shadow UGCS control of a Hunter AV via a class B handover from a Hunter native GCS
		Shadow UGCS control of a Shadow AV
Bi-Directional One System Remote Video Terminal (OSRVT)	A BI-directional capability that allows the OSRVT operator the ability to control the payloads on the large UAVs under supervised through an IOP compliant handover sequence	OSRVT control of the Gray Eagle Payload
		OSRVT control of the Shadow Payload
		OSRVT control of the Hunter Payload
Manned-Unmanned Teaming (MUM-T)	The ability to partner with Army Aviation manned platforms through the sharing of video.	Kiowa Warrior retrans through the Hunter AV to extend the range to the OSRVT operator on the ground
		Apache BLK II receipt of UAS video in Apache cockpit
		OSRVT receipt of Apache BLK II payload video
		OSRVT receipt of Kiowa Warrior payload video
Mini-Universal Ground Control Station/TRICLOPS	A common controller for the Small UAS, Raven and Puma, via the Digital Data Link as well a control of Gray Eagle TRICLOPS payloads. TRICLOPS payloads are two additional payloads on the wings of the Gray Eagle that can be accessed independently from the main payload by M-UGCS operators on the ground.	M-UGCS control of Raven
		M-UGCS control of Puma
		M-UGCS control of Gray Eagle TRICLOPS payloads

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Appendix F CASE STUDY MQ-9 REAPER

Need to Transition from CLS to Long-Term Organic Capability

The MQ-9 Reaper program began as a quick reaction capability program in October 2001. Due to the urgency to deliver the system to the field, much of the sustainment planning was skipped. The program manager determined a CLS sustainment strategy for the life of the program. After a review, based on the statutory requirements of 10 USC 2464, the Commander, Air Force Materiel Command, determined that core capability requirements were applicable to the MQ-9 and issued a core depot decision memorandum (6 August 2008). The MQ-9 program was directed to transition into the organic depot-maintenance support.

The Reaper program also relied on CLS for field-level support because of the speed with which it was fielded. As the projected number of deployed capabilities increased, this sustainment strategy proved unaffordable. The Air Force needed to transition to military maintainers. Since the program was erroneously designated CLS for life, the program manager had not developed a data strategy or established the Government's requirements and rights for technical data. The MQ-9 was dependent on OEMs for sustaining engineering support and supply support. Initial funding estimates for data and equipment to accomplish the transformation to organic depot were also not affordable in the Air Force budget.

Initial Reliability Requirements Not Met

Typical of many programs that have been rapidly developed and deployed, the reliability requirements of the Reaper system were initially not well understood or developed. The primary reliability metric being measured and tracked was mean time between critical failure (MTBCF) as documented in the CPD of August 2006. This metric received a deferment from the Air Force Requirements Oversight Council after the 2008 IOT&E report noted the original MTBCF values were not achievable based on system performance. Additionally, because of the lack of redundant systems, all failures were interpreted as "critical failures." In 2011 it was recognized that deferring the achievement of the reliability goal until a future block upgrade would not be sufficient. The Air Force needed to reevaluate the requirement against test and operational data to determine a realistic reliability goal and then establish a reliability growth program to ensure that the system could continue to meet the goal.

Sustainment Transformation

Since 2009, the program office has been executing a strategy to transform the sustainment of the Reaper program to focus on long-term affordability. The transformation planning by the program office culminated in the development of a lifecycle sustainment plan that details the results of the program's planning efforts and documents the overall framework for optimal sustainment of the MQ-9 system throughout its life cycle at minimum lifecycle cost. The plan emphasizes the following major elements: requirements stability and reliability growth, depot transition, data strategy, and business case analysis (BCA).

Requirements Stability/Reliability Growth

The program established a Joint Reliability Maintainability Evaluation Team in 2012. The team reviewed field failure data and made recommendations to the warfighter community

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for new Threshold and Objective MTBCF values. The MQ-9 reliability and maintainability growth program has been established to manage the growth of reliability with an emphasis on identifying reliability readiness and cost drivers that have a substantial return on investment to the warfighter.

Depot Transition

10 USC 2464 (a)(3)(B) states the requirement, "Core depot-level maintenance and repair capabilities and capacity, including the facilities, equipment, associated logistics capabilities, technical data, and trained personnel, shall be established not later than four years after a weapon system or item of military equipment achieves initial operational capability or is fielded in support of operations."[95] In December 2009, the program established the Depot Maintenance Actions Working Group (DMAWG) to stand up organic repair. A three-phased approach was established to target the major repair and cost drivers:

- The first phase, Early Induction, identified items with low activation risk and includes the MQ-9 EO/IR sensors and a selection of items from the aircraft, engine, and communication equipment. The initial induction program will stand up in FY2013.
- The second phase will expand the initial partnership to cover items that generate 80% of the repair costs and will be put in place between 2014 and 2015, seven years after core was first determined to be applicable.
- The final phase will include more than 500 components with low repair rates.

Throughout the DMAWG process, the program is working with the Army Gray Eagle program to identify opportunities for leveraging similar efforts. The programs are working together to establish sensor capability with the Navy's Fleet Repair Center South East in Jacksonville, Florida.

Data Strategy

PPPs between OEMs and depots is one method to assure that the Government will have access to repair data without requiring a procurement or re-procurement data package. In addition to pursuing these partnerships, the Reaper program office continues to pursue Government ownership of data and is leveraging the Army Gray Eagle program's research of the Government's rights.

The program continues to provide contractor field service representatives (FSRs) while developing interactive electronic technical manuals, which will greatly enhance the military organization-level maintainer's ability to troubleshoot and repair the system while reducing the need for contractor FSRs and depot-level field assistance.

Business Case Analysis (BCA)

In December 2009, the program began a BCA to recommend a long-term sustainment strategy for the MQ-9 weapon system. The scope of the analysis included a full evaluation of the MQ-9 sustainment alternatives, including the implementation of performance-based logistics,

[95] As amended by P.L. 112-81 in 2011. Previously there was a requirement to identify core capability within four years of IOC.

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initiation of PPPs, and the evaluation of organic sustainment support. A baseline report was presented in July 2010. After a strategic pause to incorporate critical repair data and lessons learned from other BCA efforts, the MQ-9 BCA effort resumed in May 2011 and was completed in June 2012. The final BCA recommended separate performance-based agreements for the sensors, aircraft, and engine between the OEMs and depots and recommended that supply chain management be transitioned to the Government. See Figure 42.

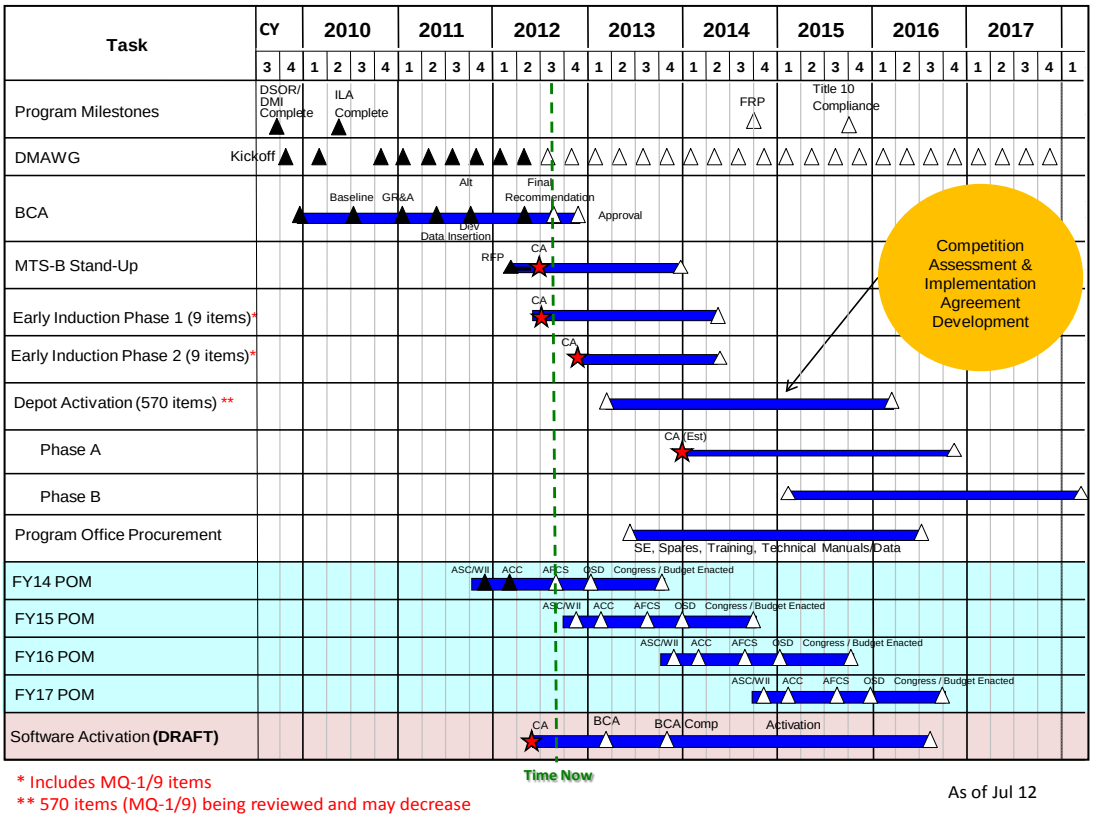


Figure 42. MQ-9 Reaper Sustainment Plan

Conclusion

The MQ-9 Reaper case study illustrates the strategy and actions required, when proper initial lifecycle sustainment planning was not done, to transform the sustainment of unmanned systems from a short-term, rapid-fielding environment to a long-term sustainment environment. The transformation of unmanned systems will require dedicated effort over the next decade to develop and execute lifecycle sustainment strategies that ensure the long-term affordability of the systems. In the case of the Reaper program, the lifecycle sustainment strategy end state of organic support is expected to be fully achieved by 2018 — almost 10 years after the Air Force established the requirement and many years after statutory mandates. As new programs are developed, it is critical for programs, in conjunction with their Services and warfighters, to begin to formulate a lifecycle sustainment strategy at program inception so that requirements for availability, reliability, and affordability are considered in the design, sustainment resources are identified early, product support packages are tested with the system, and long periods of interim contractor support are avoided once the programs are fielded.

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Appendix G POINTS OF CONTACT LIST

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Appendix H ABBREVIATIONS

…….A

A2/AD	Anti-Access and Area Denial
ABSAA	Airborne Based Sense and Avoide
ACAT	Acquisition Category
AEODRS	Advanced Explosive Ordnance Disposal Robotic Systems
AFB	Air Force Base

…….B

BAMS	Broad Area Maritime Surveillance
BCA	Business Case Analysis
BLOS	Beyond Line-of-Sight

…….C

C2	Command and Control
C4	Command, Control, Communications, and Computers
CAT	Conventional Arms Tracker
CBA	Capability-Based Assessment
CCDR	Combatant Commander
CCL	Commodity Control List
CDL	Common Data Link
CIO	Chief Information Officer
CJCSI	Chairman of the Joint Chiefs of Staff Instruction
CLS	Contractor Logistics Support
COA	Certificate or Waiver of Authorization
COE	Common Operating Environment
COLREGS	Collision Regulations
COMSATCOM	Commercial Satellite Communications
CONEMP	Concept of Employment
CONOPS	Concept of Operations
CONUS	Continental United States
COTS	Commercial Off The Shelf
CPD	Capabilities Production Document
CPI	Critical Program Information
CRADA	Cooperative Research and Development Agreements

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…….D

DAE	Defense Acquisition Executive
DARPA	Defense Advanced Research Projects Agency
DAR	Data at Rest
DCGS	Distributed Common Ground Station
DCS	Direct Commercial Sales
DEF	Defense Exportability Features
DISA	Defense Information Systems Agency
DISN	Defense Information Systems Network
DISR	DoD IT Standards and Profile Registry
DMAWG	Depot Maintenance Actions Working Group
DoC	Department of Commerce
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DoS	Department of State
DoT	Department of Transportation
DOTMLPF-P	Doctrine, Organization, Training, Materiel, Leadership and education, Personnel, Facilities, and Policy
DSA	Dynamic Spectrum Access
DSB	Defense Science Board

…….E

E3	Electromagnetic Environmental Effects
EAR	Export Administration Regulations
ECR	Export Control Reform
EMI	Electromagnetic Interface
EMS	Electromagnetic Spectrum
EO/IR	Electro-Optic/Infrared
EOD	Explosive Ordnance Disposal
EPOCHA	Estimation and Prediction of Orbits and Clocks to High Accuracy
EW	Electronic Warfare
ExCom	Executive Committee

…….F

FAA	Federal Aviation Administration
FACE	Future Airborne Capability Environment
FAR	Federal Aviation Regulation
FCB	Functional Capability Board
FMS	Foreign Military Sales
FMV	Full-Motion Vehicle
FoS	Families of Systems
FY	Fiscal Year

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FYDP	Future Years Defense Plan

…….G

GBS	Global Broadcast Service
GBSAA	Ground-Based Sense and Avoid
GCS	Ground Control Station
GEOINT	Geospatial Intelligence
GFMSA	GEOINT Functional Manager Seal of Approval
GIG	Global Information Grid
GMTIF	Ground Moving Target Indication Format

…….H

HALE	High-Altitude Long-Endurance
HiDRA	High Dynamic Range Atom
HURL	Hydra Universal Rail Launcher

…….I

ICAO	International Civil Aviation Organization
ICWG	Interface Control Working Group
IER	Information Exchange Requirements
IF	Intermediate Frequency
I-IPT	Interoperability Integrated Product Team
IMU	Inertial Measurement Unit
IOC	Initial Operational Capability
IOP	Interoperability Profile
IOT&E	Initial Operational Test and Evaluation
IP	Internet Protocol
IPL	Integrated Priority List
IPT	Integrated Product Team
ISR	Intelligence, Surveillance, and Reconnaissance
IT	Information Technology
ITAR	International Traffic in Arms Regulations

…….J

J-8	Force Structure, Resources, and Assessment Directorate of the Joint Staff
JALN	Joint Aerial Layer Network
JAUS	Joint Architecture for Unmanned Systems
JCA	Joint Capability Area
JCIDS	Joint Capabilities Integration and Development System
JIIM	Joint, Interagency, Intergovernmental, and Multinational
JITC	Joint Interoperability Test Command
JROC	Joint Requirements Oversight Council
JRRF	Joint Robotics Repair Facility

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JS	Joint Staff
JSIL	Joint Technology Center/Systems Integration Lab
JTA	Joint Technical Architecture
JUON	Joint Urgent Operational Need

…….K

KPP	Key Performance Parameter

…….L

LOS	Line-of-Sight
LPI/LPD	Low Probability of Intercept/Low Probability of Detection

…….M

MDA	Milestone Decision Authority
MIMO	Multiple-Input, Multiple-Output
MISB	Motion Imagery Standards Board
MOA	Memorandum of Agreement
MOS	Military Occupational Specialty
MPSF	Mission Package Support Facility
MTBCF	Mean Time Between Critical Failure
MTBF	Meantime Between Failure
MUM-T	Manned and Unmanned Teaming
MUSE	Multiple Unified Simulation Environment
MUSIC	Manned and Unmanned Systems Integration Capability

…….N

NAS	National Airspace System
NGA	National Geospatial-Intelligence Agency
NIAT	NSG Interoperability Action Team
NLOS	Non-Line-of Sight
NR KPP	Net Ready Key Performance Parameter
NRL	Naval Research Laboratory
NSA	National Security Agency
NSE	Nonstandard Equipment
NSG	National System for Geospatial-Intelligence
NSS	National Security Systems

…….O

O&S	Operations and Support
OA	Open Architecture
OCO	Overseas Contingency Operations
OCONUS	Outside the Continental United States
OCU	Operator Control Unit
OEM	Original Equipment Manufacturer

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OODA	Observe, Orient, Decide, Act
OPTEMPO	Operating Tempo
OSD	Office of the Secretary of Defense

…….P

PED	Processing, Exploitation & Dissemination
PEO	Project Executive Office
PINS	Precision Inertial Navigation Systems
PNT	Position, Navigation, and Timing
POM	Program Objective Memorandum
POR	Program of Record
PPBE	Planning, Programming, Budgeting, and Execution
PPP	Public-Private Partnership

…….R

RAM	Reliability, Availability, and Maintainability
RCTA	Robotic Collaborative Technology Alliance
RDT&E	Research, Development, Test, and Evaluation
RPA	Remotely Piloted Aircraft
RF	Radio Frequency
RITP	Research and Intelligence/Technology Protection
RS-JPO	Robotic Systems Joint Project Office

…….S

S&T	Science and Technology
SAA	Sense and Avoid
SAASM	Selective Availability Anti-Spoofing Module
SAE	Service Acquisition Executive
SANGB	Selfridge Air National Guard Base
SATCOM	Satellite Communications
SC	Steering Committee
SCRTF	Security Cooperation Reform Task Force
SDS	Spectrum-Dependent Systems
SECDEF	Secretary of Defense
SOA	Service-Oriented Architecture
SoS	System of Systems
SPIES	Sensor/Platform Interface and Engineering Standardization
SSRA	Spectrum Supportability and Risk Assessment
STANAG	Standardization Agreement
STUAS	Small Tactical Unmanned Aircraft System
SUAS	Small Unmanned Aircraft Systems
SWaP-C	Size, Weight, Power and Cooling

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…….T

T&E	Test and Evaluation
TAA	Technical Airworthiness Authority
TS&FD	Technology Security and Foreign Disclosure
TS/SCI	Top Secret/Secret Compartmented Info
TTP	Tactics, Techniques, and Procedures

…….U

UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
UCLASS	Unmanned Carrier Launched Airborne Surveillance and Strike System
UCS	UAS Control Segment
UGS	Unmanned Ground Systems
UGV	Unmanned Ground Vehicle
UI2	Unmanned Interoperability Initiative
UMS	Unmanned Maritime Systems
UMV	Unmanned Maritime Vehicle
U.N.	United Nations
USC	United States Code
USD	Under Secretary of Defense
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
USD(I)	Under Secretary of Defense for Intelligence
USIP	Unmanned Systems Interoperability Profile
USV	Unmanned Surface Vehicle
UUV	Unmanned Undersea Vehicle
UVDS	Unified Video Dissemination Service

…….W

WG	Working Group
WGS	Wideband Global Satellite
WMD	Weapons of Mass Destruction

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United States Government Accountability Office



Report to Congressional Committees

March 2014

DEFENSE ACQUISITIONS

Assessments of Selected Weapon Programs

GAO-14-340SP

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GAO Highlights

Highlights of GAO-14-340SP, a report to congressional committees

March 2014

DEFENSE ACQUISITIONS

Assessments of Selected Weapon Programs

Why GAO Did This Study

This is GAO's annual assessment of DOD weapon system acquisitions, an area that is on GAO's High-Risk List. DOD and Congress have taken meaningful steps to improve the acquisition of major weapon systems, yet many programs are still falling short of cost and schedule estimates. Moreover, GAO has emphasized the importance of completing developmental testing before programs enter production and pointed out risks associated with such concurrent testing and production. With expected budgetary pressures, DOD cannot afford to miss opportunities to address inefficiencies in these programs to free up resources for higher priority needs.

This report responds to a mandate in the joint explanatory statement to the DOD Appropriations Act, 2009. It includes observations on (1) the cost and schedule performance of DOD's 2013 portfolio of 80 major defense acquisition programs; (2) the knowledge attained at key junctures in the acquisition process for 38 programs that were in development or early production; and (3) key acquisition reform initiatives and program concurrency. To develop the observations in this report, GAO analyzed cost, schedule, and quantity data from DOD's Selected Acquisition Reports. GAO also collected data from program offices on technology, design, and manufacturing knowledge; the use of knowledge-based acquisition practices; and the implementation of acquisition reforms and initiatives.

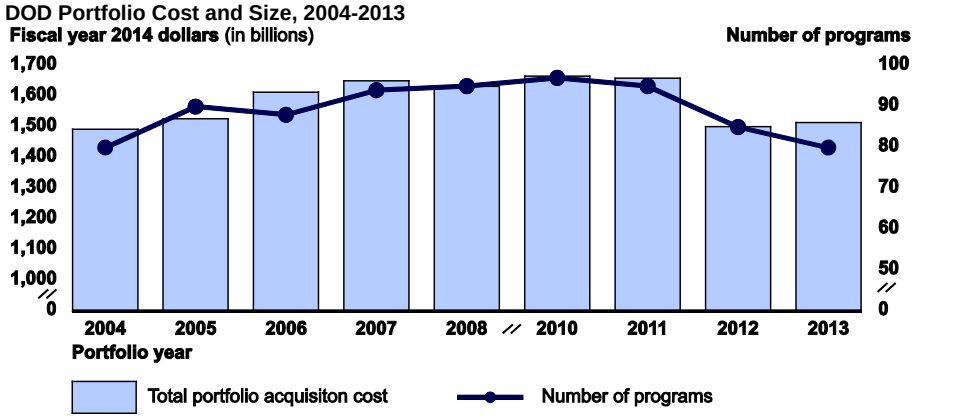
In commenting on a draft of this report, DOD cited its commitment to acquisition excellence and its positive effect on programs.

View GAO-14-340SP. For more information, contact Michael J. Sullivan at (202) 512-4841 or sullivanm@gao.gov.

What GAO Found

Over the past year, the overall size of DOD's major defense acquisition program portfolio decreased, from 85 programs to 80, while the estimated cost has increased by $14.1 billion. The average time to deliver initial capability to the warfighter also increased by 2 months. The slight cost increase can be attributed to the addition of one program, the Evolved Expendable Launch Vehicle. This furthers a trend for decreased portfolio size seen for the past three years. Although the overall cost of the 2013 portfolio increased, 50 of the 80 programs decreased costs, and 64 percent of programs increased their buying power. There are still some programs that have performed poorly, both over the past year and in the longer term. Fifty-five percent of the current portfolio funding has been appropriated, leaving approximately $682 billion needed for future funding. About forty-five percent of this remaining funding represents cost growth from initial estimates, a clear indicator that DOD needs to do more to control cost growth.

DOD Portfolio Cost and Size, 2004-2013



Source: GAO analysis of DOD data.
Note: The 2009 portfolio is excluded as the appropriate data was not available for review.

Most of the 38 programs GAO assessed this year are not yet fully following a knowledge-based acquisition approach. This held true for the seven programs that passed through one of three key decision points in the past year. Each implemented some knowledge based practices but practices—such as fully maturing technologies prior to development start and bringing all manufacturing processes under control—were not implemented. As a result, many of the 38 programs will carry unwanted risk into subsequent phases of acquisition that could result in cost growth or schedule delays.

Implementation of the reform initiatives on the 38 programs assessed above, and 18 that are not yet major defense acquisition programs, GAO analyzed varies. Specifically, while the department has been successful in implementing its "should cost" initiative to reduce contract costs and established configuration steering boards, the establishment of limits on total program costs (i.e. affordability constraints) and the need for greater competition are not being implemented to the same degree. In addition, many programs continue to commit to production before completing developmental testing.

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Abbreviations

AEHF	Advanced Extremely High Frequency
AMDR	Air and Missile Defense Radar
BMDS	Ballistic Missile Defense System
CSB	configuration steering board
DAMIR	Defense Acquisition Management Information Retrieval
DDG 51	DDG 51 Arleigh Burke Class Guided Missile Destroyer
DOD	Department of Defense
eSRS	Electronic Subcontracting Reporting System
G/ATOR	Ground/Air Task Oriented Radar
GCV	Ground Combat Vehicle
JLTV	Joint Light Tactical Vehicle
LCS	Littoral Combat Ship
MRL	manufacturing readiness level
NA	not applicable
OMB	Office of Management and Budget
PIM	Paladin Integrated Management
SAR	Selected Acquisition Report
SIBRS	Space Based Infrared System
TBD	to be determined
TRL	technology readiness level
WIN-T Inc 3	Warfighter Integration Network-Tactical Increment 3
WSARA	Weapon Systems Acquisition Reform Act

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GAO U.S. GOVERNMENT ACCOUNTABILITY OFFICE

Comptroller General of the United States

441 G St. N.W.
Washington, D.C. 20548

March 31, 2014

Congressional Committees

I am pleased to present GAO's 12th annual assessment of the Department of Defense's (DOD) major defense acquisition programs. This report offers observations on the performance of DOD's current $1.5 trillion portfolio of 80 programs. At its current size, this portfolio will require almost one-third of all expected development and procurement funding during the next 5 years. With the decline in the availability of discretionary funding, DOD cannot afford to miss opportunities to address inefficiencies in these programs to free up resources for additional high priority needs such as support of current operations. Consistent with our past recommendations, Congress and DOD have taken meaningful steps over the past several years to address long-standing problems with DOD weapon system acquisitions—an area that has been on GAO's high-risk list for more than 20 years.[1] We are encouraged about these steps, but we are also mindful that previous attempts to implement best practices and reign in cost and schedule overruns have failed or resulted in only marginal improvements.

Our current assessment shows that the estimated cost of DOD's 2013 portfolio of major defense acquisition programs is $14.1 billion more than the 2012 portfolio while the size of the portfolio decreased from 85 to 80 programs.[2] This places the size and cost of the portfolio on par with what it was for the 2004 portfolio, as opposed to the peak in size and cost seen in the $1.7 trillion, 97-program portfolio in 2010. Over the past year, the 80 programs of the 2013 portfolio have grown by a total of $12.6 billion, a net cost increase nearly all attributable to the significant procurement cost associated with one program—the Evolved Expendable Launch Vehicle. The cost growth of the portfolio as a whole is not necessarily indicative of the performance of every program as 50 of the 80 programs reduced their

[1]GAO, *High-Risk Series: An Update*, GAO-13-283 (Washington, D.C.: February 2013).

[2]Our assessment of DOD's 2012 portfolio of 86 major defense acquisition programs included the Missile Defense Agency's Ballistic Missile Defense System (BMDS). While DOD continues to report on BMDS as a major defense acquisition program, we exclude it from our assessment this year as the program lacks an acquisition program baseline comparable to the other programs, preventing us from measuring cost and schedule change in a manner consistent with our methodology. For more information on cost and schedule baselines for BMDS and the challenges for oversight they present see GAO, *Missile Defense: Opportunity to Refocus on Strengthening Acquisition Management*, GAO-13-432 (Washington, D.C.: Apr. 26, 2013).

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costs over the past year. While a large number of programs did reduce cost over the past year, the need for continued oversight and cost management remains as many programs are still not achieving the long-range targets for limited total acquisition cost growth discussed by GAO, DOD, and the Office of Management and Budget. Our assessment also shows that the implementation of knowledge-based acquisition practices varied across the portfolio, though programs that entered over the past 5 years were more likely to follow knowledge-based principles at development start thereby making them more likely to achieve their cost, schedule, and performance objectives. Finally, our analysis shows that many programs are implementing selected acquisition reforms focused on affordability and cost savings, although DOD continues to accept risks by allowing programs to begin production before completing developmental testing. This report also includes brief assessments of 56 future and current major defense programs that provide additional insights into the performance of the portfolio.

Current and anticipated fiscal constraints make it imperative that DOD continue to find ways to improve the efficiency of its major weapon systems portfolio while still delivering the capabilities required by the warfighter. While many of the recent efficiencies achieved by programs decreased their costs without reducing quantities, it is unclear how much more savings can be obtained in this manner or if the estimates of future saving based upon ongoing DOD efficiency initiatives will come to fruition. Continued strong leadership on the part of DOD is essential, whether on advancing gains made through “Better Buying Power” initiatives or in enforcing a broader implementation of best practices in all aspects of a new weapon system acquisition as it enters the portfolio.



Gene L. Dodaro
Comptroller General
of the United States

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GAO U.S. GOVERNMENT ACCOUNTABILITY OFFICE

441 G St. N.W.
Washington, D.C. 20548

March 31, 2014

Congressional Committees

In response to the mandate in the joint explanatory statement to the Department of Defense Appropriations Act, 2009, this report provides perspectives on how well the department is planning and executing its $1.5 trillion portfolio of major weapon programs, in addition, this report includes information related to small business participation pursuant to a mandate in a report accompanying the National Defense Authorization Act for Fiscal Year 2013.[1] The current portfolio's cost has declined since peaking at $1.7 trillion in 2010 and is currently at its lowest point in almost 10 years. In addition, the number of programs in the portfolio has decreased from 97 in 2010 to 80 programs in 2013. Since the first issuance of this series of reports in 2003, Congress and DOD have made meaningful improvements to the statutory and policy frameworks that govern the defense acquisition system by mandating and encouraging a more knowledge-based approach for major weapon programs. However, we have noted in the past that practice has lagged behind policy in certain areas and commensurate improvements in program outcomes are often not evident as many programs continue to cost more and take longer to develop than originally estimated. The changes in DOD's portfolio over the past few years indicate that some improvements are being realized in the near term. With the prospect of decreased defense budgets in the near future, it is imperative that DOD continue to find ways to reduce cost and improve the economy and efficiency of its acquisition practices not only in the short term, but throughout the life of current and future defense acquisition programs. Such cost reductions may be found by changing program acquisition strategies to include a more knowledge-based approach through the implementation of acquisition reforms and initiatives and the reduction of practices like concurrent testing and production, the risks of which we have identified repeatedly.

This report includes observations on (1) the cost and schedule performance of DOD's 2013 portfolio of 80 major defense acquisition programs, (2) the knowledge attained at key junctures in the acquisition

[1]See Explanatory Statement, 154 Cong. Rec. H 9427, 9526 (daily ed., Sept. 24, 2008), to the Department of Defense Appropriations Act, 2009, contained in Division C of the Consolidated Security, Disaster Assistance, and Continuing Appropriations Act, 2009, Pub. L. No. 110-329 (2008) and H.R. Rep. No. 112-479, at 284 (2012), *accompanying* Pub. L. No.112-239.

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process for 38 weapon programs in development or early production, and (3) key acquisition reform initiatives and whether programs are conducting or planning concurrent testing and production.[2]

Our observations in this report are based on three sets of programs:

- We assessed 80 major defense acquisition programs in DOD's 2013 portfolio for our analysis of cost and schedule performance. We obtained cost, schedule, and quantity data from DOD's December 2012 Selected Acquisition Reports (SAR) and from the Defense Acquisition Management Information Retrieval Purview system.

- We assessed 38 major defense acquisition programs that were mostly between the start of development and the early stages of production for our analysis of knowledge attained at key junctures and the implementation of acquisition reforms. We obtained information on the extent to which the programs follow knowledge-based practices for technology maturity, design stability, and production maturity using a data-collection instrument. We also submitted a questionnaire to program offices to collect information on issues such as systems engineering reviews, design stability, manufacturing planning and execution, and the implementation of specific acquisition reforms. We received questionnaire responses from all 38 programs from August to November 2013.

- In addition, we assessed 18 future major defense acquisition programs in order to gain additional insights into knowledge attained before the start of development and the implementation of key acquisition reform initiatives. We submitted a questionnaire to program offices to collect information on issues such as program schedule events, costs, and numerous acquisition reforms, and received responses from all 18 programs from August to November 2013.

[2]Major defense acquisition programs (MDAP) are those identified by DOD with a dollar value for all increments estimated to require eventual total expenditure for research, development, test, and evaluation of more than $480 million, or for procurement of more than $2.79 billion, in fiscal year 2014 constant dollars. DOD has a list of programs designated as future major defense acquisition programs. These programs have not formally been designated as MDAPs; however, DOD plans for these programs to enter system development, or bypass development and begin production, at which point they will likely be designated as MDAPs. We refer to these programs as future major defense acquisition programs throughout this report.

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In addition to our observations, we present individual assessments of 56 weapon programs. Selection factors include major defense acquisition programs in development or early production, future programs, and recently canceled or restructured programs.

We conducted this performance audit from June 2013 to March 2014 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings based on our audit objectives. Appendix I contains detailed information on our scope and methodology.

Observations on the Cost and Schedule Performance of DOD's 2013 Major Defense Acquisition Program Portfolio

The estimated cost of DOD's 2013 portfolio of 80 weapon programs is $14.1 billion more than the 2012 portfolio of 85 programs. The 80 programs within this year's portfolio have had estimated cost increases of $12.6 billion against their estimates from a year ago and an average of 2 months increase in schedule. This increase masks otherwise positive trends as 50 of 80 programs in the portfolio decreased their total acquisition costs and the majority of the cost increases can be traced to either the effects of additional procurement quantities or inefficiencies experienced in a few programs. Though notable, the cost reductions achieved by the programs in the 2013 portfolio over the past year need to be weighed against the increases many of these programs have had over the past five years or since their first full estimate of costs. Our analysis of DOD's 2013 portfolio allows us to make the following eight observations.

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Cost and Schedule Performance Observations

General changes in the portfolio

1. When compared to the 2012 portfolio, the size of DOD's 2013 portfolio decreased from 85 to 80 programs, but its overall cost has increased by $14.1 billion from $1,501 billion to $1,515 billion. The decrease in portfolio size follows a trend from the past 3 years.[a]
2. When comparing the cost and schedule estimates of the 80 programs in the 2013 portfolio we found cost growth of $12.6 billion and an average schedule delay of 2 months over the past year. When assessed against first full estimates, the total cost of the 2013 portfolio has increased by nearly $448 billion with an average delay of 28 months in operating capability.[b]

Factors that explain the changes

3. While the overall cost of the 2013 portfolio has increased, 50 of the 80 programs within the portfolio reduced their costs over the past year. The majority of the net cost growth can be attributed to a single program, the Evolved Expendable Launch Vehicle (EELV).
4. Our analysis shows that, when the effects of quantity changes are accounted for, DOD improved buying power on 64 percent of the programs in the portfolio over the past year.
5. As measured against metrics discussed by GAO, the Office of Management and Budget, and DOD in 2008, only 55 percent of programs in the 2013 portfolio meet the metric for less than 10 percent growth over the past 5 years and only 44 percent meet the metric for less than 15 percent growth since first full estimates; both proportions are smaller than in the 2012 portfolio, which demonstrates that a program can experience an interval of cost stability between periodic cost increases.

Other observations

6. The total acquisition cost of the portfolio is driven in large part by the 10 costliest programs, which represent 59 percent of current portfolio's total cost. These 10 programs alone incurred a net cost increase over the past year of approximately $15.4 billion due primarily to quantity increases on the EELV, while the other 70 programs reported a net cost decrease of $2.8 billion over the same period.
7. The majority of the cost of the portfolio is concentrated in two system types and the amount and type of cost growth from first full estimate, as well as the schedule delay, varied significantly by system type.
8. DOD has already been appropriated more than $833 billion for the current portfolio, leaving approximately $682 billion in costs to be funded, mostly for procurement. Approximately 45 percent of the remaining cost represents growth from first full estimates. Almost two-thirds of the future funding is needed for 10 programs, with 35 percent of the total costs remaining required for the F-35 program alone.

[a]All dollar figures are in fiscal year 2014 constant dollars, unless otherwise noted.

[b]Total acquisition cost includes acquisition-related operation and maintenance costs and system-specific military construction costs in addition to development and procurement costs.

Additional details about each observation follow.

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1. **When compared to the 2012 portfolio, the size of DOD's 2013 portfolio decreased from 85 to 80 programs, but its overall cost has increased by $14.1 billion, from $1,501 billion to $1,515 billion. The decrease in portfolio size follows a trend from the past 3 years.** With 80 programs and an estimated total cost of more than $1.5 trillion, the 2013 portfolio has fewer programs but a larger total acquisition cost when compared to the 2012 portfolio. The changes from the 2012 portfolio to the 2013 portfolio are outlined in table 1 below.

Table 1: Changes in DOD's Portfolio of Major Defense Acquisition Programs from 2012 to 2013

Fiscal year 2014 dollars in billions	
2012 portfolio (85 programs)	**$1,501.1**
Less cost of 12 exiting programs	-$73.1
Plus estimated total cost of 7 entering programs	+$101.6
Less net cost changes of 73 remaining programs	-$14.4
2013 portfolio (80 programs)	**$1,515.2**

Source: GAO analysis of DOD data.

Note: Our assessment of DOD's 2012 portfolio included the Ballistic Missile Defense System (BMDS). We exclude it from our assessment this year as the program lacks an acquisition program baseline comparable to other programs, preventing us from measuring cost and schedule change in a manner consistent with our methodology. To make the comparisons above we adjusted the 2012 portfolio estimates to reflect the removal of BMDS. Some numbers may not sum due to rounding.

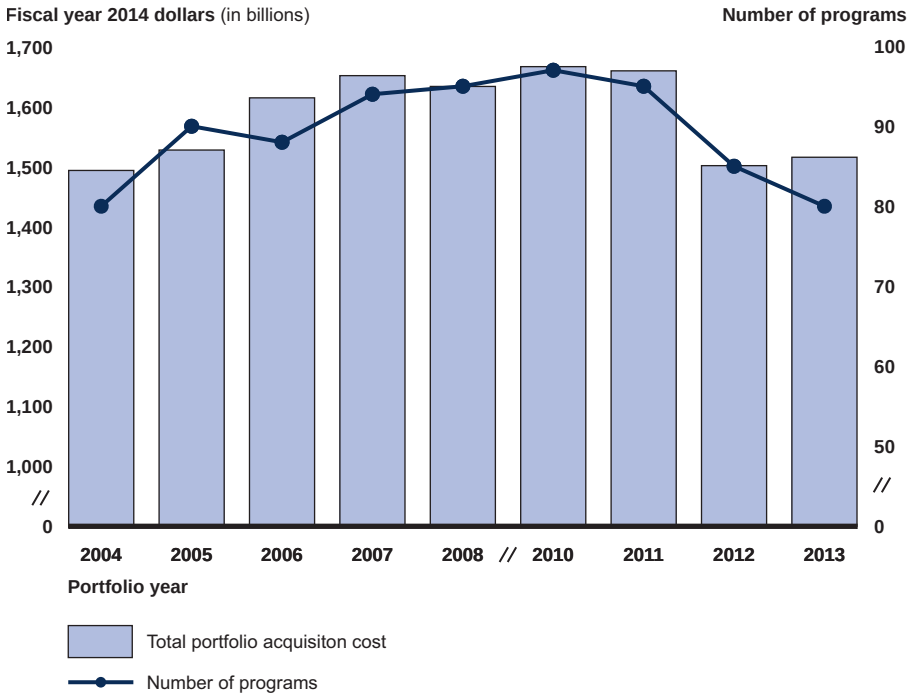
The 2013 portfolio reflects a net reduction of 5 programs—from 85 to 80—and, when all the programmatic changes are taken into account, the cost of the 2013 portfolio is $14.1 billion more than the 2012 portfolio.[3] The current size of the portfolio in terms of number of

[3]The 12 programs that exited the portfolio were AIM-9X Block I, C-130 Avionics Modernization Program, Chemical Demilitarization-Chemical Materials Agency, Cobra Judy Replacement, High Mobility Artillery Rocket System, Joint High Speed Vessel, Joint Tactical Radio System Ground Mobile Radio, Multi-Platform-Radar Technology Insertion Program, National Polar-orbiting Operational Environmental Satellite System, Stryker Family of Vehicles, Thermal Weapons Sight, Warfighter Information Network - Tactical Increment 1. The seven that entered the portfolio were Airborne Warning and Control System Block 40/45 Upgrade, AN/TPS-80 Ground/Air Task Oriented Radar, B61 Mod 12 Life Extension Program Tailkit Assembly, Evolved Expendable Launch Vehicle, Joint Light Tactical Vehicle, Next Generation Operational Control System (GPS OCX), and Ship to Shore Connector.

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programs and total cost is similar to that seen in the 2004 portfolio and furthers a trend for decreased portfolio size, and to some extent cost, seen since the 2010 portfolio. Figure 1 shows the cost and size of DOD's portfolios of major weapons acquisitions over the past 10 years.

Figure 1: DOD Portfolio Cost and Size, 2004-2013



Source: GAO analysis of DOD data.

Note: The 2009 portfolio is excluded because there were no annual SARs released for the December 2008 submission date.

A closer look at the 7 programs that entered the portfolio shows that 4 entered the portfolio at the beginning of system development. In contrast, two of the other three programs—the AN/TPS-80 Ground/Air Task Oriented Radar (G/ATOR) and the Airborne Warning and Control System Block 40/45 Upgrade—entered the portfolio long after their development start and are in production or will have a production decision in 2013. These programs were not originally planned as major acquisitions, but their costs grew past the threshold for major defense acquisition programs. For example, G/ATOR began system development in 2005 as a non-major defense acquisition program and

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was reclassified due to program cost growth realized after completing 6 years of an 8-year development effort. The final program, EELV, re-entered the portfolio in response to statutory direction and soon after reported a quantity increase and a critical breach of Nunn-McCurdy unit cost threshold.[4]

Of the 12 programs that exited the portfolio, 8 completed development and fielded a system, while three were canceled after reporting substantial development cost growth or delays to their planned initial capability or, in one case, both. A final program, the Joint High Speed Vessel, exited the portfolio after a quantity reduction caused its cost to slip below the threshold for major defense acquisition programs.

2. **When comparing the cost and schedule estimates of the 80 programs in the 2013 portfolio we found cost growth of $12.6 billion and average schedule delay of 2 months over the past year.** While the above observation states the change from the 85 program 2012 portfolio due to programs exiting and entering, in this observation we measure the change that occurred only on the 80 programs in the 2013 portfolio. Table 2 shows the changes in cost and schedule for the 2013 portfolio in the past year.

[4]Section 2433 of title 10 of the United States Code, commonly referred to as Nunn-McCurdy, requires DOD to notify Congress whenever a major defense acquisition program's unit cost experiences cost growth that exceeds certain thresholds. This is commonly referred to as a Nunn-McCurdy breach. Significant breaches occur when the program acquisition unit cost or procurement unit cost increases by at least 15 percent over the current baseline estimate or at least 30 percent over the original estimate. For critical breaches, when these unit costs increase at least 25 percent over the current baseline estimate or at least 50 percent over the original, DOD is required to take additional steps, including conducting an in-depth review of the program. Programs with critical breaches must be terminated unless the Secretary of Defense certifies to certain facts related to the program and takes other actions, including restructuring the program. 10 U.S.C. § 2433a.

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Table 2: Changes in DOD's 2013 Portfolio of 80 Major Defense Acquisition Programs over the Past Year

Fiscal year 2014 dollars in billions

	Estimated 2013 portfolio cost in 2012	Estimated 2013 portfolio cost in 2013	Increase since 2012	Percentage change since 2012
Total estimated research and development cost	$286.7	$288.7	$2.0	0.7%
Total estimated procurement cost	1,201.6	1,213.2	11.5	1.0
Total other acquisition costs[a]	14.3	13.3	-0.9	-6.3
Total estimated acquisition cost	1,502.6	1,515.2	12.6	0.8
Average delay in delivering initial capabilities	—	—	2 months	2.8%

Source: GAO analysis of DOD data.

Note: Some numbers may not sum due to rounding.

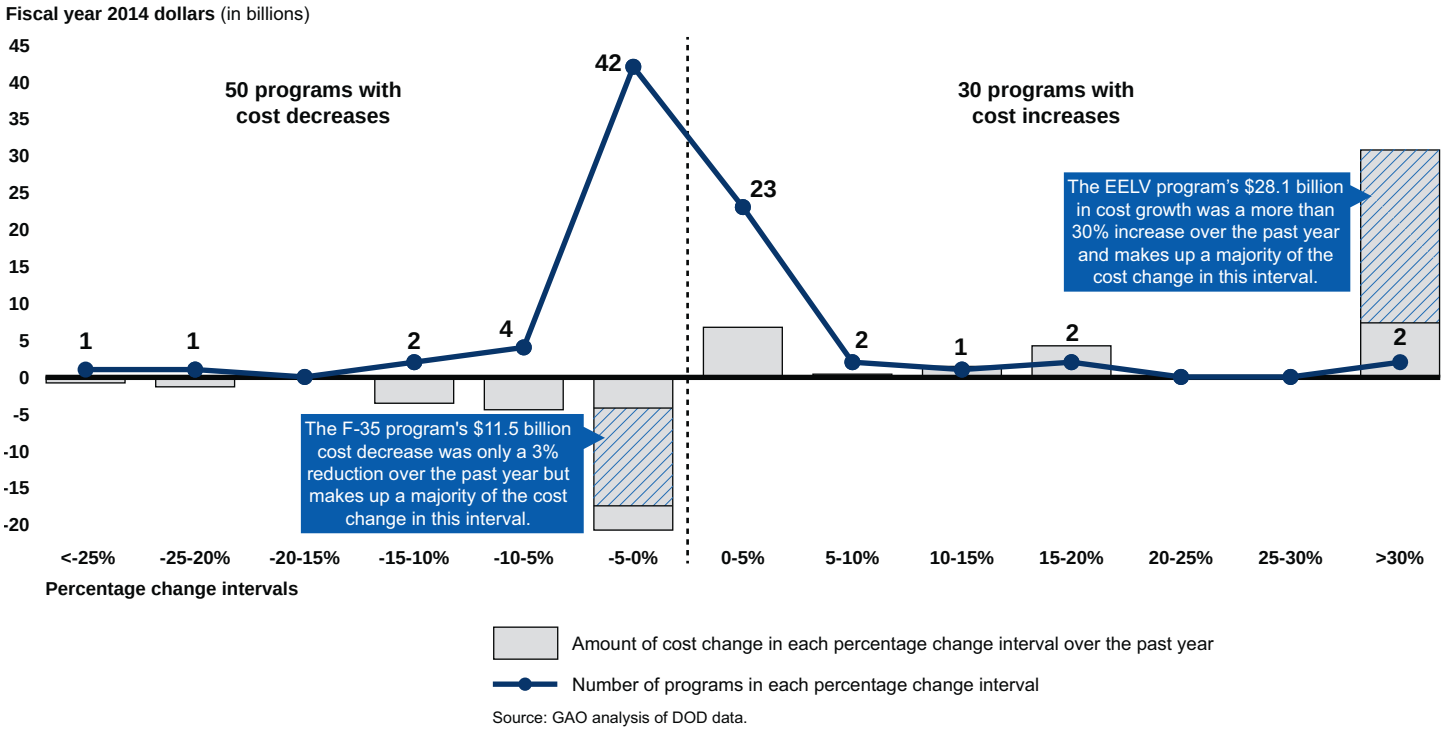
[a]In addition to research and development and procurement costs, total acquisition cost includes acquisition-related operation and maintenance and system-specific military construction costs.

The rise in total acquisition cost within the current portfolio over the past year is attributable to cost growth in both development and procurement, with procurement accounting for more than 90 percent of the total increase. Decreases in other costs, such as military construction, result in a net cost growth of $12.6 billion for these 80 programs over the past year. When measured against programs' first full estimates, the total acquisition cost of the current portfolio has grown by $447.8, or nearly 42 percent. The average delay in delivering initial capabilities has slipped an additional 2 months over the past year. The average delay against first full estimates is 28 months, on average.

3. **While the overall cost of the 2013 portfolio has increased, 50 of the 80 programs within the portfolio reduced their costs over the past year. The majority of the net cost growth can be attributed to a single program—EELV.** The $12.6 billion increase shown in table 2 above is the net result of cost changes on all 80 programs in the current portfolio. The distribution of those cost changes across the portfolio is shown below in figure 2.

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Figure 2: Distribution of the Total Acquisition Cost Change for the 2013 Portfolio



Source: GAO analysis of DOD data.

Our analysis, as represented above, shows that 50 programs experienced cost decreases totaling almost $30.9 billion during the past year while 30 programs reported cost increases totaling approximately $43.5 billion. Of the programs that decreased their total acquisition costs,

- 38 did so by finding efficiencies within the program and not by decreasing procurement quantities;
- 9 reduced their procurement quantities thereby reducing overall cost; and
- 3 increased their procurement quantities but found enough offsetting efficiencies to reduce overall cost.

The most significant of these decreases is the $11.5 billion reduction to the F-35 Joint Strike Fighter program's estimate, due solely to

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efficiencies found within the program as no decrease in quantities was reported. In contrast, 30 programs reported cost increases. Of these,

- 17 reported cost increases due to inefficiencies in the program and not any change to procurement quantities;
- 12 programs increased their procurement quantities; and
- 1 program reduced estimated procurement quantities but still reported an increase to total costs.

The most significant of the programs with increases to total acquisition cost was EELV, which reported an increase in the number of launch services it expected to procure and a $28.1 billion, or 78 percent, increase in total acquisition cost during the past year. As can be seen from the preceding tally of individual cost increases and decreases, to better understand the changes to cost the effect of changes to quantity must be understood.

4. **Our analysis shows that, when the effects of quantity changes are accounted for, DOD improved buying power on 64 percent of the programs in the portfolio over the past year.** Although procurement costs for the portfolio increased by $11.5 billion over the past year, this growth is lower than GAO's calculations of the expected cost growth due to quantity changes, indicating that programs found efficiencies in other areas and increased their buying power.[5] In general, buying power can be defined as the amount of good or service that can be purchased given a specified level of funding. Our calculation of how programs' cost and quantity changes affected their buying power are presented in table 3.

[5]A description of this calculation can be found in the detailed scope and methodology in appendix I.

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Table 3: Increases in Buying Power for the 2013 Portfolio over the Past Year

Fiscal year 2014 dollars in billions

	Number of programs	Actual procurement cost change	GAO-calculated cost change attributable to quantity changes	GAO-calculated cost change not attributable to quantity changes
Increased buying power	**51**	**-$23.0**	**$4.9**	**-$27.9**
Procurement cost decreased with no quantity change	35	-22.6	0	-22.6
Quantity increased with less cost increase than anticipated	10	4.8	7.9	-3.1
Quantity decreased with more cost decrease than anticipated	6	-5.2	-3.0	-2.2
Decreased buying power	**25**	**$34.5**	**$22.4**	**$12.1**
Procurement cost increased with no quantity change	16	4.7	0	4.7
Quantity increased with more cost increase than anticipated	5	32.1	25.3	6.8
Quantity decreased with less cost decrease than anticipated	4	-2.3	-2.9	0.5
No change in buying power	**4**	**$0**	**$0**	**$0**
Total	**80**	**$11.5**	**$27.3**	**-$15.8**

Source: GAO analysis of DOD data.

Note: Some numbers may not sum due to rounding.

Based on our analysis, a total of 51 programs increased their buying power in the past year, resulting in a total of $23 billion in procurement cost reductions. Thirty-five of the programs that decreased their procurement cost did so without reducing quantities, an indication that they found efficiencies elsewhere. Ten programs increased their expected procurement quantities but their total procurement cost increase was less than would be expected based upon the average procurement unit cost of each program used in GAO's calculation. For example, over the past year the DDG 51 program added two ships to its planned procurement, at an estimated unit cost of more than $1.3 billion. If the resulting procurement cost increase from these additional quantities is ignored the cost for the program actually decreases, due to the fact that it found efficiencies elsewhere that increased the program's buying power even as the program increased quantities. An additional 6 programs decreased their quantities but achieved cost reductions in excess of that anticipated by GAO's cost calculations. For example, the Littoral Combat Ship (LCS) program reported a procurement cost decrease of over $3 billion. While a significant portion of this reduction was achieved by removing three ships from the planned procurement, almost half, $1.2 billion, was due to factors

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other than the quantity reduction, such as a revised estimate that reflects lower future costs.

Increases in buying power such as these could be expected to continue as many of the programs that responded to our questionnaire indicated that they expected large amounts of "should-cost" savings in the future. The "should-cost" initiative, introduced through DOD's "Better Buying Power" initiatives, emphasizes the importance of driving cost improvements during contract negotiation and program execution to control costs, improvements that could lead to program efficiencies which increase buying power. For example, the AIM-9X Block II Air-to-Air Missile program realized a procurement cost decrease of approximately $327 million with no change in quantity over the past year and also reported $128 million in "should-cost" savings that are expected in the future. In another case, the MQ-4C Triton Unmanned Aircraft System also realized decreasing procurement costs of $274 million over the past year while maintaining the same quantity and reported that another $480 million in "should-cost" savings are expected in the future.

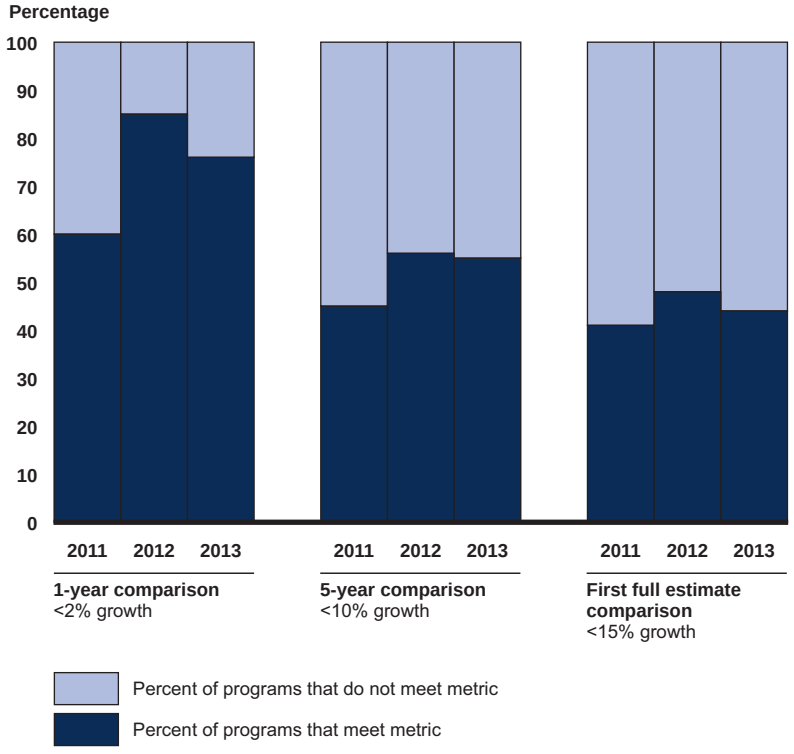
Our analysis in table 3 above also shows that procurement costs for 25 programs increased by $34.5 billion, but by our calculation only $22.4 billion can be attributed to the cost of procuring additional units, with $12.1 billion of that increase attributable to other factors. The most significant increase was that of the EELV program, which reported increasing its expected launches, the program's measure of quantity, by 60 resulting in an estimated $28 billion procurement cost increase, $6 billion of which was not attributable to the quantity increase.

5. **As measured against metrics discussed by GAO, the Office of Management and Budget (OMB), and DOD in 2008, only 55 percent of programs in the 2013 portfolio meet the metric for less than 10 percent cost growth over 5 years and 44 percent meet the metric for less than 15 percent growth since full first estimates; both proportions are smaller than in the 2012 portfolio, which demonstrates that a program can experience an interval of cost stability between periodic cost increases.** In December 2008, DOD, OMB, and GAO, discussed a set of outcome metrics and goals to measure program cost performance over time. The metrics are intended to measure total program cost-performance on a percentage basis over three time periods: the preceding year, the preceding 5 years, and the period since first full program estimates were

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established. We have reported on these outcomes in past assessments. Seventy-six percent of the programs in the 2013 portfolio are meeting the one-year cost performance metric by limiting their total acquisition cost growth to less than 2 percent, consistent with the cost decreases and increases explained earlier. Fewer programs, however, are meeting the metrics for limited growth in the past five years and since first full estimates; 55 percent meet the 5-year metric while 44 percent are meeting the since first full estimate metric. This demonstrates that some programs with reduced or stable costs over the past year have previously had one or more cost increases. Programs do not generally experience cost change in a linear fashion with set amounts of increase or decrease every year, rather they have periods of more dramatic change interspersed with periods of stability. The performance of the 2013 portfolio, as well as the two previous weapon system portfolios, against these metrics is shown in figure 3.

Figure 3: Comparison of the Cost Performance of DOD's 2011, 2012, and 2013 Portfolios



Source: GAO analysis of DOD data.

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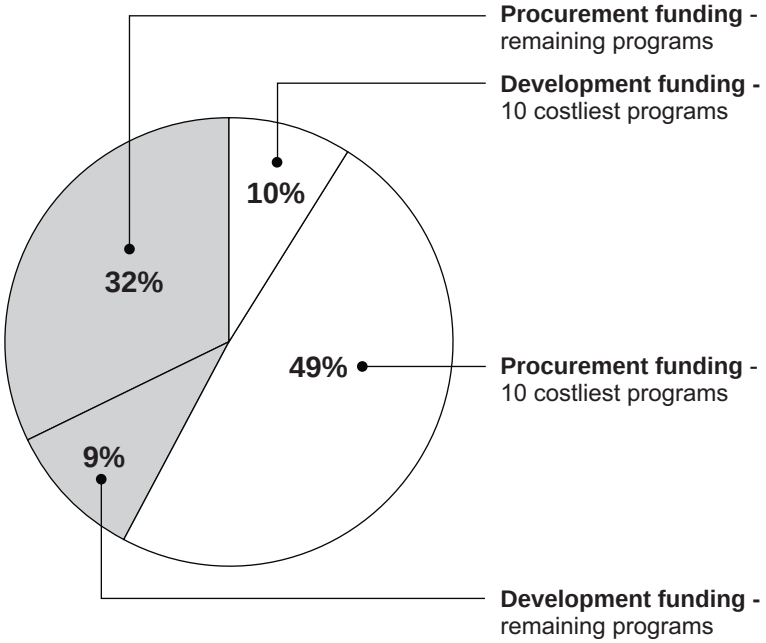
Note: Cost growth metric is defined as the percentage change in total program acquisition cost. Analysis includes the evaluation of cost growth on individual programs in the portfolio for each year. For programs where cost growth is measured on separate program sub-element, the elements were combined to calculate the cost growth on the entire program as a whole.

As a whole, aggregate cost performance of the 2013 portfolio has degraded across all three metrics from that observed in the 2012 portfolio. The percentage increase from 2012 to 2013 in programs that do not meet the cost metrics is attributable to two factors. First, many of the 12 programs that are no longer in the portfolio were meeting one or more of the three cost metrics while 2 of the 7 that entered—EELV and G/ATOR—do not meet one or more metrics. Second, performance against the cost metrics has grown worse on some of the ongoing programs. For example, the number of programs that do not meet the 1-year cost growth metric increased by 5—eight programs improved to meet this criterion in 2013 while the cost performance on 13 other programs worsened over the past year. Despite decreases in this metric in the past year, the portfolio's performance for 2013 is an improvement on the 2011 portfolio, the first year we used this metric.

6. **The 10 highest-cost programs account for 59 percent of the development and procurement cost and the majority of cost growth.** As we have reported in past assessments, the total acquisition cost of the portfolio is driven in large part by the 10 costliest programs, which currently represent 59 percent of the portfolio's development and procurement cost as shown in figure 4 below.

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Figure 4: Proportion of Development and Procurement Funding for the 10 Costliest Programs



Source: GAO analysis of DOD data.

Interestingly, 6 of the 10 costliest programs in the current portfolio were also in the list of 10 costliest programs in the 2004 portfolio, and if each of these programs had executed according to the baseline approved at development start, 3 of them would have completed acquisition and exited the portfolio.

Over the past year, the 10 costliest programs incurred a net cost increase of approximately $15.4 billion, due primarily to quantity increases on the EELV program. In contrast, the other 70 programs reported a combined cost decrease of $2.8 billion. Similarly, the 10 costliest programs also account for almost 60 percent of all cost growth—or $124.4 billion—over the past 5 years in the current portfolio. Table 4 identifies the 10 costliest programs and lists their total acquisition cost and cost growth in the past year.

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Table 4: Cost Changes in DOD's 10 Costliest Programs in Comparison to the Rest of the Current Portfolio

Fiscal Year 2014 dollars in billions

Program name	Current total estimated acquisition cost	Change in acquisition cost over the past year
F-35 Joint Strike Fighter	$332.3	-$11.5
DDG 51 *Arleigh Burke* Class Destroyer	107.8	2.4
Virginia Class Submarine	84.4	-2.3
Evolved Expendable Launch Vehicle	63.9	28.1
V-22 Osprey	60.7	0.8
F/A-18E/F Super Hornet	59.7	-1.0
Trident II Missile	55.5	0.6
KC-46 Tanker	44.5	-1.2
CVN 78 *Gerald R. Ford* Class Aircraft Carrier	36.0	-0.3
P-8A Poseidon	34.3	-0.04
10 costliest programs	**$880.0**	**$15.4**
Total for rest of the current portfolio	**$635.2**	**-$2.8**
2013 portfolio total	**$1,515.2**	**$12.6**

Source: GAO analysis of DOD data.

Note: Some numbers may not sum due to rounding.

7. **The majority of the cost of the portfolio is concentrated in two system types and the amount and type of cost growth from first full estimate, as well as the schedule delay, varied significantly by system type.** Over 60 percent of the current portfolio's cost is accounted for by two system types—fixed wing manned aircraft and shipbuilding programs, both of which experienced unfavorable cost and schedule growth from first full estimates. The amount of cost growth, and whether that growth occurred in development or procurement, varied by the type of system acquired. Table 5 shows the amount of cost growth for development and acquisition unit cost experienced by each system type as well as the amount of schedule growth.

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Table 5: Cost and Schedule Change since First Full Estimates by System Type

System type	Total development cost percentage increase	Procurement unit cost percentage increase	Percentage increase in time to deliver initial capabilities
Shipbuilding	113%	19%	53%
Unmanned vehicle	86	22	58
Rotary wing	78	74	30
Satellite	55	85	93
Fixed wing	43	55	34
C4ISR	42	-8	26
Munition	17	-10	16
Missile	13	79	30
Ground	5	62	19

Source: GAO analysis of DOD data.

Note: The procurement unit cost growth estimate was calculated using a weighted average based each program's current procurement cost that gives more expensive programs a greater value. Three of the 80 programs in the current portfolio—Chemical Demilitarization-Assembled Chemical Weapons Alternatives, EELV, and Ship to Shore Connector—were not assessed here as they do not correspond with any of the nine system types used.

The development cost growth for shipbuilding programs is the greatest among all system types and, at approximately 113 percent, is more than double that experienced by the portfolio as a whole. For example, the DDG 1000 and LCS have experienced more than 342 percent and 148 percent growth, respectively, in development costs from first full estimates. Shipbuilding programs have also experienced significant schedule delays with four out of seven programs reporting delays to the delivery of initial capability of 2 years or more. We have an extensive body of work that covers the problems DOD has experienced in developing these systems.[6]

[6]GAO, *Navy Shipbuilding: Significant Investments in the Littoral Combat Ship Continue Amid Substantial Unknowns about Capabilities,* GAO-13-530 (Washington, D.C.: July 22, 2013); *Ford-Class Carriers: Lead Ship Testing and Reliability Shortfalls Will Limit Initial Fleet Capabilities*, GAO-13-396 (Washington, D.C.: Sept. 5, 2013); *Arleigh Burke Destroyers: Additional Analysis and Oversight Required to Support the Navy's Future Surface Combatant Plans*, GAO-12-113 (Washington, D.C.: Jan. 24, 2012); *Best Practices: High Levels of Knowledge at Key Points Differentiate Commercial Shipbuilding from Navy Shipbuilding*, GAO-09-322 (Washington, D.C.: May 13, 2009); and *Defense Acquisitions: Cost to Deliver Zumwalt-Class Destroyers Likely to Exceed Budgets*, GAO-08-804 (Washington, D.C.: July. 31, 2008).

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Rotary wing systems have also experienced exceptionally high levels of development cost change, with 4 out of 9 rotary wing programs experiencing more than 150 percent growth. Rotary wing programs have also experienced high amounts of growth in procurement unit cost. As an example, both the H-1 Upgrades and CH-47F Improved Cargo Helicopter have each experienced more than 150 percent growth in their average procurement unit cost since first full estimates. Satellite programs show above average growth in development cost, procurement unit cost, and schedule growth since first full estimates when compared to the portfolio as a whole. For example, Wideband Global SATCOM and Space Based Infrared System (SIBRS) High, have each experienced more than 100 percent growth in their development costs while another satellite program, the Advanced Extremely High Frequency (AEHF) Satellite, has experienced almost 200 percent growth in its average procurement unit cost. Three satellite programs have also experienced schedule growth well above the portfolio average of 36 percent with each of them reporting delays of 4 years or more. Unmanned vehicles have also experienced greater than average schedule delays with three of six unmanned vehicle programs reporting delays of 3 years or more.

8. **DOD has already been appropriated more than $833 billion for the current portfolio, leaving approximately $682 billion in costs to be funded, mostly for procurement. Approximately 45 percent of the remaining cost represents growth from first full estimates. Almost two-thirds of the future funding is needed for 10 programs, with 35 percent of the total costs remaining required for the F-35 program alone.** A larger share of the current portfolio's cost is now appropriated than had been appropriated for the portfolios from 10 or even 5 years ago. Fifty-five percent of the costs for the 2013 portfolio have already been appropriated, more than $200 billion more than in the 2004 portfolio. Forty-five percent of the total cost of the current portfolio—or $682 billion—has not yet been funded and almost 94 percent of the remaining funding—or $638 billion—is needed for procurement.

   Approximately 45 percent—or $311.6 billion—of that future funding is needed to cover cost growth from first full estimates for programs in the current portfolio. These funds represent resources that will not be available to support other defense or government priorities. We recognize that for some programs a portion of this cost growth from first full estimates may be attributable to a quantity increase. For

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example, the $14 billion in future funding needed for the DDG 51 *Arleigh Burke* Class Guided Missile Destroyer (DDG 51) is a result of quantity increases and the program has realized a significant decrease in its average procurement unit cost from first full estimates. However, in our assessments since 2011 we have found that a substantial amount of the change in the portfolio's total procurement cost could be attributable to factors other than quantity change such as production problems, inefficiencies, or flawed initial cost estimates. For example, the F-35 program requires $107 billion in future funding to cover cost growth, even though it will procure 409 fewer aircraft than originally planned. Two-thirds of all remaining funding—or $463 billion—is required by the 10 programs with the highest future funding needs and F-35 alone requires about one-third of all funding to go. The other 70 programs have only $218.8 billion in costs remaining, less than the amount of future funding needed for the F-35 program. Table 6 shows the amount of future funding needed as well as how much of that funding represents cost growth from first full estimates.

Table 6: Future Funding and Future Funding Required Due to Cost Growth from First Full Estimates

Fiscal year 2014 dollars in billions

Program name	Future funding required	Amount of future funding due to cost growth from first full estimates
F-35 Joint Strike Fighter	$239.6	$107.0
Evolved Expendable Launch Vehicle	42.9	38.4
KC-46 Tanker	40.8	0
Virginia Class Submarine	28.2	16.2
Joint Light Tactical Vehicle	23.0	0
CH-53K Super Stallion	20.7	7.4
Littoral Combat Ship	19.6	19.6
CVN 78 *Gerald R. Ford* Class Aircraft Carrier	17.5	0
P-8A Poseidon	16.8	1.7
DDG 51 *Arleigh Burke* Class Destroyer	14.0	14.0
10 programs with the largest future funding requirements	**$463.2**	**$204.3**
Totals for rest of portfolio	**$218.8**	**$107.3**
2013 portfolio total	**$682.0**	**$311.6**

Source: GAO analysis of DOD data.

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Notes: Future funding is measured as all fiscal year 2014 funding to completion of procurement. Some numbers may not sum due to rounding.

Observations from Our Assessment of Knowledge Attained by Programs at Key Acquisition Junctures

Our 2014 assessment shows that DOD continues to show progress in following a knowledge-based approach to reduce risk; however, it has significant room for improvement. While programs that have recently passed through major decision points have demonstrated best practices—such as constraining development times and achieving design stability—key practices like demonstrating technology maturity or controlling manufacturing processes are still not being fully implemented. As a result, many programs will carry risk into subsequent phases of acquisition that could result in cost growth or schedule delays.

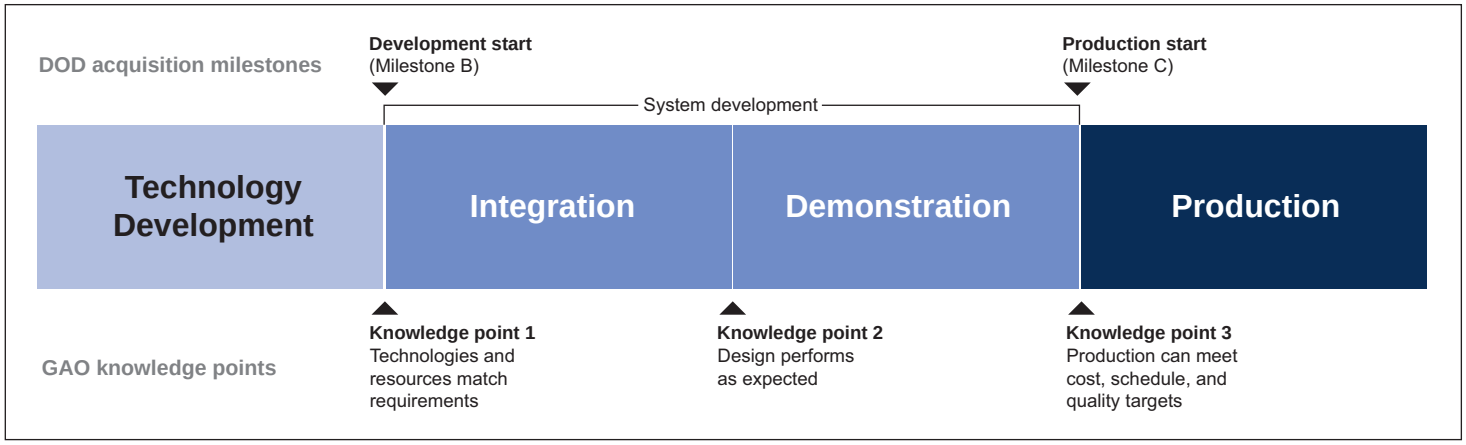
Positive acquisition outcomes require the use of a knowledge-based approach to product development that demonstrates high levels of knowledge before significant commitments are made. In essence, knowledge supplants risk over time. In our past work examining weapon acquisition and best practices for product development, we have found that leading commercial firms and successful DOD programs pursue an acquisition approach that is anchored in knowledge, whereby high levels of product knowledge are demonstrated at critical points in the acquisition process. This work led to multiple recommendations that DOD generally or partially agreed with and has made progress in implementing.[7] On the basis of this work, we have identified three key knowledge points during the acquisition cycle—development start, the system-level critical design review, and production start—at which programs need to demonstrate critical levels of knowledge to proceed. Figure 5 aligns the acquisition milestones described in DOD's primary acquisition policy with these knowledge points. In this report, we refer to DOD's engineering and

[7]GAO, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*, GAO/NSIAD-99-162 (Washington, D.C.: July 30, 1999); *Best Practices: Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes*, GAO-01-288 (Washington, D.C.: Mar. 8, 2001); *Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*, GAO-02-701 (Washington, D.C.: July 15, 2002); *Defense Acquisitions: A Knowledge-Based Funding Approach Could Improve Major Weapon System Program Outcomes*, GAO-08-619 (Washington, D.C.: July 2, 2008); *Best Practices: High Levels of Knowledge at Key Points Differentiate Commercial Shipbuilding from Navy Shipbuilding*, GAO-09-322 (Washington, D.C.: May 13, 2009); and *Best Practices: DOD Can Achieve Better Outcomes by Standardizing the Way Manufacturing Risks Are Managed*, GAO-10-439 (Washington, D.C: Apr. 22, 2010).

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manufacturing development phase as system development. Production start typically refers to a program's entry into low-rate initial production.

Figure 5: DOD's Acquisition Cycle and GAO Knowledge Points



Source: GAO.

The building of knowledge consists of information that should be gathered at these three critical points over the course of a program:

Knowledge point 1: Resources and requirements match. Achieving a high level of technology maturity by the start of system development is one of several important indicators of whether this match has been made. This means that the technologies needed to meet essential product requirements have been demonstrated to work in their intended environment. In addition, the developer should complete a series of systems engineering reviews culminating in a preliminary design of the product that shows the design is feasible. Constraining the development phase of a program to 5 to 6 years is also recommended because it aligns with DOD's budget planning process and fosters the negotiation of trade-offs in requirements and technologies. For shipbuilding programs, critical technologies should be matured into actual system prototypes and successfully demonstrated in a realistic environment before a contract is awarded for detail design of a new ship.

Knowledge point 2: Product design is stable. This point occurs when a program determines that a product's design will meet customer requirements, as well as cost, schedule, and reliability targets. A best

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practice is to achieve design stability at the system-level critical design review, usually held midway through system development. Completion of at least 90 percent of engineering drawings at this point provides tangible evidence that the product's design is stable, and a prototype demonstration shows that the design is capable of meeting performance requirements. Shipbuilding programs should demonstrate design stability by completing 100 percent of the basic and functional drawings as well as the three-dimensional product model by the start of construction for a new ship. Programs can also improve the stability of their design by conducting reliability growth testing and completing failure modes and effects analyses so fixes can be incorporated before production begins. At this point, programs should also begin preparing for production by identifying manufacturing risks, key product characteristics, and critical manufacturing processes.

Knowledge point 3: Manufacturing processes are mature. This point is achieved when it has been demonstrated that the developer can manufacture the product within cost, schedule, and quality targets. A best practice is to ensure that all critical manufacturing processes are in statistical control—that is, they are repeatable, sustainable, and capable of consistently producing parts within the product's quality tolerances and standards—at the start of production. Demonstrating critical processes on a pilot production line is an important initial step in this effort. In addition, production and postproduction costs are minimized when a fully integrated, capable prototype is demonstrated to show that the system will work as intended in a reliable manner before committing to production. We did not assess shipbuilding programs for this knowledge point due to differences in the production processes used to build ships.

Knowledge in these three areas builds over time. A knowledge deficit early in a program can cascade through design and production leaving decision makers with less knowledge to support decisions about when and how best to move into subsequent acquisition phases that commit more budgetary resources. Demonstrating technology maturity is a prerequisite for moving forward into system development, during which the focus should be on design and integration. A stable and mature design is likewise a prerequisite for moving forward into production where the focus should be on efficient manufacturing. Additional details about key practices at each of the knowledge points can be found in appendix IV.

For this report, we assessed the knowledge attained by key junctures in the acquisition process for 38 current weapon programs, which are mostly

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in development or early production.[8] Not all programs included in our review of knowledge-based practices provided information for every knowledge point or had reached all of the knowledge points—development start, design review, and production start—at the time of this review.

Our analysis of data from these 38 major defense acquisition programs allows us to make three observations.

Knowledge Point Observations

1. The two programs that began system development in 2013—F-22 Increment 3.2B and Air and Missile Defense Radar—did not demonstrate all their critical technologies in a realistic environment and one of the two did not complete all relevant systems engineering reviews as it failed to hold a preliminary design review prior to system development. Both programs, however, intend to constrain their development phase to 6 years or less. This is consistent with the majority of the portfolio. Of the other programs we assessed, only 4 matured their technologies and 8 completed preliminary design review in time for system development, but 19 planned for a constrained development phase.

2. Of the three programs that held critical design reviews in 2013—KC-46 Tanker, Joint Light Tactical Vehicle, and Warfighter Information Network-Tactical Increment 3—two demonstrated design stability by releasing 90 percent of planned engineering drawings and all three satisfied some of the best practices related to preparation for production; but none tested an early system-level integrated prototype or demonstrated all program critical technologies in a realistic environment prior to design review. For the other programs we assessed that reported information on this review, only 6 fully matured their designs and 3 tested system-level prototypes by the time this review was held. Significant numbers had conducted activities to plan for production.

3. The two programs that held production decisions since our last assessment—Paladin Integrated Management and Ground/Air Task Oriented Radar—reported mature technologies and stable designs. Only one demonstrated performance through the testing of a production-representative prototype. Consistent with our prior assessments, neither program has demonstrated that all their critical manufacturing processes are in statistical control, and only one program used a pilot production line before beginning production. Few of the other programs in our assessment that held production decisions implemented these practices; 3 had critical processes in control and 6 had used a pilot production line.

Additional detail about these observations follows.

[8]Because knowledge points and best practices differ for shipbuilding programs, we exclude the five shipbuilding programs from some of our analysis at each of the three knowledge points.

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1. **The two programs that began system development in 2013 completed two systems engineering reviews before beginning development and plan to constrain their development phase, but one program did not carry out a preliminary design review, and neither demonstrated all its critical technologies in a realistic environment.** Both the F-22 Increment 3.2B and the Air and Missile Defense Radar (AMDR) programs entered system development with critical technologies nearing maturity—that is, demonstrated in a relevant environment—in accordance with DOD policy and statutory requirements.[9] Knowledge-based acquisition practices, however, recommend that programs fully mature technologies and demonstrate them in a realistic or operational environment prior to entering system development. Achieving this higher level of technology maturity is a better indicator of whether a program has achieved a resource and requirements match with the attainment of additional knowledge about the technologies' form, fit, and function, as well as the effect of the intended environment on those technologies.[10] Neither the F-22 Increment 3.2B nor the AMDR programs satisfied this best practice and the lower maturity level attained by these programs is consistent with our observations in past assessments on programs entering system development. Figure 6 shows the extent to which recommended acquisition practices for knowledge point 1 have been implemented on F-22 Increment 3.2B and AMDR as well as the other 36 programs we assessed.

[9]According to DOD policy at the time of our questionnaire, technology should be demonstrated in a relevant environment or, preferably, in an operational environment. In addition, a major defense acquisition program generally may not receive approval for development start until the milestone decision authority certifies that the technology in the program has been demonstrated in a relevant environment. 10 U.S.C. § 2366b(a)(3)(D).

[10]Demonstration in a relevant environment is Technology Readiness Level (TRL) 6. Demonstration in a realistic environment is TRL 7. See app. V for detailed description of TRLs.

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Figure 6: Implementation of Knowledge-Based Practices for Programs in System Development

Knowledge-based practices at development start	F-22 Inc 3.2 B	AMDR	Other 36 programs ●	Other 36 programs ○	Other 36 programs ––
Demonstrate all critical technologies in a relevant environment	●	●	15	11	10
Demonstrate all critical technologies in a realistic environment	○	○	4	22	10
Complete system functional review and system requirements review before development start	●	●	10	25	1
Complete preliminary design review before development start	●	○	8	22	6
Constrain development phase to 6 years or less	●	●	19	4	13

● Practice implemented

○ Practice not implemented

––– Practice not applicable or information not available per the program office response

Source: GAO analysis of DOD data.

Of the remaining 36 current programs we assessed, only 4—Excalibur Precision 155mm Projectiles (Increment 1b), Global Positioning System III, LHA 6 *America* Class Amphibious Assault Ship, and Ship-to-Shore Connector—reported that all their critical technologies were matured to best practice standards when they began development.[11] Another 11 programs we assessed reported having all critical technologies nearing maturity prior to system development. The remaining 21 programs reported either having one or more immature technologies at the start of development or reported no information on technology maturity at this critical point in the acquisition process. Of

[11]The MQ-9 Reaper program also reported all critical technologies as fully mature at development start. However, that technology assessment reflects the Reaper Block 5 configuration and not the original program. Our historical data shows that the Reaper program began development in 2004 with its technologies nearing maturity.

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the 15 programs that had reported their critical technologies as at least nearing maturity at development start, 9 have thus far constrained research and development cost growth to 15 percent or less since first full estimate. In contrast, for the 11 programs reporting one or more immature critical technologies at development start, only 2 successfully constrained research and development cost growth to 15 percent or less since their first full estimate.

Knowledge-based acquisition best practices recommend and statute requires that programs hold systems engineering events, such as a preliminary design review, before the start of development to ensure that requirements are defined and feasible and that the proposed design can meet those requirements within cost, schedule, and other system constraints. The Weapon Systems Acquisition Reform Act of 2009 (WSARA) made it a statutory requirement that major defense acquisition programs generally hold a preliminary design review before the start of system development.[12] According to the program offices, the F-22 Increment 3.2B program conducted a preliminary design review prior to entering system development, but the AMDR program did not, and instead sought and received a waiver to this requirement. Currently, AMDR plans to conduct a preliminary design review in June 2014. Of the remaining 36 current programs we assessed, only 8 held a preliminary design review prior to development start, including 4 programs that began development start before 2009, and another 4 programs that started development after implementation of WSARA. Our analysis of the current portfolio shows that programs that conducted a preliminary design review prior to development start have, on average, experienced a lower rate of research and development cost growth and a lower rate of total acquisition cost growth, compared with programs that did not have a preliminary design review before development start. Of the eight assessed programs that held this review prior to development start, six have thus far constrained research and development cost growth to less than 15 percent since first full estimate. Of the 22 assessed programs that did not carry out a

[12]Pub. L. No. 111-23, § 205(a). A major defense acquisition program may not receive milestone B approval until the program has held a preliminary design review and the milestone decision authority has conducted a formal post-preliminary design review assessment and certified on the basis of such assessment that the program demonstrates a high likelihood of accomplishing its intended mission unless a waiver is properly granted by the milestone decision authority. 10 U.S.C. § 2366b(a)(2), (d)(1).

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preliminary design review prior to development start, only 8 were successful in restraining development cost growth below 15 percent.

In addition to the preliminary design review, knowledge-based acquisition best practices recommend the completion of two additional systems engineering reviews: one review to ensure that system requirements have been properly identified, which helps ensure mutual understanding between government and contractor; and a system functional review to establish a functional baseline for the system. Both the F-22 Increment 3.2B and AMDR programs completed these reviews prior to entering system development. Of the remaining 36 programs we assessed, only 10 completed both reviews prior to development start—five that entered system development before 2009 and another 5 that began system development after 2009.

Knowledge-based acquisition practices also recommend that a program constrain the development phase to just 5 or 6 years, and both the F-22 Increment 3.2B and AMDR programs plan to do so.[13] By limiting development time in this manner, a program increases the predictability of funding needs, as well as the likelihood of program success by fostering the negotiation of trade-offs in requirements and technologies.[14] For the remaining 31 non-ship programs we assessed, 19 had plans to limit their development phases to 6 years or less at the time of development start. This includes 13 out of 23 programs that began development prior to 2009 and another 6 out of 8 programs that began system development during or after 2009.

As part of our analysis, we also assessed 18 future programs that expect to become major defense acquisition programs. These programs provided information on the knowledge they planned to obtain and best practices they intend to implement before their development start is approved. Seven of 18 future programs reported

[13]We did not assess shipbuilding programs against this recommended practice to limit the development phase, as their development cycles do not align in a manner consistent with other programs.

[14]DOD policy in place at the time of our review provided that a condition for exiting the technology development phase is that a system or increment be developed for production within a short time frame, defined as normally less than 5 years for weapon systems. Department of Defense Instruction 5000.02, *Operation of the Defense Acquisition System*, enc. 2, para. 5.d(7) (Dec. 8, 2008) (hereinafter cited as DODI 5000.02 (Dec. 8, 2008). An interim version of this instruction was issued in November 2013.

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that their technologies are expected to be nearing maturity; that is demonstrated in a relevant environment, at the time of development start. Ten of the future programs plan to hold a preliminary design review before the start of development and only seven plan to conduct both a system functional and system requirements review before the start of development. Nine of the future programs reported plans to limit the program development phase to 6 years or less. If these plans continue unaltered, programs will enter system development with insufficient knowledge about their ability to meet cost, schedule, and performance requirements. The decision to proceed without this knowledge involves more than the program at hand, it sends signals across the portfolio of programs on what is acceptable. If programs that do not abide by sound acquisition principles win funding, then seeds of poor outcomes are planted. Top decision makers must ensure that new programs exhibit desirable principles before they are approved and funded; the proper time to establish that is at program start.

2. **Of the three programs that held critical design reviews in 2013, two demonstrated design stability by releasing 90 percent of expected engineering drawings, but none tested an early integrated prototype or demonstrated all critical technologies in a realistic environment prior to this design review.** Knowing a product's design is stable before system demonstration reduces the risk of costly design changes as manufacturing begins and investments in acquisition become more significant. Just as programs that enter system development with immature technologies cost more and take longer to deliver their operational capabilities to the warfighter, programs that hold their critical design review before achieving a stable design also experience higher average costs and longer schedule delays. Figure 7 presents whether the programs implemented this, as well as other, best practices.

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Figure 7: Implementation of Knowledge-Based Practices for Programs at Critical Design Review

Knowledge-based practices at critical design review	JLTV	KC-46	WIN-T INC 3	●	○	––
				Other 30 programs		
Demonstrate all critical technologies in a realistic environment	○	○	○	6	18	6
Release at least 90 percent of drawings or 100 percent of 3D zones	●	●		6	18	6
Test a system-level integrated prototype	○	○	○	3	18	9
Establish a reliability growth curve	●	●	●	14	12	4
Identify key product characterisitics	●	●	●	26	1	3
Identify critical manufacturing processes	○	●	●	21	3	6
Conduct producibility assessments to identify manufacturing risks for key technologies	●	●		23	3	4
Complete failure modes and effects analysis	●	●		21	4	5

● Practice implemented

○ Practice not implemented

––– Practice not applicable or information not available per the program office response

Source: GAO analysis of DOD data.

Of the three programs that held their critical design review in 2013, both the KC-46 Tanker and the Joint Light Tactical Vehicle (JLTV) demonstrated design stability by releasing over 90 percent of each program's expected design drawings.[15] According to the Warfighter Integration Network-Tactical Increment 3 (WIN-T Inc 3) program office this practice was not applicable as the system relies primarily on

[15]According to JLTV program officials, a series of design understanding reviews were held with each of the program's three current contractors that served as the equivalent of a single critical design review. At the time of these reviews, all long-lead and critical designs had been completed and all three contractors had more than 90 percent of the design files under configuration control.

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software for its functionality.[16] Of the remaining programs we assessed, 30 reported information about the practices they implemented at their critical design review. Of these, only 6 non-ship programs released at least 90 percent of their total expected design drawings before holding this review, and no shipbuilding programs met the shipbuilding-specific best practice of completing 100 percent of their three-dimensional design models prior to the start of fabrication. All 6 of the programs with a stable design held their critical design review since 2009.

The use of early system prototypes during development is another useful practice for demonstrating that a system has a stable design, will work as intended, and can be built within cost and schedule. None of the three programs reported testing an integrated system prototype before their critical design review or its equivalent. Instead, the JLTV program reported conducting this system prototype testing 7 months after its design review, and the KC-46 Tanker program will not begin flight testing a system-level prototype that integrates the civilian aircraft and military sub-systems until January 2015, 18 months after its critical design review. WIN-T Inc 3 did not plan to test a system-level prototype until October 2015, 22 months after its critical design review. Of the 25 non-ship programs we assessed that have held a critical design review, 21 report they tested or plan to test an early integrated prototype but only 3 programs conducted this testing before their critical design review.[17] For the other 18 programs, prototype testing followed the review by an average of nearly 3 years (or 33 months). This use of early system prototypes among programs we assessed is much the same as past assessments.

Reliability growth testing provides visibility over how reliability is improving and uncovers design problems so fixes can be incorporated before production begins. All three programs reported establishing a reliability growth curve by their critical design review. Of the remaining

[16]While the WIN-T Inc 3 program held a critical design review in December of 2013 that assessed the entirety of the developmental program, it later had its requirements and capabilities reduced through descoping options recommended at a configuration steering board review and approved by the Army acquisition executive in January 2014.

[17]We did not assess the five shipbuilding programs against this recommended practice as testing early system prototypes in these programs may not be practical.

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30 programs we assessed that have held critical design review, or its equivalent, 14 had a reliability growth curve at that time.

The programs we assessed also reported use of other knowledge-based practices to increase confidence in the stability of their product's design. Those practices include the identifying key product characteristics; identifying critical manufacturing processes; conducting producibility assessments to identify manufacturing risks; and completing failure modes and effects analysis to identify potential failures and early design fixes. The KC-46 Tanker program carried out all four of these practices, while the JLTV program carried out three and the WIN-T Inc 3 program implemented two. For the 30 other programs we assessed with a critical design review prior to 2013, a little more than half of them reported having used all four of these practices. This rate of implementation is similar to what we observed in our prior year assessment.

3. **The two programs that held production decisions since our last assessment reported mature technologies and stable designs, and one of the two demonstrated performance through the testing of a production-representative prototype; neither demonstrated that all their manufacturing process capabilities were in control.** Capturing critical manufacturing knowledge before entering production helps ensure that a weapon system will work as intended and can be manufactured efficiently to meet cost, schedule, and quality targets. This knowledge can be captured and demonstrated through the use of various proactive methods, including the use of statistical process control data, pilot production lines, manufacturing readiness levels, and prototype testing. Figure 8 shows the extent to which programs that have held a production decision have implemented associated knowledge-based practices.

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Figure 8: Implementation of Knowledge-Based Practices for Programs at Production Decision

Knowledge-based practices at production start	PIM	G/ATOR	Other 16 programs: ●	Other 16 programs: ○	Other 16 programs: ––
Demonstrate all critical technologies in a realistic environment	●	●	8	4	4
Release at least 90 percent of drawings	●	●	6	5	5
Demonstrate manufacturing process capabilities are in control	○	○	3	7	6
Demonstrate critical processes on a pilot production line	○	●	6	4	6
Test a production-representative prototype in its intended environment	○	●	6	5	5

● Practice implemented

○ Practice not implemented

––– Practice not applicable or information not available per the program office response

Source: GAO analysis of DOD data.

Neither the Paladin Integrated Management (PIM) program, which held a production decision in 2013, nor the G/ATOR program, which held a production decision in January 2014, demonstrated that their manufacturing process capabilities were in control at production start.[18] Of the remaining programs we assessed, 16 non-ship programs held production decisions prior to 2013, of which only 3 provided data indicating that critical manufacturing processes were in control at production start.[19] Though the PIM program did not test a pilot production line prior to production start, the G/ATOR program reported that it has. Of the 16 programs that held production decisions prior to

[18]To determine whether critical processes are in control, we used program reported process capability index data and manufacturing readiness level assessments of the process capability and control sub-thread.

[19]The five shipbuilding programs we assessed were excluded from this portion of our analysis due to the differences in the production processes used to build ships.

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2013, only 6 have demonstrated manufacturing processes on a pilot production line. Another 14 programs we assessed plan to hold a production decision in the future and only 6 indicated that they intend to test a pilot production line before production start.

Production and postproduction costs are also minimized when a fully integrated, production-representative prototype is demonstrated to show that the system will work as intended in a reliable manner. DOD policy has also required that a system be demonstrated in its intended environment using a production-representative article before entering production, which has led to an increase in the number of programs doing so.[20] The G/ATOR program has tested a production-representative prototype in its intended environment in advance of their production decision, but PIM has not. Of the 16 programs we assessed that held a production decision prior to 2013, only 6 tested production-representative prototypes prior to their production start. For the other 14 programs we assessed that plan to hold a production decision in the future, only 5 currently have plans to test a production-representative prototype before reaching this key juncture. In not testing such prototypes these programs risk repeating the experiences of the past when issues were discovered late in testing, triggering the need for expensive re-tooling of production lines and retrofitting of production articles.

Observations about DOD's Implementation of Key Acquisition Reform Initiatives and Program Concurrency

During the past few years, the Congress and DOD have made policy changes and begun other reform initiatives to improve the way the department acquires major weapon systems and address the symptoms of an acquisition system that include frequent program cost overruns and delays in operational capability delivery. More specifically, the enactment of the Weapon Systems Acquisition Reform Act of 2009, the promulgation of multiple "Better Buying Power" memorandums by the Under Secretary of Defense for Acquisition, Technology, and Logistics, and the revision of DOD Instruction 5000.02 in 2008 and interim revision in 2013, represent efforts to increase competition in weapon programs, decrease acquisition

[20]DODI 5000.02, enc. 2, para. 6.c(6)(d) (Dec. 8, 2008).

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costs, and ensure that programs are more affordable.[21] We focused our analysis on efforts within the "Better Buying Power" memorandums, particularly affordability constraints and "should-cost" analysis. These efforts attempt to control program costs by introducing, respectively, constraints on total cost and a review process to eliminate unnecessary costs from contracts. We also analyzed the implementation of two reforms addressed in legislation, the requirement to increase competition throughout the acquisition life cycle and the requirement that major defense acquisition programs hold annual configuration steering board reviews to consider changes regarding program requirements and maximize capabilities. GAO has previously made recommendations or observations on the implementation of a number of these reform initiatives and DOD, which has generally concurred or partially concurred with the recommendations, is working to implement them.[22] In addition, we evaluated the amount of concurrency between developmental testing and production for programs we assessed that have started production as well as those that plan to begin production in the coming years.[23] We have consistently emphasized the importance of completing developmental

[21]Pub. L. No. 111-23. Office of the Under Secretary of Defense, Acquisition, Technology, and Logistics Memorandum: "Better Buying Power: Mandate for Restoring Affordability and Productivity in Defense Spending" (June 28, 2010). Office of the Under Secretary of Defense, Acquisition, Technology, and Logistics Memorandum: "Better Buying Power: Guidance for Obtaining Greater Efficiency and Productivity in Defense Spending" (Sept. 14, 2010). Office of the Under Secretary of Defense, Acquisition, Technology, and Logistics Memorandum: "Implementation Directive for Better Buying Power - Obtaining Greater Efficiency and Productivity in Defense Spending" (Nov. 3, 2010). Office of the Under Secretary of Defense, Acquisition, Technology, and Logistics Memorandum: "Better Buying Power 2.0: Continuing the Pursuit for Greater Efficiency and Productivity in Defense Spending" (Nov. 13, 2012). DODI 5000.02 (Dec. 8, 2008) and Interim DODI 5000.02, *Operation of the Defense Acquisition System* (Nov. 25, 2013). As our data was collected prior to the release of the latest revision of DODI 5000.02, we did not use the new instruction as criteria for our assessments.

[22]GAO, *Weapons Acquisition Reform: Reform Act Is Helping DOD Acquisition Programs Reduce Risk, but Implementation Challenges Remain*, GAO-13-103 (Washington, D.C.: Dec. 14, 2012); *Defense Acquisitions: DOD Can Improve Its Management of Configuration Steering Boards,* GAO-11-640 (Washington, D.C.: July 7, 2011); *Defense Acquisitions: Assessments of Selected Weapon Programs*, GAO-13-294SP (Washington, D.C.: Mar. 28, 2013).

[23]This analysis reflects 30 non-ship programs out of the 38 programs we assessed and does not include three non-ship programs for which a production start date was not identified as well as five shipbuilding programs. Shipbuilding programs are excluded from this analysis as we assess production knowledge for ships differently.

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testing before entering production, and pointed out the increased risks associated with concurrent testing and production.[24]

To gain some perspectives on the implementation of key aspects of policy changes and reform initiatives within DOD's current portfolio, we analyzed questionnaire data collected from 38 current major defense acquisition programs—the same programs reflected in our knowledge point analysis—and 18 additional programs identified by DOD as future major defense acquisition programs.

Implementation of the reform initiatives we analyzed varies across programs. The department has largely been successful in implementing its "should-cost" initiative with significant cost savings being reported. In addition, many programs reported holding configuration steering board reviews. In contrast, the department has had less success in implementing affordability constraints and utilizing measures to ensure competition before and after development start—initiatives that also have the potential to result in savings. In addition, many programs are committing to production prior to completing the developmental testing necessary to assure that the system will function as intended, introducing unnecessary risk to cost and schedule. Our current analysis allows us to make the following five observations concerning key acquisition reform initiatives and program concurrency.

[24]*GAO, Joint Strike Fighter: DOD Actions Needed to Further Enhance Restructuring and Address Affordability Risks,* GAO-12-437 (Washington, D.C.: June 14, 2012); *Missile Defense: Opportunity Exists to Strengthen Acquisitions by Reducing Concurrency,* GAO-12-486 (Washington, D.C.: Apr. 20, 2012); and *Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*, GAO-02-701 (Washington, D.C.: July 15, 2002).

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Acquisition Reform and Concurrency Observations

1. Only 30 of the 56 current and future programs we assessed have established an affordability constraint, an implementation rate that has not improved from our prior year assessment, but all programs with a cap that we assessed reported they are on track to meet it.

2. About 82 percent of the current programs we assessed have conducted a "should-cost" analysis resulting in anticipated savings of approximately $24 billion; over half of this amount has or will be reallocated from these programs for other priorities.

3. Many of the future programs we assessed do not plan to conduct competitive prototyping before development start and many current programs do not have acquisition strategies that ensure competition through the end of production. Fifteen future and current programs reported they will not take actions to promote any competitive measures before or after development start.

4. All but 1 of the 38 current programs we assessed had conducted a configuration steering board review with 29 programs reporting that this review occurred during the past year. Only 10 programs reported that changes were approved or recommended at their last review.

5. Fifteen of the 18 current programs we assessed that have started production plan to perform 30 percent or more of their developmental testing during production despite the increased risk of design changes and costly retrofits. Five of these programs expect to place substantial procurement quantities under contract before developmental testing is completed.

Additional details about each observation follow.

1. **Only 30 of the 56 current and future programs we assessed have established an affordability constraint, an implementation rate that has not improved from our prior year assessment, but all programs with a cap that we assessed reported they are on track to meet it.** In September 2010, the first of several memorandums were issued by the Under Secretary of Defense for Acquisition, Technology, and Logistics directing programs to consider affordability a key program requirement and outlining how this initiative was to be

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implemented across the department.[25] The memorandums emphasize the need to treat affordability, defined as conducting a program at a cost constrained by the resources that DOD can allocate, as a key requirement at the start of development. Affordability constraints are intended to force prioritization of requirements, enable cost trades and ensure that unaffordable programs do not enter the acquisition process.[26] More than half of the current and future programs (30 of 56) we assessed have established an affordability constraint as directed by the "Better Buying Power" initiatives and all these programs reported that they are on track to meet their established constraint. The rate of implementation of this reform has not improved from the level reported in our prior assessment. For the 38 current programs, 18 have not established an affordability cap and almost all of these programs are nearing a production decision or are already in production. In general, these 18 programs are older and have smaller percentages of funding remaining than those current programs with an affordability cap. Similarly, for the 18 future programs, 8 reported a lack of an established affordability goal. Two of them reported holding a milestone A review during 2013—where an affordability goal would normally be established—while a third program held its milestone A review in 2009 before the affordability requirement was established by DOD policy and the remaining 5 responded that the timeframe for this review was "to be determined" or "not applicable."

2. About 82 percent of the current programs we assessed have conducted a "should-cost" analysis resulting in anticipated

[25]Office of the Under Secretary of Defense, Acquisition, Technology, and Logistics Memorandum: "Better Buying Power: Guidance for Obtaining Greater Efficiency and Productivity in Defense Spending" (Sept. 14, 2010). Office of the Under Secretary of Defense, Acquisition, Technology, and Logistics Memorandum: "Implementation Directive for Better Buying Power - Obtaining Greater Efficiency and Productivity in Defense Spending" (Nov. 3, 2010). Office of the Under Secretary of Defense, Acquisition, Technology, and Logistics Memorandum: "Better Buying Power 2.0: Continuing the Pursuit for Greater Efficiency and Productivity in Defense Spending" (Nov. 13, 2012). Office of the Under Secretary of Defense, Acquisition, Technology, and Logistics Memorandum: "Implementation Directive on Better Buying Power 2.0: Achieving Greater Efficiency and Productivity in Defense Spending" (Apr. 24, 2013).

[26]Affordability goals are established at milestone A, the entry into technology development. After systems engineering trade-offs are completed during the technology development phase, these affordability goals then become affordability caps at milestone B, the start of system development, when a match is to be made between requirements and resources. We refer to the goals and caps collectively as affordability constraints.

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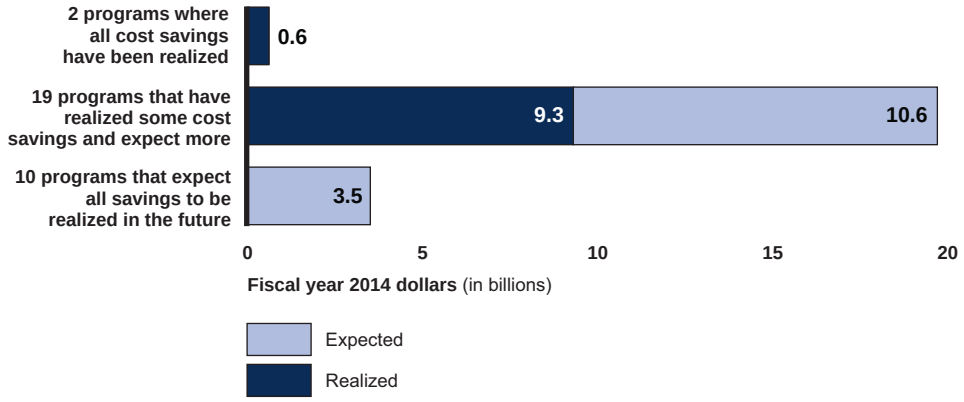
savings of approximately $24 billion; over half of this amount has or will be pulled from these programs for other priorities. DOD's "Better Buying Power" initiatives also emphasize the importance of driving cost improvements during contract negotiation and program execution to control costs both in the short-term and throughout the product life cycle. In accordance with direction provided in memorandums issued by the Under Secretary, each program must conduct a "should-cost" analysis which includes justifying each cost under the program's control with the aim of reducing negotiated prices for contracts and obtaining other efficiencies in program execution. More broadly, "should-cost" is the concept that program managers are to proactively control expenditures by setting cost targets below what has been budgeted for their program's activities and manage with the intent to achieve these lower targets.

According to our analysis of questionnaire responses, 32 of 38 current programs we assessed conducted a "should-cost" analysis as directed by the "Better Buying Power" initiatives and 31 of the programs reported that they had realized or expect to realize cost savings totaling approximately $24 billion in fiscal year 2014 dollars as shown in figure 9 below.[27]

[27]One of the 32 programs that conducted a "should-cost" analysis—the LCS program—reported "should-cost" savings of $5.8 billion in then-year dollars, which were not comparable to the base year data we received from other programs and is not reflected in the $24 billion fiscal year 2014 constant dollar amount.

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Figure 9: Realized and Expected "Should-Cost" Savings Reported by 31 Programs



Source: GAO analysis of questionnaire data.

Approximately 41 percent, $9.9 billion, of all the "should-cost" savings were identified as realized, with the other 59 percent, or $14.1 billion, expected in the future. When savings were converted into fiscal year 2014 constant dollars, 6 of the programs reported savings of more than $1 billion, the largest of which was the KC-46 Tanker program which reported a savings total of $6.8 billion with nearly $6.4 billion of this amount already realized. For the 6 current programs that reported they did not conduct a "should-cost" analysis, 3 were being restructured during our assessment after reporting an increase in cost or schedule above their acquisition program baselines, and another had recently entered system development.

The 18 programs that reported some or all of their "should-cost" savings as realized cited several activities as being responsible including

- improved vendor/supply chain management (10 programs),
- developmental or operational testing efficiencies (12 programs), and
- design trades conducted to balance affordability and capability (12 programs).

As a specific example, the DDG 51 program reported that nine different activities were carried out to obtain approximately $506 million in realized cost savings including the three activities above, while the

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JLTV program cited two activities—design trades balancing affordability and capability and changes in requirements—to achieve $206 million in realized cost savings with another $412 million in savings expected in the future. These savings may manifest themselves in the program by lower contract prices, lower program cost estimates, and possibly lower funding requests.

Achieving efficiency needs to be done with caution as the short-term savings could come at the expense of long-term needs. For example, six of the programs that reported implementing testing efficiencies for savings are also planning to conduct concurrent developmental testing and production which leaves these programs at risk to deficiencies being discovered during production that could require substantial and costly modifications to systems already built. Similarly, four programs that started production before 2011 reported that changes in design or requirements will result in some savings, but carrying out this "should-cost" activity after production start could contribute to design instability. In addition, 7 programs stated that savings are being realized from the increased use of modeling and simulation but only 3 of these programs reported that all the models being used for operational and live fire testing were officially reviewed and certified as acceptable for their intended use. While the use of models and simulations can reduce the time and resources needed to conduct the required testing, using models that are not fully accredited to meet weapons system testing objectives increases the likelihood that an inappropriate or unsuitable simulation is being used.

Of the approximately $24 billion in realized and anticipated "should-cost" savings, a total of $12.6 billion was reallocated to meet other service and DOD priorities. For example, the KC-46 Tanker program reported that all of its "should-cost" savings, totaling $6.8 billion, will be reinvested in other service and Office of the Secretary of Defense priorities. Approximately $6.3 billion was reported as retained by 16 programs we assessed. While several other programs reported that their savings, a total of $3.6 billion, were split among different activities with some amounts retained and some reallocated for other priorities. For example, the F-35 program reported that some of the $884 million in expected savings will be put to use by the program while other amounts will be reinvested in other service and Office of the Secretary of Defense priorities. An additional $1.5 billion in savings was reported as a part of our questionnaire but programs stated that they did not know or had not yet determined how these funds would be

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re-allocated. The concept of allowing programs to keep at least some of their savings is appropriate, but the department should take care to use this incentive effectively.

Of the 18 future programs that we assessed, 6 reported that they conducted a "should-cost" analysis prior to entering system development which identified approximately $26 billion in realized and expected savings. The vast majority of this amount was reported by the Ohio Replacement and Ground Combat Vehicle (GCV) programs with $16 billion and $8.5 billion, respectively, in "should-cost" savings. The Ohio Replacement program reported that all $16 billion in procurement and other savings were expected in the future and would result from several ongoing affordability initiatives including design for producibility initiatives and potentially procuring boats in a multi-year procurement block buy with *Virginia* Class submarines. In contrast, the GCV program reported all its $8.5 billion in savings as realized. The program claims savings were due to design trades to balance affordability and capability and the award of a fixed-price development contract among other activities. The decision to eliminate competition during system development and production was reported as responsible for a decrease in the program's expected cost.

3. **Many of the future programs we assessed do not plan to conduct competitive prototyping before development start and many current programs do not have acquisition strategies that ensure competition through the end of production. Fifteen future and current programs reported they will not take actions to promote any competitive measures before or after development start.** Competition is a critical tool for achieving the best return on the government's investment. Major defense acquisition programs are required to provide for the use of competitive prototypes before a program enters system development and have acquisition strategies that ensure competition or the option of competition throughout the acquisition life cycle.[28] Table 7 shows the activities programs report using or plan to use to ensure competition or the possibility of competition.

[28]Pub. L. No. 111-23, §§ 202, 203.

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Table 7: Use of Activities to Ensure Competition Reported by Future and Current Programs

Activity to ensure competition is utilized[a]		Of the 18 future programs	Of the 38 current programs
Competitive prototyping prior to development start	Competitive prototyping planned or conducted	9	16
	No competitive prototyping planned or conducted	8	22
Measures to ensure competition after development start included in program strategy[b]	Measures to ensure competition are planned or have taken place	8	21
	No measures included	8	17
	Actions taken to promote competition both prior to and after development start	5	10
	No actions taken to promote competition	4	11

Source: GAO analysis of questionnaire data.

[a]One future program—the Amphibious Combat Vehicle—was not included in the totals above for competitive prototyping as it did not know whether such a competition would be conducted prior to development start. Two future programs—the Amphibious Combat Vehicle and Indirect Fire Protection Capability Increment 2—were not counted in the totals for measures to ensure competition as they both did not know whether their technology development or acquisition strategies would call for competition between development start and the completion of production.

[b]We use program strategy to refer to both technology development strategies used by future programs and the acquisition strategies used by current programs.

Only 25 of 56 current and future programs we assessed reported conducting or planning for any form of competitive prototyping prior to the start of system development. Of the 22 current programs with no competitive prototyping, only 2 reported that the requirement was waived pursuant to DOD policy implementing WSARA. The other 20 programs that reported the competitive prototyping requirement was not waived either began development before December 2009, when WSARA was implemented, or proceeded directly to production. The future programs we assessed reported that they plan to conduct competitive prototyping at a slightly higher rate than the current programs we assessed. However, 8 future programs still reported that they do not intend to conduct competitive prototyping. Of these, 7 plan to seek a waiver to this requirement with the remaining one reporting that the requirement to seek a waiver was not applicable.

Measures in a program's acquisition strategy to ensure competition or the option of competition after a program enters system development may include approaches such as the use of modular, open architectures to enable competition for upgrades or the use of build-to-print approaches to enable production through multiple

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sources.[29] But as shown in table 7 above, only 29 of 56 current and future programs reported that their acquisition strategies currently include measures to ensure competition after the start of development. Twenty-six of these programs stated that some or all of their activities to promote competition will take place in the future.

Overall, only 10 current programs and 5 future programs have taken or plan to take actions to promote competition both before and after the start of the development. In contrast, 11 current programs and 4 future programs reported that they have not taken any actions, nor do they plan to take any, to ensure competition or the option of competition for acquisition at any point after program initiation. This does not mean that these programs will have no competition at any point during their acquisition; only that they do not intend to ensure competition through the specific activities we assessed.

4. **All but one of the 38 current programs we assessed had conducted a configuration steering board (CSB) review, 29 reported that this review occurred during the past year. Only 10 programs reported that proposed changes were approved or recommended at the most recent review.** According to statute and DOD's acquisition policy at the time of our review, major defense acquisition programs are required to conduct annual configuration steering boards to review proposed changes to the program's requirements or significant technical configuration changes that may impact cost and schedule performance.[30] Thirty-seven current programs we assessed had conducted such a review. The Air and Missile Defense Radar program was the only exception, as it just started development in October 2013 and was not required to complete the review by the time of our assessment. A majority, 29 out of 37 programs, reported that this review occurred in the 12 months prior to the submission of our questionnaire.

[29]Open systems architecture is a design approach that includes standard interfaces and the use of modular components within a product (like a computer) that can be replaced easily. This allows the product to be refreshed with new, improved components made by a variety of suppliers.

[30]Duncan Hunter National Defense Authorization Act for Fiscal Year 2009, Pub. L. No. 110-417, § 814 (2008).

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Only 12 of the current programs we assessed reported presenting any changes at their last CSB review. Of these, 10 programs had proposed requirements changes, configuration changes, descoping options, or some combination of these, which they reported were approved or recommended for approval. For example, the DDG 1000 *Zumwalt* Class Destroyer program reported that both configuration changes and descoping options were approved or recommended for approval at their June 2012 review, while the F-35 program reported that requirements changes were approved or recommended at their March 2013 review. However, some changes to capabilities have occurred outside of the CSB process. For the 38 current programs we assessed, 14 reported that planned system capabilities have either increased or decreased since the start of development. Only 5 of these programs indicated that a CSB review was one of the contributing reasons for the change. Many of these 14 programs reported that requirements changes since development start have caused cost and schedule changes as well.

5. **Fifteen of the 18 current programs we assessed that have started production plan to perform 30 percent or more of their developmental testing during production despite the increased risk of design changes and costly retrofits. Five of these programs expect to place substantial procurement quantities under contract before developmental testing is completed.** Beginning production before demonstrating that a design is mature and that a system will work as intended increases the risk of discovering deficiencies during production that could require substantial design changes and costly modifications to systems already built. The intent of developmental testing is to demonstrate the maturity of a design and to discover and fix design and performance problems before a system enters production. However, 15 out of the 18 programs we assessed that have started production intend to or have already executed 30 percent or more of their developmental testing concurrent with production. Seven of these 15 programs have completed developmental testing with 4 of them reporting quality problems during production.

   Five of the other 8 programs currently conducting concurrent testing and production, expect to have more than 10 percent of their procurement quantities under contract before developmental testing completes. The F-35 program in particular plans to have 530 aircraft, more than 20 percent of its total procurement quantity, under contract

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at a cost of approximately $57.8 billion before developmental testing is completed in 2017.[31] When considering the point at which budgets to support those procurements are typically approved—up to 18 months in advance—it places the commitment of funding that much further ahead of the completion of developmental testing.

Another twelve programs we assessed are scheduled to make a production decision in the coming years and 6 of them intend to execute 30 percent or more of their developmental testing concurrent with production. Two out of these six programs expect to have more than 10 percent of their total procurement quantity under contract before developmental testing is finished running the risk of costly retrofits to existing systems or changes to active production lines.

Assessments of Individual Programs

This section contains assessments of individual weapon programs. Each assessment presents data on the extent to which programs are following a knowledge-based acquisition approach to product development, and other program information. In total, we present information on 56 programs. For 37 programs, we produced two-page assessments discussing the technology, design, and manufacturing knowledge obtained, as well as other program issues. Each two-page assessment also contains a comparison of total acquisition cost from the first full estimate for the program to the current estimate. The first full estimate is generally the cost estimate established at development start; however, for a few programs that did not have such an estimate, we used the estimate at production start instead. For shipbuilding programs, we used their planning estimates if those estimates were available. For programs that began as non–major defense acquisition programs, we used the first full estimate available. Thirty-four of these 37 two-page assessments are of major defense acquisition programs, most of which are in development or early production and 3 assessments are of programs that were projected to become major defense acquisition programs during or soon after our review. See figure 10 for an illustration of the layout of each two-page assessment. In addition, we produced one-page assessments on the

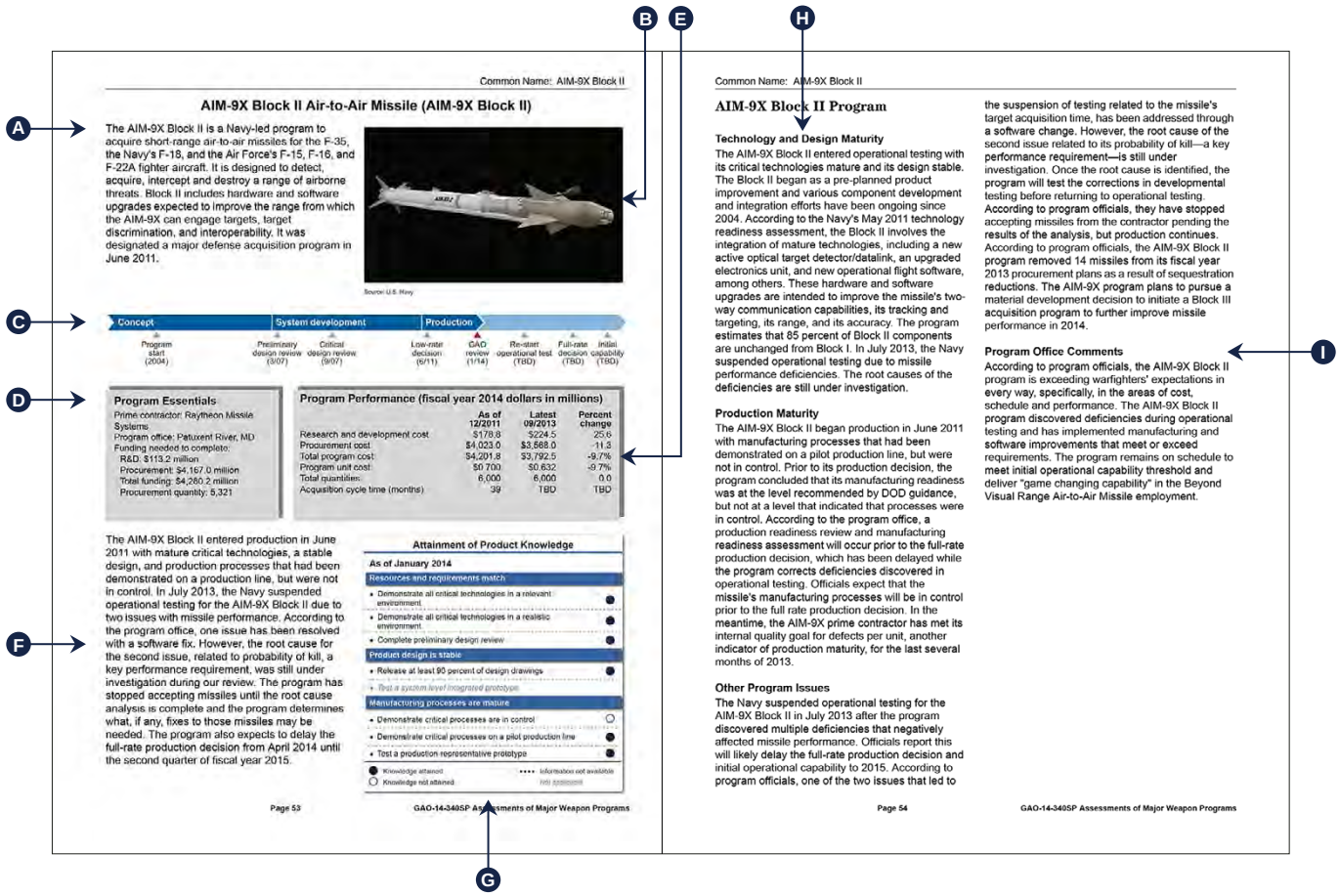
[31]The cost of the F-35 aircraft under contract before the completion of developmental testing was calculated using the average procurement unit cost for both the airframe and engine as reported in the program's December 2012 Selected Acquisition Report. This unit cost estimate assumes the quantity benefits from additional purchases of F-35 aircraft by international partners and other foreign military sales.

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current status of 19 programs, which include 15 future major defense acquisition programs, 2 major defense acquisition programs that are well into production, and 2 major defense acquisition programs that were recently restructured or curtailed.

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Figure 10: Illustration of Program Two-Page Assessment



- **A** Program description
- **B** Illustration or photo of system
- **C** Schedule timeline identifying key dates for the program including the start of development, major design reviews, production decisions, and planned operational capability
- **D** **Program Essentials** Programmatic information including the prime contractor, program office location, and funding needed to complete
- **E** **Program Performance** Cost and schedule baseline estimates and the latest estimate provided as of January 2014
- **F** Brief summary describing the program's implementation of knowledge-based acquisition practices and its current status
- **G** **Attainment of Product Knowledge** Depiction of selected knowledge-based practices and the program's progress in attaining that knowledge
- **H** Assessment of program's technology, design, and production maturity, as well as other program issues
- **I** **Program Office Comments** General comments provided by the cognizant program office

Source: GAO analysis.

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For our two-page assessments, we depict the extent of knowledge gained in a program by the time of our review with a scorecard and narrative summary at the bottom of the first page of each assessment. As illustrated in figure 10 above, the scorecard displays eight key knowledge-based acquisition practices that should be implemented by certain points in the acquisition process. The more knowledge the program has attained by each of these key points, the more likely the weapon system will be delivered within its estimated cost and schedule. A knowledge deficit means the program is proceeding without sufficient knowledge about its technologies, design, or manufacturing processes, and faces unresolved risks that could lead to cost increases and schedule delays.

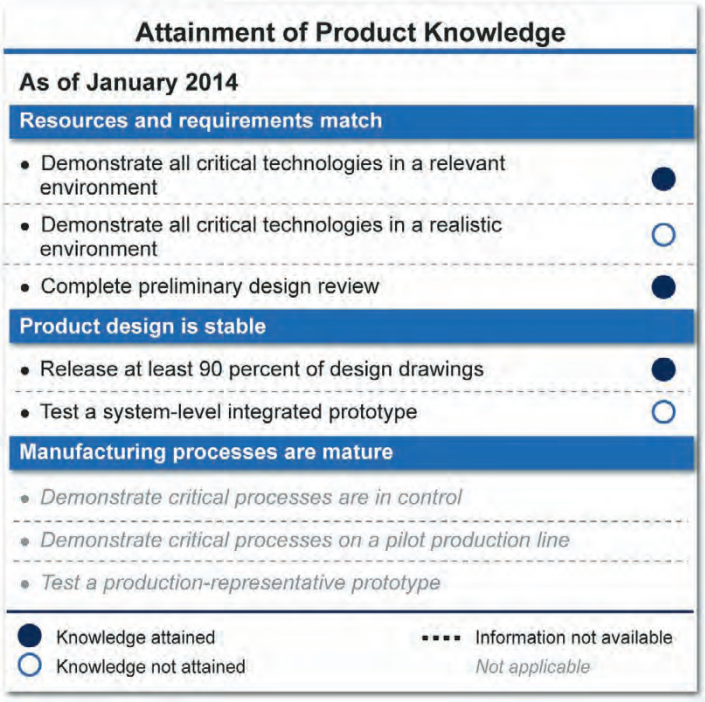
For each program, we identify a knowledge-based practice that has been implemented with a closed circle. We identify a knowledge-based practice that has not yet been implemented with an open circle. If the program did not provide us with enough information to make a determination, we show this with a dashed line. A knowledge-based practice that is not applicable to the program is grayed out. A knowledge-based practice may not be applicable to a particular program if either the point in the acquisition cycle when the practice should be implemented has not yet been reached, or if the particular practice is not relevant to the program. For programs that have not yet entered system development, we show a projection of knowledge attained for the first three practices. For programs that have entered system development but not yet held a critical design review, we assess actual knowledge attained for these three practices. For programs that have held a critical design review but not yet entered production, we assess knowledge attained for the first five practices. For programs that have entered production, we assess knowledge attained for all eight practices.

We make adjustments to both the key points in the acquisition cycle and the applicable knowledge-based practices for shipbuilding programs. For shipbuilding programs that have not yet awarded a detailed design contract, we show a projection of knowledge attained for the first three practices. For shipbuilding programs that have awarded this contract but not yet started construction, we would assess actual knowledge attained for these three practices. For shipbuilding programs that have started construction, we assess the knowledge attained for the first four practices. We do not assess the remaining four practices for shipbuilding programs. See figure 11 for examples of the knowledge scorecards we use to assess these different types of programs.

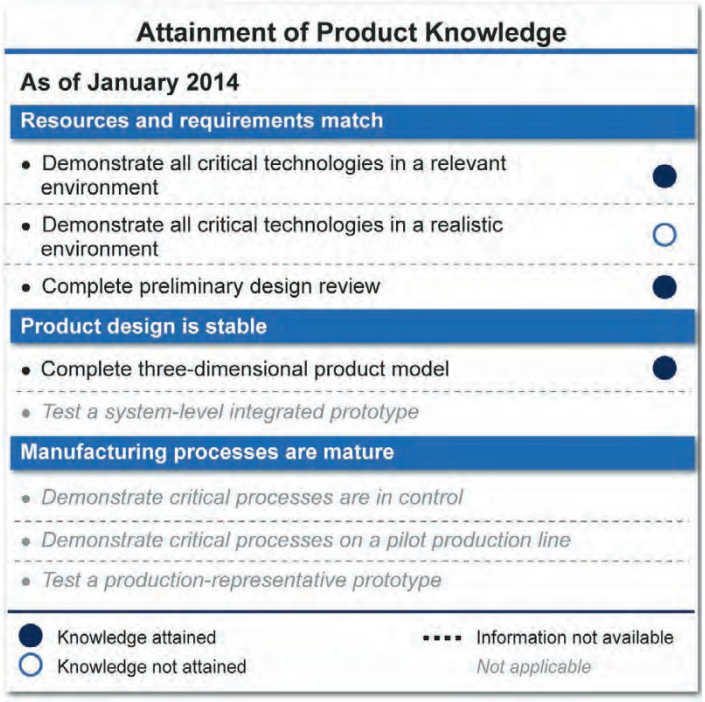
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Figure 11: Examples of Knowledge Scorecards

Program in production



Shipbuilding program



Source: GAO.

Statement on Small Business Participation

Pursuant to a mandate in the report accompanying the National Defense Authorization Act for Fiscal Year 2013, we reviewed whether individual subcontracting reports from a program's prime contractor or contractors were accepted on the Electronic Subcontracting Reporting System (eSRS).[32] We reviewed this information for 36 of the major defense acquisition programs in our assessment using the contract information reported in available Selected Acquisition Reports. The contract numbers for each program's or element's prime contracts were entered into the eSRS database to determine whether the individual subcontracting reports from the prime contractors had been accepted by the government. The government uses individual subcontracting reports on eSRS as one

[32]H.R. Rep. No. 112-479, at 284 (2012), *accompanying* Pub. L. No.112-239

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method of monitoring small business participation, as the report includes goals for small business subcontracting. Not all prime contracts for major defense acquisition programs are required to submit individual subcontracting reports. For example, some contractors report small business participation at a corporate level as opposed to a program level and this data is not captured in the individual subcontracting reports. Information gathered for this analysis is presented in appendix VI.

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AIM-9X Block II Air-to-Air Missile (AIM-9X Block II)

The AIM-9X Block II is a Navy-led program to acquire short-range air-to-air missiles for the F-35, the Navy's F-18, and the Air Force's F-15, F-16, and F-22A fighter aircraft. It is designed to detect, acquire, intercept and destroy a range of airborne threats. Block II includes hardware and software upgrades expected to improve the range from which the AIM-9X can engage targets, target discrimination, and interoperability. It was designated a major defense acquisition program in June 2011.



Source: U.S. Navy.



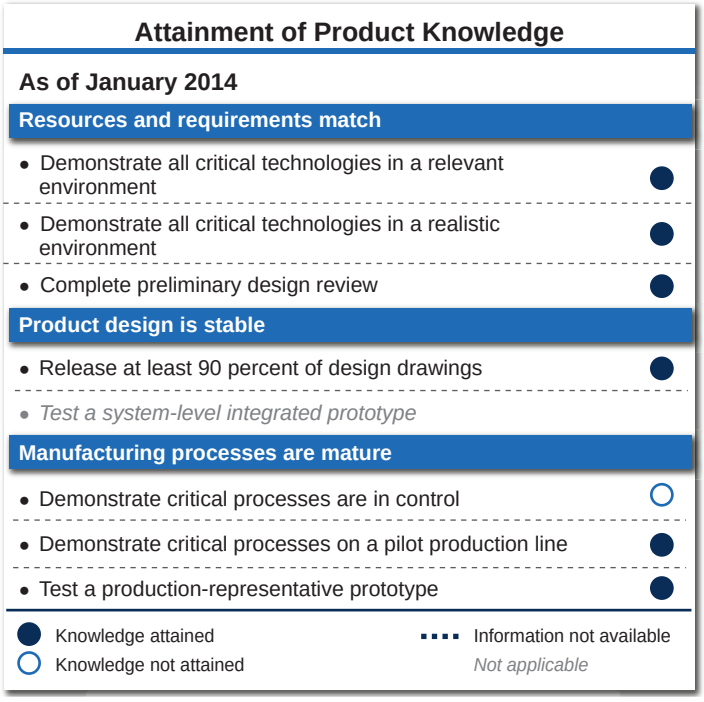
Program Essentials

Prime contractor: Raytheon Missile Systems
Program office: Patuxent River, MD
Funding needed to complete:
- R&D: $113.2 million
- Procurement: $4,167.0 million
- Total funding: $4,280.2 million
- Procurement quantity: 5,321

Program Performance (fiscal year 2014 dollars in millions)

	As of 12/2011	Latest 09/2013	Percent change
Research and development cost	$178.8	$224.5	25.6
Procurement cost	$4,023.0	$3,568.0	-11.3
Total program cost	$4,201.8	$3,792.5	-9.7%
Program unit cost	$0.700	$0.632	-9.7%
Total quantities	6,000	6,000	0.0
Acquisition cycle time (months)	39	TBD	TBD

The AIM-9X Block II entered production in June 2011 with mature critical technologies, a stable design, and production processes that had been demonstrated on a production line, but were not in control. In July 2013, the Navy suspended operational testing for the AIM-9X Block II due to two issues with missile performance. According to the program office, one issue has been resolved with a software fix. However, the root cause for the second issue, related to probability of kill, a key performance requirement, was still under investigation during our review. The program has stopped accepting missiles until the root cause analysis is complete and the program determines what, if any, fixes to those missiles may be needed. The program also expects to delay the full-rate production decision from April 2014 until the second quarter of fiscal year 2015.



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AIM-9X Block II Program

Technology and Design Maturity

The AIM-9X Block II entered operational testing with its critical technologies mature and its design stable. The Block II began as a pre-planned product improvement and various component development and integration efforts have been ongoing since 2004. According to the Navy's May 2011 technology readiness assessment, the Block II involves the integration of mature technologies, including a new active optical target detector/datalink, an upgraded electronics unit, and new operational flight software, among others. These hardware and software upgrades are intended to improve the missile's two-way communication capabilities, its tracking and targeting, its range, and its accuracy. The program estimates that 85 percent of Block II components are unchanged from Block I. In July 2013, the Navy suspended operational testing due to missile performance deficiencies. The root causes of the deficiencies are still under investigation.

Production Maturity

The AIM-9X Block II began production in June 2011 with manufacturing processes that had been demonstrated on a pilot production line, but were not in control. Prior to its production decision, the program concluded that its manufacturing readiness was at the level recommended by DOD guidance, but not at a level that indicated that processes were in control. According to the program office, a production readiness review and manufacturing readiness assessment will occur prior to the full-rate production decision, which has been delayed while the program corrects deficiencies discovered in operational testing. Officials expect that the missile's manufacturing processes will be in control prior to the full rate production decision. In the meantime, the AIM-9X prime contractor has met its internal quality goal for defects per unit, another indicator of production maturity, for the last several months of 2013.

Other Program Issues

The Navy suspended operational testing for the AIM-9X Block II in July 2013 after the program discovered multiple deficiencies that negatively affected missile performance. Officials report this will likely delay the full-rate production decision and initial operational capability to 2015. According to program officials, one of the two issues that led to the suspension of testing related to the missile's target acquisition time, has been addressed through a software change. However, the root cause of the second issue related to its probability of kill—a key performance requirement—is still under investigation. Once the root cause is identified, the program will test the corrections in developmental testing before returning to operational testing. According to program officials, they have stopped accepting missiles from the contractor pending the results of the analysis, but production continues. According to program officials, the AIM-9X Block II program removed 14 missiles from its fiscal year 2013 procurement plans as a result of sequestration reductions. The AIM-9X program plans to pursue a material development decision to initiate a Block III acquisition program to further improve missile performance in 2014.

Program Office Comments

According to program officials, the AIM-9X Block II program is exceeding warfighters' expectations in every way, specifically, in the areas of cost, schedule and performance. The AIM-9X Block II program discovered deficiencies during operational testing and has implemented manufacturing and software improvements that meet or exceed requirements. The program remains on schedule to meet initial operational capability threshold and deliver "game changing capability" in the Beyond Visual Range Air-to-Air Missile employment.

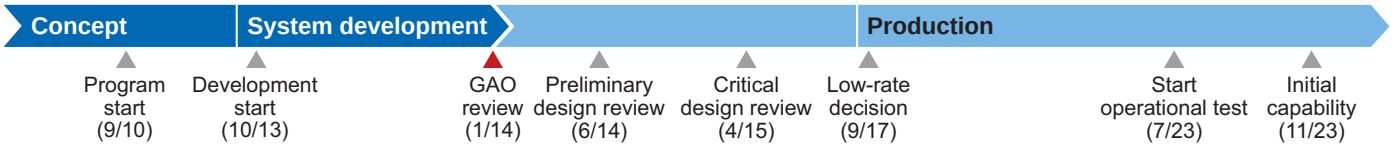
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Air and Missile Defense Radar (AMDR)

The Navy's Air and Missile Defense Radar (AMDR) will be a next-generation radar system designed to provide ballistic missile defense, air defense, and surface warfare capabilities. AMDR will consist of an S-band radar for ballistic missile defense and air defense, X-band radar for horizon search, and a radar suite controller that controls and integrates the two radars. AMDR will initially support DDG 51 Flight III. The Navy expects AMDR to provide the foundation for a scalable radar architecture that can be used to defeat advanced threats.



Source: U.S. Navy.



Program Essentials

Prime contractor: Raytheon
Program office: Washington, DC
Funding needed to complete:
R&D: $881.1 million
Procurement: $3,919.8 million
Total funding: $4,800.9 million
Procurement quantity: 22

Program Performance (fiscal year 2014 dollars in millions)

	As of	Latest 10/2013	Percent change
Research and development cost	NA	$1,895.3	NA
Procurement cost	NA	$3,919.8	NA
Total program cost	NA	$5,844.4	NA
Program unit cost	NA	$265.655	NA
Total quantities	NA	22	NA
Acquisition cycle time (months)	NA	158	NA

AMDR entered system development in October of 2013 with all four of its critical technologies approaching full maturity. This was 6 months later than planned, leading to a delay in many of the program's future events. These delays might impact the Navy's plan to design the DDG 51 Flight III, intended to carry the radar. The Navy and shipbuilders have determined that a 14-foot active radar is the largest that can be accommodated by the existing DDG 51 though AMDR is also being developed as a scalable design. A new X-Band portion will be developed under a separate program at a later date, with AMDR initially using a SPQ-9B radar in its place.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ○

Product design is stable

- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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AMDR Program

Technology and Design Maturity

All four of the AMDR's critical technologies are approaching full maturity and were demonstrated using a 1000-element radar array. The array is a smaller version of the planned AMDR arrays. According to the program, two technologies previously identified as the most challenging—digital-beam-forming and transmit-receive modules, have been demonstrated in a relevant environment. Program officials stated digital-beam-forming is necessary for AMDR's simultaneous air and ballistic missile defense mission. The AMDR's transmit-receive modules—the individual radiating elements of the radar—use gallium nitride technology instead of the legacy gallium arsenide technology for potential efficiency gains. The other two critical technologies are related to software and digital receivers and exciters. Officials stated that software development will require a significant effort. A series of software builds are expected to deliver approximately 1 million lines of code and are designed to apply open system approaches to commercial, off-the-shelf hardware. Integrating the X-band radar will require further software development.

According to officials, much of AMDR's hardware has been demonstrated ahead of the preliminary design review, scheduled for June 2014, though the number of design drawings is still pending. The Navy obtained a waiver to hold this review after the start of system development citing cost concerns and a belief that the prototype array satisfactorily demonstrates AMDR's critical technologies.

Other Program Issues

AMDR entered system development in October of 2013—6 months later than planned, with corresponding delays to future program milestones. These delays might have an impact on the ability of the AMDR program to maintain its planned schedule for delivery in 2019. Additionally, the delays might also hinder timely delivery of necessary information related to AMDR's parameters, such as power, cooling, and space requirements needed for ongoing and planned design studies related to Flight III development. However, program officials do not anticipate a delay for AMDR's planned 2019 availability for integration into the first planned DDG 51 Flight III. The X-band portion of AMDR will be comprised of an upgraded version of an existing rotating radar (SPQ-9B), instead of the new design initially planned. The new radar will instead be developed as a separate program at a later date and integrated with the thirteenth AMDR unit. According to the Navy, the upgraded SPQ-9B radar fits better within the Flight III's sea frame and expected power and cooling availability. Program officials state that the SPQ-9B radar will have capabilities equal to the new design for current anti-air warfare threats, it will not perform as well against future threats.

The Navy plans to install a 14-foot variant of AMDR on Flight III DDG 51s starting in 2019. According to draft AMDR documents, a 14-foot radar is needed to meet threshold requirements, but an over 20-foot radar is required to fully meet the Navy's desired integrated air and missile defense needs. However, the shipyards and the Navy have determined that a 14-foot active radar is the largest that can be accommodated within the existing DDG 51 deckhouse. Navy officials stated that AMDR is being developed as a scalable design but a new ship would be required to host a larger version of AMDR.

Program Office Comments

The program office concurred with this assessment and provided technical comments which were incorporated where appropriate.

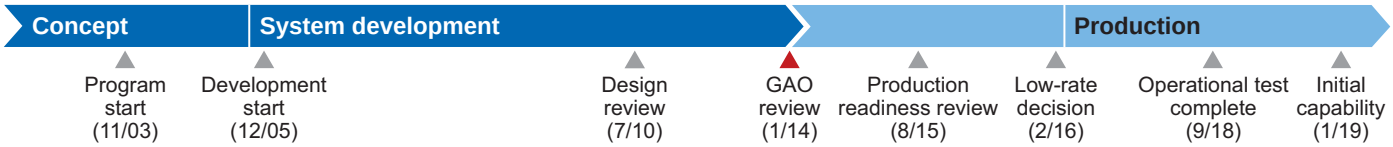
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CH-53K Heavy Lift Replacement Helicopter (CH-53K)

The Marine Corps' CH-53K heavy-lift helicopter is intended to transport armored vehicles, equipment, and personnel to support operations deep inland from a sea-based center of operations. The CH-53K is expected to replace the legacy CH-53E helicopter and provide increased range and payload, survivability and force protection, reliability and maintainability, and coordination with other assets, while reducing total ownership cost.



Source: 2013 Sikorsky Aircraft Corporation.



Program Essentials

Prime contractor: Sikorsky Aircraft Corporation
Program office: Patuxent River, MD
Funding needed to complete:
R&D: $2,258.5 million
Procurement: $18,366.2 million
Total funding: $20,668.6 million
Procurement quantity: 194

Program Performance (fiscal year 2014 dollars in millions)

	As of 12/2005	Latest 08/2013	Percent change
Research and development cost	$4,605.4	$6,395.4	38.9
Procurement cost	$12,808.2	$18,366.2	43.4
Total program cost	$17,413.6	$24,805.5	42.4
Program unit cost	$111.625	$124.028	11.1
Total quantities	156	200	28.2
Acquisition cycle time (months)	119	157	31.9

The CH-53K program continues to move forward toward production, but has not yet fully matured its critical technologies or demonstrated that its design can perform as expected. As a result, the risk of design changes remains. According to program officials, the ground test vehicle has been delivered. However, a number of problems with producibility and qualification of parts have resulted in a delay in production of approximately 6 months and delays to qualification and flight testing.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ○

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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CH-53K Program

Technology Maturity

The CH-53K program began system development in 2005 with immature critical technologies. Nearly 9 years later the program's two critical technologies—the main rotor blade and main gearbox—are approaching maturity. The program expects these technologies to be demonstrated in a realistic environment by its planned February 2016 production decision, a delay in 6 months over last year's schedule. Program officials reported that they conducted a three-blade whirl test that produced results that exceeded required outcomes. Flight testing is expected to begin in late 2014.

Design Maturity

The CH-53K design appears stable, but it has not been demonstrated using a system-level prototype to show that it will perform as expected. The program has reported that they are relying on delivery of test vehicles to demonstrate their design. However, delivery of three of four of those test vehicles is projected to be delayed. Defense Contract Management Agency (DCMA) officials reported that the delays were caused by a number of factors such as late qualification testing, qualification test failures, re-testing, and the qualification of software. The delays have affected aircraft test schedules as well.

Production Maturity

Delivery of the ground test vehicle, which began production in July 2011, took place in October 2012. However, light off of the ground test vehicle—which will include testing of the main gear box and the rotor blades—was delayed until December 2013. Late component deliveries and parts shortages have delayed additional test aircraft deliveries. Test vehicle production is now approximately 10 months behind schedule, which has delayed the program's first test flight by approximately 4 months. These delays also resulted in a 6-month delay for the CH-53K's production decision, which has been moved to February 2016.

Other Program Issues

The CH-53K development contract was modified in April 2013 to reflect a new acquisition program baseline that reflects long standing increases in the program's cost and schedule. The program office reported that part of the increase to the development contract was to include four system demonstration test articles. Program officials reported that in July 2011, the contract's estimated cost increased by $724 million to $3.4 billion. However, recent Defense Contract Management Agency independent cost estimates place the cost closer to $3.7 billion, a total cost increase of approximately $1 billion. The program's schedule contains concurrency between production and testing, which represents risk to the program and may require costly retrofits to aircraft after they have already been produced.

Program Office Comments

In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated as appropriate.

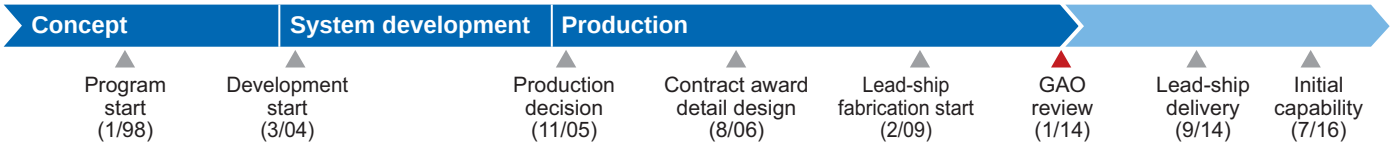
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DDG 1000 Zumwalt Class Destroyer (DDG 1000)

The Navy's DDG 1000 destroyer is a multimission surface ship designed to provide advanced capability for littoral operations and land-attack in support of forces ashore. The ship will feature a low radar profile and an advanced gun system. The lead ship was launched in October 2013 and the ship (comprised of the hull and mechanical and electrical systems) is currently scheduled for delivery in September 2014, with activation of the mission systems starting in 2015. Fabrication is underway on the remaining two ships in the class.



Source: © 2013 General Dynamics Bath Iron Works.



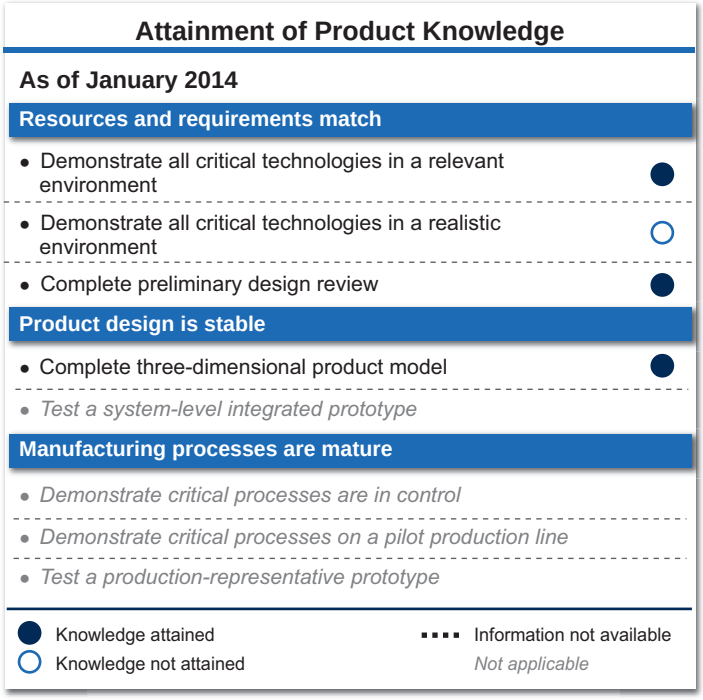
Program Essentials

Prime contractor: BAE Systems, Bath Iron Works, Huntington Ingalls Industries, Raytheon
Program office: Washington, DC
Funding needed to complete:
- R&D: $569.4 million
- Procurement: $768.8 million
- Total funding: $1,338.2 million
- Procurement quantity: 0

Program Performance (fiscal year 2014 dollars in millions)

	As of 1/1998	Latest 08/2013	Percent change
Research and development cost	$2,395.9	$10,593.2	342.2
Procurement cost	$34,205.7	$11,406.4	-66.7
Total program cost	$36,601.6	$21,999.6	-39.9
Program unit cost	$1,143.799	$7,333.213	541.1
Total quantities	32	3	-90.6
Acquisition cycle time (months)	128	222	73.4

The DDG 1000 program has made progress in developing its critical technologies and the ship design is largely mature. While few design changes resulted from lead ship construction, the Navy decided to build the third ship's deckhouse and hangar with steel rather than composite materials due to manufacturing and integration challenges on the first two ships and as a long-term cost saving measure. The program is also incorporating technical configuration changes to maintain capability and minimize cost. Delivery of the lead ship (hull, mechanical and electrical systems) may slip past the currently scheduled date of September 2014 due to difficulties in completing the ship's electrical systems which is impacting test and activation events.



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DDG 1000 Program

Technology Maturity

The DDG-1000 program has made progress in developing its critical technologies. However, only 3 of 11 are mature and the remaining 8 will not be demonstrated in a realistic environment until after installation on the lead ship. Guided flight tests of the gun system's long-range land-attack projectile were successfully completed in October 2013. After significant cost growth and development challenges, all six software releases for the total ship computing environment have been completed and certified to support lead ship activation and delivery and a software spiral update is under contract timed to support initial operating capability. Following a critical Nunn-McCurdy unit-cost breach in 2010, DOD restructured the program and removed the volume search radar from the ship's design. A modified multifunction radar is expected to begin land based testing in 2014, followed by at-sea testing in 2015.

Design and Production Maturity

The DDG 1000 design is largely mature. According to the program manager and ship builder, as of October 2013, production and test efforts for the first two ships were 88 and 70 percent complete, respectively. While few design changes have resulted from lead ship construction, shipbuilders have experienced challenges with the manufacture and integration of the composite deckhouse for the first and second ships, resulting in rework and schedule delays particularly on the first ship. The Navy has emphasized a joint inspection process whereby the prime contractors and the Navy validate product quality and completeness prior to integration with the hull. After assessing alternatives and conducting a competition, the Navy decided to build the third ship's deckhouse and hangar with steel as a cost saving measure as the program manager noted that the Navy has better cost insights into the long-term maintenance of steel compared to composite materials.

Other Program Issues

Delivery of the lead ship (hull, mechanical and electrical systems) may slip past the currently scheduled date of September 2014 and the Navy is in the process of assessing the delivery date. If delivery slips past October 2014, the program will breach its acquisition program baseline schedule requirements. According to the Navy, the delay is the result of difficulties in completing the ship's electrical systems, which is impacting test and activation events.

The program has awarded all major contracts for the three ships in the DDG 1000 class among four prime contractors. As the integrator, the Navy is responsible for ensuring on-time delivery of products and bears the costs of schedule delays that affect another contractor. Bath Iron Works is now producing the hull for all three ships. In August 2013, the Navy awarded a fixed price contract to Bath Iron Works for a steel deckhouse, hangar, and aft peripheral vertical launching system for the third ship. According to the program manager, the shipbuilder negotiated a 5- and 10-month delivery delay for the second and third ship, respectively.

Program officials also reported that the program absorbed sequestration reductions of $70 million in fiscal year 2013 by delaying testing and the award of contracts for mission-related equipment. The program is also incorporating technical configuration changes resulting from the configuration steering board and Nunn-McCurdy annual cost review aimed at maintaining capability and minimizing costs. For example, the program manager told us the program assessed alternatives to the close in gun system and chose a legacy system that met requirements with about half the weight and cost.

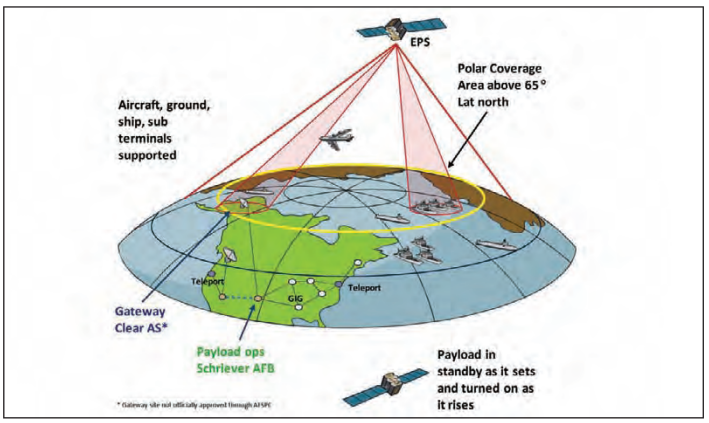
Program Office Comments

In commenting on a draft of this assessment the Navy noted that the DDG 1000 lead ship was successfully launched in October 2013, a christening is scheduled for April 2014, and activation activities continue. For the second ship, keel laying and hangar erection have occurred, hull integration is underway, and deckhouse delivery is scheduled for spring 2014. The Navy noted that significant integration efforts between four prime contractors continue with a focus on cost reduction and schedule performance. The Navy also provided technical comments, which were incorporated where deemed appropriate.

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Enhanced Polar System (EPS)

The Air Force's Enhanced Polar System (EPS) is to provide next-generation protected extremely high frequency (EHF) satellite communications in the polar region. It will replace the current Interim Polar System and serve as a polar adjunct to the Advanced EHF (AEHF) system. EPS is to consist of two EHF payloads hosted on classified satellites, a gateway to connect modified Navy Multiband Terminals to other communication systems, and a control and planning segment (CAPS).



Source: LinQuest Corporation.

Concept | **System development/Production**

Program initiation (12/07)	GAO review (1/14)	Development start (2/14)	Design review (7/14)	Payload-1 on orbit (Q2 FY15)	Payload-2 on orbit (Q2 FY17)	End operational test (2/18)	Operational capability (6/18)

Program Essentials

Prime contractor: Northrop Grumman Information Systems
Program office: Los Angeles AFB, CA
Funding needed to complete:
R&D: $398.1 million
Procurement: $0.0 million
Total funding: $398.1 million
Procurement quantity: 0

Program Performance (fiscal year 2014 dollars in millions)

	As of	Latest 07/2013	Percent change
Research and development cost	NA	$1,505.3	NA
Procurement cost	NA	$0.0	NA
Total program cost	NA	$1,505.3	NA
Program unit cost	NA	$752.625	NA
Total quantities	NA	2	NA
Acquisition cycle time (months)	NA	126	NA

The three segments of the EPS are in various stages of development. Although the EPS program's two payloads are built, funding constraints resulted in reductions to the requirements of the control and planning segment and gateway segment, which delayed initial operational capability by 2 years. However, the reduction of capabilities also reduced the amount of development necessary and allowed for a revised acquisition strategy that, according to the program office, reduced risk and cost.

Attainment of Product Knowledge

Projected as of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment ●
- *Demonstrate all critical technologies in a realistic environment*
- Complete preliminary design review ●

Product design is stable

- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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EPS Program

Technology and Design Maturity

EPS was initiated in 2007 to fill a gap identified in the Advanced Polar System study. The Under Secretary of Defense for Acquisition, Technology, and Logistics directed the program to proceed to system development to synchronize the program's payload schedule with the host satellite's production timeline. The host program awarded the payload development contract in July 2008, following an acquisition board equivalent to a system development decision. Payload development proceeded and all six critical technologies are fully mature, according to the program office. Both payloads are built and the first payload is fully integrated into the host satellite, which is currently undergoing system-level testing.

In contrast, the control and planning segment (CAPS) and gateway development was delayed. Because of funding constraints, the program office used a design-to-cost approach to reduce CAPS and gateway development to the minimum capability needed. The revised EPS acquisition strategy incorporating changes to CAPS and gateway development was approved in January 2012. The CAPS design contract was awarded in December 2012, with a planned system development decision in July 2014. The gateway requires integration of existing commercial off-the-shelf and government furnished equipment and is considered low risk by the program office.

Other Program Issues

The reduction in capabilities for the CAPS and gateway allowed a change in acquisition strategy that reduced cost and risk but also delayed operational capability from fiscal year 2016 to 2018. Under the original acquisition strategy, CAPS was planned as a follow-on increment to the AEHF mission control segment. A sole source award was to be made to AEHF's prime contractor for CAPS, while the gateway was to be competitively awarded. The reduced requirements and revised acquisition strategy allowed for CAPS to be competitively awarded. The reduction of requirements nearly eliminated the development work for the gateway. Consequently, the Navy's Space and Naval Warfare Systems Command (SPAWAR) System Center Pacific will be responsible for integrating, testing, installing, certifying, and sustaining the gateway segment. According to the program office, this approach also reduces cost and schedule as it would take time for a contractor to develop the expertise and test beds that SPAWAR System Center Pacific already has. The reduction in requirements and revised acquisition strategy reduced overall program cost by about $1 billion, according to program officials.

The payloads are expected to be on orbit in fiscal years 2015 and 2017 respectively. By the current schedule, CAPS site installation will occur in late fiscal year 2016. According to the program office, CAPS is not required for payload on-orbit testing, but it is required for inter-segment testing scheduled for the first quarter of fiscal year 2017 and for overall functioning of the EPS system. There is adequate schedule margin according to officials, but any additional delays such as delayed funding or program milestones will result in a further delay in operational capability.

Program Office Comments

In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated where deemed appropriate.

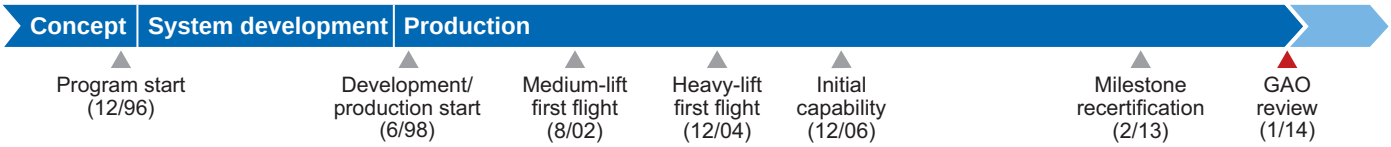
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Evolved Expendable Launch Vehicle (EELV)

The Air Force's EELV program acquires launch services to provide critical space support to DOD, national security, and other government missions. The United Launch Alliance is currently the sole provider of launch vehicles for U.S. military and intelligence satellites. However, the Air Force may certify new launch providers to compete for future launch services. Today, the program consists of two families of launch vehicles, support systems, and launch site operations. We assessed the Atlas V and the Delta IV.



Source: © 2012 United Launch Alliance.



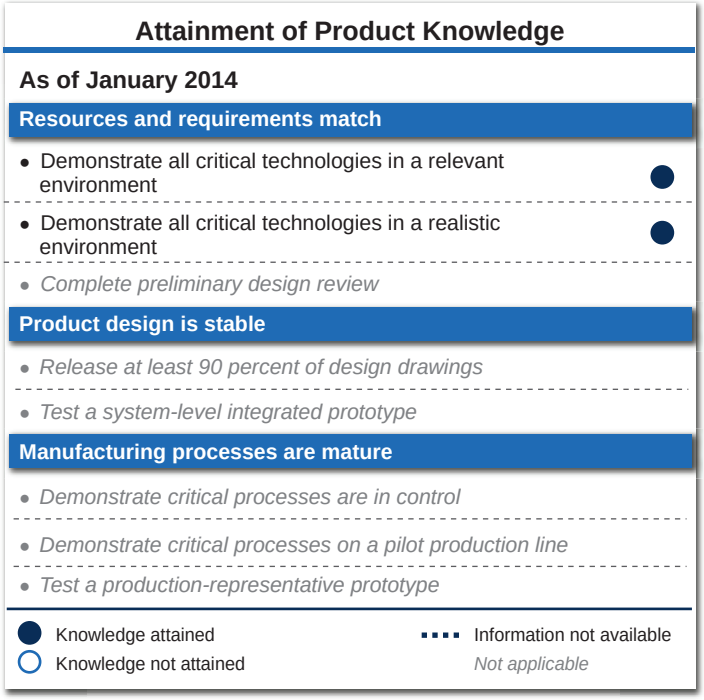
Program Essentials

Prime contractor: United Launch Services, LLC
Program office: El Segundo, CA
Funding needed to complete:
R&D: $81.4 million
Procurement: $42,848.3 million
Total funding: $42,929.7 million
Procurement quantity: 89

Program Performance (fiscal year 2014 dollars in millions)

	As of 10/1998	Latest 08/2013	Percent change
Research and development cost	$1,872.6	$2,460.6	31.4
Procurement cost	$16,403.2	$61,463.2	274.7
Total program cost	$18,275.9	$63,923.7	249.8
Program unit cost	$100.972	$420.551	316.5
Total quantities	181	152	-16.0
Acquisition cycle time (months)	NA	120	NA

We assessed EELV technology as mature with 66 successful launches as of December 2013. We could not assess design or production maturity using our best practices. All of the 14 EELV launch vehicle variants have launched at least once. However, only three variants—the Atlas V 401, the Delta IV Medium, and the Delta IV Heavy—have launched seven times, proving production maturity according to an Aerospace Corporation measure developed for the program. EELV completed recertification after reporting Nunn-McCurdy critical unit cost breaches in the March 2012 Selected Acquisition Report and transitioned back into the production phase in February 2013. The program is estimated to cost over $70 billion through 2030. EELV program officials are currently conducting activities to certify new launch providers and signed a contract modification to procure additional EELV launches.



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EELV Program

Technology, Design, and Production Maturity

While EELV's technology is mature, we could not assess design and production maturity because the Air Force does not obtain information from the contractor that would facilitate this assessment. According to the Aerospace Corporation's measurement known as the "3/7 reliability rule," once a vehicle variant is launched successfully three times its design can be considered mature. Similarly, if a vehicle is successfully launched seven times, both the design and production process can be considered mature. Based on this rule, few variants have reached maturity for both design and production. Each of the 9 Atlas V variants and the five Delta IV variants has flown at least once, demonstrating the viability of their technologies, and 10 of the Atlas and Delta variants have flown three times, demonstrating design maturity according to Aerospace's rule. However, only 3 of the 14 EELV variants have demonstrated production maturity with seven flights. Until a launch vehicle configuration demonstrates design and production maturity, problems with fleetwide designs or production processes may go undiscovered, which could cause significant cost and schedule risk.

The Air Force is investigating the root cause of an anomaly with the Delta IV upper stage engine which did not perform as expected during a launch in October 2012. According to the EELV program office, the initial phase of the investigation was completed in May 2013 but a root cause determination was not made. While the engine has performed normally on launches in May and August 2013, the Air Force delayed a third launch of the Delta IV scheduled for October 2013, due to new conclusions from the investigation and to fully understand the anomaly and reduce any potential risks.

Other Program Issues

Due to a program restructuring stemming from the Nunn-McCurdy breaches reported in the March 2012 Selected Acquisition Report, the program developed a new acquisition program baseline, which was approved in early 2013. The estimated costs for the program are about $70 billion based on the need for 151 launches through the year 2030. This estimate is around $35.7 billion more than the previous estimate reported in March 2012. The program identified several causes for this cost growth including extension of the program life-cycle from 2020 to 2030, procurement of 60 additional launch vehicles, the inherently unstable nature of the demand for launch services, and industrial base instability.

The Air Force signed a contract modification in December 2013 to procure additional EELV launches and has revised its acquisition strategy to meet some of DOD's EELV-class launch vehicle needs. EELV-class is defined as a vehicle or family of vehicles that can reliably launch a variety of payloads up to 13,500 pounds to geosynchronous earth orbit. The revised strategy outlines how to certify a new provider's launch vehicle based on risk classifications for individual payloads. After a new provider completes its first successful flight, the Air Force will award early integration study contracts for the payloads the vehicle is projected to be capable of launching. In November 2012, the Air Force awarded an EELV-class launch service contract to Space Exploration Technologies (SpaceX), in an effort to support the demonstration of its capabilities as part of the certification process. In September and December 2013, SpaceX launched its first and second vehicles toward certification respectively.

Program Office Comments

The Air Force provided technical comments, which were incorporated as appropriate.

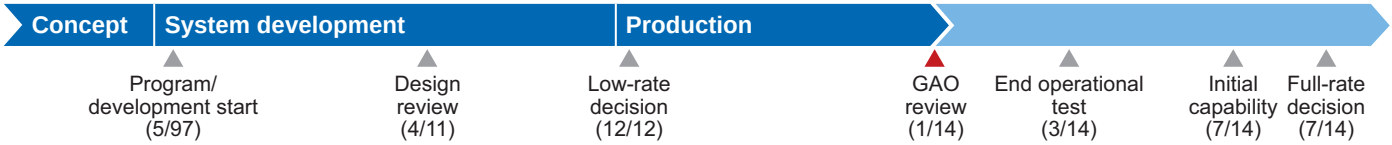
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Excalibur Precision 155mm Projectiles (Excalibur)

The Army's Excalibur is a family of global positioning system-based, fire-and-forget, 155mm cannon artillery precision munitions intended to provide improved range and accuracy. The near-vertical angle of fall is expected to reduce collateral damage, making it more effective in urban environments. The Army is using an incremental approach to deliver capabilities. Increment Ia-1 is fielded, Ia-2 is in production, and Ib, which is expected to increase reliability and lower unit costs, began production in 2012. We assessed increment Ib.



Source: U.S. Army.



Program Essentials

Prime contractor: Raytheon
Program office: Picatinny Arsenal, NJ
Funding needed to complete:
- R&D: $7.9 million
- Procurement: $75.9 million
- Total funding: $83.9 million
- Procurement quantity: 952

Program Performance (fiscal year 2014 dollars in millions)

	As of 02/2003	Latest 08/2013	Percent change
Research and development cost	$805.1	$1,137.6	41.3
Procurement cost	$4,218.4	$702.0	-83.4
Total program cost	$5,023.5	$1,839.6	-63.4
Program unit cost	$0.066	$0.281	328.4
Total quantities	76,677	6,555	-91.5
Acquisition cycle time (months)	NA	206	NA

Note: Total quantities include 2,849 increment Ib projectiles.

The Excalibur program has made multiple design changes to address reliability concerns since 2012, including a risk that it may not meet its reliability threshold requirement. The Ib round still does not meet insensitive munitions requirements. According to program officials, however, it does meet military standards and the program has projected test dates to address concerns of the Army Insensitive Munitions Board. The program reduced the number of rounds planned for procurement due to a recommendation in the conference report accompanying the Consolidated and Further Continuing Appropriations Act, 2013 and sequestration but has requested restitution of those funds in fiscal years 2015 and 2016.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match
- Demonstrate all critical technologies in a relevant environment ●
- Demonstrate all critical technologies in a realistic environment ●
- Complete preliminary design review ●

Product design is stable
- Release at least 90 percent of design drawings ●
- Test a system-level integrated prototype ●

Manufacturing processes are mature
- Demonstrate critical processes are in control ○
- Demonstrate critical processes on a pilot production line ●
- Test a production-representative prototype ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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Excalibur Program

Technology and Design Maturity

The Excalibur program's critical technology is fully mature. The program has made multiple incremental design changes intended to increase reliability since the low-rate production decision in 2012. For example, the contractor producing the Global Positioning System (GPS) receiver made hardware and software changes to increase receiver reliability in the gun launch environment. Additionally, the program has made changes to the guidance assembly and the fuze safe and arm device to address failures during Ib round developmental testing. There have been no design changes to the warhead or the operational flight software. The Ib round still does not meet requirements related to insensitive munitions—ensuring that a round will not detonate under any condition other than its intended mission. According to program officials, however, it does meet military standards. The program reports that a follow-up test to meet the Army Insensitive Munitions Board requirements, which was delayed due to sequestration and furloughs during the government shutdown, is projected for early 2014. Ensuring compliance with this requirement could require design changes and the program is uncertain of the total number of drawings that will ultimately be required.

The program reported that it received a funding increase in fiscal year 2014 of $5 million to support the completion of initial operational test and evaluation, which was subsequently reduced due to sequestration for a net increase of $4.3 million. All performance and safety requirements have been met, but reliability testing will not be complete until after production has begun.

Production Maturity

According to program officials, the program is at low risk of not meeting its reliability threshold of 90 percent and at moderate-to-high risk of not meeting its reliability objective. However, given test results since the low-rate decision, the program expects to meet the threshold reliability requirement. The program has been authorized to procure 1800 rounds in low-rate production and will seek authorization to procure the remaining rounds at the full-rate production decision, tentatively scheduled for mid-2014.

Other Program Issues

The program is still projecting to produce 3,455 Ib rounds, but its fiscal year 2013 procurement funding was cut by $47.5 million due to a recommendation in the conference report accompanying the Consolidated and Further Continuing Appropriations Act, 2013 and sequestration. As a result the program is reporting a 17 percent reduction of rounds for procurement. The program, however, has requested restoration of funding for those rounds in fiscal years 2015 and 2016. The project originally planned for funding to end in fiscal year 2014; spreading funding into future years will increase the life of the program and may have additional costs.

Program Office Comments

In commenting on a draft of this assessment, program officials stated that Excalibur continues to provide commanders with an organic precision targeting capability resulting in over 700 rounds being fired in combat to date. They also stated that the program continues to execute within all acquisition program baseline parameters and is meeting or exceeding all five of its key performance parameters. Excalibur Increment Ib has shown performance improvements and continues to execute to the plan approved by both the Army and joint insensitive munitions board and has seen improvements in the area of less sensitive reactions.

Program officials stated that the final Excalibur increment began low-rate initial production in first quarter fiscal year 2014 and successfully completed first article testing in December 2013. The current Excalibur production contract contains fixed price procurement options to ensure consistent procurement costs through fiscal year 2016. The program also provided technical comments, which were incorporated as appropriate.

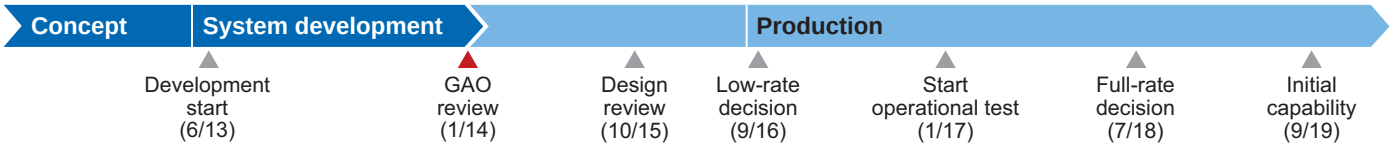
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F-22 Increment 3.2B

The Air Force's F-22 Raptor is a stealthy air-to-air and air-to-ground fighter/attack aircraft. The Air Force established an F-22 modernization and improvement program in 2003 to add enhanced air-to-ground, information warfare, reconnaissance, and other capabilities and to improve the reliability and maintainability of the aircraft. Increment 3.2B, the fourth increment of the modernization program, was initially managed as part of the F-22 baseline program, but is now being managed as a separate major defense acquisition program.



Source: U.S. Air Force.



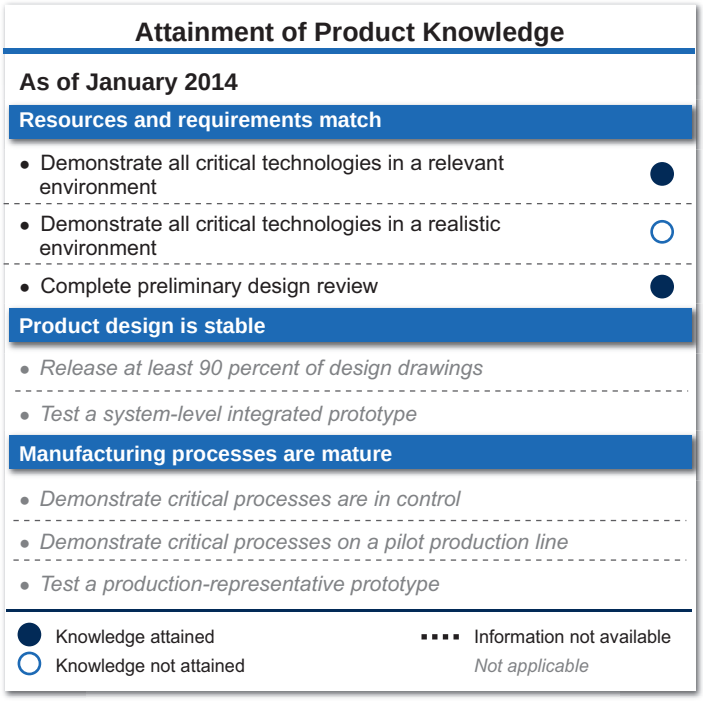
Program Essentials

Prime contractor: Lockheed Martin
Program office: Wright-Patterson AFB, OH
Funding needed to complete:
R&D: $543.1 million
Procurement: $339.1 million
Total funding: $882.2 million
Procurement quantity: 143

Program Performance (fiscal year 2014 dollars in millions)

	As of 06/2013	Latest 09/2013	Percent change
Research and development cost	$1,222.1	$1,218.8	-0.3
Procurement cost	$344.6	$339.1	-1.6
Total program cost	$1,566.7	$1,557.9	-0.6
Program unit cost	$10.308	$10.249	-0.6
Total quantities	152	152	0.0
Acquisition cycle time (months)	72	75	4.2

Increment 3.2B is an enhancement to the F-22, bringing upgraded electronic protection, geolocation, and intra-flight data link capabilities, and integrating AIM-9X and AIM-120D missiles. The Air Force received approval to begin system development of Increment 3.2B as a separate major defense acquisition program in June 2013. The one reported critical technology has been demonstrated in a relevant, but not a realistic, environment. Full maturity is expected by the critical design review in October 2015, by which point the Air Force also anticipates achieving full design stability. There may be a production gap of two to four years between qualification of hardware for the program and the beginning of low-rate initial production. The program office stated that it has mitigated risk related to AIM-9X software development.



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F-22 Inc 3.2B Program

Technology and Design Maturity

Increment 3.2B's sole, identified critical technology, a geolocation algorithm, is not yet fully mature having been demonstrated only in a relevant environment. The program office expects the technology to reach full maturity by October 2015. The Air Force also anticipates achieving full design stability by the October 2015 critical design review as 92 percent of system level drawings are currently releasable. A knowledge-based acquisition approach is a cumulative process, and mature technology is a prerequisite for moving into system development. The program intends to demonstrate that the design can perform as expected by integrating and testing all key subsystems and components prior to the critical design review.

Production Maturity

Prior to system development, DOD systems engineering personnel identified a production gap of two to four years between qualification of hardware for Increment 3.2B and the beginning of low-rate initial production as a risk as some of the electronic components used may no longer be available when production begins. The program office stated that it is working closely with suppliers to mitigate identified risks through an advance procurement contract. Program officials partly attributed the gap to an early start made on hardware development given initial assumptions about the amount of development involved. Additionally, the Defense Contract Management Agency has noted supplier developmental issues with displays and processing modules which support Increment 3.2B.

Other Program Issues

Consistent with direction from Congress and the Office of the Secretary of Defense, the Air Force designated F-22 Increment 3.2B as a distinct major defense acquisition program rather than managing it as part of the F-22 baseline program. About half of the program's $1.2 billion estimated development cost was spent under the F-22 baseline program. Originally scheduled for December 2012, the approval to formally initiate the Increment 3.2B acquisition program and begin system development was delayed until June 2013 as it took longer than expected to prepare Air Force and independent cost estimates. According to cost estimators, the delay is attributable to their having to reconstruct missing cost information from prior modernization increments in order to estimate costs for Increment 3.2B.

An initial risk assessment noted that if the Increment 3.2B program did not receive the customized software that allows the F-22 to use the AIM-9X air-to-air missile in time for operational testing, it might face a delay in its overall fielding schedule. The F-22 program office stated that it has mitigated risk related to missile software development, and has signed an agreement with the AIM-9X program office on technical and schedule requirements for integrating the missile. The F-22 program office plans to field limited AIM-9X capabilities prior to the completion of Increment 3.2B by including them as part of an earlier software update.

Program Office Comments

The Air Force provided technical comments, which were incorporated as appropriate.

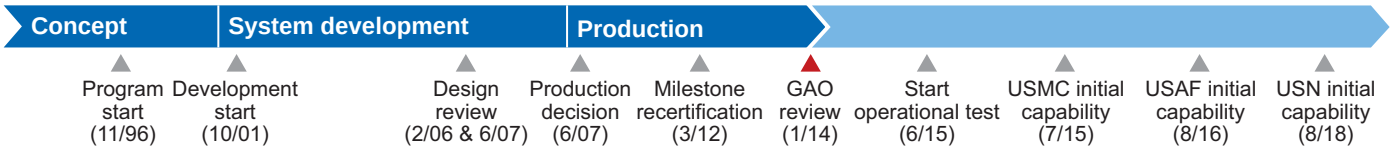
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F-35 Lightning II Program (F-35)

DOD's F-35 program is developing a family of stealthy, strike fighter aircraft for the Navy, Air Force, Marine Corps, and U.S. allies, with the goal of maximizing commonality to minimize life-cycle costs. The carrier-suitable variant will complement the Navy F/A-18E/F. The Air Force variant is expected to replace the air-to-ground attack capabilities of the F-16 and A-10, and complement the F-22A. The short take-off and vertical landing (STOVL) variant is expected to replace the Marine Corps F/A-18 and AV-8B aircraft.



Source: Courtesy of Lockheed Martin.



Program Essentials

Prime contractor: Lockheed Martin, Pratt and Whitney
Program office: Arlington, VA
Funding needed to complete:
R&D: $5,516.9 million
Procurement: $231,243.5 million
Total funding: $239,559.1 million
Procurement quantity: 2,293

Program Performance (fiscal year 2014 dollars in millions)

	As of 10/2001	Latest 08/2013	Percent change
Research and development cost	$40,995.1	$61,795.8	50.7
Procurement cost	$181,875.9	$266,469.1	46.5
Total program cost	$224,774.7	$332,320.0	47.8
Program unit cost	$78.428	$135.254	72.5
Total quantities	2,866	2,457	-14.3
Acquisition cycle time (months)	116	237	104.3

Although the F-35 program has invested billions of dollars and ordered 150 production aircraft, gaps in product knowledge persist. Four critical technologies are not mature and the program continues to experience design changes. Development testing is progressing but is far from complete and will likely drive more changes in design and manufacturing processes. While manufacturing efforts are improving, only twenty-five percent of the program's critical manufacturing processes are mature and capable of consistently producing quality parts, and fewer planes were produced in 2013 than initially planned. Software development has progressed; but if additional delays are encountered initial operating capability dates could be at risk. Long-term affordability and sustainment costs remain challenging.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ○
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ●

Manufacturing processes are mature

- Demonstrate critical processes are in control — ○
- Demonstrate critical processes on a pilot production line — ●
- Test a production-representative prototype — ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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F-35 Program

Technology Maturity

Three of the program's critical technologies are nearing maturity while one is immature. The program has made progress addressing technical risks including the helmet mounted display, which is needed for the aircraft to fully perform its missions, and the Autonomic Logistics Information System (ALIS), which is critical to the operations and sustainment of the fleet. The program recently chose to end development of an alternate helmet due to progress made on the original helmet design and work on development of a newer generation helmet. ALIS integration and testing continues with the next, more capable version expected to be delivered in 2014.

Design Maturity

Although the three aircraft designs were not stable at critical design reviews in 2006 and 2007, all expected engineering drawings have since been released. However, issues discovered in testing continue to drive design changes. In 2013, bulkhead and rib cracks were discovered in the STOVL variant that may require the program to make changes to production and retrofit aircraft. The carrier variant's new arresting hook system successfully completed a critical design review and is expected to be ready for carrier use by October 2014. With significant testing remaining, additional design changes are likely.

Production Maturity

DOD has invested about $35 billion in procuring 150 aircraft through 2013. The contractor uses statistical process controls as one means to assess critical manufacturing processes. Twenty five percent of those processes are currently judged capable of consistently producing quality parts at the best practice standards. Production efforts have improved as the production line continues to show efficiencies and quality metrics show positive trends. However, in 2013, problems with engine hoses, engine turbines, and specialty metals halted production deliveries for three months. In 2013, 35 planes were delivered to the government—eight less than originally planned. Aircraft deliveries were postponed for one month while the runway at the final assembly facility was resurfaced.

Other Program Issues

In 2013, the military services re-established initial operating capability dates for their respective F-35 variants. To achieve those dates, the Marine Corps and Air Force will accept basic warfighting capabilities provided by software Blocks 2B and 3I respectively, while the Navy intends to wait for the full suite of capabilities provided by software Block 3F. Block 2B development is currently behind schedule, which could impact the development of Block 3I, and subsequently 3F. Any additional software delays could put initial operating capability dates at risk as software is essential to achieve aircraft capabilities such as sensor fusion, weapons and fire control, maintenance diagnostics, and propulsion. In addition, the program's long-term affordability remains a challenge. The amount of annual funding required to complete development and procurement of the F-35 is more than $12 billion on average, while the cost to operate and support the aircraft is estimated at more than $1 trillion over its life-cycle. These estimates may change over time as testing progresses and more concrete information becomes available.

Program Office Comments

In addition to providing technical comments, the program noted that it appreciates GAO's reviews in assisting the program by identifying areas for improvement. The program has made great strides in the past year to further stabilize technology, design, and production maturity, and work continues on identified areas to improve program performance. The program ended development of the alternate F-35 helmet as further testing indicated it is acceptable for USMC initial operating capability. Continued improvements will be made in the Gen III helmet. This decision includes a guarantee from industry to reduce the unit cost by 12 percent from previous estimates. Aircraft and engine quality continues to improve as manufacturing processes mature, and unit costs continue to come down lot over lot. The program has taken steps to improve management of concurrency risk and minimize costs to the services by reducing the time required to implement changes into the production line so that fewer aircraft need post-production retrofits.

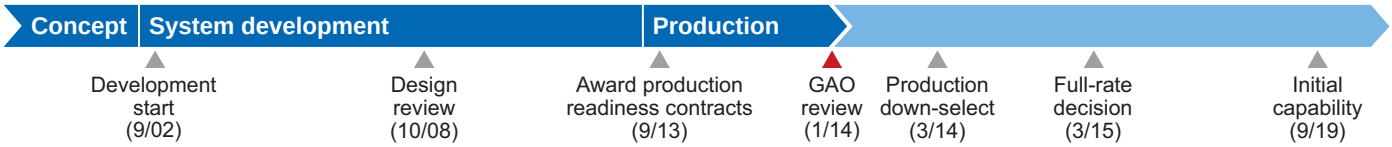
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Family of Beyond Line-of-Sight - Terminals (FAB-T)

The Air Force's FAB-T program plans to provide a family of satellite communications terminals for airborne and ground-based users to replace many program-unique terminals. It is being designed to work with current and future communications capabilities and technologies. FAB-T is expected to provide voice and data over military satellite communications for nuclear and conventional forces through ground command posts and E-6 and E-4 aircraft, and was originally planned to provide force element capabilities on B-2, B-52, and RC-135 aircraft.



Source: U.S. Air Force.



Program Essentials

Prime contractor: Boeing, Raytheon
Program office: Bedford, MA
Funding needed to complete:
R&D: $196.0 million
Procurement: $2,190.6 million
Total funding: $2,386.6 million
Procurement quantity: 216

Program Performance (fiscal year 2014 dollars in millions)

	As of 12/2006	Latest 10/2013	Percent change
Research and development cost	$1,616.7	$2,406.0	48.8
Procurement cost	$1,736.9	$2,212.0	27.4
Total program cost	$3,353.6	$4,618.0	37.7
Program unit cost	$15.526	$18.772	20.9
Total quantities	216	246	13.9
Acquisition cycle time (months)	129	204	58.1

The latest cost data do not reflect the current cost of the program and the latest quantities do not reflect recent program decisions. A new acquisition program baseline has not yet been approved.

The program is approaching a production decision with a stable, demonstrated design but without having conducted key assessments. Due to continued cost and schedule growth in developing this design, the Air Force signed a development contract with an additional vendor in September 2012 to establish an alternate source for a system with capabilities similar to the original vendor's FAB-T effort. An acquisition baseline updated to reflect the award to a second vendor, and other changes to the program strategy since 2010, has been delayed and will not be approved until after the Air Force determines which vendor will move forward into production. Despite numerous changes to the program, an independent cost estimate has not been conducted since 2009, but is expected in early 2014.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment ●
- Demonstrate all critical technologies in a realistic environment ●
- Complete preliminary design review ●

Product design is stable

- Release at least 90 percent of design drawings ●
- Test a system-level integrated prototype ●

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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FAB-T Program

Technology Maturity

According to the program office, all of the critical technologies for both vendors are fully mature based on the vendors' self-assessments. The program does not currently plan to conduct an independent technology readiness assessment for the alternate vendor. The program office also stated that both vendors have functional prototypes being utilized for testing.

Design Maturity

According to the program office, FAB-T's design is stable for both the original and alternate vendor development programs. The original vendor completed functional qualification testing in August 2013. The alternate vendor completed a system-level design review in June 2013 and demonstrated a system-level integrated prototype in October 2013.

Production Maturity

In 2012, FAB-T's acquisition strategy was changed to initiate two possible production paths: one providing both command and force element terminals, and the other only command terminals. Both vendors submitted proposals to compete for both approaches. In December 2013, the Air Force chose to pursue the command terminal only approach and the program plans to make a down-select decision to one vendor in the second quarter of fiscal year 2014. Depending on which vendor is chosen, the low-rate production decision is planned for either March 2014 or September 2014.

A 2012 acquisition decision memorandum called for several steps before the award of FAB-T's production contracts, including: an independent cost estimate; a revised acquisition program baseline; and a defense acquisition board review. Program officials stated that neither the cost estimate nor the revised baseline will be completed prior to the down-select decision. Department officials stated that the review has been delayed and not yet rescheduled. Also, FAB-T does not plan to independently assess manufacturing readiness levels prior to the down-select decision. Air Force decisions to commit to a production contractor before the program is fully assessed introduce additional acquisition risk.

Other Program Issues

In October 2010, an independent review team noted that the program was likely in breach of critical Nunn-McCurdy unit cost thresholds but a breach has not yet been reported by the program. In 2012, the FAB-T program made several revisions to its acquisition strategy—including modification of the original development contract from cost plus award fee to firm fixed-price and the addition of competition by awarding the alternate vendor contract in response to these concerns about cost growth. However, a new acquisition program baseline and independent cost estimate that reflect these changes and their projected costs will not be completed until 2014.

According to Department officials, the requirement for the force element terminals remains in the program but is not currently funded. If not integrated with the B-2 and B-52 bomber platforms, FAB-T may not meet its full range of planned communications capabilities as some are based on the interaction of bomber aircraft with intelligence, surveillance, and reconnaissance aircraft and command terminals.

Program Office Comments

According to program officials, the FAB-T program office continued to execute the revised acquisition strategy in 2013. Significant progress was made by both contractors on their respective development contracts. With respect to production efforts, production planning contracts were awarded to lock down prices. In addition, the competition for command terminals is on-going, and the Air Force has scheduled a down select decision in the second quarter of fiscal year 2014. The independent cost estimate and acquisition program baseline will then be updated to re-baseline the program. To address the cost thresholds and breach concerns, program officials said they are confident that adequate technology and manufacturing assessments, along with the revised cost and schedule evaluation, will be conducted prior to the decision to exercise the first production option. The program office's assessment is that there will be a stable and mature design, with a reliable manufacturing process, to proceed into operational unit production for this critical operational capability.

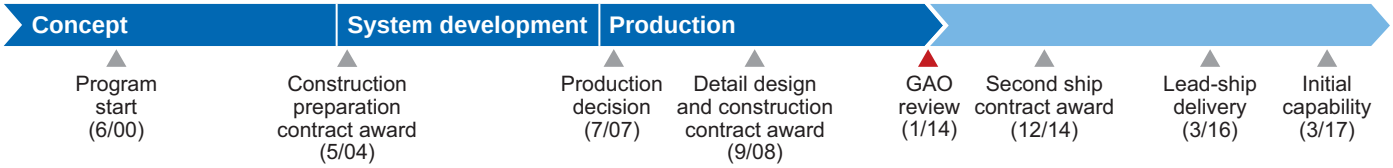
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Gerald R. Ford Class Nuclear Aircraft Carrier (CVN 78)

The Navy's CVN 78 class of nuclear-powered aircraft carriers is designed to improve operational efficiency, enable higher sortie rates, and reduce manpower through the use of advanced propulsion, aircraft launch and recovery, and survivability technologies. The lead ship, CVN 78, was 70 percent complete at launch; however, its delivery is delayed until March 2016. Also, contract negotiations prompted the Navy to defer the construction contract for CVN 79 until early fiscal year 2015.



Source: U.S. Navy.



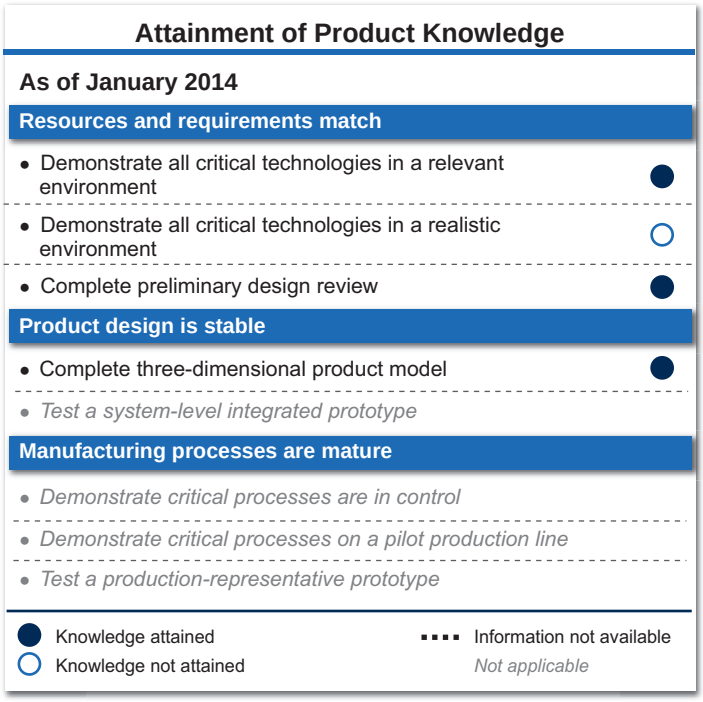
Program Essentials

Prime contractor: Huntington Ingalls Industries
Program office: Washington, DC
Funding needed to complete:
R&D: $533.6 million
Procurement: $16,971.8 million
Total funding: $17,508.7 million
Procurement quantity: 1

Program Performance (fiscal year 2014 dollars in millions)

	As of 04/2004	Latest 08/2013	Percent change
Research and development cost	$5,051.9	$4,867.4	-3.7
Procurement cost	$32,363.3	$31,081.1	-4.0
Total program cost	$37,415.2	$36,008.1	-3.8
Program unit cost	$12,471.733	$12,002.694	-3.8
Total quantities	3	3	0.0
Acquisition cycle time (months)	137	155	13.1

The Navy awarded a construction contract for CVN 78 in September 2008 when only 5 of the ship's 13 current critical technologies were mature and the ship's three-dimensional (3D) product model was incomplete. Since then, the lead ship's procurement costs have grown by over 22 percent, from $10.5 billion to $12.8 billion. At present, 7 of the currently planned technologies are mature, with the rest approaching maturity, and the ship's 3D product model is complete. However, maintaining design stability depends on currently immature technologies fitting within the space, weight, cooling, and power reservations allotted them within the ship. Construction to date has been impeded by critical technology system delays, material shortages, and engineering challenges.



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CVN 78 Program

Technology Maturity

According to the Navy, 7 of the 13 critical technologies for CVN 78 are mature, and the remaining 6 are approaching maturity. To meet required installation dates aboard CVN 78, the Navy produced several of these technologies, such as the volume search radar (VSR), prior to demonstrating their maturity—a strategy GAO's prior work has shown introduces risk of late and costly design changes and rework. The VSR is a component of the dual band radar (DBR), which has been delivered to CVN 78, and is undergoing design modifications needed to complete shipboard integration. According to the Navy, testing in the spring of 2015 will show whether these modifications were successful or a more extensive redesign of the system is required, which could delay DBR deliveries by up to 4 years. Deficiencies affecting water twister components—used to absorb energy when arresting aircraft—of the advanced arresting gear (AAG) technology continue to disrupt the system's development. Recent water twister redesign proved unsuccessful in testing last year. The Navy resolved problems with the redesign and is planning for concurrent testing. Despite these steps, the Navy forecasts AAG land-based testing to be complete in August 2016—a new delay of nearly two years—and after the Navy has accepted CVN 78 delivery. The electromagnetic aircraft launch system (EMALS) has successfully launched aircraft during land-based testing using a single launcher and four motor generators. The shipboard system will employ a more complex configuration with more launchers and generators sharing a power interface.

Design Maturity

CVN 78 completed its 3D product model in November 2009—over a year after the construction contract award. While the model is now considered functionally complete, maintaining design stability depends on technologies fitting within the space, weight, cooling, and power reservations allotted them. Shipboard testing may reveal a need for design changes. Also, as construction progresses, the shipbuilder is discovering "first-of-class" type design changes, which it is using to update the model prior to CVN 79 construction.

Production Maturity

According to program officials, CVN 78 is approximately 70 percent complete. Lead ship procurement costs for the lead ship have grown by over 22 percent since construction authorization in fiscal year 2008 due in part to problems encountered in construction. Out-of-sequence work driven largely by material shortfalls, engineering challenges, and delays developing and installing certain critical technologies the Navy provides to the shipbuilder for installation has affected construction progress.

Other Program Issues

The Navy deferred award of the CVN 79 detail design and construction contract from late fiscal year 2013 to the first quarter of fiscal year 2015. According to the Navy, continuing contract negotiations provide an opportunity to incorporate process improvements into construction plans. The Navy has undertaken an in-depth review of CVN 79 requirements and capabilities to identify cost trades, which it hopes can facilitate an agreement on contract terms. These actions are consistent with recommendations we made in September 2013 to defer the CVN 79 construction contract and to conduct a cost-benefit analysis on Ford-class capability requirements and the time and money needed to field systems to provide these capabilities.

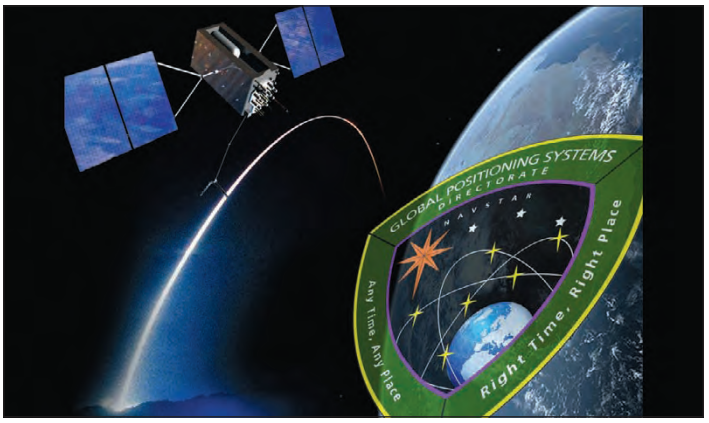
Program Office Comments

According to the program office, CVN 78 displaced 77,000 tons and was 70 percent complete at launch—the highest levels achieved in aircraft carrier new construction. The program office also reported that labor inefficiencies during ship erection are past and the principal risk remaining is in shipboard testing. Concerns over system integration within platform space, weight, and power reservations have been resolved. Land based testing for EMALS and DBR has progressed enough that program officials do not anticipate significant redesign. Further, the AAG test schedule remains on track to support ship delivery and sea trials. Lastly, the Navy plans to modify the CVN 79 construction preparation contract to extend the terms of the contract and avoid a production break during negotiations on the detail design and construction contract without delaying ship delivery. Program officials also provided technical comments that were incorporated where deemed appropriate.

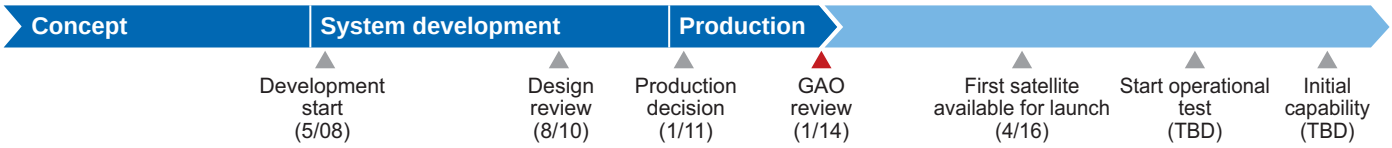
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Global Positioning System III (GPS III)

The Air Force's Global Positioning System III (GPS III) program plans to develop and field a new generation of satellites to supplement and eventually replace GPS satellites currently in use. Other programs are developing the ground system and user equipment. GPS III is to be developed incrementally. We assessed the first increment, which intends to provide capabilities such as a stronger military navigation signal to improve jamming resistance and a new civilian signal that will be interoperable with foreign satellite navigation systems.



Source: U.S. Air Force.



Program Essentials

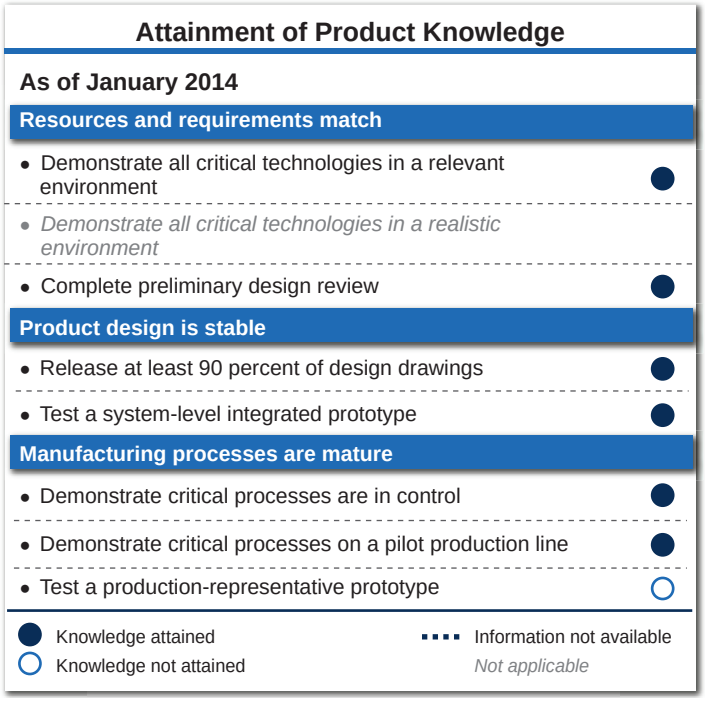
Prime contractor: Lockheed Martin
Program office: El Segundo, CA
Funding needed to complete:
R&D: $261.2 million
Procurement: $495.4 million
Total funding: $756.6 million
Procurement quantity: 2

Program Performance (fiscal year 2014 dollars in millions)

	As of 05/2008	Latest 11/2013	Percent change
Research and development cost	$2,654.8	$2,795.0	5.3
Procurement cost	$1,490.5	$1,581.5	6.1
Total program cost	$4,145.4	$4,376.5	5.6
Program unit cost	$518.169	$547.059	5.6
Total quantities	8	8	0.0
Acquisition cycle time (months)	NA	NA	NA

We could not calculate acquisition cycle times for the first increment of the GPS III program because initial operational capability will not occur until satellites from a future increment are fielded.

The GPS III program's eight critical technologies have been assessed as mature, but three have yet to complete qualification testing. The program reported that its design and production processes are currently mature and a prototype was constructed to reduce risk. However, design changes have been required due to issues identified in testing. Late hardware delivery resulted in delayed testing of the prototype. The GPS III program delayed the first space vehicle's availability for launch from April 2014 to April 2016—a 24 month delay—due to late hardware deliveries and technical problems identified in testing.



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GPS III Program

Technology and Design Maturity

The program office reports that all eight of its critical technologies are mature and that its design is stable. Three of the GPS III critical technologies, including the timekeeping system and the key GPS signal generator, have not yet completed qualification testing, which is behind schedule. Based on the number of design drawings released to manufacturing, the design has been mature since the program's 2010 design review. However, design changes have been required due to problems identified in testing of key components. The program office reported that it has demonstrated that the design can meet requirements by testing a system-level integrated prototype that includes all key subsystems and components just with less redundancy in the GPS III satellites.

Production Maturity

At the time of GPS III's production decision, the program office reported a level of manufacturing process maturity that indicated its processes were in control and production could begin. However, a complete GPS III satellite was not tested prior to the production decision nor has one been tested to date. To mitigate risk, the program developed a prototype to prove out production processes prior to integrating and testing the first space vehicle. Delivery of the prototype's navigation payload was delayed by a year, which the program office acknowledged resulted in some concurrency in developing and integrating the prototype and the first space vehicle. Program officials stated that the prototype helped the program identify problems and reduce assembly time required for the first space vehicle.

Other Program Issues

The program office recently moved its estimate for the first space vehicle's available for launch date from April 2014 to April 2016—a 24 month delay. This delay was in part driven by late hardware deliveries and multiple technical problems identified in testing, which have also negatively affected costs. The program office stated that the navigation payload for the first GPS satellite was delivered over a year late. The program is still working to address technical problems associated with the mission data unit, the brain of the GPS III navigation mission. Testing revealed radio frequency isolation issues, which can result in signal degradation.

This delay more closely aligns the space vehicle's delivery with the availability of GPS III's ground system, GPS Operational Control Segment (OCX). The synchronization of GPS III's and OCX's schedules continues to be a risk. GPS III satellites cannot be integrated into the constellation or be considered operational until OCX Block 1 is delivered, which is planned for October 2016.

The program is considering dual launching GPS III satellites, potentially beginning as early as the fifth GPS III space vehicle. Our prior work has shown that design changes during production can have significant cost and schedule consequences, including expensive retrofitting and production delays.

Program Office Comments

The Air Force also provided technical comments, which were incorporated where deemed appropriate.

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Ground/Air Task Oriented Radar (G/ATOR)

The Marine Corps' Ground/Air Task Oriented Radar (G/ATOR) is an active electronic scanned array three-dimensional short/medium range multi-role radar designed to detect cruise missiles, air breathing targets, rockets, mortars, and artillery. It replaces five different legacy radars. G/ATOR is a block acquisition; later blocks are mostly software upgrades. According to the program office, developmental testing concluded in August 2013, and a low-rate production decision took place in January 2014, followed by a March 2014 contract award.



Source: U.S. Marine Corps.



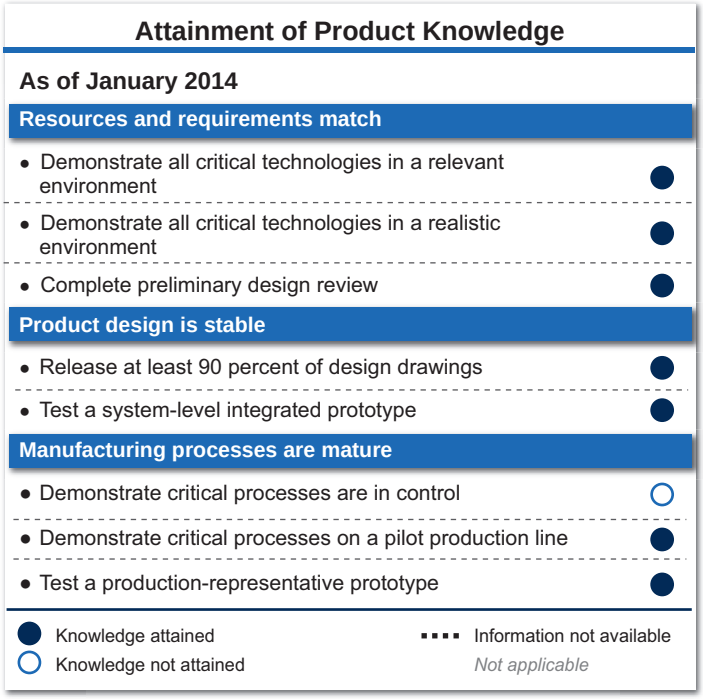
Program Essentials

Prime contractor: Northrop Grumman
Program office: Quantico, VA
Funding needed to complete:
- R&D: $285.9 million
- Procurement: $2,089.4 million
- Total funding: $2,381.5 million
- Procurement quantity: 55

Program Performance (fiscal year 2014 dollars in millions)

	As of 08/2005	Latest 09/2013	Percent change
Research and development cost	$372.4	$981.1	163.5
Procurement cost	$1,169.3	$1,668.7	42.7
Total program cost	$1,541.7	$2,656.1	72.3
Program unit cost	$24.089	$46.597	93.4
Total quantities	64	57	-10.9
Acquisition cycle time (months)	66	133	101.5

The G/ATOR technologies are mature and its design is stable and demonstrated but its production processes are not yet mature. In addition, the program's reliability is beneath the value needed to meet requirements due to software issues. To address this shortfall, the program plans to develop and incorporate software fixes into low-rate initial production. There may be insufficient time to test all fixes prior to the start of production. Production processes were demonstrated on a pilot production line, but they did not demonstrate stable, adequate control. The program office intends to award a contract for four low-rate production systems in March 2014. According to the program office, these systems are needed to conduct operational and environmental testing in order to meet the initial operational capability.



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G/ATOR Program

Technology Maturity

All six G/ATOR critical technologies are fully mature. However, according to the program office, testing revealed issues with the radar's software causing it to require a reboot more frequently than anticipated. The problems are driven by a number of lower-level software issues with system startup, random crashes, operator control console freezes, and an unstable command and control interface. The G/ATOR program office has put together a plan to incorporate software fixes to correct system start up and prevent crashes. Some hardware alterations may be required. The program office plans to increase and improve system performance by upgrading the software integration lab to support accelerated testing and conducting field testing with users every six months to demonstrate reliability growth and operational relevance. In addition, the gallium nitride technology, which will be used to upgrade the radar's transmit and receiving modules, is maturing on schedule. This new semi-conductor technology is expected to achieve better performance at a lower cost and will be installed on the last low-rate production lot.

Design Maturity

According to the program office, the G/ATOR design is mature, with 100 percent of design drawings released and testing of system-level prototypes completed in August 2013, well after the critical design review but before the program enters production. Risk of additional design changes exists, due to modifications planned for the production units. If these modifications are not incorporated into the design and tested before beginning production, there may be schedule delays if the program chooses to continue production and retrofit systems at a later date.

Production Maturity

According to the program office, the G/ATOR production readiness review was completed in September 2013 and the program demonstrated that its manufacturing processes meet DOD's requirement for the start of low-rate production. However, the manufacturing readiness level does not indicate that its production processes are stable and in control as preferred by commercial best practices. The program plans to begin low-rate production with four systems in March 2014. According to program officials, these systems are needed to conduct developmental, operational, and environmental qualification testing in order to meet the scheduled Block I initial operational capability.

Other Program Issues

The program is authorized to procure 57 G/ATOR systems; however, only 45 were funded in the fiscal year 2014 President's budget. According to the program office, the 12 unfunded G/ATOR systems will require funding by fiscal year 2016 in order to meet initial operational capability. In addition, the concurrent development and production of G/ATOR may be adversely affected by personnel shortages caused, in part, by the impending retirement of highly experienced acquisition workforce staff.

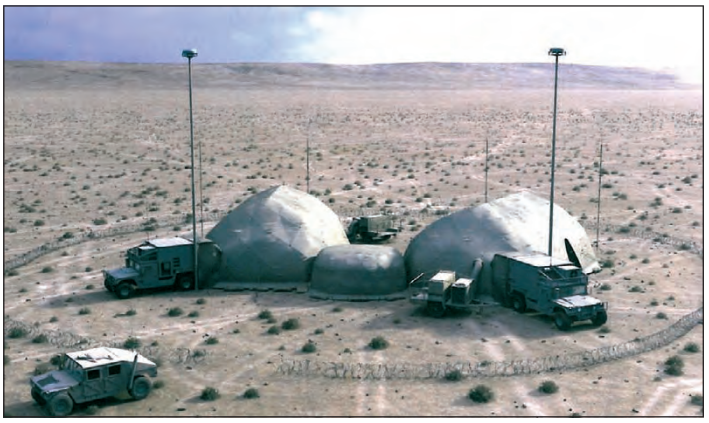
Program Office Comments

In commenting on a draft of this assesment, the program office noted that in October 2011, G/ATOR's performance requirements were revised, which resulted in a re-designation of the program to a major defense acquisition program. At that time, cost estimates were rebaselined; since then G/ATOR has remained on schedule and its total estimated cost decreased. This reduction is due, in part, from implementing better buying power and should cost initiatives. Technical comments were provided by the program office, which were incoporated where deemed approrpiate.

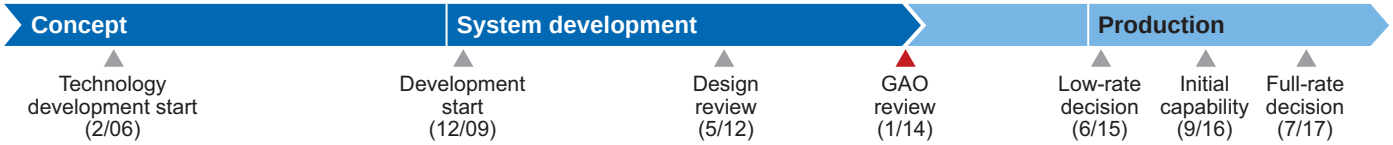
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Integrated Air and Missile Defense (IAMD)

The Army's Integrated Air and Missile Defense (IAMD) program is being developed to network sensors, weapons, and a common battle command system across an integrated fire control network to support the engagement of air and missile threats. The IAMD Battle Command System (IBCS) will provide a capability to control and manage IAMD sensors and weapons, such as the Sentinel radar and Patriot launcher and radar, through an interface module that supplies battle management data and enables networked operations.



Source: Northrop Grumman.



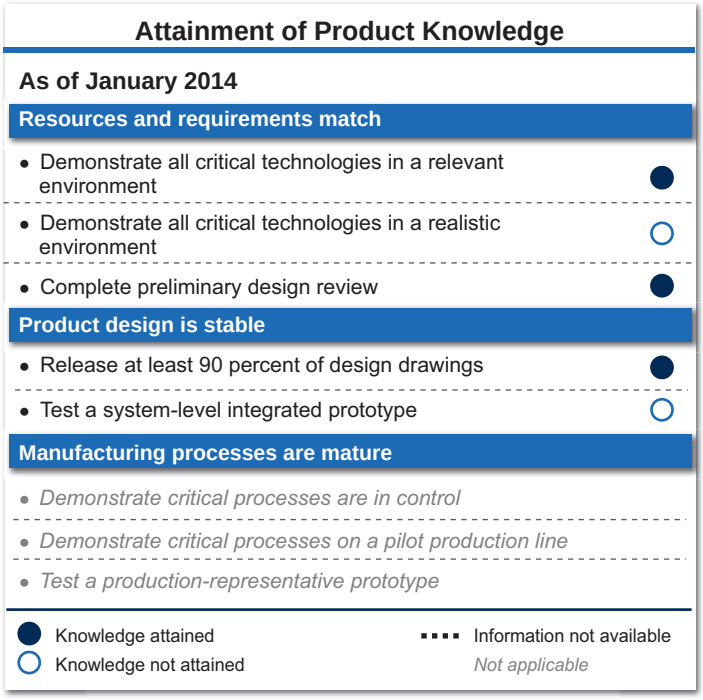
Program Essentials

Prime contractor: Northrop Grumman Space & Mission Systems Corp, Raytheon Integrated Defense Systems
Program office: Huntsville, AL
Funding needed to complete:
R&D: $1,188.0 million
Procurement: $3,399.0 million
Total funding: $4,587.0 million
Procurement quantity: 431

Program Performance (fiscal year 2014 dollars in millions)

	As of 12/2009	Latest 12/2012	Percent change
Research and development cost	$1,677.7	$2,405.0	43.4
Procurement cost	$3,611.0	$3,399.0	-5.9
Total program cost	$5,288.7	$5,804.0	9.7
Program unit cost	$17.867	$12.984	-27.3
Total quantities	296	447	51.0
Acquisition cycle time (months)	80	81	1.2

IAMD completed its critical design review in May 2012 with a stable design and technologies nearing full maturity, but does not plan to demonstrate the design can perform as expected until February 2014. IAMD's mission has not changed, but changes to its plans for integrating with other systems has significantly increased the size of its software effort, delayed its subsystem design reviews and increased development costs by over $717 million. These changes include adding Patriot launcher and radar functionality directly onto the integrated fire control network and increasing the number of units by 146 to 431 total units. WIN-T integration is also a significant risk.



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IAMD Program

Technology Maturity

Program officials estimate that IAMD technologies will not be fully mature until its planned production decision in 2015. The IAMD program entered system development in December 2009 with its four critical technologies—integrated battle command, integrated defense design, integrated fire control network, and distributed track management—nearing maturity, according to an Army technology readiness assessment based on a notional design. The Army updated the technology readiness assessment in March 2011 based on the winning contractor's design and reached the same conclusion about the technologies' maturity. The Office of the Assistant Secretary of Defense for Research and Engineering concurred with the assessment, but noted that integration with the Warfighter Information Network-Tactical (WIN-T) is a significant risk. It also noted that the assessment was based on modeling and simulations of WIN-T and assumptions about performance. As a result, it recommended realistic, full-scale testing with WIN-T prior to a production decision.

Design Maturity

While the IAMD program has released nearly all of its total expected drawings and held a system level design review in May 2012, software problems and the Army's decision to operationalize the 32nd Test Battalion could cause further schedule delays and add substantial costs. For example, as a result of software development problems associated with the integrated battle command system, the IAMD program realigned software deliveries with key test activities. The revised software plan was approved in April 2013, resulting in a program delay of four months. Failure to properly develop, test, and integrate software could result in delay of capabilities being fielded to the warfigther. Also, the operationalization of the Patriot Test Battalion removes over 50 percent of the resources for both the Patriot and IAMD test programs. The IAMD and Patriot programs are working with the Army's test group to consider several options to mitigate potential risks, including delaying all test activities until Patriot test activities are complete and conducting tests with fewer assets. Further, tests of a fully integrated system-level prototype are not expected to begin until February 2014, over 20 months after design review.

Other Program Issues

IAMD's development costs have risen by about 48 percent, or over $717 million, since beginning development and may increase further. The Army restructured the program in 2011 to incorporate the Patriot launchers and radars directly on the integrated fire control network and to increase the number of units procured from 285 to 431 to account for adjustments to the battalion force structure and accelerating the fielding of capabilities. However, overall procurement costs have decreased by $194 million. According to program officials, increasing the number of units will provide for a common command and control at all organizational levels. Program officials estimate the size of the software development effort at over 6.6 million lines of code—a 37 percent increase over the estimate at development start. In addition, about 63 percent of this code will be newly developed code or auto-generated code which requires less effort to develop than newly developed or modified code.

Program Office Comments

In commenting on a draft of this assessment, the program office noted that since the software replan in early 2013, deliveries of software have been on schedule allowing for successful demonstration of the IAMD hardware/software architecture in late 2013 to the user. This demonstration also served as risk mitigation for early integration leading up to the developmental test program and limited user test in fiscal year 2014 and fiscal year 2015. Active risk plans are in place to manage program risks and the program office continues to work with other programs which IAMD is dependent on to ensure technical and programmatic risks are managed properly across programs. The loss of the test battalion will potentially result in some changes to the IAMD test program, but those changes are actively being worked with all stakeholders. Currently, it does not appear this resource challenge will affect IAMD's schedule. All program changes depicted in this report are captured in appropriate acquisition decision memorandums and the program's acquisition program baseline. The program office also provided technical comments which were incorporated where deemed appropriate.

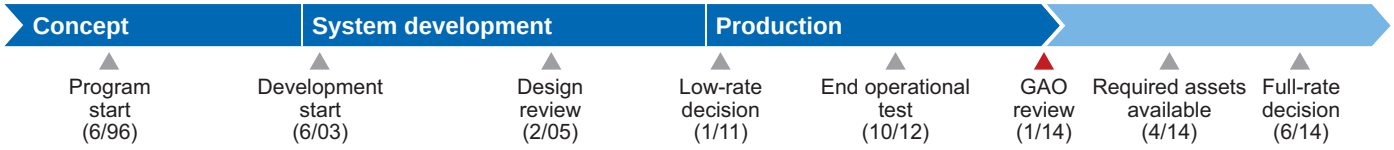
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Joint Air-to-Surface Standoff Missile Extended Range (JASSM-ER)

The Air Force's JASSM-ER program plans to field a next-generation cruise missile capable of destroying the enemy's war-sustaining capability from outside its air defenses. JASSM-ER missiles are low-observable, subsonic, and have a range of greater than 500 miles. They provide both fighter and bomber crews the ability to strike heavily defended targets early in a campaign. JASSM-ER is a follow-on program to the JASSM baseline program. The two missiles' hardware is 70 percent common and their software is 95 percent common.



Source: U.S. Air Force.



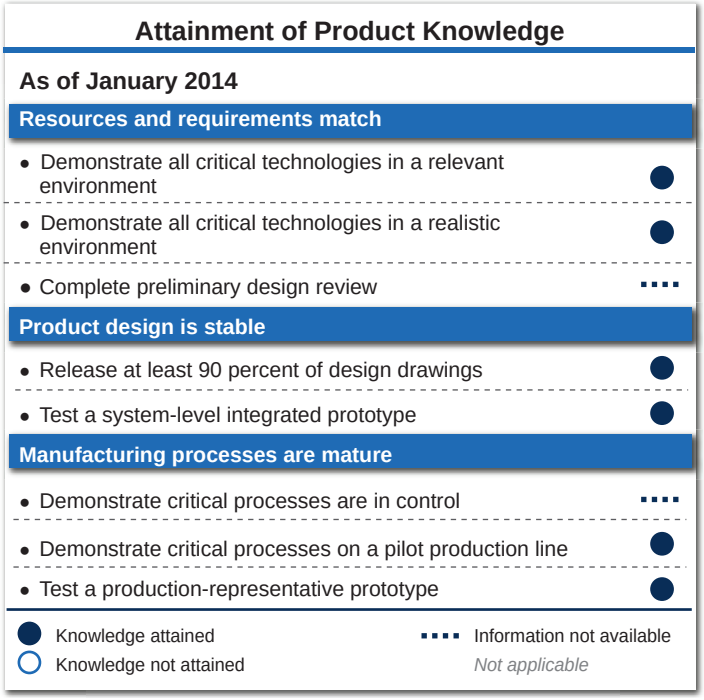
Program Essentials

Prime contractor: Lockheed Martin
Program office: Eglin AFB, FL
Funding needed to complete:
- R&D: $25.1 million
- Procurement: $3,468.3 million
- Total funding: $3,493.4 million
- Procurement quantity: 2,847

Program Performance (fiscal year 2014 dollars in millions)

	As of 04/2011	Latest 08/2013	Percent change
Research and development cost	$286.8	$253.6	-11.6
Procurement cost	$3,636.3	$3,670.3	0.9
Total program cost	$3,923.1	$3,923.9	0.0
Program unit cost	$1.550	$1.318	-15.0
Total quantities	2,531	2,978	17.7
Acquisition cycle time (months)	NA	130	NA

The JASSM-ER program has experienced production issues that have resulted in delays to the full-rate production decision and may delay the deliveries required to provide for initial availability. The program has yet to accept any ER missile deliveries due to these production issues. Although significant, production issues are primarily limited to the new ER missile engine, as the rest of baseline and ER missile production has generally proceeded on schedule. Sequestration cuts for fiscal year 2013 have resulted in the Air Force deferring some missile purchases beyond fiscal year 2017, expanded obsolescence risk, and caused an increase in unfunded requirements.



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JASSM-ER Program

Technology Maturity

According to the program office, JASSM-ER's five critical technologies—the engine lube system, engine system, fuze, low observable features, and global positioning system—are mature and have been tested in a realistic environment using a production-representative test missile.

Design Maturity

JASSM-ER's design is currently stable and has been successfully demonstrated in operational tests. According to the program office, the number of configuration changes has decreased over time with only one significant design change in the last three years.

Production Maturity

The full-rate production decision for JASSM-ER has been delayed due to production issues which may also delay initial availability for the assets required. The program has yet to accept any ER missile deliveries because of these production issues.

The most significant of these issues is with the engine lubrication pump. Program officials stated they found that for some of the engine pumps produced, the internal metal components within the pump were chafing, releasing metal into the lubrication that could reduce performance. The program plans to change the component design and implement changes during production ramp up while relying on the current design and production line screening to remove faulty pumps in low-rate production. Also, the program experienced a supplier issue with the fuel control unit—an engine component that controls the fuel throttle, affecting missile speed and acceleration. They discovered the component supplier had used diluted glue which was weaker than what had been used during component qualification testing. Program officials stated all 30 of the first ER missiles produced are potentially affected and they placed a hold on accepting ER missile deliveries until an agreement is reached with Lockheed Martin on how to address those missiles.

Aside from engine lube pump and fuel control unit issues, the program states production of the remaining 98 percent of ER subsystems and components have generally proceeded according to schedule. Production of the JASSM baseline variant has also largely been unaffected by ER production issues. Production of Lot 10 baseline missiles began in September 2013 with missile deliveries expected to begin in January 2014 while start of low-rate production of the second lot of ER missiles was delayed until January 2014.

Other Program Issues

According to the program office, sequestration cuts for fiscal year 2013 have resulted in the Air Force deferring some JASSM purchases to the out-years, increasing obsolescence risk, and increasing unfunded requirements. Prior to sequestration cuts, the program planned to reach its economic order quantity of 360 missiles per year in fiscal year 2016 but now plans to purchase missiles at the minimum sustainment rate for the foreseeable future. The program has some obsolescence issues that are not funded because of sequestration cuts, according to the program, which could lead to production gaps. Also, the program maintains sequestration cuts have resulted in unfunded requirements, such as warranties for upcoming missile purchases, production tooling for full rate production ramp up, and some evaluation testing.

Program Office Comments

In commenting on a draft of this assessment, the Air Force provided technical comments, which were incorporated where deemed appropriate.

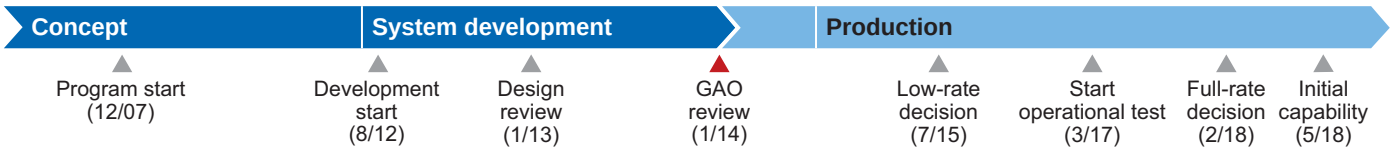
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Joint Light Tactical Vehicle (JLTV)

The Army and Marine Corps' JLTV is a family of vehicles being developed to replace the High Mobility Multipurpose Wheeled Vehicle (HMMWV) for some missions. The JLTV is expected to provide better protection for passengers against current and future battlefield threats, increased payload capacity, and improved automotive performance over the up-armored HMMWV; it must also be transportable. Two- and four- seat variants are planned with multiple mission configurations.



Sources: JPO JLTV EMD Industry Contractors (AM General, Oshkosh Corp. & Lockheed Martin)



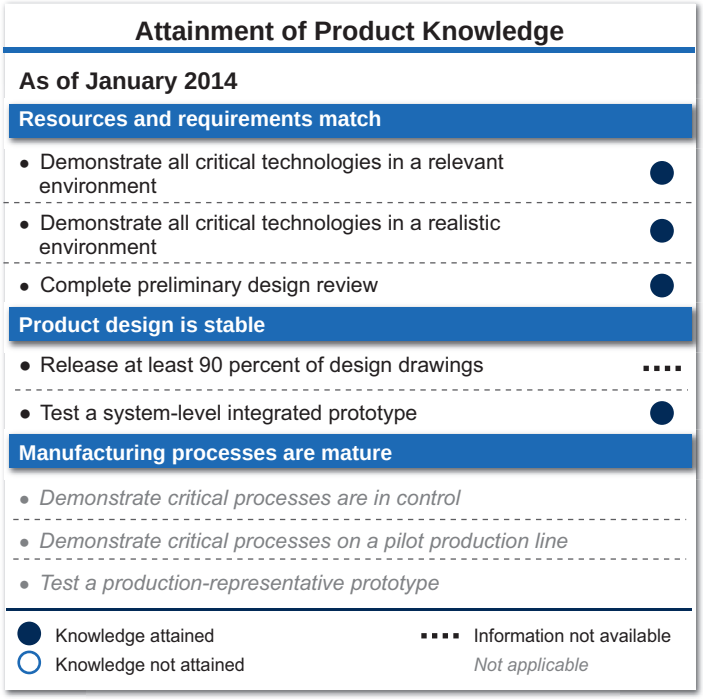
Program Essentials

Prime contractor: AM General, Lockheed Martin, Oshkosh
Program office: Harrison Township, MI
Funding needed to complete:
R&D: $377.3 million
Procurement: $22,651.7 million
Total funding: $23,046.9 million
Procurement quantity: 54,599

Program Performance (fiscal year 2014 dollars in millions)

	As of 10/2012	Latest 07/2013	Percent change
Research and development cost	$1,001.1	$981.0	-2.0
Procurement cost	$22,661.3	$22,651.7	0.0
Total program cost	$23,699.8	$23,650.5	-0.2
Program unit cost	$0.433	$0.432	-0.2
Total quantities	54,730	54,730	0.0
Acquisition cycle time (months)	125	125	0.0

JLTV's two critical technologies have been demonstrated in a realistic environment on prototype vehicles, according to program officials. In lieu of a critical design review, the program held a design understanding review in January 2013, and according to program documents, confirmed that all three contractors had more than 90 percent of design files under configuration control. A recent manufacturing readiness assessment concluded that all three vendors were on track to achieve production maturity by low-rate initial production. All variants are envisioned to meet transportability requirements, and testing is ongoing to confirm this with production representative versions



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JLTV Program

Technology Maturity

According to the program office, its critical technologies—underbelly protection armor and side-kit armor—are fully mature. According to program officials, ballistic testing conducted since November 2012—including armor samples, vehicle cabs, and chassis—confirmed this, and both technologies have been demonstrated in fielded systems. However, integrating the technologies to meet all system-level requirements for transportability, protection, and mobility could prove challenging,

Design Maturity

The program office did not hold a formal critical design review for JLTV, but conducted design understanding reviews with contractors between December 2012 and January 2013. According to program officials, these reviews were at a level of detail similar to a critical design review and were held to support the requirement for mature vehicle designs at the time of contract award for system development. At the time of these reviews, all long-lead and critical designs had been completed and all three contractors had more than 90 percent of the design files under configuration control. The Office of the Deputy Assistant Secretary of Defense (Systems Engineering) affirmed that the exit criteria for system development had been satisfied. According to program documentation, contractors will maintain responsibility for configuration control and will inform the government of changes. The government will assume control of the design after the planned award of one low-rate initial production contract in 2015.

Production Maturity

The Army does not intend to use process capability index data to assess production maturity, as recommended by our best practices. Instead, it intends to use other metrics, such as predicted assembly times and feasibility studies to assess production maturity by the production readiness review, scheduled for September 2014. The program recently conducted a manufacturing readiness assessment with all three vendors to evaluate manufacturing readiness, including a self-assessment of manufacturing readiness levels by the vendors. The program office believes all three vendors are on track to be production capable by low-rate initial production contract award in 2015. Production processes are not expected to be fully in control as program officials noted that tooling will not be fully documented until this point due to the large capital investment required.

Other Program Issues

On the basis of the knowledge gained from the technology development phase, the Army and Marine Corps concluded the JLTV could not meet requirements for both protection levels and transportability because of weight and relaxed the requirement to transport the vehicle by helicopter at high altitude and at certain temperatures. Program officials acknowledge some risk still exists in vehicles achieving relaxed weight requirements, but the prototype weigh-ins were on track, thus diminishing risk. Prototype vehicle testing will continue through October 2014, and the results will be used to determine whether the vehicles meet system requirements. Army officials recognize that the test schedule is compressed, and that slips in the limited user test could result in a slip of the program's production decision planned for July 2015. However, program officials believe that the results of testing will be available in sufficient time.

At the end of the system development phase, a low-rate initial production contract will be awarded to a single source. The program office will seek approval to limit competition to the three current vendors, but if not approved will revert to a full and open competition strategy. The program office does not believe there are any viable sources for JLTV production other than the three current vendors.

Finally, the Army plans to begin procuring JLTV while simultaneously procuring the Armored Multi-Purpose Vehicle. The simultaneous procurement of these programs is expected to continue for a decade or more.

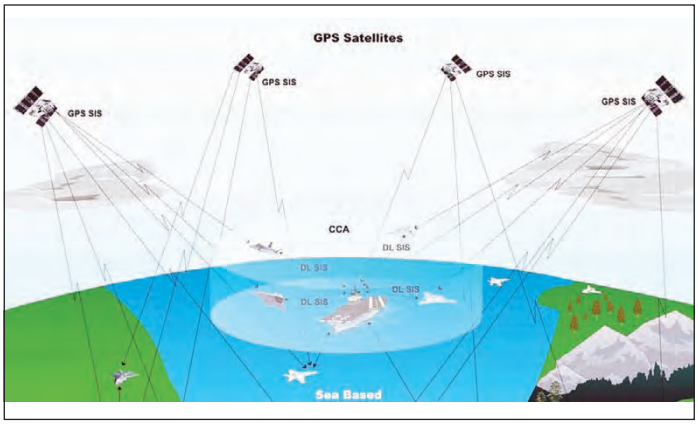
Program Office Comments

In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated where deemed appropriate.

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Joint Precision Approach and Landing System Increment 1A (JPALS Inc 1A)

JPALS Increment 1 is a Navy-led program to develop a GPS-based aircraft landing system to replace current radar-based systems on its ships. It is designed to provide reliable precision approach and landing capability in adverse environmental conditions and improved interoperability. Increment 1A is the ship-based system and increment 1B will integrate JPALS with sea-based aircraft. Both are needed to provide the full capability. We assessed increment 1A and made comments on increments 1B, 2, and other follow-on efforts.



Source: U.S. Navy.



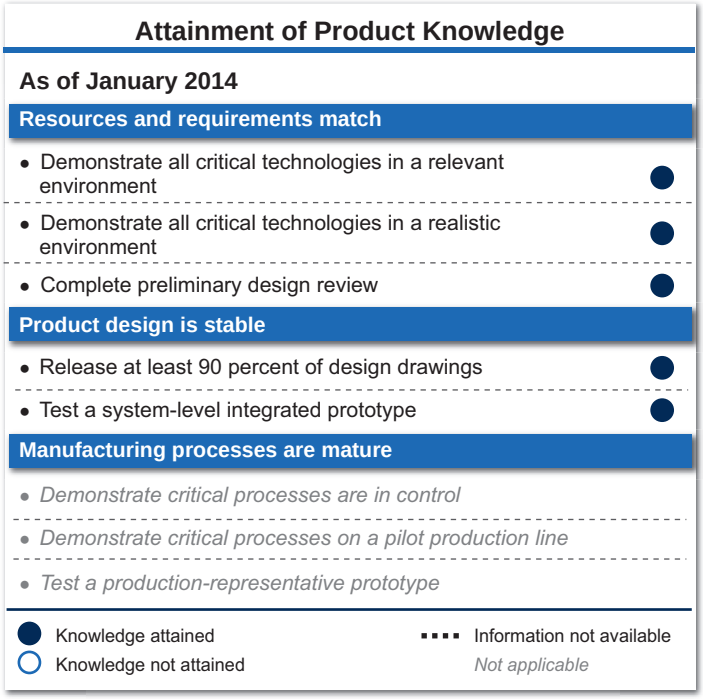
Program Essentials

Prime contractor: Raytheon
Program office: Lexington Park, MD
Funding needed to complete:
- R&D: $115.8 million
- Procurement: $257.7 million
- Total funding: $373.5 million
- Procurement quantity: 27

Program Performance (fiscal year 2014 dollars in millions)

	As of 07/2008	Latest 09/2013	Percent change
Research and development cost	$833.1	$859.3	3.1
Procurement cost	$224.3	$257.7	14.9
Total program cost	$1,064.7	$1,124.2	5.6
Program unit cost	$28.775	$30.385	5.6
Total quantities	37	37	0.0
Acquisition cycle time (months)	75	96	28.0

JPALS Increment 1A's two critical technologies are mature and have been demonstrated in a realistic environment. Program officials reported completing baseline software development as of April 2012. The program began system-level development testing in July 2012 and sea-based testing in December 2012. The program completed 108 integrated flight tests with no major anomalies reported. Increment 1A's production decision scheduled for November 2013 was cancelled due to budget reductions, with a new date to be determined. Ship availability delays for installation and procurement changes resulted in schedule and cost breaches, respectively, of thresholds in the program's baseline. Increment 1B is scheduled to start system development in 2015. Lead responsibility for Increment 2, land-based JPALS, transferred from the Air Force to the Navy beginning in fiscal year 2014.



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JPALS Inc 1A Program

Technology Maturity

JPALS Increment 1A's two critical technologies are mature and have been demonstrated in a realistic environment. Program officials reported demonstrating the technologies during sea-based flight testing in 2013. JPALS functionality is primarily software-based, and the program reported that its software development and integration effort was complete as of April 2012. The program will continue developmental testing, with operational testing planned to begin in 2016.

Design Maturity

The JPALS program held its critical design review in December 2010 and released all of its expected design drawings to manufacturing at that time. The JPALS design is currently stable, and the program began system-level development testing of a prototype in July 2012 to show that it will perform as expected. Sea-based testing began in December 2012 and program officials reported completing 108 integrated flight tests as of July 2013, with no major anomalies identified. Shore-based auto-landing demonstrations began in October 2013, and program officials reported completing 70 ship-based auto-landing demonstrations as of November 2013.

Production Maturity

According to JPALS program officials, the program has not identified any critical manufacturing processes and the system's hardware is comprised primarily of off-the-shelf components. The program has accepted delivery of all eight of its engineering development models, seven of which are production representative.

Other Program Issues

The program's production decision, scheduled for November 2013, was cancelled and a new date has yet to be determined. Program officials stated that budget reductions due to sequestration eliminated funding for the low-rate initial production contract. They noted that a new date will not be scheduled until the Navy resolves this funding issue. The program previously delayed the production decision from May 2013 to November 2013 because the aircraft carrier needed to conduct ship-based integrated testing was not available for installation. As a result, the program reported a schedule breach of the acquisition program baseline.The program also extended planned production to avoid acquiring systems earlier than needed and moved the purchase of one unit from development to procurement. These changes increased procurement costs and resulted in a cost breach of a threshold set in the acquisition baseline.

System development for JPALS Increment 1B—which will integrate JPALS with sea-based aircraft—is scheduled for 2015. Program officials stated that increment 1B will be developed to provide JPALS functionality in a packaged way that allows for integration with any aircraft rather than tailoring efforts to each individual platform. Increment 2 is the land-based version of JPALS and system development is scheduled for 2015. Beginning with fiscal year 2014, lead service responsibility for JPALS Increment 2 transferred from the Air Force to the Navy.

Program officials stated that the recently conducted successful auto-land demonstrations may allow for the incorporation of capabilities planned for future increments. Incorporating auto-land and unmanned aerial vehicle capabilities into increments 1A and 1B will provide enabling technology for the Navy's future ship classes and the Unmanned Carrier-Launched Surveillance and Strike program for which JPALS was selected as the primary landing system.

Program Office Comments

In commenting on a draft of this assessment, the JPALS program office noted that it concurred with our review and that flight testing was highly successful and the system performed as intended with no significant design or performance issues identified to date. The program is working aggressively with the Navy and the Office of Secretary of Defense to resolve the cost and schedule breaches, and anticipates corrective actions will be incorporated in the fiscal year 2015 President's budget submission. The progam office also provided technical comments, which were incorporated where deemed appropriate.

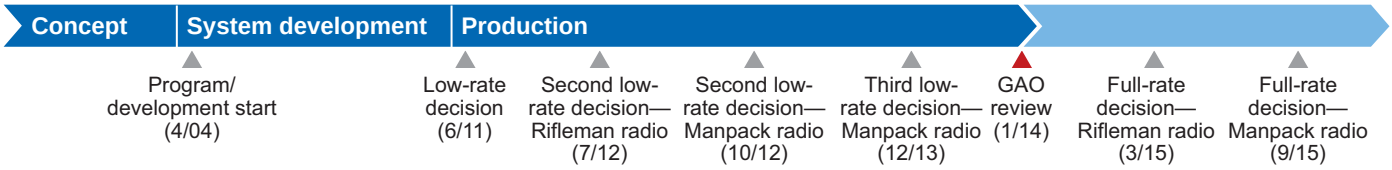
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Joint Tactical Radio System Handheld, Manpack, and Small Form Fit Radios (JTRS HMS)

DOD's JTRS program is developing software-defined radios that will interoperate with existing radios and increase communications and networking capabilities. The JTRS HMS program is currently developing two radios: the Rifleman radio for unclassified use and the Manpack radio for use in a classified domain. A subset of the Manpack radios will be interoperable with the Mobile User Objective System (MUOS), a satellite communication system.



Source: © 2012 General Dynamics C4S.



Program Essentials

Prime contractor: General Dynamics C4 Systems, Inc.
Program office: Aberdeen Proving Ground, MD
Funding needed to complete:
- R&D: $31.3 million
- Procurement: $6,706.3 million
- Total funding: $6,737.7 million
- Procurement quantity: 236,240

Program Performance (fiscal year 2014 dollars in millions)

	As of 05/2004	Latest 09/2013	Percent change
Research and development cost	$572.9	$1,255.8	119.2
Procurement cost	$9,984.0	$7,680.2	-23.1
Total program cost	$10,556.9	$8,935.9	-15.4
Program unit cost	$0.032	$0.033	2.6
Total quantities	328,674	271,202	-17.5
Acquisition cycle time (months)	85	112	31.8

The JTRS HMS program continues to conduct operational testing on both the Rifleman and Manpack variants and has demonstrated full maturity of all technologies, but has not demonstrated its production processes. Program officials have taken steps to address the Manpack reliability shortfalls identified during operational testing in May 2012 and plan to demonstrate the radio's capabilities during follow-on testing in May 2014. Full-rate production decisions for both variants have been delayed to fiscal year 2015 because of a change in the program's acquisition strategy to allow new vendors to compete for the contracts. In December 2013, the program received approval to increase the low-rate initial production quantity for the Manpack radio. The program is working with the Army to manage capability gaps resulting from both radios' full-rate production delays.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match
- Demonstrate all critical technologies in a relevant environment ●
- Demonstrate all critical technologies in a realistic environment ●
- Complete preliminary design review ●

Product design is stable
- Release at least 90 percent of design drawings ●
- Test a system-level integrated prototype ●

Manufacturing processes are mature
- Demonstrate critical processes are in control ○
- Demonstrate critical processes on a pilot production line ○
- Test a production-representative prototype ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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JTRS HMS Program

Technology Maturity

According to a program official, JTRS HMS has fully demonstrated the maturity of all its critical technologies for both the Rifleman and Manpack radios. The program has conducted operational testing on both variants for over four years, and plans to conduct additional testing in fiscal year 2014.

Design Maturity

According to program officials, the designs of both variants are stable, but reliability issues for the Manpack radio could require design modifications. Following operational testing in May 2012, DOD test officials reported that the Manpack was not operationally effective or suitable because it failed to demonstrate a reliability requirement. Program officials said they have taken steps to address the Manpack's reliability shortfalls and plan to demonstrate all remaining capabilities during follow-on testing in May 2014.

Production Maturity

According to JTRS HMS officials, the program's manufacturing readiness is at a level consistent with DOD guidance, but not yet at a level that demonstrates that its critical manufacturing processes are in control.

Other Program Issues

Both variants of JTRS HMS have experienced additional schedule slips since last year's assessment. The program revised its acquisition strategy following an Office of the Secretary of Defense directive that JTRS HMS conduct full and open competition for the full-rate contracts for both variants. As a result, the program office expects the full-rate production decisions for the Rifleman and Manpack radios to slip from the second half of fiscal year 2013 to March and September 2015, respectively. Prior to the full-rate production decisions, the program must solicit proposals from new vendors and, according to program officials, will likely award new contracts and test new radios. The Army would have to demonstrate that these new radios meet the Rifleman and Manpack requirements in an operationally-realistic environment. This delay puts the program nearly three years behind the originally scheduled full-rate production decisions for the Rifleman radio in May 2012 and the Manpack radio in December 2012. The program manager said he is working with Army operations and resource management staff to manage capability gaps resulting from both radios' full-rate production delays. They will establish deployment quantities and locations for the HMS radios procured through low-rate initial production to meet the Army's immediate needs. The program received approval for an additional lot of 1,500 Manpack radios in December 2013, but has not received authorization to increase the low-rate initial production quantity for the Rifleman radio over the current level set by the Office of the Secretary of Defense in July 2012.

Additionally, demonstrating the Manpack with the MUOS antenna and waveform remains a technical risk for the program. The JTRS HMS program is currently scheduled to field the MUOS-capable Manpack radios in 2014, but officials stated that they will wait to demonstrate the Manpack with the MUOS antenna and waveform until after the MUOS program successfully completes its own operational testing, which is scheduled for June 2014.

Program Office Comments

In commenting on a draft of this assessment, program officials noted that in 2012, HMS early operational tests were conducted on low-rate initial production variants of the HMS Manpack radio. Since this test, numerous corrected deficiencies have been implemented, including production improvements and extended environmental stress screening, significant improvement has been documented in follow-on performance verification testing and will be formally demonstrated at the Network Integration Evaluation 14.2 in May 2014. HMS Rifleman and Manpack radios have been successfully fielded and are in use by operational units in support of global operations. To meet operational needs, in December 2013, the Office of the Secretary of Defense approved an additional low-rate initial production allotment of HMS Manpack radios, while also indicating support for a multi-vendor, multi-award construct for HMS full rate production.

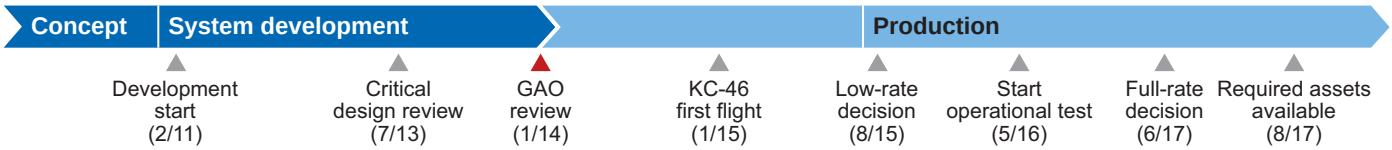
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KC-46 Tanker Modernization Program (KC-46)

The Air Force's KC-46 program plans to convert an aircraft designed for commercial use into an aerial refueling tanker in order to refuel Air Force, Navy, Marine Corps, and allied aircraft. The program is the first of three planned phases to replace the Air Force's aging fleet of KC-135 aerial refueling tankers. The KC-46 has been designed to improve on the KC-135's refueling capacity, efficiency, capabilities for cargo and aeromedical evacuation, and to integrate defensive systems.



Source: © 2011 Boeing. All rights reserved.



Program Essentials

Prime contractor: Boeing
Program office: Wright-Patterson AFB, OH
Funding needed to complete:
R&D: $3,355.6 million
Procurement: $33,848.5 million
Total funding: $40,829.3 million
Procurement quantity: 175

Program Performance (fiscal year 2014 dollars in millions)

	As of 02/2011	Latest 12/2012	Percent change
Research and development cost	$7,206.3	$7,045.5	-2.2
Procurement cost	$34,992.9	$33,848.5	-3.3
Total program cost	$46,090.0	$44,519.2	-3.4
Program unit cost	$257.486	$248.710	-3.4
Total quantities	179	179	0.0
Acquisition cycle time (months)	78	78	0.0

The program held its critical design review in July 2013 with its critical technologies nearing full maturity and its design stable but not demonstrated. To reduce risk and improve schedule, Boeing decided to develop situational awareness software internally prior to the critical design review. This resulted in replacing one of the program's critical technologies and re-using software code. Boeing is currently manufacturing the four development aircraft, but test boom production has been delayed by almost a year due to design changes and late parts. The program has demonstrated that it can produce the required military subsystems in a production representative environment, but these processes will not be in control by the low-rate production decision. The Air Force and Boeing are working through software and hardware integration and flight test risks.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ○

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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KC-46 Program

Technology Maturity

The KC-46 entered system development with its critical technologies—a three-dimensional display to monitor and enable aerial refueling activities and a software module designed to increase situational awareness—nearing full maturity, but not yet demonstrated in a realistic environment. In March 2013, almost four months before the program's critical design review, Boeing decided to develop the situational awareness software internally. Boeing's version of this development effort replaced the prior software modules with a new one. The new software module is nearing full maturity, but has not yet been demonstrated in a realistic environment. To reduce risk and improve schedule, Boeing re-used some of the situational awareness software code from prior programs. The program plans to fully mature its critical technologies prior to its low-rate production decision.

Design Maturity

The program held its critical design review in July 2013 with over 90 percent of its design drawings releasable, but before fully maturing its technologies and testing an aircraft that integrates the military sub-systems. The program will not begin testing an aircraft that integrates military sub-systems until January 2015, 18 months after its critical design review. Best practices call for completing a full system-level prototype demonstration by the critical design review in order to show that the design is capable of meeting performance requirements.

Production Maturity

Boeing has begun production of the four development aircraft, and is also manufacturing a test refueling boom and a boom for the first development aircraft. Test refueling boom production has been delayed by almost a year due to design changes and late parts deliveries. Boeing officials said the test refueling boom is a risk reduction effort and lessons learned will be applied to future boom builds. The program reported that it is primarily using manufacturing readiness levels to assess manufacturing risk. As of July 2013, the program demonstrated that it is capable of producing the applicable military subsystems, such as several aerial refueling and defensive subsystems, in a production representative environment. The low-rate initial production decision is currently scheduled for August 2015, but the program will not have its production processes for military subsystems in control at that time as recommended by best practices.

Other Program Issues

The Air Force has identified software and hardware integration and the aggressive nature of the KC-46 flight test schedule as top program risks. While most software and hardware integration has progressed according to plan, these efforts have largely addressed commercial rather than military unique components to date, and some aerial refueling and avionics software has not been delivered on time. The flight test pace is more aggressive than other military aircraft development programs, and Boeing's test approach requires a significant amount of coordination among key stakeholders. The program office and Boeing are working together to mitigate these risks by, for example, conducting dry runs prior to flight testing.

Program Office Comments

In commenting on a draft of this assessment, the program stated they mitigated risk by negotiating the competitive fixed-price incentive development contract with firm-fixed and not-to exceed pricing for production. The program noted that about 50 percent of the development work has been completed thus far and Boeing has met or exceeded all contractual requirements. The program is closely tracking software as a risk, however, it does not believe there are significant software-related issues at this time. The program further stated that it plans to mitigate the risk posed by concurrency by ensuring that adequate testing is completed prior to the production decision. In addition, Boeing's contract requires it to incorporate fixes into production aircraft at no additional cost. DOD and the Air Force also provided technical comments, which were incorporated as appropriate.

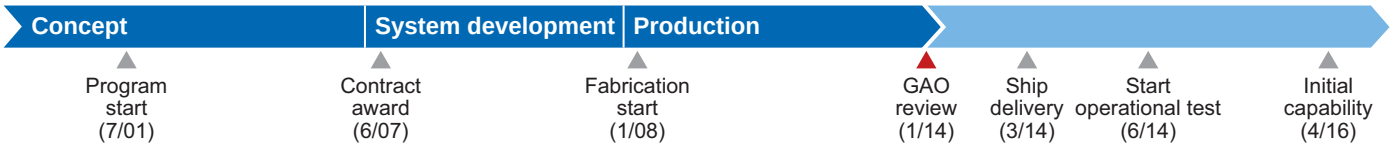
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LHA 6 *America* Class Amphibious Assault Ship (LHA 6)

The Navy's LHA 6 class will replace the LHA 1 *Tarawa* class amphibious assault ships. LHA 6 class is based on the fielded LHD 8 and consists of three ships. The ships will feature enhanced aviation capabilities and are designed to support Marine Corps assets in an expeditionary strike group. LHA 6 construction began in December 2008 and ship delivery is expected in March 2014. LHA 7 construction began in July 2013 and delivery is expected in December 2018. The Navy intends to award the construction contract for LHA 8 in fiscal year 2017.



Source: Huntington Ingalls Industries



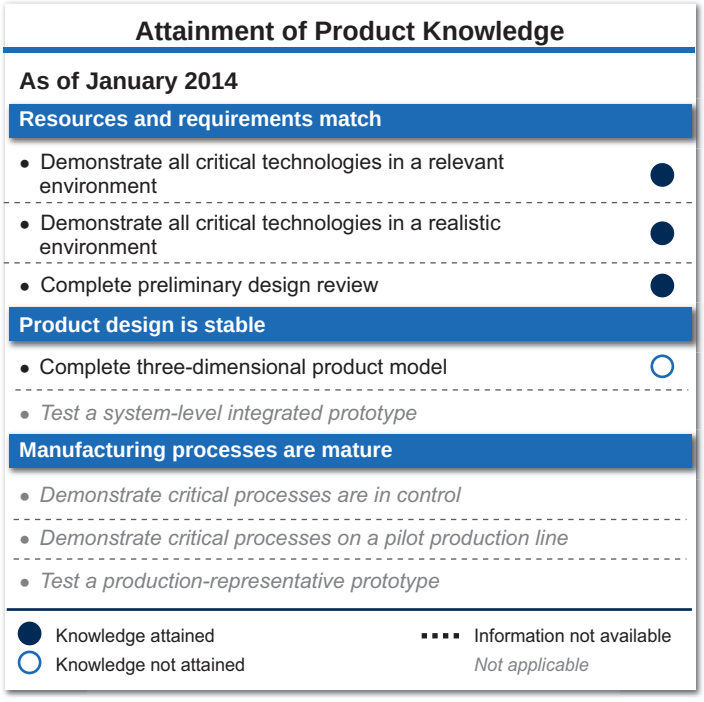
Program Essentials

Prime contractor: Huntington Ingalls Industries
Program office: Washington, DC
Funding needed to complete:
- R&D: $75.6 million
- Procurement: $3,570.5 million
- Total funding: $3,647.2 million
- Procurement quantity: 1

Program Performance (fiscal year 2014 dollars in millions)

	As of 01/2006	Latest 12/2012	Percent change
Research and development cost	$232.4	$397.1	70.9
Procurement cost	$3,112.3	$9,710.6	212.0
Total program cost	$3,344.6	$10,109.7	202.3
Program unit cost	$3,344.647	$3,369.910	0.8
Total quantities	1	3	200.0
Acquisition cycle time (months)	146	177	21.2

LHA 6 began construction in December 2008 with mature technologies and a design that was only 65 percent complete. After a 19 month delay, the Navy expects delivery will occur in March 2014. LHA 6 will also incur an estimated $42.4 million in cost growth due to postdelivery rework of the ship's deck to cope with Joint Strike Fighter exhaust and downwash. Construction of LHA 7 (which largely shares the LHA 6 design) began in July 2013 and the program office believes that the issues that led to cost increases and schedule delays on LHA 6 have been largely resolved and are unlikely to cause problems for LHA 7. Design changes to LHA 8 are more significant and include the addition of a well deck. The Navy plans to competitively award a construction contract for LHA 8 and has awarded contracts with two shipyards to assist with early design work.



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LHA 6 Program

Technology, Design, and Production Maturity

All LHA critical technologies were mature when the program awarded its construction contract in June 2007. Although not considered critical technologies, the program has identified an additional six key subsystems necessary to achieve capabilities. Five of these subsystems are mature. The sixth, the Joint Precision Approach and Landing System, is still in development, but LHA 6 can use backup aviation control systems to meet requirements. There are no new critical technologies expected for LHA 7 or LHA 8, but requirements for LHA 8 are still in development.

In January 2014, the Navy and the shipbuilder conducted acceptance trials on LHA 6 and Navy officials anticipate ship delivery will occur in March 2014, 19 months later than the contracted delivery date. At the time of acceptance trials, the LHA 6 design was at least 99 percent complete and construction was over 97 percent complete. LHA 6 began construction in December 2008 with only 65 percent of its design complete, and subsequent design quality issues have caused more design changes than anticipated and higher levels of rework. Following the delivery of LHA 6, the Navy will spend an estimated $42.4 million to reconfigure the ship's flight deck to cope with exhaust and downwash from the Joint Strike Fighter.

Construction of LHA 7 (which largely shares the same design as LHA 6) began in July 2013 and flight deck modifications due to JSF are still being incorporated into the design. Officials, however, do not believe that this will interfere with the ship's construction. Other design changes to LHA 7 include a new firefighting system and updates to the radar and the command, control, communications, computers, and intelligence systems. Design changes to LHA 8 will be more significant as the Navy will incorporate a well deck that can accommodate two landing craft. Program officials note that the new design also allows for better maintenance of aviation capabilities. The program may also incorporate a flexible infrastructure—which would allow compartments to be reconfigured to meet changing mission needs with less rework—into some low risk areas of the LHA 8 design should the Navy determine that it results in lifecycle cost savings.

Other Program Issues

Program officials believe that as a result of increasing the number of design drawing reviews and ensuring additional lead time for material orders on LHA 7, the program will not experience the high level of rework that led to cost growth and schedule delays during construction of LHA 6. In order to improve quality and shipyard performance on LHA 7, the Navy included contract incentives of up to $41 million; although officials note that it is too soon to determine whether the incentives are effective at keeping rework rates low.

The Navy intends to competitively award a construction contract for LHA 8, and in November 2012 awarded early industry involvement contracts to two shipbuilding contractors that it determined are capable of building the ship without major recapitalization. The contracts allow the shipbuilders to participate in early stage design work and investigate opportunities for potential cost reductions, and were recently modified to extend the period of performance past the past the original April 2014 contract expiration date.

Program Office Comments

In commenting on a draft of this assessment, the program program office stated that based on the success of LHA 6's acceptance trials, the Navy's independent assessor—the Board of Inspection and Survey—recommended that the Navy accept delivery of the ship. The extension of the periods of performance of the early industry involvement contracts for LHA 8 efforts will allow the joint industry/government team to continue working on identifying innovative ways to reduce the projected cost of the ship. The program office also provided technical comments, which were incorporated as appropriate.

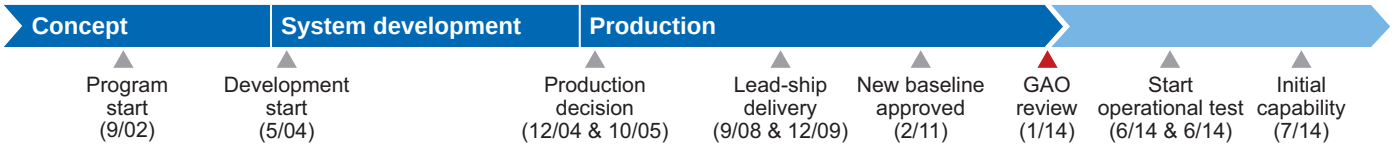
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Littoral Combat Ship (LCS)

The Navy's LCS is designed to perform mine countermeasures, antisubmarine warfare, and surface warfare missions. It consists of the ship itself, or seaframe, and the mission packages it deploys. The Navy bought the first four seaframes in two unique designs—one based on a steel semi-planing monohull (Freedom variant) and the other based on an aluminum trimaran hull (Independence variant)—and subsequently awarded a contract for a block buy of up to 10 ships to both contractors. We assessed both seaframe designs



Sources: Lockheed Martin (left); General Dynamics (right).



Program Essentials

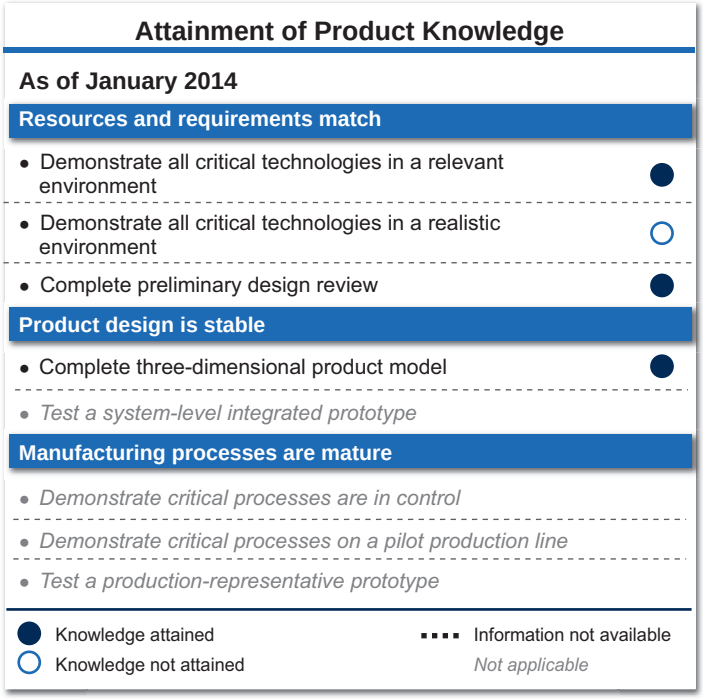
Prime contractor: Austal USA, Lockheed Martin
Program office: Washington Navy Yard, DC
Funding needed to complete:
R&D: $704.1 million
Procurement: $18,775.1 million
Total funding: $19,631.6 million
Procurement quantity: 36

Program Performance (fiscal year 2014 dollars in millions)

	As of 05/2004	Latest 12/2012	Percent change
Research and development cost	$932.9	$3,596.3	285.5
Procurement cost	$496.0	$26,214.6	5,185.2
Total program cost	$1,428.9	$30,027.0	2,001.4
Program unit cost	$357.225	$577.442	61.6
Total quantities	4	52	1,200.0
Acquisition cycle time (months)	41	122	197.6

Cost data are for the seaframe only. Research and development funding includes detail design and construction of two ships. DOD recently announced plans to reduce total seaframe quantities to 32.

The LCS seaframe program has demonstrated the maturity of 16 of its 18 critical technologies and continues to make design and production process changes. Additional design changes have been endorsed by the LCS Council for fiscal year 2015: bridge wings and a seven-meter rigid hull inflatable boat for the Independence variant and stronger stern ramp for the Freedom variant. The Navy accepted delivery of LCS 4 in September 2013, a delay of 6 months, and is in steady production with 12 hulls under contract and/or construction. The next block-buy is scheduled for fiscal year 2016, when 24 seaframes will already be delivered, constructed, or under contract.



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LCS Program

Technology Maturity

Sixteen of the 18 critical technologies for both LCS designs are mature and have been demonstrated in a realistic environment. The two remaining technologies—LCS 1's overhead launch and retrieval system and LCS 2's aluminum structure are nearing maturity—according to our best practice standards. Though program officials believe that LCS 2's aluminum structure hull is mature as the ship is operational, there are still unknowns related to the hull structure. As a result, full maturity will not be demonstrated until the completion of shock and survivability trials to validate survivability and the ship's ability to achieve a 20-year service life. These tests are not expected to begin until August 2015.

Design and Production Maturity

The Navy started construction of LCS 1 and 2 without a stable design and has had to incorporate design changes on follow-on seaframes. LCS 1 and LCS 2 are still undergoing testing, and the Navy is incorporating design fixes for identified deficiencies into the designs of follow-on ships. In addition, a series of additional design changes for both variants have been approved by the LCS Council for fiscal year 2015; including bridge wings and a seven-meter rigid hull inflatable boat for the Independence variant and stronger stern ramp for the Freedom variant. LCS 4 experienced delays and was delivered six months after its expected contract delivery date of March 2013. LCS 5 through LCS 12 are currently in various stages of construction. The Navy is concerned about both contractors' ability to meet construction schedules without impacting follow-on hulls.

LCS 1 completed a ten-month deployment to the western pacific in December 2013 where it operated out of Singapore. During this deployment it encountered two significant engineering issues that significantly curtailed its ability to get underway: the lubrication cooling system ruptured and the ship service diesel engine generator had reliability issues. In addition to these engineering issues, LCS 1 had a number of combat system and other material failures; including radar underperformance and the combat system unexpectedly rebooting during operations.

Other Program Issues

The Navy added 20 permanent berths to LCS 1 to support additional manning for its deployment to Singapore in 2013. In May 2013, the Navy determined that additional permanent accommodations for a total crew size of 98 should be incorporated in all LCS class ships. The LCS program executive office has been directed to add these permanent accommodations through either forward -or back-fitting the ships. Although the habitability modification installed on LCS 1 in support of its deployment did not include the addition of increased storage and water supplies, the forward fit installs will address the required services and auxiliary system modifications associated with the installation of the additional berthing. Following LCS 1's 2013 deployment, the Navy will evaluate lessons learned and future manning options. The Navy expects to complete this evaluation in fiscal year 2014 and incorporate any proposed manning changes beginning in fiscal year 2015 ahead of the next block buy decision in 2016, when 24 seaframes will already be delivered, constructed, or under contract.

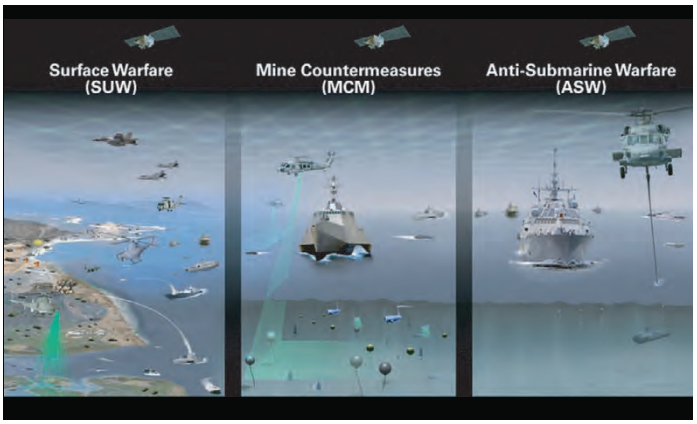
Program Office Comments

In commenting on a draft of this assessment, the program office noted that LCS 4 showed significant improvement from LCS 2 in level of completeness and number of high priority trial cards deficiencies at delivery. Twelve block buy ships are funded on the block buy contract and are in pre-production or construction, following thorough production readiness reviews. LCS 5 and 6 launched in December 2013. LCS 1 deployment successfully validated major portions of the LCS concept of operations for crew rotation and contracted overseas maintenance. Ship service diesel generator and seawater cooler reliability issues were satisfactorily addressed during deployment. Engineering changes have been incorporated to prevent and mitigate those issues in the future. Material failures of the radar were a result of a procedural error causing the system to reboot, however the radar performed to design specifications. The program office also provided technical comments, which were incorporated where deemed appropriate.

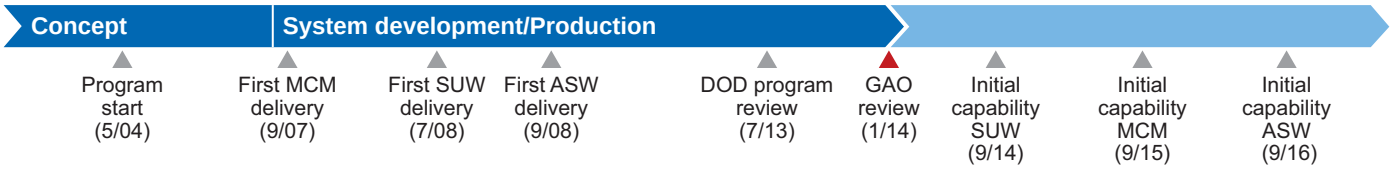
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Littoral Combat Ship - Mission Packages (LCS MP)

The Navy's Littoral Combat Ship (LCS) will provide mine countermeasures (MCM), surface warfare (SUW), and antisubmarine warfare (ASW) capability using mission packages. Packages include weapons and sensors launched and recovered from LCS seaframes and operated from MH-60 helicopters and unmanned vehicles. The Navy plans to deliver capability to the fleet in increments. We are assessing the Navy's progress in achieving full baseline performance capability, including all planned increments needed to achieve this capability for each package.



Source: © Northrop Grumman Corporation.



Program Essentials

Prime contractor: Northrop Grumman Corporation M&TS
Program office: Washington Navy Yard Washington, DC
Funding needed to complete:
R&D: $1,647.1 million
Procurement: $3,656.4 million
Total funding: $5,334.9 million
Procurement quantity: 51

Program Performance (fiscal year 2014 dollars in millions)

	As of 08/2007	Latest 01/2014	Percent change
Research and development cost	$517.2	$3,103.4	NA
Procurement cost	$3,427.8	$4,108.7	19.9
Total program cost	$3,954.7	$7,243.5	NA
Program unit cost	$61.792	$113.180	NA
Total quantities	64	64	0.0
Acquisition cycle time (months)	NA	NA	NA

The 2007 RDT&E cost estimate does not reflect full program costs and cost growth is not applicable. Current estimate does not include $3.6 billion of procurement money for replacement and other items.

In November 2013, DOD approved the baseline for the LCS Mission Packages program and previously, in October 2012, transferred decision authority to the Navy which approved the programs milestone B decision. The Navy held the milestone B event, which normally indicates development start, in January 2014 but has been developing the packages since 2004 and has delivered eight partial packages. As a part of this event, the Navy produced the first full lifecycle cost estimate. The program's acquisition cost is now $7.24 billion, an increase of $3.29 billion based upon its 2007 estimate, which did not include full development costs. The Navy plans to deliver mission package capabilities in increments, the MCM and SUW mission packages are not currently expected to field their baseline performance capability until the Navy has purchased 32 and takes delivery of 24 seaframes.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ○
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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LCS Packages Program

Mine Countermeasures (MCM)

The Navy has accepted four packages without demonstrating that they meet requirements and plans to accept two more in fiscal 2014. The package will be fielded in four increments: the first intends to remove sailors from the minefield and improve mine detection, classification, and destruction over legacy vessels. Although DOD states that all systems in increment one are fully mature, developmental testing has shown performance problems that led to changes in planned tactics, removal of systems, and lowered testing requirements. For example, corrections to the mine-hunting sonar's reliability have yet to be validated in operational testing, and two systems, intended to sweep for and neutralize mines, had to be removed for safety and performance issues. Also, the Navy now requires multiple searches to identify mines, adding time to the process, and has lowered increment one testing requirements for mine clearance rates. If operational testing proves successful, this package will not be able to replace all legacy capability until increment three completion in fiscal 2017.

Surface Warfare (SUW)

The Navy has taken delivery of four packages, each comprised of two 30 millimeter guns, as well as a rigid hull inflatable boat prototype, boarding gear, and armed helicopters. Following the cancellation of the non-line-of-sight launch system, the Navy planned to field the Griffin missile in 2015 as an initial capability. However, program officials stated that the Navy is rethinking this and a solution is not yet known.

Antisubmarine Warfare (ASW)

The Navy restarted development of an ASW package with new requirements as the initial package was not going to deliver enough capability over legacy assets. The Navy is assessing a replacement, with initial delivery planned in 2016, that is expected to include, among other technologies, a variable-depth sonar—which, according to officials, performed well in initial tests—and a towed array. The maturity of these technologies has not yet been independently assessed.

Other Program Issues

The Navy held a preliminary design review in 2004, but the packages have substantively changed. The program held a milestone B event in January 2014 with an estimated acquisition cost of $7.24 billion. Tests for increment one and two of the SUW and increment one of the MCM package are scheduled for fiscal 2014 and 2015 respectively. These assessments evaluate progress in achieving baseline performance capability, which includes all planned increments for each package. The Navy plans to purchase 32 LCS seaframes and take delivery of at least 24 by the time the baseline performance capabilities of the MCM and SUW packages are proven and fielded.

Program Office Comments

The Navy states that our assessment of program cost growth incorrectly compares the acquisition program baseline against a fiscal 2008 baseline, which does not reflect the total acquisition. Further, the Navy states that this assessment disregards near term operational requirements as the data presented indicates that the program should be delayed. The Navy also states that our assertion of excessive program risk, due to concurrency, is unfounded because developmental testing, combined with capability proven during early deployments, has significantly reduced technical risk. This is evidence, according to the Navy, that the LCS will successfully complete operational testing. Lastly, the current missile procurement was delayed due to sequestration; the Navy states that the program is on track to deliver a capability in late 2016.

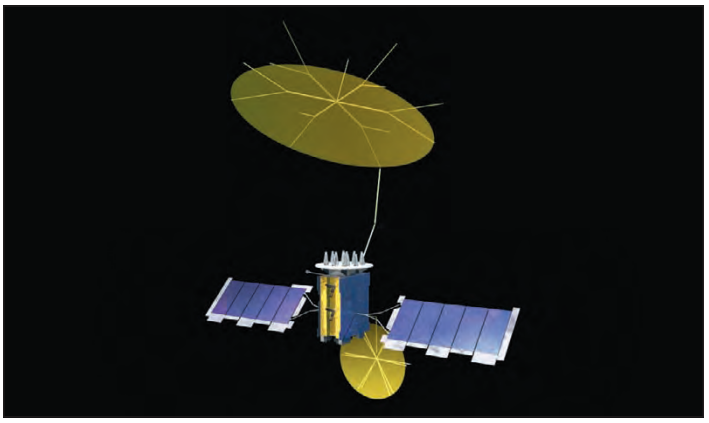
GAO Response

In comparing the 2007 estimate with the acquisition program baseline, we used the Navy's 2007 data, which included full procurement costs but only five years of development cost. The Navy has acquired eight packages without proving capability through operational testing. In the absence of a defined increment-based approach for the full baseline capability to sequentially gain knowledge and meet these requirements, the Navy's acquisition approach is not in accordance with best practices or DOD guidance in place at the time of our review.

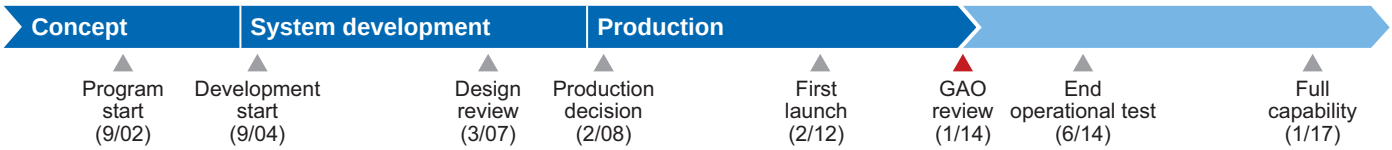
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Mobile User Objective System (MUOS)

The Navy's MUOS, a satellite communication system, is expected to provide a worldwide, multiservice population of mobile and fixed-site terminal users with increased narrowband communications capacity and improved availability for small terminal users. MUOS will replace the Ultra High Frequency (UHF) Follow-On (UFO) satellite system currently in operation and provide interoperability with legacy terminals. MUOS consists of a network of satellites and an integrated ground network. We assessed both the space and ground segments.



Source: © 2007 Lockheed Martin.



Program Essentials

Prime contractor: Lockheed Martin Space Systems
Program office: San Diego, CA
Funding needed to complete:
- R&D: $176.9 million
- Procurement: $975.1 million
- Total funding: $1,152.0 million
- Procurement quantity: 1

Program Performance (fiscal year 2014 dollars in millions)

	As of 12/2004	Latest 09/2013	Percent change
Research and development cost	$3,836.4	$4,511.6	17.6
Procurement cost	$3,192.1	$2,867.4	-10.2
Total program cost	$7,069.1	$7,448.1	5.4
Program unit cost	$1,178.186	$1,241.345	5.4
Total quantities	6	6	0.0
Acquisition cycle time (months)	90	NA	NA

Latest acquisition cycle time could not be calculated because the most recent MUOS program baseline does not estimate dates for operational capability.

The MUOS program's critical technologies are mature, its design is stable, and according to the program office, its manufacturing process maturity has increased. The first satellite was launched in February 2012—26 months later than planned at development start—and the second satellite was launched in July 2013. Subsequent launches of MUOS satellites remain important due to the past operational failures of two UFO satellites and predicted end-of-life of on-orbit UFO satellites, one of which was taken off-line in November 2012. A remaining challenge is that users will not be able to utilize advanced MUOS capabilities in large part because of delays in the development, testing, and fielding of new user terminals. Current MUOS user terminal procurement and fielding are managed by the Army's Tactical Radios Project Office.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match
- Demonstrate all critical technologies in a relevant environment ●
- Demonstrate all critical technologies in a realistic environment ●
- Complete preliminary design review ●

Product design is stable
- Release at least 90 percent of design drawings ●
- *Test a system-level integrated prototype*

Manufacturing processes are mature
- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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MUOS Program

Technology, Design, and Production Maturity

The MUOS program's technologies are mature, its design is stable, and its manufacturing process maturity has increased. The first two satellites have been launched and three other satellites are being built. We could not assess whether critical manufacturing processes were in control as the program does not collect statistical process control data. The program has experienced quality problems in the past that resulted in cost increases and schedule delays; however, the number of manufacturing defects on the space segment has decreased over time. According to the program, multiple corrective action boards collect and track all defects in manufacturing processes and the program uses this data to assess the maturity of production. Examples of specific metrics used include number of defects per 1,000 hours of touch labor, amount of deferred work and associated risk, and rate of resolving nonconformance issues. According to the program office, these metrics indicate continuing increases in MUOS production maturity and show program goals are being met.

Other Program Issues

The first MUOS satellite was launched in February 2012, 26 months later than initially planned, and the second satellite was launched in July 2013. According to the program office, the remaining MUOS satellites are needed because most on-orbit UFO satellites are past their design lives. Two of these unexpectedly failed—one in June 2005 and another in September 2006—and a third was taken off-line in November 2012. Program officials stated that the required availability level of legacy UHF communication capabilities has been provided and based on the projected launch schedule for the remaining MUOS satellites, the required availability of legacy UHF communication capabilities is predicted to be maintained through May 2020.

Since 2007, we have reported that synchronizing deliveries of MUOS satellites with compatible Joint Tactical Radio System (JTRS) Handheld, Manpack, and Small Form Fit (HMS) terminals has been a challenge. Launching MUOS satellites is important to sustain legacy UHF communications capability. However, utilization of over 90 percent of MUOS's planned capability is dependent on the development of the MUOS waveform—which completed formal qualification testing in November 2012—and porting the MUOS capability onto operational user terminals. The Army's HMS program is developing the first operational terminal to incorporate the MUOS waveform. Additionally, according to the MUOS program, other vendors wanting to integrate the MUOS waveform into their radios are being supported with MUOS waveform software and government-operated MUOS test resources.

To date, the HMS program has conducted multiple developmental tests on the Manpack radio and an operational test was conducted in 2012. This testing, conducted without the MUOS waveform, found that the terminals did not meet all performance and reliability requirements. However, according to the MUOS program, the radio demonstrated improved performance at subsequent test events and was selected for fielding to Army units without the MUOS waveform due to the capability increases it would provide. Limited testing has been conducted on terminals with the MUOS waveform to date. Operational testing and initial fielding of the HMS terminals with the MUOS waveform is planned to begin in 2014.

Program Office Comments

In commenting on a draft of this assessment, the program officials provided technical comments, which were incorporated as appropriate.

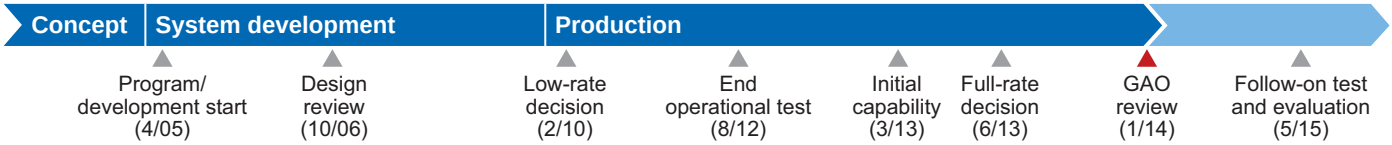
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MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle)

The Army's MQ-1C Gray Eagle unmanned aircraft system (UAS) will perform reconnaissance, surveillance, target acquisition, and attack missions either alone or with other platforms such as the Longbow Apache helicopter. Each platoon-sized system includes four aircraft, payloads, data terminals, automatic take off and landing systems, ground control stations, and support equipment. The Army procured less-capable quick reaction capability variants to address urgent needs, but these systems are not included as part of the Gray Eagle program.



Source: General Atomics Aeronautical Systems, Inc.



Program Essentials

Prime contractor: General Atomics Aeronautical Systems, Inc.
Program office: Redstone Arsenal, AL
Funding needed to complete:
R&D: $76.8 million
Procurement: $849.5 million
Total funding: $1,115.4 million
Procurement quantity: 6

Program Performance (fiscal year 2014 dollars in millions)

	As of 04/2005	Latest 08/2013	Percent change
Research and development cost	$362.7	$1,006.5	177.5
Procurement cost	$705.1	$3,227.8	357.8
Total program cost	$1,067.8	$4,859.2	355.1
Program unit cost	$213.552	$156.750	-26.6
Total quantities	5	31	520.0
Acquisition cycle time (months)	50	95	90.0

Total quantities include 31 platoon systems consisting of four aircraft and related equipment. The program will also buy 21 aircraft to replace attrition losses and 7 training aircraft, for a total of 152.

The Gray Eagle program received approval to begin full-rate production in June 2013 with its technologies, design, and manufacturing processes mature. However, design changes and supplier base issues put the program's cost and schedule at risk. Program officials said they are considering a change to the aircraft tail, which would be costly and require retrofitting the entire fleet. The program is also developing a new ground control station which will not undergo operational testing until May 2015. In addition, a production readiness review conducted in support of the program's full-rate production decision identified several high risk supplier base issues that pose uncertainty for the program's cost and schedule. The program is tracking these risks and program officials said its suppliers have mitigation strategies in place.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment ●
- Demonstrate all critical technologies in a realistic environment ●
- Complete preliminary design review ●

Product design is stable

- Release at least 90 percent of design drawings ●
- Test a system-level integrated prototype ●

Manufacturing processes are mature

- Demonstrate critical processes are in control ●
- *Demonstrate critical processes on a pilot production line*
- Test a production-representative prototype ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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MQ-1C Gray Eagle Program

Technology and Design Maturity

The Gray Eagle program reported that all five of its critical technologies are mature and have been demonstrated in a combat environment. Program officials stated that the design is generally stable; however, there is the potential for design changes if the program decides to integrate a new aircraft tail that the program's contractor is developing in response to an aircraft accident in 2009. Program officials said that integrating the new tail design would be costly as it would require retrofitting the entire Gray Eagle fleet, although it would provide increased reliability and endurance. A decision is expected in fiscal year 2014 on whether to move forward with the retrofit based on affordability considerations.

Production Maturity

The Gray Eagle's 2013 production readiness assessment reported that its manufacturing processes are mature and at the level recommended by DOD guidance for the start of full-rate production. The program was approved to begin full-rate production of 49 aircraft and support equipment in June 2013 and awarded the first of three planned full-rate production contracts in September 2013. However, the program is tracking several risks related to its supplier base. For example, the Gray Eagle prime contractor is currently flight testing a new aircraft engine to replace the legacy engine because the legacy engine supplier went into bankruptcy. Program officials noted they have enough engines on hand for the first full-rate production lot, identifying a new engine source poses technical, cost, and schedule risks to the program, according to the production readiness review. The program and the Defense Contract Management Agency are also tracking other risk items related to multiple suppliers' financial concerns as well as quality control, but program officials said its suppliers have mitigation strategies to address these risks.

Other Program Issues

The Gray Eagle system completed initial operational test and evaluation in August 2012. DOD's Director, Operational Test and Evaluation (DOT&E), found the system to be operationally effective with the potential to provide effective support to combat units and suitable at meeting its performance and combat availability requirements. However, several recommended improvements were identified related to tactics, techniques, and procedures; training; and the design of the ground control station shelter. Specifically, DOT&E found that the Army needs to improve integration of Gray Eagle into employment concepts and improve soldier training. In addition, the design of the current ground control station degrades aircraft operator efficiency. According to the program office, the Army has already begun to address these issues and plans to re-evaluate them at the planned follow-on test and evaluation in May 2015. The follow-on test will also be used to assess new hardware and software the program is developing to replace the current ground control station as well as assess its net readiness capabilities. Once testing is complete, program officials said the Army will deploy the new ground control station to fielded units and will train Gray Eagle operators on the new system.

Program Office Comments

In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated as appropriate.

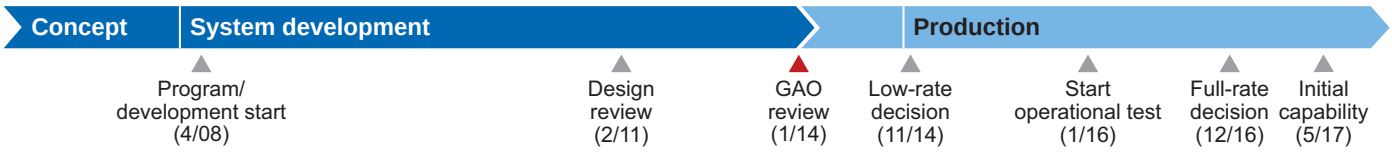
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MQ-4C Triton Unmanned Aircraft System (MQ-4C Triton)

The Navy's MQ-4C Triton is intended to provide a persistent maritime intelligence, surveillance, and reconnaissance (ISR) capability even when no other naval forces are present. Triton will operate from five land-based sites worldwide as a part of a family of maritime patrol and reconnaissance systems that recapitalizes the Navy's airborne ISR assets. Planned improvements include a signals intelligence capability and an upgrade to the systems communication relay. The Triton is based on the Air Force's RQ-4B Global Hawk air vehicle.



Source: Northrop Grumman.



Program Essentials

Prime contractor: Northrop Grumman Systems Corporation
Program office: Patuxent River, MD
Funding needed to complete:
- R&D: $770.8 million
- Procurement: $9,542.6 million
- Total funding: $10,519.3 million
- Procurement quantity: 65

Program Performance (fiscal year 2014 dollars in millions)

	As of 02/2009	Latest 12/2012	Percent change
Research and development cost	$3,304.2	$3,639.0	10.1
Procurement cost	$9,805.7	$9,592.7	-2.2
Total program cost	$13,512.2	$13,544.2	0.2
Program unit cost	$193.032	$193.488	0.2
Total quantities	70	70	0.0
Acquisition cycle time (months)	92	109	18.4

The Triton's critical technology is mature, the design is stable—although not yet demonstrated—and the program reports that manufacturing processes will be ready to support low-rate production. Testing on the first development aircraft began in September 2012 and first flight occurred in May 2013. However, the program discovered design challenges during integration and testing and had its production budget reprioritized in fiscal year 2014. Alternatives for an air-to-air radar subsystem are being considered and the program's production decision has been delayed by about one year. The program office authorized the prime contractor to develop a new target baseline and schedule that takes into account the program's increased costs and schedule delays.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match
- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable
- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ○

Manufacturing processes are mature
- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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MQ-4C Triton Program

Technology and Design Maturity

The Triton program's one critical technology—a hydrocarbon sensor—was found to be mature by an April 2011 technology readiness assessment. However, the air-to-air radar subsystem (AARSS), which will enable Triton to sense and avoid other aircraft, has faced developmental delays and cost overruns. As a result, the Navy ordered work to be stopped on the subsystem in April 2013 and is currently examining alternatives.

The Triton design is stable and according to the program office, all design drawings are releaseable to manufacturing, but a fully outfitted system-level prototype has not yet been tested. Testing of the first development aircraft began in September 2012, followed by first flight in May 2013. Program officials expect the second development aircraft, which was expected to be the first with a full sensor suite and a sense-and-avoid capability, to begin testing in 2014. However, as a result of developmental delays, they do not plan for AARSS to be incorporated on the aircraft until 2016 for operational evaluation. Software development and maturity also remain areas of potential risk. The program plans to utilize nearly 8 million lines of code, more than 20 percent of which will be new. Though some software integration challenges discovered during testing were resolved in 2013, two more phases of software development and installation are scheduled for completion before the aircraft enters into operational evaluation.

Production Maturity

In November 2011, the program received approval to build three air vehicles and ground stations, in part to demonstrate its manufacturing processes prior to production. Program officials noted that one of these three aircraft will no longer be produced because of new priorities within the Navy's budget. The program reports that manufacturing processes will be able to support low rate initial production after the production decision is made. The Triton aircraft is based on the Air Force's RQ-4B Global Hawk and uses sensor components and subsystems from other platforms. There are some structural changes to the airframe, but none of these require significant changes to manufacturing processes. The program plans to award a contract for long lead material one year prior to the low-rate initial production contract award.

Other Program Issues

The Triton program's production decision has been delayed by about one year because of design adjustments to ensure airworthiness and software stability issues discovered during system integration and testing as well as the Navy's decision to reprioritize the program's production funding for fiscal year 2014. The program office authorized the prime contractor to develop a new target baseline and schedule to take into account increased costs and delays. Program officials expected to receive the revised baseline and schedule in December 2013. According to program officials, the delay has allowed the contractor to resolve some technical issues.

In September 2013, the Global Hawk program experienced an anomaly with a navigation system held in common with Triton. Though the Triton program did not experience the same anomaly, test flights were suspended until a work around was identified. The Air Force is continuing its investigation into the cause of the navigation system issue.

Program Office Comments

In addition to providing technical comments, the program office noted that the Triton UAS program continues to demonstrate success during its system development and demonstration phase as evidenced by the nine initial envelope expansion flights conducted to date. As reported in the December 2012 Selected Acquisition Report, the program breached the acquisition program baseline cost threshold for research, development, test and evaluation and the schedule thresholds for reaching production start, operational evaluation start, full rate production, and initial operational capability. The program has been re-planned to adjust the cost and schedule remaining for the system development and demonstration contract. A proposed program baseline revision is in work and all parameters will be reviewed, to include the operating and support cost estimate. The program continues to benefit from strong support within the Department of the Navy.

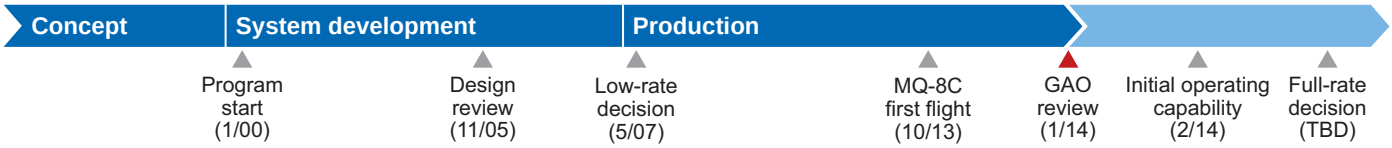
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MQ-8 (Fire Scout)

The Navy's MQ-8 unmanned aerial vehicle is intended to provide real-time imagery and data in support of intelligence, surveillance, and reconnaissance missions. An MQ-8 system is comprised of up to three air vehicles with sensors, two ground control stations, and one recovery system. The air vehicle launches and lands vertically, and operates from ships and land. The MQ-8 is intended for use in various operations, including surface, anti-submarine, and mine warfare. We assessed the latest variant, the MQ-8C.



Source: Northrop Grumman Corporation.



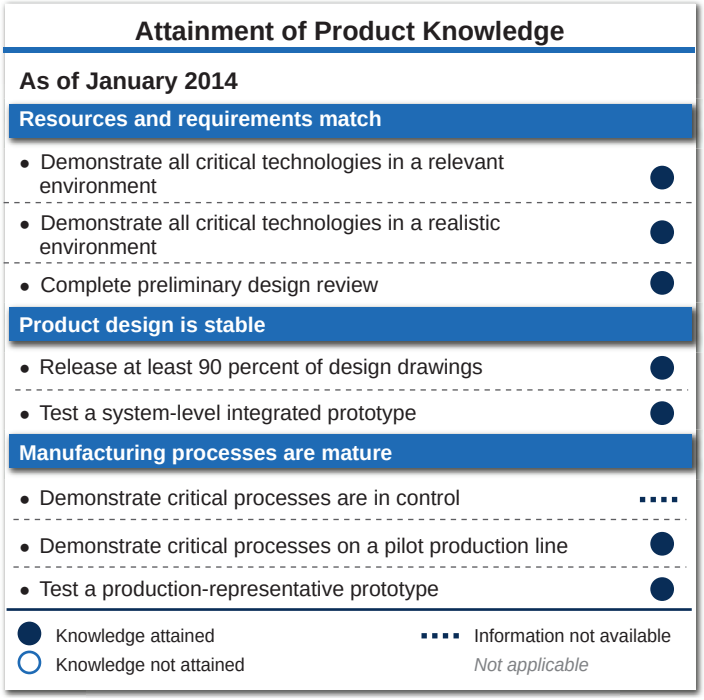
Program Essentials

Prime contractor: Northrop Grumman
Program office: Patuxent River, MD
Funding needed to complete:
- R&D: $0.0 million
- Procurement: $1,685.1 million
- Total funding: $1,685.1 million
- Procurement quantity: 145

Program Performance (fiscal year 2014 dollars in millions)

	As of 12/2006	Latest 09/2013	Percent change
Research and development cost	$629.0	$711.8	13.2
Procurement cost	$1,769.6	$2,099.4	18.6
Total program cost	$2,750.7	$2,811.2	2.2
Program unit cost	$15.540	$16.064	3.4
Total quantities	177	175	-1.1
Acquisition cycle time (months)	104	169	62.5

The Navy ceased production of the MQ-8B variant and in April 2012 awarded a contract to begin development and production of the new MQ-8C with a larger airframe to improve range, endurance, payload, and future carrying capacity. MQ-8C relies on common, mature technologies with the MQ-8B. The engineering design of the MQ-8C is complete as it is based on the MQ-8B design, which appeared to be stable before halting production. The program completed operational test and evaluation of MQ-8B in December 2013 and a Quick Reaction Assessment of MQ-8C will be completed in the fourth quarter of fiscal year 2014. The program plans to conduct an acquisition strategy review in the first quarter of fiscal year 2014 that assesses overall program health, including production readiness. In 2015, the program plans to test the MQ-8C on the Littoral Combat Ship, the platform originally intended for MQ-8B.



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Fire Scout Program

Technology and Design Maturity

According to the program office, MQ-8C is 90 percent common with the previously developed MQ-8B, with the primary difference being structural modifications to accommodate the MQ-8C's larger airframe and fuel system. The MQ-8C relies on mature technologies common to the MQ-8B and does not introduce any new technologies. Program officials stated that the engineering design of MQ-8C is complete, as it is based on the MQ-8B design, which appeared to be stable prior to the Navy's decision to cease production of the system in 2012. Program officials noted that a revision to the air vehicle to accommodate increased payload remains to be completed, but they expect the issue to be resolved by early calendar year 2014. The first flight of the MQ-8C occurred in October 2013.

Production Maturity

The program plans to produce the MQ-8C on the same production line as the MQ-8B and officials stated that they have not experienced challenges in transitioning production between the systems. The program's production processes for MQ-8B have been demonstrated, but we could not assess whether critical manufacturing processes were in control as the program does not collect data on statistical process controls or assess process capabilities using manufacturing readiness levels. The program suspended production of MQ-8B and awarded a development and production contract for 8 MQ-8Cs in April 2012. The program earlier intended to resume production of the MQ-8B aircraft in 2015 to align with the delivery of the Littoral Combat Ship—the platform from which MQ-8B is intended to operate—but the Navy plans to continue MQ-8C production instead. The Navy plans to award a third production contract for MQ-8C in March 2014 in support of the Joint Emergent Operational Need. Program officials stated that the date of the full-rate production decision has not been determined. Future procurements will be addressed in the updated acquisition strategy.

Other Program Issues

The program has shifted its focus to MQ-8C—an upgraded variant of the aircraft with improved range, endurance, payload, and future carrying capacity—due to a joint urgent operational need from U.S. Africa Command. According to program officials, the program is not requesting new funds for MQ-8C, but plans to use funding slated for MQ-8B. MQ-8C is not required to conform to many of the acquisition practices followed by other programs as it is being developed to fill a joint urgent operational need. However, a Quick Reaction Assessment is planned for MQ-8C 3 to 4 months prior to ship deployment, which is expected to be in the first quarter of fiscal year 2015. The program is planning to test the MQ-8C at-sea in 2014 on the DDG-109 and on the Littoral Combat Ship in 2015. The program completed operational test and evaluation of MQ-8B in December 2013 and a Quick Reaction Assessment of MQ-8C will be completed in the fourth quarter of fiscal year 2014. The program plans to conduct an acquisition strategy review in the first quarter of fiscal year 2014 that assesses overall program health, including production readiness.

Program Office Comments

According to the program office, the MQ-8 Fire Scout system has accumulated over 4,500 flights totaling more than 12,000 flight hours with the MQ-8B air vehicle. In the first quarter of fiscal year 2014, the system was assessed by the Navy Operational Test community aboard USS Roberts and completed an Initial Operational Capability Supportability Review in preparation for fleet transition and Initial Operational Capability in second quarter fiscal year 2014. The Fire Scout system with the MQ-8C Endurance Upgrade aircraft is being procured in response to a Joint Emergent Operational Need from Africa Command. The Navy is planning to incorporate the MQ-8C variant into the Fire Scout system as part of its updated acquisition strategy. First flight of the MQ-8C occurred on October 31, 2013. As of January 2014, the MQ-8C has performed more than 32 test flights and accumulated over 46 flight hours. In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated where deemed appropriate.

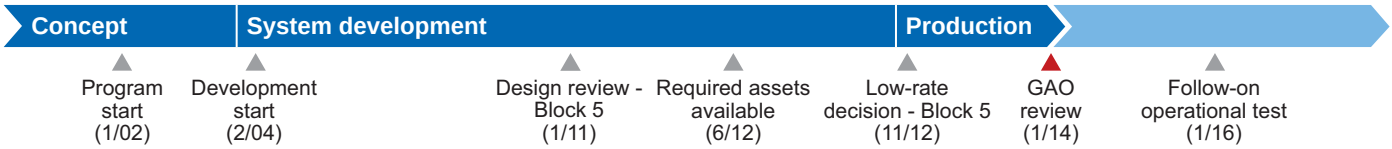
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MQ-9 Reaper Unmanned Aircraft System (MQ-9 Reaper)

The Air Force's MQ-9 Reaper is a multirole, medium-to-high-altitude endurance unmanned aircraft system capable of flying at higher speeds and altitudes than its predecessor, the MQ-1 Predator A. The Reaper is designed to provide a ground-attack capability to find, fix, track, target, engage, and assess small ground mobile or fixed targets. Each system consists of four aircraft, a ground control station, and a satellite communications suite. We assessed the increment I Block 5 configuration and made observations on Block 1.



Source: U.S. Air Force.



Program Essentials

Prime contractor: General Atomics Aeronautical Systems, Inc.
Program office: Wright-Patterson AFB, OH
Funding needed to complete:
R&D: $843.3 million
Procurement: $6,055.7 million
Total funding: $6,921.1 million
Procurement quantity: 161

Program Performance (fiscal year 2014 dollars in millions)

	As of 02/2008	Latest 09/2013	Percent change
Research and development cost	$441.9	$1,613.0	265.0
Procurement cost	$2,220.7	$10,826.4	387.5
Total program cost	$2,773.5	$12,517.3	351.3
Program unit cost	$26.414	$30.983	17.3
Total quantities	105	404	284.8
Acquisition cycle time (months)	79	100	26.6

The Reaper's critical technologies are mature and all design drawings have been released. Delays in manufacturing, delivery of technical data, and developmental testing have pushed back critical software releases for both Block 1 and Block 5 configurations. The MQ-9 Reaper was approved for low-rate initial production in November 2012, but has not yet demonstrated that critical manufacturing processes are in control. The program originally expected to complete operational testing no later than October 2014; however manufacturing and other delays have caused the program to postpone the completion of testing until January 2016. The program's full-rate production decision was changed to an in-process review because more than half of the aircraft will be procured prior to a full-rate production decision.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ●

Manufacturing processes are mature

- Demonstrate critical processes are in control — ○
- Demonstrate critical processes on a pilot production line — ○
- Test a production-representative prototype — ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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MQ-9 Reaper Program

Technology and Design Maturity

The Reaper's critical technologies are considered mature and its design is stable. Manufacturing issues, as well as delays in the delivery of technical data and developmental testing have pushed back critical Block 1 and Block 5 configuration software releases by 8 months and 15 months, respectively. Program officials now plan to field the Block 5 software in March 2016. The Block 5 configurations include capability enhancements from the Block 1 configuration such as updates to the radar, data link, sensor, landing gear, software, and ground control stations. Until testing is completed, the Block 5 system remains at risk of design changes.

Production Maturity

The Air Force approved low-rate initial production of the MQ-9 Reaper Block 5 Increment in November 2012. According to program officials, the Block 5 manufacturing processes have reached the level of maturity recommended by DOD guidance for the start of low-rate production. However, the program's manufacturing readiness level did not indicate that its production processes were in statistical control, as recommended by our best practices. MQ-9 Reaper production deliveries have slowed over the past year because of delinquencies in completing technical data, software delays, and fuel tank issues that required engineering design changes to the production line and retrofitting aircraft that had already been produced. As of December 2013, 21 Block 1 aircraft have been produced, but are still awaiting the necessary software capability upgrades before they can be delivered. Until these software upgrades are complete, aircraft are only being delivered based on urgent needs. According to program officials, the program has developed an aircraft delivery recovery plan that should allow deliveries to be back on track by April 2014.

Other Program Issues

The program office declared a breach to the MQ-9 Block 5 program's schedule baseline in May 2013 because of delays associated with manufacturing, technical data, and developmental testing. The program originally expected to complete operational testing no later than October 2014. Operational testing will now be complete in January 2016. This schedule change was approved by the configuration steering board in December 2013. At this time, the full-rate production decision was changed to an in-process review since more than half of the aircraft will be procured prior to the full rate production decision. The program office is in the process of updating the acquisition program baseline.

Program Office Comments

In commenting on a draft of this assesment, program officials noted that since the program office declared a breach in May 2013, the program office and contractor resolved issues that delayed schedule and are implementing processes to improve quality for future success. The re-baselined MQ-9 Block 5 schedule was approved at the Air Force review board in August 2013 and the configuration steering board in December 2013. The program office is updating the acquisition program baseline to reflect program changes. Follow-on test and evaluation is now planned to complete in January 2016. The program office is currently in formal developmental test of Block 5. The program office also took delivery of the first Block 5 aircraft in November 2013 to assist with developmental test and technical order development. The program office also provided technical comments that were incorporated as appropriate.

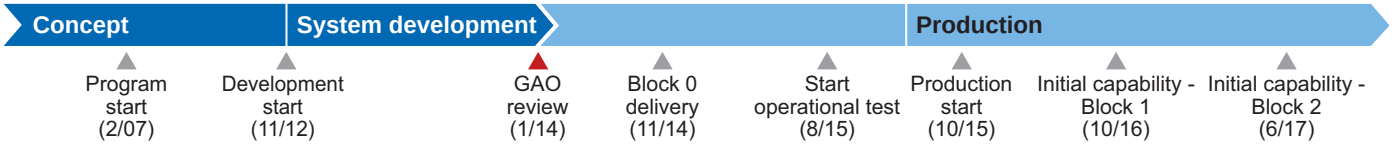
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Next Generation Operational Control System (GPS OCX)

The Air Force's Global Positioning System Next Generation Operational Control System (GPS OCX) is to replace the current ground control system for legacy and new GPS III satellites. GPS OCX is expected to ensure reliable and secure delivery of position and timing information to military and civilian users. The Air Force plans to develop GPS OCX in blocks, with each block delivering upgrades as they become available. We assessed the initial three blocks, which support the launch, checkout, and operation of GPS II and III satellites.



Source: U.S. Air Force.



Program Essentials

Prime contractor: Raytheon
Program office: El Segundo, CA
Funding FY14 to FY19:
R&D: $1,662.8 million
Procurement: $0.0 million
Total funding: $1,662.8 million
Procurement quantity: 0

Program Performance (fiscal year 2014 dollars in millions)

	As of	Latest 12/2012	Percent change
Research and development cost	NA	$3,470.3	NA
Procurement cost	NA	$0.0	NA
Total program cost	NA	$3,470.3	NA
Program unit cost	NA	$3,470.350	NA
Total quantities	NA	1	NA
Acquisition cycle time (months)	NA	55	NA

Table includes costs through fiscal year 2019.

GPS OCX entered system development in November 2012. The program consists of three blocks: Block 0, intended to support the launch and checkout of GPS III satellites; Block 1, designed for command and control of the GPS II and III satellites; and Block 2, which is expected to support, monitor, and control additional navigation signals. The program's 14 critical technologies are nearing maturity, but seven of those technologies are not expected to reach full maturity until the end of fiscal year 2015 or later, nearly 3 years after the program began system development. Aligning the schedules for GPS OCX and GPS III is a risk for both programs. Block 1 is scheduled to become operational by October 2016, 6 months after the date of GPS III's availability for launch.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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GPS OCX Program

Technology Maturity

GPS OCX entered system development in November 2012 with all of its 14 critical technologies tested in a relevant environment, but not a realistic environment. According to program officials, these technologies will not reach full maturity until the program integrates together all of the key subsystems and components and tests them in the factory. The first of these tests is scheduled to occur near the end of fiscal year 2014 and is expected to result in seven of the technologies reaching full maturity. The remaining seven technologies are not expected to reach full maturity until the end of fiscal year 2015 or later, nearly three years after the program began system development.

Design and Production Maturity

GPS OCX is primarily a software development program and is expected to provide capabilities in three block deliverables. Block 0 is intended to provide initial capability for launch control and checkout of GPS III satellites. Block 1 is designed to operate legacy and new GPS satellites, including new civilian signals, and Block 2 is expected to add operational control of new international and modernized military signals.

According to the program office, software is being developed and tested incrementally with a critical design review after each stage to ensure the design is stable. Software development for Block 0 is nearly complete and all remaining testing is scheduled for completion at the beginning of fiscal year 2015. The program has started development activities for Block 1, which program officials expect to be completed in October 2016.

Program officials expect to integrate the software and hardware components for all of Blocks 0 and 1 and test them as a prototype to ensure the system will work as intended. According to GAO's best practices, this integrated prototype test should occur before critical design review. However, program officials stated that the test will not happen until December 2015, 18 months after the final critical design review and ten months before Block 1 is scheduled to be complete. Program officials reported that they had used other knowledge-based practices to increase confidence in the stability of the design such as identifying key product characteristics and establishing a reliability growth curve.

Other Program Issues

The program experienced significant schedule delays while in technology development. This, combined with the program's late start relative to GPS III, has resulted in considerable risk in aligning the schedules of GPS OCX and GPS III satellites. Block 1, which is to provide command and control for GPS III satellites on orbit, is not scheduled to become operational until October 2016, 6 months after the first GPS planned GPS III satellite is expected to be available for launch. Until Block 1 is operational, the GPS III satellite will have very limited capabilities and Air Force officials said they do not plan to launch a second GPS III satellite until that time.

Program Office Comments

In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated as appropriate.

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P-8A Poseidon Multi-Mission Maritime Aircraft (P-8A)

The Navy's P-8A Poseidon is a commercial derivative aircraft that will replace the P-3C Orion. Its primary roles are antisubmarine warfare, antisurface warfare, and intelligence, surveillance, and reconnaissance. The P-8A is part of a family of systems, including the MQ-4C Triton unmanned aircraft system, which will perform maritime patrol missions and support the Navy's maritime warfighting capability. The program plans to field capabilities in three increments. We assessed increment one and made observations on increments two and three.



Source: U.S. Navy.



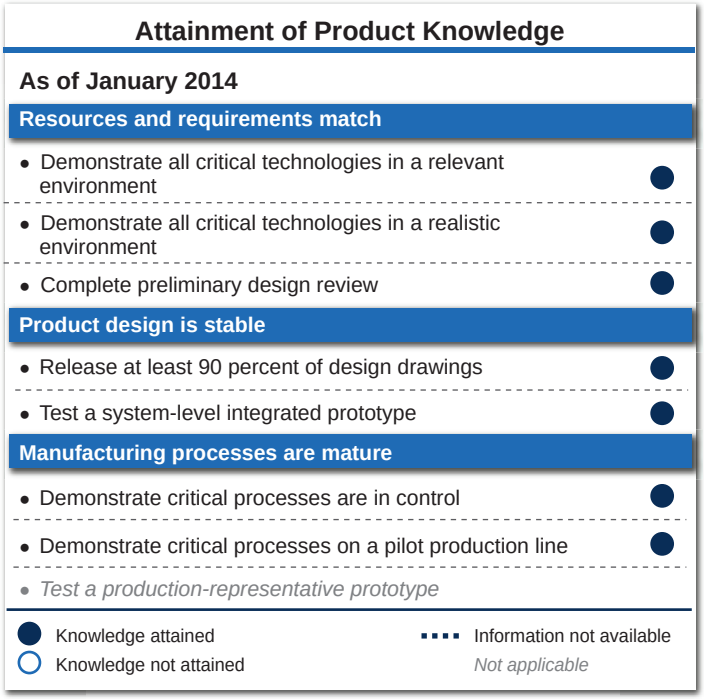
Program Essentials

Prime contractor: The Boeing Company
Program office: Patuxent River, MD
Funding needed to complete:
R&D: $552.4 million
Procurement: $15,984.3 million
Total funding: $16,811.2 million
Procurement quantity: 80

Program Performance (fiscal year 2014 dollars in millions)

	As of 06/2004	Latest 08/2013	Percent change
Research and development cost	$7,921.2	$8,826.6	11.4
Procurement cost	$24,574.2	$25,122.3	2.2
Total program cost	$32,640.1	$34.336.0	5.2
Program unit cost	$283.827	$281.442	-0.8
Total quantities	115	122	6.1
Acquisition cycle time (months)	160	164	2.5

The P-8A entered production in August 2010 with mature technology, a stable design, and proven production processes. The P-8A completed initial operational testing in March 2013 and was found to be operationally suitable and effective. The test report identified five significant deficiencies and recommended that the P-8A be introduced to the fleet with several operational restrictions. According to the program office, it has plans in place to correct or otherwise resolve these deficiencies. The program's full rate production decision was delayed from July 2013 until January 2014 in part to enable additional assessment of deficiency corrections from developmental test and evaluation. To maintain production continuity, and utilize available funding, the program awarded a fourth low-rate production contract. The first P-8A operational deployment began in December 2013.



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P-8A Program

Technology Maturity

The P-8A entered production in August 2010 with a fully mature and sole critical technology, the hydro-carbon sensor. The sonobuoy launcher, which at one time was also considered a critical technology, has experienced issues in testing and fixes are still being made to improve its performance and reduce operator errors.

Design Maturity

Overall, the design of the P-8A is stable, but the number of design drawings continues to grow due to deficiencies discovered in testing. The number of releasable drawings increased by 16 percent since our last assessment and 95 percent of the total drawings have been released.

Production Maturity

The manufacturing processes for P-8A are mature and the program has improved the acceptance process after minor anomalies and maintenance issues were discovered with each of the first five production aircraft. According to program officials, Boeing has implemented additional pre-acceptance flights, which have reduced the number of issues discovered by the government during the formal acceptance process. More recently, the Defense Contract Management Agency reported the late delivery of spare parts could affect aircraft deliveries by reducing the program's ability to swap out defective parts when needed. The program office stated that it has addressed this issue and aircraft deliveries had not been impacted to date.

Other Program Issues

The P-8A program completed initial operational test and evaluation in March 2013. The final test report found the aircraft to be operationally effective and suitable. The report identified five significant deficiencies that are typically corrected before operational deployment and the operational test staff recommended that the P-8A enter the fleet with several operational restrictions. According to the program office, it has plans in place to correct or otherwise resolve these deficiencies. For example, to maintain main fuel tank temperatures within required operating limits during hot weather ground operations, the program is re-qualifying key components to higher operating limits and developing new planning tools and fueling procedures. The first operational deployment of P-8A commenced in December 2013. Follow-on operational testing, which includes verifying test fixes discovered previously in developmental testing, began in October 2013.

The Navy delayed the program's full rate production decision from July 2013 until January 2014 in order to allow enough time for the program to assess deficiency corrections. To maintain production line continuity, and utilize available program funding, the program awarded a fourth low-rate initial production contract for 13 aircraft.

During increments 2 and 3, the program plans to integrate additional capabilities into the P-8A. Increment 2, which is being managed as a series of engineering changes rather than a separate development effort, includes various improvements to the system's antisubmarine warfare and other capabilities. The program eventually plans to retrofit previously manufactured aircraft with the planned Increment 2 capabilities. The Navy plans to conduct a separate system development phase for increment 3. The improvements include changes to the P-8A's system architecture to allow for rapid integration of new applications and services. The program plans to conduct full and open competition for its increment 3 contracts and to purchase the data rights for the new, more open architecture.

Program Office Comments

In commenting on a draft of this assessment, the program office stated that following an extensive operational test period, the Navy's operational test authority reported that the P-8A aircraft is operationally effective and suitable and recommended it for fleet introduction. The program office added that this conclusion is consistent with the fleet's experience with the aircraft during extensive aircraft transition and pre-deployment training cycles. The first such cycle began with the delivery of the first P-8A aircraft to an operational squadron in May 2012, included the attainment of initial operational capability in November 2013, and culminated with the departure of the first fully trained squadron for operational deployment later that same month. In December 2013, the thirteenth of 37 low-rate initial production aircraft was delivered to fleet squadrons, with all deliveries on or ahead of schedule. The program office also provided technical comments, which were incorporated as appropriate.

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Paladin Integrated Management (PIM)

The Army's Paladin Integrated Management (PIM) system consists of two individual platforms, a self-propelled howitzer (SPH) and a tracked ammunition carrier that provides operational support. The SPH is a tracked, aluminum armored vehicle with a 155 millimeter cannon. The PIM will provide improved sustainability over the current Paladin M109A6 howitzer fleet through the incorporation of a newly designed hull; modified M2 Bradley infantry fighting vehicle power train, suspension system, and track; and a modernized electrical system.



Source: U.S. Army.



Program Essentials

Prime contractor: BAE Systems Land & Armament L.P.
Program office: Warren, MI
Funding needed to complete:
- R&D: $367.7 million
- Procurement: $5,684.8 million
- Total funding: $6,052.5 million
- Procurement quantity: 556

Program Performance (fiscal year 2014 dollars in millions)

	As of 02/2012	Latest 10/2013	Percent change
Research and development cost	$1,060.1	$1,101.7	3.9
Procurement cost	$5,973.4	$5,886.3	-1.5
Total program cost	$7,033.5	$6,987.9	-0.6
Program unit cost	$12.085	$12.523	3.6
Total quantities	582	558	-4.1
Acquisition cycle time (months)	118	118	0.0

The program was approved for low-rate initial production in October 2013 with the first production delivery scheduled for March 2015. Program officials stated that a lack of available staff, staff furloughs, loss of workforce overtime, and a reduction in travel funding due to sequestration caused the production decision date to slip from June 2013 to October 2013. The program was approved for production with its two critical technologies fully mature and a stable design. The program, as originally structured, was not a major defense acquisition program, but was elevated to major defense acquisition program status due to rising cost estimates. The program has also experienced schedule slippage due to delays in the start of developmental testing and changes to force protection and survivability requirements that drove the addition of new armor kits and a new ballistic hull and turret.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ●
- Test a system-level integrated prototype — ●

Manufacturing processes are mature

- Demonstrate critical processes are in control — ○
- Demonstrate critical processes on a pilot production line — ○
- Test a production-representative prototype — ○

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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PIM Program

Technology Maturity

The program office identified two technologies critical to the PIM program; power pack integration and the ceramic bearing of the generator assembly. Both technologies have been assessed as fully mature. The program office identified these technologies as critical based on concerns about their performance at high temperatures. While neither technology is new or novel, failure of either would represent major program risk. In addition, increases in vehicle weight due to the addition of material to improve survivability, minimal power pack space, and other integration issues may degrade the ability to meet automotive performance requirements.

Design Maturity

According to the program office, the design is currently stable with all of the expected drawings released; however, the program faces a number of design challenges as it moves forward. The current contractor for the engine and transmission may cease production due to lack of orders. If this occurs, production with another vendor may be necessary and could result in a redesign of the engine and engine compartment. Production with another vendor has the potential for cost growth between $32 to $100 million and a significant schedule delay. Additionally, after the critical design review, the program manager identified a number of corrective actions, producibility, and obsolescence engineering changes to the PIM design that are scheduled to be implemented between low-rate initial production and initial operational test and evaluation. If significant issues are uncovered during the testing of these engineering changes, then there is potential for cost growth and delays in production.

Production Maturity

The program was approved for low-rate initial production in October 2013 with the first production vehicle scheduled for delivery in March 2015. As of August 2013, the program office indicated that a number of manufacturing processes and systems are below the maturity levels required by best practices. The program reported that the capability to produce the vehicles in a pilot-line environment will be not be demonstrated until after production begins. Our best practices work has shown that programs risk missing cost and schedule targets if their manufacturing processes are not demonstrated and in control before production begins. Program officials have indicated that there is a minimal risk that the PIM final assembly facility may not be ready in time to support initial PIM shipments.

Other Program Issues

The program's current plans are schedule driven, with limited time for correction of deficiencies identified in developmental testing and little flexibility with individual component test schedules. The program is waiting for low-rate initial production vehicles before verifying most corrective actions. Additionally, program officials stated that the PIM and the Bradley infantry fighting vehicle programs currently share a common path for the suspension and power train, but if the Bradley program diverges from this path there could be cost and schedule impacts for the PIM program.

Program Office Comments

In commenting on a draft of this assessment, the Army stated that the PIM program is on track for its full-rate decision scheduled for January 2017. Additionally, technical comments were provided, which were incorporated as appropriate.

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Presidential Helicopter Fleet Replacement Program (VXX)

The Navy's VXX program is to provide a replacement helicopter fleet that will be used to transport the President, Vice President, heads of state, and others. As a successor to the terminated VH-71 program, the VXX fleet of 21 new helicopters will replace the current fleet of 19 VH-3D and VH-60N legacy helicopters and two training aircraft (to be delivered in 2014). The program plans to enter system development in March 2014. Until the VXX helicopters are available, the Navy is extending the availability of the legacy aircraft.



Source: U.S. Navy.



Program Essentials

Prime contractor: TBD
Program office: Patuxent River, MD
Funding FY14 to FY18:
- R&D: $2,316.2 million
- Procurement: $0.0 million
- Total funding: $2,316.2 million
- Procurement quantity: 0

Program Performance (fiscal year 2014 dollars in millions)

	As of	Latest 11/2013	Percent change
Research and development cost	NA	$2,532.0	NA
Procurement cost	NA	$0.0	NA
Total program cost	NA	$2,523.0	NA
Program unit cost	NA	TBD	NA
Total quantities	NA	23	NA
Acquisition cycle time (months)	NA	77	NA

Table includes costs through fiscal year 2018.

The Navy made progress in establishing a limited development effort that reflects trade-offs made among cost, schedule, risk, and performance. Since April 2012, the program completed its analysis of alternatives, in which affordability and cost control are key factors, finalized the requirements and acquisition strategy, and was granted a waiver to the competitive prototyping requirement. Program affordability and timeliness are achieved by maintaining a candidate platform's current airworthiness certification, leveraging mature technologies, and through Government definition of the mission systems architecture and related avionics. To minimize risk, a sub-system preliminary technical readiness assessment was conducted in February 2013. However, a system level preliminary design review has been deferred until after the March 2014 start of system development.

Attainment of Product Knowledge

Projected as of January 2014

Resources and requirements match
- Demonstrate all critical technologies in a relevant environment — ○
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ○

Product design is stable
- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature
- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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VXX Program

Technology Maturity

The program reports the key technologies to be provided the government for integration into the VXX platform either already exist or are in development, some as legacy fleet aircraft upgrades. To minimize technical risk, the program completed a preliminary technical readiness assessment in February 2013; it was limited to the mission communication system (the only new technology envisioned for the VXX platform). As a result of this assessment, it was deemed the VXX mission communication system does not include any components that would be considered immature and classified as a critical technology element. Although the program has conducted a sub-system preliminary design review, it does not currently plan to conduct a preliminary design review until after the program enters system development. The statutory requirement for a preliminary design review has been waived, and will be conducted after the start of system development. To be consistent with the program's approved acquisition strategy, the language in the request for proposals encourages the use of mature off-the-shelf technologies that should only require standard engineering development practice to integrate and achieve installed systems performance.

Design Maturity

The VXX acquisition strategy is based on the integration of mature subsystems into an existing air vehicle. While minor changes to the platform, to accommodate integration of subsystems, are inevitable, change to major components such as drive train, rotors, engines and basic structure is highly discouraged. Any design elements that contain immature technology or that might be deemed a critical technology element are discouraged. The request for proposals encouraged offerors to remain within the existing airworthiness qualification of the baseline aircraft from which the VXX would be derived. The government does not intend to impose bottom-up airworthiness criteria that would drive redesign, but plans to leverage the current certification basis with the cognizant civil or U.S. military airworthiness certification authority to achieve a Naval Air Systems Command flight clearance.

Production Maturity

This program will leverage "green air vehicle" production by randomly selecting aircraft off the existing production line. This will save the government time and money by avoiding infrastructure costs associated with constructing a unique production facility and allow the program to meet its security production and supply requirements.

Other Program Issues

The program intends to award a single fixed-price type contract for the system development phase that will include options for low-rate initial production, full rate production, and associated logistics elements. The total aircraft quantity includes six aircraft to support system development, 17 production aircraft in three lots (six aircraft each in lot 1 and 2, and 5 in lot 3). The total period of performance will be approximately 8 years.

Program Office Comments

In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated where deemed appropriate.

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RQ-4A/B Global Hawk Unmanned Aircraft System (RQ-4A/B Global Hawk)

The Air Force's Global Hawk is a high-altitude, long-endurance unmanned aircraft that provides intelligence, surveillance, and reconnaissance capabilities. After a successful technology demonstration, the system entered development and limited production in March 2001. The early RQ-4A, similar to the original demonstrators, was retired in 2011, leaving a fleet of the larger and more capable RQ-4Bs, produced in three configurations—Block 20, 30, and 40.



Source: Northrop Grumman.



Program Essentials

Prime contractor: Northrop Grumman
Program office: Wright-Patterson AFB, OH
Funding needed to complete:
R&D: $318.6 million
Procurement: $170.1 million
Total funding: $488.7 million
Procurement quantity: 0

Program Performance (fiscal year 2014 dollars in millions)

	As of 03/2001	Latest 08/2013	Percent change
Research and development cost	$1,095.6	$4,028.2	267.7
Procurement cost	$4,542.3	$5,708.1	25.7
Total program cost	$5,671.1	$9,874.5	74.1
Program unit cost	$90.017	$219.432	143.8
Total quantities	63	45	-28.6
Acquisition cycle time (months)	55	TBD	TBD

The Global Hawk program has mature technologies, a stable design, and mature manufacturing processes that are in statistical control. Congress directed the program to purchase the final three Block 30 aircraft and the program office awarded an advanced procurement contract in September 2013. All 45 Global Hawk aircraft have been purchased without a full-rate production decision. Congress directed the program to maintain the operational capability of Block 30 aircraft through December 2014. The Air Force will determine the final force structure following fiscal year 2015 and 2016 budget decisions. Block 40 aircraft operational testing has been delayed 6 months and delivery of a fully operational Block 40 capability has not been determined. The program fielded two Block 40 aircraft in September 2013, providing limited capability to the warfighter.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment ●
- Demonstrate all critical technologies in a realistic environment ●
- Complete preliminary design review ●

Product design is stable

- Release at least 90 percent of design drawings ●
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- Demonstrate critical processes are in control ●
- Demonstrate critical processes on a pilot production line ●
- Test a production-representative prototype ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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RQ-4A/B UAS Global Hawk Program

Technology, Design, and Production Maturity

The critical technologies for the RQ-4B are mature, the basic airframe design is stable, and its manufacturing processes are mature and in statistical control. The RQ-4B aircraft consist of three configurations. Block 20 aircraft are equipped with an enhanced imagery intelligence payload, Block 30 aircraft have both imagery and signals intelligence payloads, and Block 40 aircraft have an advanced radar surveillance capability. The program is concurrently testing and fielding the multiple platform radar, the key capability for Block 40 aircraft. Due to software delays associated with another government system, Block 40 operational testing has slipped an additional 9 months, from January 2014 to October 2014, almost 4 years from the original estimate. Despite this, two Block 40 aircraft with the advanced radar capability were fielded in September 2013, providing a limited capability to the warfighter. Program officials stated that there is currently no formal date for the program to deliver a full capability Block 40 aircraft for operational use.

Other Program Issues

As part of its fiscal year 2013 budget request, DOD proposed terminating the Block 30 system in an effort to reduce program cost. However, in January 2013, Congress directed the Global Hawk program to purchase its remaining three planned Block 30 aircraft and mandated that the Air Force maintain the operational capability of Block 30 aircraft until December 31, 2014. The program reported that operating Block 30 aircraft beyond 2014 would create operational challenges and would require a substantial investment. According to officials, the Air Force will make a decision about the program force structure following future budget decisions. If the Air Force decides to retire Block 30 aircraft, almost half of all aircraft procured will be affected. In September 2013, the Air Force awarded an advanced procurement contract for the remaining three Block 30 aircraft and intends to award a firm fixed-price production contract in July 2014.

The Global Hawk program continues to operate without an established cost and schedule baseline, as its prior baseline was rescinded due to the program's Nunn-McCurdy breach in April 2011. The program had originally planned to re-establish its baseline in June 2011, but that review was superseded by the Air Force's proposed termination of Block 30. Program officials stated they are working with the Office of the Secretary of Defense and the Air Force to establish a new baseline.

Production continues for Block 30 and Block 40 aircraft, despite the lack of an official full-rate production review. All 45 Global Hawk aircraft have been procured through low-rate initial production. The program does not plan to hold a production decision and, according to officials, continues to sustain operational aircraft.

The program had planned to begin development of a restructured ground control station and communications system to achieve a common architecture for both the Global Hawk and the Navy's Triton unmanned aircraft systems, has a similar design to Global Hawk. However, according to program officials the program could no longer afford the development effort due to fiscal constraints. Program officials noted that they have chosen to continue to maintain the current system and address obsolescence issues on an as-needed basis.

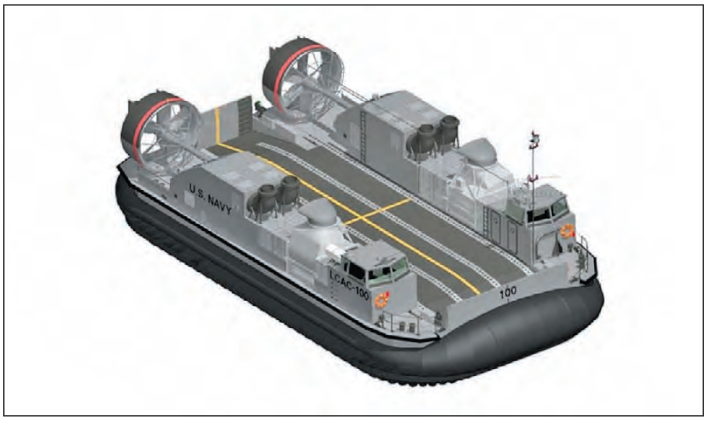
Program Office Comments

In commenting on a draft of this assessment, Air Force officials noted that the Air Force Operational Test and Evaluation Center completed the Block 40 operational utility evaluation in April 2013 in support of a Block 40 early operational capability. The two Block 40 aircraft that fielded in September 2013 were part of the early operational capability which provided the military with additional ground moving target support ahead of schedule. The Air Force also provided technical comments, which were incorporated as appropriate.

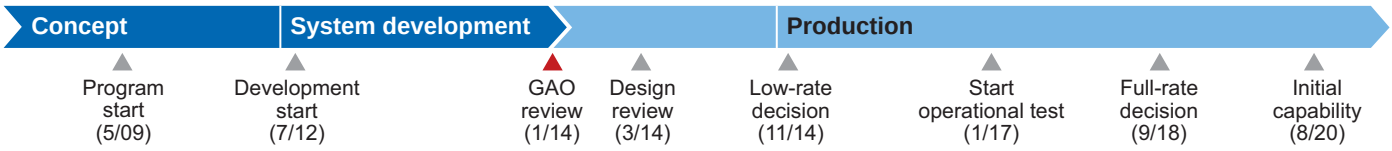
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Ship to Shore Connector Amphibious Craft (SSC)

The Navy's SSC is an air-cushioned landing craft intended to transport personnel, weapon systems, equipment, and cargo from amphibious vessels to shore. SSC is the replacement for the Landing Craft, Air Cushion, which is approaching the end of its service life. The SSC is designed to deploy in Navy well deck amphibious ships, such as the LPD 17 class, and for use in assault and nonassault operations. The program entered system development in July 2012 and is scheduled for a critical design review in March 2014.



Source: U.S. Navy.



Program Essentials

Prime contractor: Textron Inc.
Program office: Washington, DC
Funding needed to complete:
R&D: $166.8 million
Procurement: $3,462.9 million
Total funding: $3,648.9 million
Procurement quantity: 71

Program Performance (fiscal year 2014 dollars in millions)

	As of 07/2012	Latest 09/2013	Percent change
Research and development cost	$585.4	$571.2	-2.4
Procurement cost	$3,552.6	$3,462.9	-2.5
Total program cost	$4,157.6	$4,053.3	-2.5
Program unit cost	$56.953	$55.524	-2.5
Total quantities	73	73	0.0
Acquisition cycle time (months)	135	135	0.0

The SSC program entered system development in July 2012 with its one critical technology—the fire suppressant system—mature. Two other technologies designated as technology watch items leverage existing mature technologies, but will need to be modified for use on SSC. The program has completed approximately 5 percent of expected design drawings seven months prior to critical design review scheduled for March 2014. Fabrication for the first two craft is scheduled to start three months after the critical design review. The acquisition strategy identified the plan to construct the first two craft concurrently as a risk due to the potential for design changes.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment ●
- Demonstrate all critical technologies in a realistic environment ●
- Complete preliminary design review ●

Product design is stable

- *Release at 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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SSC Program

Technology Maturity

The SSC program's one identified critical technology, the fire suppression system, entered system development as mature. According to program officials, the prime contractor is in the process of selecting a subcontractor to develop this system. According to the Navy, the system is expected to be lighter and more environmentally friendly than the system for the legacy craft.

DOD identified two other technologies—the gas turbine engine and the command, control, communications, computer and navigation (C4N) system—as critical technology watch-list items because of the possibility new technologies would need to be developed or modified for SSC. According to program officials, the gas turbine engine is mature, but needs modifications to convert it from aircraft to amphibious craft usage. In addition, program officials said that the prime contractor has selected a subcontractor to develop the C4N system and believes that the technology is low risk since it will leverage existing code from the legacy craft. Officials expect that the system will provide new operational features, including a pilot/co-pilot configuration that allows each operator to bring up the same display at separate consoles.

Design Maturity

As of August 2013, the contractor has released 42 of the 856 engineering drawings expected—almost 5 percent. Best practices suggest that completion of 90 percent of engineering drawing provides evidence of design stability. The program plans to demonstrate the stability of the SSC design at the program's production readiness review, currently planned for May 2014—2 months after the program's scheduled design review.

Fabrication of the first two craft are scheduled to begin in June 2014. The program office does not plan to assess critical manufacturing processes by the start of production. Program officials stated that they plan to have these processes partially demonstrated on a pilot production line before production start, noting that the program has pursued low risk technologies and a low risk design effort.

Production Maturity

The Navy plans to begin construction of the lead and follow-on craft concurrently—a strategy that has been identified as potentially risky due to the possibility that design changes identified in the first test and training craft would have to be incorporated in the second craft during construction. Despite this risk, the SSC program exercised an option to construct the second craft in December 2012—3 months earlier than planned. Program officials noted that the option was exercised earlier to take advantage of better pricing for certain long-lead construction materials. Overall, the program plans to exercise options for a total of six craft prior to delivery of the test and training craft in February 2017.

Program Office Comments

In commenting on a draft of this assessment, the program office noted that the Ship to Shore Connector is a technically mature, low risk program which is proceeding toward demonstration of design maturity. A detail design and construction contract was awarded in July 2012. The shipbuilder is conducting preliminary and critical design reviews of all major craft subsystems. The first craft's start of fabrication is planned for the third quarter of fiscal year 2014. The program office also provided technical comments which were incorporated where deemed appropriate.

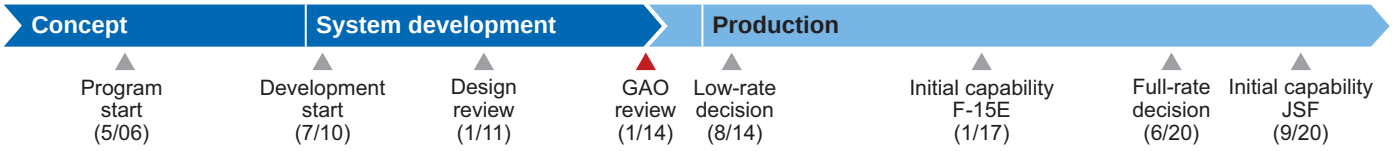
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Small Diameter Bomb Increment II (SDB II)

The Air Force's Small Diameter Bomb Increment II (SDB II) is designed to provide attack capability against mobile targets in adverse weather from standoff range. It combines radar, infrared, and semiactive laser sensors in a tri-mode seeker to acquire, track, and engage targets. It uses airborne and ground data links to update target locations as well as GPS and an inertial navigation system to ensure accuracy. SDB II will be integrated with F-15E, Joint Strike Fighter (JSF), F/A-18E/F, F-16C, and F-22A, as funding becomes available.



Source: © 2009 Raytheon Company.



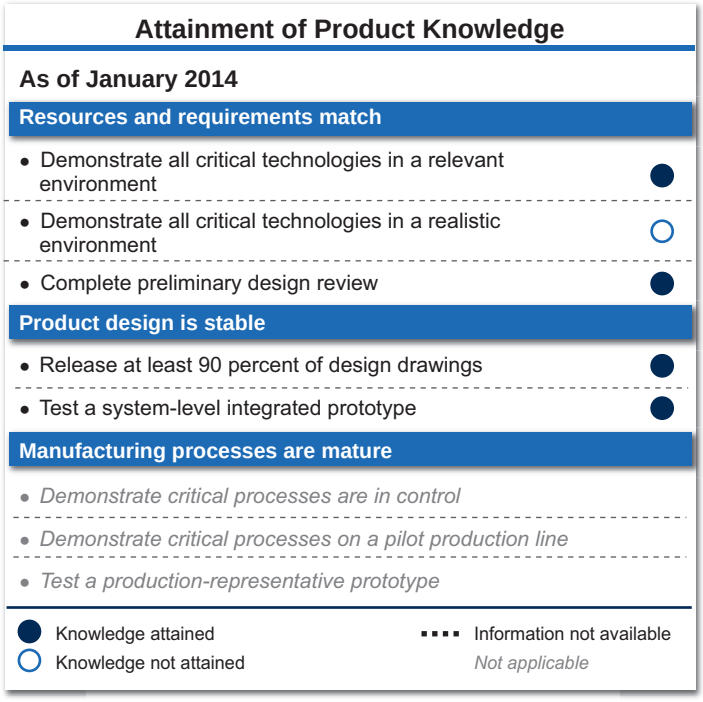
Program Essentials

Prime contractor: Raytheon
Program office: Eglin AFB, FL
Funding needed to complete:
- R&D: $612.3 million
- Procurement: $2,175.3 million
- Total funding: $2,787.6 million
- Procurement quantity: 17,000

Program Performance (fiscal year 2014 dollars in millions)

	As of 10/2010	Latest 08/2013	Percent change
Research and development cost	$1,729.7	$1,649.5	-4.6
Procurement cost	$3,215.2	$2,177.3	-32.3
Total program cost	$4,944.9	$3,826.7	-22.6
Program unit cost	$0.288	$0.223	-22.6
Total quantities	17,163	17,163	0.0
Acquisition cycle time (months)	72	79	9.7

The SDB II Program expects all of its critical technologies to reach full maturity by the time it enters low-rate production, which is planned to occur no earlier than August 2014—a 7-month delay from earlier estimates. The flight test program has experienced two failures, prompting a 6 month halt to flight testing in mid-2013. Since resuming flight test activities in October 2013, the program has conducted three successful flight tests. Although the design is stable, future design changes may be needed to address problems found in previous flight test failures. The flight test schedule is optimistic, requiring seven successful flight tests in 5 months. If additional flight test failures occur it could result in additional delays for the low-rate production decision.



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SDB II Program

Technology Maturity

SDB II's four critical technologies—guidance and control, multi-mode seeker, net ready data link, and payload—are scheduled to reach full maturity when the program has its low-rate production decision in August 2014, 4 years after the program entered system development. According to program officials, critical technologies have not directly contributed to any flight test failures.

Design Maturity

The number of design drawings is stable and the program has completed five successful guided flight tests. However, the flight test program experienced two failures that resulted in a 6-month halt in all guided test vehicle events until the program determined a root cause for the failures. The two failures were the result of the dome cover not deploying, preventing the seeker from acquiring the target, and a navigation error. Guided flight test activities resumed in October 2013 and, since then, the program has recorded three successful flight tests. Program officials stated that all of the failed tests have to be retested at a future date. Moreover, prior to the low-rate production decision, the program's test plan requires11 successful flight tests, including two live fire events.

Production Maturity

The program's low-rate production decision is expected no earlier than August 2014, a 7-month slip due to a delay in the program's system verification review, a prerequisite for this decision. The verification review will evaluate all of the program's flight tests and the system qualification testing. Eleven of the 12 subsystems have successfully passed qualification testing. However, all up round environmental qualification testing has been on hold since September 2013 due to subsystem issues.

According to program officials, the seeker subsystem is the final subsystem to complete qualification. The subsystem qualification was halted for issues related to a leak in the warhead case and seeker encoders that failed during vibration testing. A correction has been identified for the encoders and will be incorporated before testing resumes. The all up round qualification program has been placed on hold until the leak in the warhead case is resolved. The program has yet to identify a correction for the leak in the warhead. These delays have absorbed the entire 1-month qualification testing margin and contributed to the delayed system verification review, now scheduled for May 2014. According to program officials, the contractor will be adding additional vehicles to the all up round qualification program to lessen the effect that the pause has on the overall program schedule.

Other Program Issues

The program's test schedule prior to the low-rate production decision is optimistic. In addition to a 5-month delay in 2012, the test program recently ended a 6-month delay due to two flight test failures. According to program officials, the test program must have six successful flight tests prior to the May 2014 verification review. Additional flight test failures would likely further delay the low-rate production decision. Program officials also noted that future sequestration funding cuts may result in reduced production quantities or the inability to exercise contract options. This could force a renegotiation with the contractor for the first five production lots and the program could lose money that it saved through competition.

Program Office Comments

The Air Force concurred with this assessment. The Air Force also provided technical comments, which were incorporated as appropriate.

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Space Fence

The Air Force's Space Fence program is developing a system of large ground-based radars that will replace the Air Force Space Surveillance System, which became operational in 1961 and was recently shut down. Space Fence will use higher radio frequencies to detect and track more and smaller earth-orbiting objects than is currently possible. The Air Force currently plans to award a contract for construction of one radar with an option for a second.



Source: U.S. Air Force.



Program Essentials

Prime contractor: TBD
Program office: Hanscom AFB, MA
Funding needed to complete:
- R&D: $958.2 million
- Procurement: $103.2 million
- Total funding: $1,061.4 million
- Procurement quantity: 1

Program Performance (fiscal year 2014 dollars in millions)

	As of	Latest 10/2013	Percent change
Research and development cost	NA	$1,565.2	NA
Procurement cost	NA	$103.3	NA
Total program cost	NA	$1,668.5	NA
Program unit cost	NA	$1,668.463	NA
Total quantities	NA	1	NA
Acquisition cycle time (months)	NA	116	NA

The Space Fence program has seven critical technologies, which are expected to demonstrate full maturity during or after the critical design review. The program delayed development start and awarding of the system development contract to May 2014, a delay of almost 2 years. As a result, the program delayed initial operational capability by a year to November 2018. DOD budget reductions also led to the early shutdown of the Air Force Space Surveillance System, which was originally planned to be operational through Space Fence's initial operations. A new data processing system is being developed by the Air Force, separate from Space Fence, to accommodate the projected increase in the volume of data generated.

Attainment of Product Knowledge

Projected as of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- *Release at least 90 percent of design drawings*
- *Test a system-level integrated prototype*

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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Space Fence Program

Technology Maturity

All seven of the program's critical technologies are currently nearing full maturity and are not expected to demonstrate full maturity until the critical design review, scheduled for 9 months after development start, or later. According to program officials, the critical technologies are not particularly challenging advances in technology. The risk for the program is in deploying radars on the very large scale needed. The program's technology development phase included competitive development of two fully working prototypes by separate contractors to reduce program risk. If a second radar site is deemed necessary, the technologies used for that site may differ, depending on the final program design.

Design and Production Maturity

The contract for the final Space Fence system development contract has not yet been awarded, so the program does not have a final system design and thus we did not assess design or production maturity.

Other Program Issues

The Air Force plans to competitively award a single system development and production contract in May 2014. This date reflects the second significant delay to contract award from the original date of July 2012. The first delay was due to an internal DOD program review required before the contract proposal could be issued. The program office attributes the additional delay in awarding the contract and initiating development to the strategic choices management review, which looked at affordability of future acquisitions DOD-wide.

The Air Force plans to award a fixed-price incentive contract for system development activities for the first radar site, with a contract option for the second site. If the option for the second site is exercised, it is planned to be operational 36 months after the program meets initial operational capability. However, funding for the second site is uncertain, and it potentially may not be needed depending on whether the first site exceeds its design capability. Program officials stated that the decision on whether or not to build a second site will likely be made after the first site is operational. In addition, the program has pushed back the anticipated initial operational capability date by more than a year, to 2018.

The Air Force Space Surveillance System, the legacy system that Space Fence will replace, ended operations in October 2013. The Air Force originally intended to keep that system functioning until Space Fence became operational. According to the Air Force, the decision to end operations early was made due to funding constraints caused by sequestration. Air Force officials said they have modified the operations of other space surveillance assets in a way that will maintain a roughly equivalent level of space surveillance until Space Fence is operational.

The Joint Space Operations Center (JSpOC) at Vandenberg AFB is acquiring a new data processing capability—JSpOC Mission System (JMS)—to process the increased volume of data expected from Space Fence. JMS is being developed through a separate acquisition program and, according to Space Fence program officials, is required to process the amount of data Space Fence is expected to generate. Currently, JMS is scheduled to become operational by December 2016, enabling input and processing of data from Space Fence in time for its initial operational capability.

Program Office Comments

In commenting on a draft of this assessment, the program office noted that the Office of the Secretary of Defense chose to delay the Space Fence system development certification in light of the strategic choices Management review outcomes. The Air Force amended the Space Fence request for proposals issued in November 2013. This amendment reflects the change to the initial operational capability delivery date, specified as 56 months after contract award (first quarter fiscal year 2019), as well as a full operational capability date, specified as 36 months after initial operational capability (first quarter fiscal year 2022). It also reflects an update to the total projected budget to more closely reflect the current fiscal reality. Having resumed source selection, award of a single fixed price incentive contract is expected in the third quarter of fiscal year 2014. The program also provided technical comments, which were incorporated where appropriate.

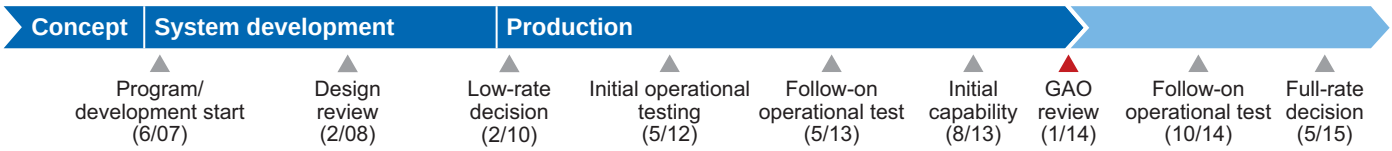
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Warfighter Information Network-Tactical Increment 2 (WIN-T Inc 2)

WIN-T is the Army's high-speed and high-capacity backbone communications network. It connects units with higher levels of command and provides the Army's tactical portion of the Global Information Grid. WIN-T was restructured following a March 2007 Nunn-McCurdy unit-cost breach of the critical threshold, and will be fielded in four increments. We assessed the second increment, which is expected to provide the Army with an initial networking on-the-move capability.



Source: U.S. Army.



Program Essentials

Prime contractor: General Dynamics C4 Systems, Inc.
Program office: Aberdeen Proving Ground, MD
Funding needed to complete:
R&D: $22.3 million
Procurement: $2,285.1 million
Total funding: $2,307.3 million
Procurement quantity: 661

Program Performance (fiscal year 2014 dollars in millions)

	As of 10/2007	Latest 08/2013	Percent change
Research and development cost	$250.9	$296.6	18.2
Procurement cost	$3,649.2	$4,749.6	30.2
Total program cost	$3,900.2	$5,046.2	29.4
Program unit cost	$2.060	$2.341	13.6
Total quantities	1,893	2,156	13.9
Acquisition cycle time (months)	50	74	48.0

The Army was directed in September 2013 to update the cost position and program baseline. These changes are not reflected in the latest column above.

WIN-T Increment 2 entered production in February 2010 with mature critical technologies and, according to program office metrics, a stable design, but before bringing manufacturing processes under control. A recent assessment of the program's manufacturing readiness levels indicates that these processes are now demonstrated and under control as the program approaches full rate production. However, during its May 2012 initial operational test, the program did not demonstrate required performance and reliability. A follow-on operational test in May 2013 showed improved reliability and performance but revealed that deficiencies remain. Consequently, the milestone decision authority has delayed the full rate production decision until the Army completes an additional follow-on operational test and confirms that deficiencies have been corrected.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ●
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ▪▪▪▪
- Test a system-level integrated prototype — ●

Manufacturing processes are mature

- Demonstrate critical processes are in control — ●
- *Demonstrate critical processes on a pilot production line*
- Test a production-representative prototype — ●

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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WIN-T Increment 2 Program

Technology Maturity

All 15 WIN-T Increment 2 critical technologies were mature by its February 2010 production decision. In August 2012, an independent manufacturing readiness assessment prepared by the Army concluded that the prime contractor had achieved an acceptable level of technology maturity to continue to full rate production.

Design Maturity

According to the WIN-T program, it has integrated and tested its key technologies and subsystems to demonstrate that the system's design is capable of working as intended. The program office does not track the metric we use to measure design maturity—the number of releasable drawings—as WIN-T is primarily an information technology integration effort. Instead, design performance is measured through a series of component, subsystem, configuration item, and network-level tests designed to demonstrate performance at increasing levels of system integration. Design stability is measured through problem-tracking report trends.

Production Maturity

The WIN-T Increment 2 program began production in February 2010 and began testing a production-representative prototype 13 months later in March 2011. The program indicates that its manufacturing processes—as determined by an Army manufacturing readiness assessment—are now in control, but had not yet been demonstrated or brought in control at production start. During its May 2012 initial operational test, the program did not demonstrate required performance and reliability. A follow-on operational test in May 2013 showed improved reliability and performance but revealed that deficiencies remain. In particular, three of the program's nine configuration items were assessed as not operationally effective and two were not operationally suitable due to complexity of operations and reliability problems. In addition, the program demonstrated cyber security vulnerabilities that need improvement. Consequently, the milestone decision authority has delayed a full rate production decision until the Army completes an additional follow-on operational test in November 2014 as part of the Army's Network Integration Evaluation 15.1 that confirms that deficiencies have been corrected. A full-rate production decision is planned for May 2015.

Other Program Issues

While the milestone decision authority has not yet approved a full-rate production decision, the Army declared that the program attained its initial capability in August 2013. This decision was based on the Army's assertion that initial operational capability was reached when the first brigade combat team and its division headquarters was equipped and fully trained with the new equipment and the follow on operational test had been successfully completed. However, as noted above, the May 2013 follow-on operational test revealed deficiencies with the program that must be corrected and these corrections must be confirmed during an additional follow-on operational test.

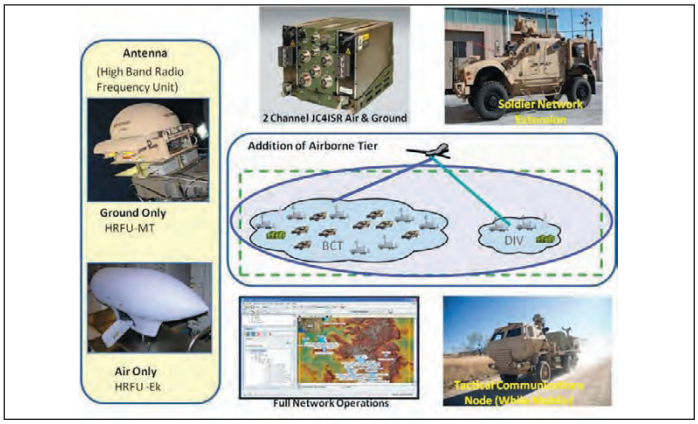
Program Office Comments

In commenting on a draft of this assessment, the Army noted that in September 2013, it received approval from the Defense Acquisition Board for an additional low-rate initial production lot and an acceptance to field existing lots of WIN-T Increment 2. The Army has fielded five Brigade Combat Teams and two divisions, and remains on track to field Capability Set 14 to units, including Stryker Brigade Combat Teams. Using soldier feedback from theater and test results, the Army intends to continue to improve WIN-T Increment 2 capabilities with the primary focus being on simplifying the operations and maintenance of the equipment. The program office also provided technical comments, which were incorporated where deemed appropriate.

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Warfighter Information Network-Tactical Increment 3 (WIN-T Inc 3)

WIN-T is the Army's high-speed and high-capacity backbone communications network. It connects units with higher levels of command and provides the Army's tactical portion of the Global Information Grid. WIN-T was restructured following a March 2007 Nunn-McCurdy unit-cost breach of the critical threshold, and will be fielded in four increments. We assessed the third increment, which is expected to provide the Army a full networking on-the-move capability.



Source: U.S. Army.



Program Essentials

Prime contractor: General Dynamics C4 Systems, Inc.
Program office: Aberdeen Proving Ground, MD
Funding needed to complete:
- R&D: $728.0 million
- Procurement: $12,850.7 million
- Total funding: $13,578.7 million
- Procurement quantity: 3,449

Program Performance (fiscal year 2014 dollars in millions)

	As of 05/2009	Latest 08/2013	Percent change
Research and development cost	$2,826.4	$2,563.0	-9.3
Procurement cost	$14,387.9	$12,850.7	-10.7
Total program cost	$17,214.3	$15,413.7	-10.5
Program unit cost	$4.944	$4.388	-11.3
Total quantities	3,482	3,513	0.9
Acquisition cycle time (months)	165	199	20.6

The Army is restructuring the program. Changes to the program's costs, quantities, and schedule from this restructuring are not reflected in the latest column above.

According to an Army representative, 12 of WIN-T Increment 3's 18 current critical technologies are mature and 6 are nearing maturity following the critical design review of the program in December 2013. However, the program is being restructured based on the recommendations of a configuration steering board held in November 2013. This restructuring could affect the program's need for certain critical technologies. The program does not use the number of design drawings released or alternative methods to assess design stability. However, the program plans to begin capturing software design stability metrics once a baseline system design is established.

Attainment of Product Knowledge

As of January 2014

Resources and requirements match

- Demonstrate all critical technologies in a relevant environment — ●
- Demonstrate all critical technologies in a realistic environment — ○
- Complete preliminary design review — ●

Product design is stable

- Release at least 90 percent of design drawings — ▪▪▪▪
- Test a system-level integrated prototype — ○

Manufacturing processes are mature

- *Demonstrate critical processes are in control*
- *Demonstrate critical processes on a pilot production line*
- *Test a production-representative prototype*

● Knowledge attained
○ Knowledge not attained
▪▪▪▪ Information not available
Not applicable

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WIN-T Increment 3 Program

Technology Maturity

According to an Army representative, 12 of the program's 18 current critical technologies are mature, and 6 are nearing maturity following the critical design review of the program in December 2013. However, in January 2014 the Army acquisition executive directed the program executive officer with oversight of the WIN-T Increment 3 program to restructure the program based on the recommendations of the Army's configuration steering board.

The program's restructuring could affect its need for certain critical technologies. For example, the Army's configuration steering board has recommended descoping the air tier from the program. According to an Army representative, the program will need to complete a follow-on critical design review once it has been restructured, at which point the critical technologies will need to be reassessed.

Design Maturity

The program does not use the number of design drawings released or any alternative methods to assess design stability. According to the program office, the number of design drawings is not meaningful as WIN-T is not a manufacturing effort, but a software development and hardware integration effort. The program asserts that it has appropriate software metrics and tracks design stability through its configuration management software production plan.

Other Program Issues

According to an Army representative, the Army is in the process of conducting a "network capability" review to determine the "right mix"of tactical networking capabilities to provide to brigade combat teams. In addition, the program is awaiting the final assessments from the Army's recently completed configuration steering board. These two events will factor into the scope of the restructured program. According to an Army representative, restructuring considerations may include maximizing the use of the capabilities currently being fielded under the WIN-T Increment 2 program while maintaining focus on WIN-T Increment 3 network operations efforts and balancing affordability, as DOD and the Army face long-term budgetary challenges.

Program Office Comments

In commenting on a draft of this assessment, the Army noted that as of early 2014, the WIN-T Increment 3 program is anticipating a final program assessment from the Department following the program's critical design review and is also awaiting Department's approval of a program transition strategy based on the WIN-T Increment 3 configuration steering board meeting held in November 2013. These events, coupled with ongoing Army tactical network capability review decisions, will provide guidance on the scope of the program's effort going forward.

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Airborne and Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS)

The Army's AMF JTRS program plans to acquire two non-developmental software-defined radios, the Small Airborne Link 16 Terminal (SALT) and the Small Airborne Networking Radio (SANR), and associated equipment for integration into Army rotary wing and unmanned aerial systems. Previously, the program had been developing software-defined radios and associated equipment for integration into nearly 160 different types of aircraft, ships, and fixed stations to increase communications and networking capabilities.



Source: U.S. Army.

Current Status

The Under Secretary of Defense for Acquisition, Technology, and Logistics, in July 2012, restructured the AMF JTRS program due to concerns about the potential for unbounded cost increases, and continued schedule and contractor performance risk. Market research also determined that non-developmental items could be modified to meet users' revised needs and priorities. The Under Secretary also transferred responsibility for program management to the Army. While the use of a non-developmental item approach will likely reduce some technical risk, the Army will need to manage the integration of government-developed waveforms into the non-developmental item radios and the radios into various platforms.

AMF JTRS now plans to acquire two non-developmental software-defined radios. The SALT is designed to be a 2-channel radio capable of running the Link 16 waveform and the Soldier Radio Waveform (SRW). The program plans to introduce production hardware into the Apache AH-64E assembly line in fiscal year 2016. Until then, according to program officials, the Apache program office is pursuing an interim solution, the Small Tactical Terminal (STT), which will run only Link 16. The Army acquisition strategy for SALT calls for full and open competition. The Army plans to release the SALT request for proposals in the second quarter of fiscal year 2014 and a full rate production decision is scheduled for fiscal year 2016.

The SANR is designed as a 2-channel radio capable of running the SRW, Single Channel Ground and Airborne Radio System waveform, and the Wideband Networking Waveform. The SANR acquisition strategy plans a full and open competition to select two contractors for SANR test assets. A low rate initial production decision is scheduled for fiscal year 2016 and full rate production is scheduled for fiscal year 2018.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program: $3,582.7 million
Research and development: $1,849.3 million
Procurement: $1,733.4 million
Quantity: 15,652 channels

Next Major Program Event: SALT full-rate production and SANR low-rate initial production decisions in first quarter 2016.

Program Office Comments: The program office concurred with the assessment.

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Amphibious Combat Vehicle (ACV)

The Marine Corps' ACV is intended to transport troops from ship to shore and secure a beachhead. The Marine Corps has a requirement to replace the existing amphibious assault vehicle (AAV) but the Secretary of Defense terminated the initial effort, the Expeditionary Fighting Vehicle (EFV) program, in January 2011 due to technology problems, development delays, and cost increases.



Source: U.S. Marine Corps.

Current Status

A December 2011 materiel development decision memorandum directed that a "highly tailored" approach be used to acquire the ACV and that this effort focus on a cost-effective solution, emphasizing engineering and design analysis through establishment of affordability targets. According to officials, the Marine Corps completed an ACV analysis of alternatives (AOA) in July 2012 and the Navy forwarded it to the Office of the Secretary of Defense. According to ACV program officials, although high-water speed had been a primary requirement for the EFV, it was not part of the initial ACV AOA study. Instead, the study was based on a speed requirement that was about half of the EFV's, which would make the ACV a "displacement" vehicle more similar in water speed to the AAV. Marine Corps leadership subsequently directed that the affordability of a high-water speed amphibious vehicle be studied before the ACV began acquisition. This feasibility analysis is ongoing.

Officials reported that the Marine Corps is studying trade-offs in ACV capability to find the ACV design that will provide improvements in amphibious capability-speed, range, lethality, and survivability-over the current amphibious vehicle at an affordable cost. They added that, following the feasibility analysis, the Marine Corps Commandant will make a decision on whether the ACV acquisition program will formally begin at technology development or system development. Expectations are that the ACV will not reach initial operating capability before 2023. To address the delay in fielding an amphibious vehicle to replace the legacy AAVs, 392 current AAVs will undergo survivability upgrades that will address deficiencies in survivability.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program: TBD
Research and development (fiscal years 2012-2017): $1,047.1 million
Procurement: TBD
Acquisition related operation and maintenance (fiscal years 2012-2017): $18.9 million
Quantity: TBD

Next Major Program Event: System development start, TBD

Program Office Comments: The Marine Corps was provided a draft of this assessment and did not offer any comments.

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Armored Multi-Purpose Vehicle (AMPV)

The Army's Armored Multi-Purpose Vehicle (AMPV) fleet is the proposed replacement to the M113 family of vehicles in the armored brigade combat team. The AMPV will replace the M113 in five mission roles: general purpose, medical evacuation, medical treatment, mortar carrier, and mission command. The Army has determined that development of the AMPV is necessary due to mobility deficiencies identified in the M113, as well as space, weight, power and cooling limitations that prevent the incorporation of future technologies.



Source: U.S. Armv.

Current Status

Based on direction at the August and November 2013 defense acquisition board reviews, AMPV's acquisition strategy was updated and approved before a request for proposals was released in November 2013. The program's acquisition strategy is based on modifying an existing platform and bypasses the technology development phase to begin in system development. The program is still working to define key technologies, and as a result, will require potential contractors to include data related to the technology maturity of their design in each proposal. AMPV's acquisition strategy also calls for selection of a single contractor for system development, and provides for three low-rate initial production options within the system development contract. The program currently plans to award a cost plus incentive fee contract for system development with a fixed price incentive option for low-rate initial production. The AMPV contract will include engineering and manufacturing development and low-rate initial production incentives for cost and reliability.

Procurement of AMPV, with an estimated total acquisition cost of up to $10.2 billion, will occur at about the same time as the Army's Joint Light Tactical Vehicle program. The procurement of these programs is expected to continue for a decade or more.

Estimated Total Program Cost and Quantity (fiscal year 2014 dollars)
Total Program: $10,223 million
Research and development: $779.9 million
Procurement: $9,443.0 million
Quantity: 2,907

Next Major Program Event: Start of system development, first quarter fiscal year 2015

Program Office Comments: In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated where deemed appropriate.

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B-2 Defensive Management System Modernization (B-2 DMS)

The Air Force's B-2 DMS modernization program is expected to upgrade the aircraft's analog defensive management system to a digital capability to detect, identify and avoid threats. The modernization is intended to update pilot displays and enhance the in-flight capability to avoid unanticipated air defense threats. Improvement in frequency coverage, sensitivity of the electronic warfare suite, and reliability and maintainability are also anticipated. The latter is expected to improve the B-2's readiness rate.



Source: U.S. Air Force.

Current Status

In October 2012, the program entered a second technology development phase, which continued throughout 2013. The program had scheduled a preliminary design review prior to beginning system development in April 2014, but officials told us they are currently restructuring the program due to expected future budget reductions. Program documentation indicates moderate technical risk due to the program's schedule and nuclear hardening activities. Also, the antenna design, the software schedule, and the availability of test aircraft are risk areas. Early in the program, an independent assessment identified six critical technologies; however, currently the program does not believe any critical technologies exist. Another independent technology readiness assessment, scheduled prior to system development, will identify the final list of critical technologies.

We have previously reported that the program was implementing a rapid acquisition initiative to reduce its acquisition time by up to 3 years and lower costs by as much as $500 million. To achieve these results, several activities were planned including: early software prototyping, reducing the time required for flight testing, and improving antenna installation times. By conducting these activities, it was anticipated the program might take 7 years to complete and cost $1.58 billion. While some parts of the initiative have yielded positive results, including a subcontractor competition for antenna development that officials told us saved time and money, the program's start of development, flight testing, and full operational capability have all been delayed. The program now expects to complete acquisition in almost 9 years at a cost of over $2 billion, which means most of the expected reductions in cost and schedule from the initiative will not be realized.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program: $2,036 million
Research and development: $1,385 million
Procurement: $651 million
Quantity: 20

Next Major Program Event: System development start, April 2014

Program Office Comments: In commenting on a draft of this assessment, DOD officials told us the assessment is accurate based on the fiscal year 2014 budget. They added that the B-2 DMS modernization program remains the top B-2 modernization priority. The program office also provided technical comments which were incorporated as appropriate.

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Combat Rescue Helicopter (CRH)

The Air Force's Combat Rescue Helicopter (CRH) program, formerly called HH-60 Recapitalization, is an effort to replace aging HH-60G Pave Hawk helicopters. The CRH's primary mission is to recover personnel from hostile or denied territory; it will also conduct humanitarian, civil search and rescue, disaster relief, and non-combatant evacuation missions. The program is the second effort to replace the HH-60G. The first, the Combat Search and Rescue Replacement Vehicle (CSAR-X), was canceled because of cost concerns in 2009.



Source: 2013 Sikorsky Aircraft Corp. Used with permission for support of CRH.

Current Status

The Air Force expects that the CRH will be an existing helicopter with modifications to integrate mature technology subsystems and associated software. The CRH program received its materiel development decision in March 2012 and DOD authorized the program to bypass technology development and enter the acquisition process at system development. The program successfully completed a defense acquisition board review in September 2012 which approved its acquisition strategy and release of a request for proposals for a full and open competition in October 2012. Depending upon the availability of future funding, the CRH program office plans to enter system development in March 2014, delayed from the originally scheduled August 2013. The program is preparing to then award a fixed price incentive firm target development contract to Sikorsky, which was the only contractor who responded to the request for proposals. However, the program does not intend to conduct any systems engineering technical reviews until after the development contract is awarded. According to officials from the Office of the Secretary of Defense, the program was granted a waiver in late 2012 to conduct its preliminary design review after the start of system development, as well as a waiver for the requirement to conduct competitive prototyping. In our previous work, we have found that acquisition programs which successfully complete robust systems engineering early in the acquisition process and conduct a preliminary design review prior to starting system development typically have better outcomes. Initial operational capability for the helicopter is expected in the fourth quarter of fiscal year 2019.

Estimated Total Program Cost (fiscal year 2014 dollars):
Total program: TBD
Research and development (fiscal years 2012-2018): $1,310.9 million
Procurement (fiscal years 2016-2018): $ 2,187.7 million
Military construction: TBD
Acquisition operations and maintenance: TBD
Total quantity: 112

Next Major Program Event: System development start, March 2014

Program Office Comments: In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated where deemed appropriate.

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Common Infrared Countermeasure (CIRCM)

The Army's CIRCM, the next generation of the Advanced Threat Infrared Countermeasures (ATIRCM), will be used with a missile warning system and a countermeasure dispenser capable of employing expendables, such as flares and chaff, to defend aircraft from infrared-guided missiles. The CIRCM program will develop a laser-based countermeasure system for rotary-wing, tilt-rotor, and small fixed-wing aircraft across DOD. CIRCM is one of three subprograms that make up the ATIRCM/CMWS major defense acquisition program.



Sources: © 2011 BAE Systems (left); Northrop Grumman (right)

Current Status

The CIRCM program began in 2009 when the Under Secretary of Defense for Acquisition, Technology and Logistics supported the Army's decision to restructure the ATIRCM/CMWS program. In June 2009, the Army received approval to award five contracts to provide prototype systems for testing. After testing these prototypes, the Army concluded that the systems were not mature enough for entry into system development. The Army subsequently decided that the program should proceed with a technology development phase that will include additional prototyping efforts to further mature CIRCM technologies and awarded two contracts in January 2012.

The Army held preliminary design reviews in July and August, 2013 with both contractors. The review report stated that the system's preliminary design satisfies the operational and suitability requirements. Also, the Army recently conducted a preliminary technology readiness assessment based on contractor testing in which nine critical technology elements were identified and are approaching full maturity leading up to system development. A final technology readiness assessment will be conducted prior to development to verify technology and design maturity and will be based on government-witnessed testing.

In October 2013, the two CIRCM contractors completed prototypes deliveries. According to the Army, both designs are mature and are low risk of not meeting the specified requirements even with the current configurations. The Army plans to make a system development decision in December 2014 and plans to award one contractor a cost plus fixed fee/firm fixed price contract with technical performance incentives focused on achievement of weight and reliability goals.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total Program: $3,599.8 million
Research and development: $788.8 million
Procurement: $2,811.0 million
Quantity: 1,076

Next Major Program Event: System development start, December 2014

Program Office Comments: In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated where deemed appropriate.

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DDG 51 Destroyer (DDG 51)

The DDG 51 destroyer is a multimission ship designed to operate against air, surface, and subsurface threats. After a nearly 4-year break, the Navy restarted Flight IIA production and plans to buy at least nine ships between fiscal years 2013 and 2017. The Navy plans to procure three Flight III ships, a modification of the Flight IIA design, beginning in fiscal year 2016. Flight III is expected to have an increased focus on missile defense and will include the Air and Missile Defense Radar (AMDR), initially an S-band radar developed under a separate program.



Source: Bath Iron Works.

Current Status

Four DDG 51 Flight IIA ships are under construction and an additional nine ships are under contract. The design of the Flight IIA ships will be modified to include an upgraded Aegis combat system currently being developed. The Navy will also replace the existing SPS-67 radar with SPQ-9B, currently installed on several Navy ships, beginning in fiscal year 2014. The Navy believes that it has largely resolved issues with production of a new reduction gear.

DDG 51 Flight III ships are expected to feature new electric plants, new air-conditioning plants, and the AMDR. According to the Navy, the new electric plants are based on a design used on DDG 1000 and modification will be required for integration with DDG 51. The DDG 1000 electrical system has faced delays in completing testing. Detail design work for Flight III will begin at the end of fiscal year 2014, according to the Navy. Adding AMDR to DDG 51 will result in a significant redesign of the ship and the Navy expects that Flight III will result in changes to more than 25 percent of Flight IIA drawings, although the Navy believes many of these will be minor alterations. The Navy will need AMDR's design assumptions, such as its size, shape, weight, and power and cooling requirements in order to accurately redesign the ship. However, the Navy only recently awarded a contract for AMDR system development and the AMDR program is at least 6 months behind schedule. Based on its current schedule, the Navy plans to begin detail design work for Flight III at the end of fiscal year 2014—before AMDR has demonstrated full maturity-adding risk and uncertainty to the DDG 51 program.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program (fiscal years 2010 to 2018): $23,089.5 million
Research and development (fiscal years 2010 to 2018): $900 million
Procurement (fiscal years 2010 to 2018): $22,189.6 million
Quantity: 15

Next Major Program Event: Defense acquisition board review of Flight III modifications, third quarter fiscal year 2014.

Program Office Comments: According to program officials, the Flight III schedule integrates all equipment development efforts into the overall ship detail design effort. This is the same process successfully implemented on previous flight upgrades. Due to the AMDR technology development phase, which produced working 1000-element arrays, the current design maturity supports commencement of detail design. Flight III is on track to be implemented on the second fiscal year 2016 ship.

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F-15 Eagle Passive/Active Warning and Survivability System (F-15 EPAWSS)

The Air Force's F-15 EPAWSS program is intended to upgrade the electronic warfare system on fielded F-15 aircraft. The program seeks to improve the aircraft's internal self-protection electronic warfare systems to enable operations in current and future threat environments. The program is also expected to improve the F-15's survivability by enhancing its ability to detect, identify, locate, deny, degrade, disrupt, and defeat air and ground threat systems.



Source: U.S. Air Force.

Current Status

In November 2012, the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics approved the Air Force's plans to conduct an analysis of alternatives and to award a pre-engineering and manufacturing development characterization contract for the F-15 EPAWSS program, which occurred in fiscal year 2013. The Air Force plans to leverage non-developmental electronic warfare technologies and components, currently used in other Air Force and Navy aircraft, to create a state-of-the-art wide bandwidth digital electronic warfare system capable of protecting the F-15 aircraft against advanced enemy threats. The Air Force is currently updating the program's requirements documentation and intends to conduct a preliminary design review before starting system development in fiscal year 2016. The program office plans to award a production contract in fiscal year 2018.

An early Air Force assessment of F-15 EPAWSS identified digital receiver technology—both the hardware and the associated software—as a critical technology that the program does not intend to fully mature prior to the start of system development. According to program officials, a key risk is integration of the electronic warfare system with all other on-board and off-board systems, so that it operates properly in its intended operational environment. The program expects to add future capabilities as new electronic warfare threats emerge.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program: TBD
Research and development: $614.9 million (fiscal years 2014 to 2018)
Procurement: TBD
Quantity: 392

Next Major Program Event: Defense acquisition board review of acquisition strategy, February 2014

Program Office Comments: According to the Air Force, the program office continues to refine the planning for the F-15 EPAWSS program based on in-work requirements documentation and final acquisition strategy approval by the Milestone Decision Authority.

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Ground Combat Vehicle (GCV)

The Ground Combat Vehicle (GCV) is an incremental program to replace segments of the Army's combat vehicle inventory. The first variant is intended to be the service's next infantry fighting vehicle, replacing a portion of the current M2 Bradley fleet. The Army expects GCV to provide a full-spectrum capability to perform offensive, defensive, stability, and support operations; carry a nine-soldier squad; emphasize force protection; and be operational within 7 years of beginning technology development.



Source: U.S. Army.

Current Status

In August 2011, the Under Secretary of Defense for Acquisition, Technology, and Logistics approved GCV's entry into technology development. The Army awarded contracts to two contractor teams, but resolving a bid protest prevented the start of technology development until December 2011. Since then, the Army has been involved in three activities: updating the analysis of alternatives, assessing upgrades to existing vehicles, and funding two contractors' efforts to build and demonstrate key subsystem prototypes.

On January 16, 2013, the Under Secretary directed a number of changes to the program, including extending the technology development phase six months, delaying both system development and production, and directing that a single prime contractor be selected for system development. These actions provide significant reductions to the funding necessary to execute the program.

An independent review team identified three candidate critical technologies—all nearing full maturity—that could be incorporated into the GCV design. The program will continue monitoring these technologies and consider their maturity and risk as part of the full and open competition planned for system development. Since our last report, both contractors continued technology development by maturing preliminary designs and subsystems, completing multiple tests of their respective mine blast protection designs, and testing engines and drive trains. After holding preliminary design reviews to determine whether the proposed designs could satisfy requirements, a defense acquisition board will determine the program's readiness to proceed into system development, which is expected to begin in June 2014.The Army plans to begin procuring GCV while simultaneously procuring other new and costly combat vehicles including the Joint Light Tactical Vehicle.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program: $29,219.6 million
Research and development: $4,968.5 million
Procurement: $24,229.1 million
Quantity: 12 (development), 1,874 (procurement)

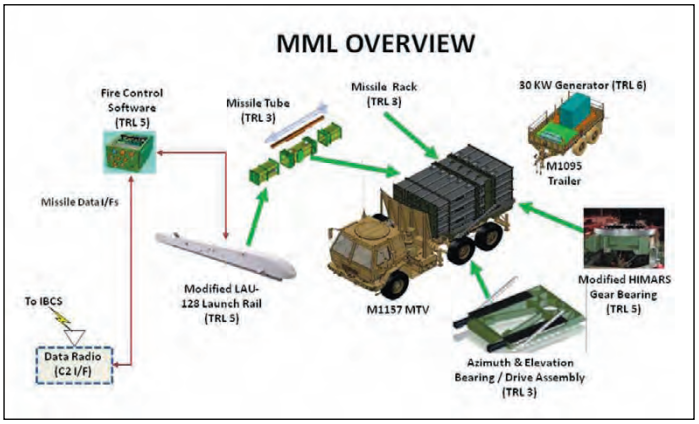
Next Major Program Event: System development start, June 2014

Program Office Comments: According to officials in the office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, the GCV program was cancelled on the order of the Secretary of Defense.

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Indirect Fire Protection Capability-Increment 2 (IFPC Inc 2)

The Army's IFPC Increment 2 consists of three blocks, each a separate major defense acquisition program, to detect, assess, and defend against threats from rockets, artillery, mortars, cruise missiles, and unmanned aircraft. The first IFPC increment, fielded in 2004, provides a short-range capability to counter rockets, artillery, and mortar threats. IFPC Increment 2, Block 1 establishes the capability to counter cruise missiles and unmanned aircraft. The remaining blocks add to and extend the range and capability.



Source: U.S. Army.

Current Status

In 2004, after the first increment of IFPC was fielded, users developed a new requirement to counter unmanned aircraft and cruise missiles. The Surface Launched Advanced Medium-Range Air-to-Air Missile was originally set to fulfill this requirement, but was cancelled. To replace it, in 2011, the Army proposed a new interceptor, launcher, and radar. The $1.6 billion estimate for developing this new system, however, was deemed unaffordable. The Army then proposed a three block alternative, each a separate major defense acquisition program, which leverages an existing interceptor and sensor and competitively awards the development of a new launcher. Block 1 is scheduled for fielding in fiscal year 2019. The review to begin technology development for Block 1 was held October 22, 2013, but final approval is pending until January 2014 due to budget concerns, including sequestration, according to officials. Program officials noted that the most significant risk is integration with the existing systems being leveraged, such as the AIM 9 Class Interceptor and the Sentinel radar. Successful integration is necessary to avoid increased costs or overall failure to meet requirements. According to program officials, the program is reusing existing technologies to promote affordability and using open systems architecture for the launcher to enable it to work with a variety of current and future missiles. Blocks 2 and 3 are scheduled to begin development in fiscal years 2019 and 2027, respectively.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program: $2.5 billion
Research and development: $510 million
Procurement: $2.0 billion
Quantity: 5 (development), 344 (procurement)

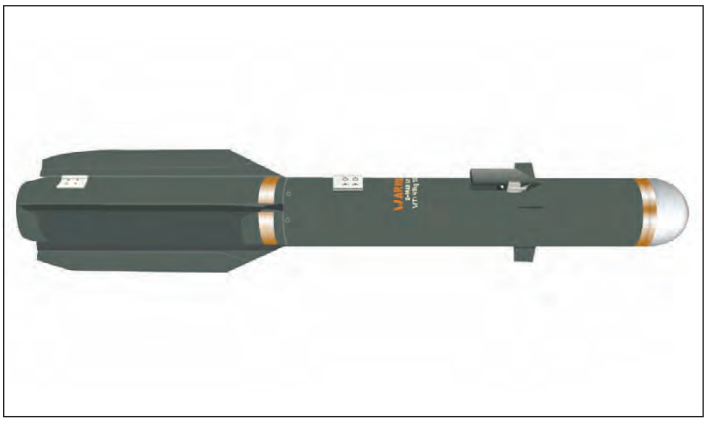
Next Major Program Event: System requirement review, January 2014

Program Office Comments: In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated where deemed appropriate.

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Joint Air-to-Ground Missile (JAGM)

The Joint Air-to-Ground missile is an Army-led program with joint requirements from the Navy and Marine Corps. The missile is designed to be air-launched from helicopters and unmanned aircraft systems to target tanks; light armored vehicles; missile launchers; command, control, and communications vehicles; bunkers; and buildings. It is intended to provide line-of-sight and beyond line-of-sight capabilities and deploy in a fire-and-forget mode or a precision attack mode. JAGM will replace all variants of HELLFIRE missiles.



Source: U.S. Army.

Current Status

In early 2012, the Army restructured JAGM extending technology development by more than 2 years to explore evolutionary alternatives to the acquisition strategy, refine requirements and explore a more affordable solution. In August and November 2012, the Army awarded letter contracts to Lockheed Martin and Raytheon for this extended technology development. Program officials stated that these efforts focus on the guidance section, the key technology that provides the capabilities required by the Army, Marine Corps, and Navy. Preliminary design reviews of each contractor's design were held in February and April 2013, respectively.

The Assistant Secretary of the Army for Acquisition, Technology, and Logistics conducted a program status review informed by the preliminary design reviews to assess the program's cost, schedule, and performance risk. Based on funding shortfalls of $36 million and findings of the risk assessment, in August 2013, the Assistant Secretary of the Army for Acquisition, Technology, and Logistics directed the JAGM program to execute the continued technology development phase with a single contractor in order to meet technology development objectives on schedule. According to program officials, Raytheon's technical performance was not on track to meet program goals or Army requirements. As a result, the government did not award a follow-on contract to extend performance after April 2013. Lockheed Martin will continue with technology development under their existing contract. Upon completion of all objectives and technology development exit criteria, approval of the acquisition strategy, and completion of the source selection evaluation board, the Army is planning for a system development decision in fiscal year 2015. The acquisition strategy will allow for a competitive contract award for system development.

Estimated Total Program Cost and Quantity (fiscal year 2014 dollars):
Total Program: TBD
Research and development (fiscal years 2008-2018): $656.4 million
Procurement (fiscal years 2008 to 2018): $116.8 million
Quantity: 167

Next Major Program Event: Subcomponent critical design review, January 2014

Program Office Comments: In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated where deemed appropriate.

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Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS)

The Army's JLENS is designed to provide elevated, persistent, over-the-horizon surveillance and fire control quality data enabling protection of U.S. and coalition forces and critical assets. A JLENS orbit consists of two systems: a fire control radar system and a surveillance radar system. Each system is comprised of a 74-meter tethered aerostat, a mobile mooring station, communication and processing stations, and ground support equipment. The program was restructured following a Nunn-McCurdy unit-cost breach of the critical threshold.



Source: U.S. Army.

Current Status

In August 2013, the Under Secretary of Defense for Acquisition, Technology, and Logistics approved the program's revised acquisition program baseline, re-designated the program's acquisition category and delegated milestone decision authority to the Secretary of the Army. The JLENS program satisfied developmental testing and evaluation requirements and is proceeding with plans to execute a 3-year operational combatant command exercise. The exercise is expected to demonstrate JLENS capabilities for homeland defense and inform a future decision for enduring operational employment.

The program reported that recent operational test events at the Utah Test and Training Range and at the White Sands Missile Range demonstrate that JLENS performs as expected. Phase two of the second early user test—which assessed system performance and reliability and allowed for soldier training on system configuration—was successfully completed in June 2013, and, according to program officials, eliminated the need for the third series of developmental tests. Integrated fire control testing occurred in July 2013 and demonstrated JLENS capabilities in acquiring, tracking and providing sensor track data. The program will need to complete "friend or foe" identification system and communication link certification events before it can participate in the exercise. Site construction for the deployment of the exercise will begin at Aberdeen Proving Ground after the February 2014 construction contract award. The construction will involve completing aerostat pads, roads, operation and support facilities, and infrastructure. The initial system is expected to arrive at the exercise site location in June 2014 and initial capability delivery is expected for the surveillance radar in September 2014 and the fire control radar system in December 2014.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program: $2,782.12 million
Research and development: $2,741.61 million
Military construction: $40.51 million
Quantity: 2

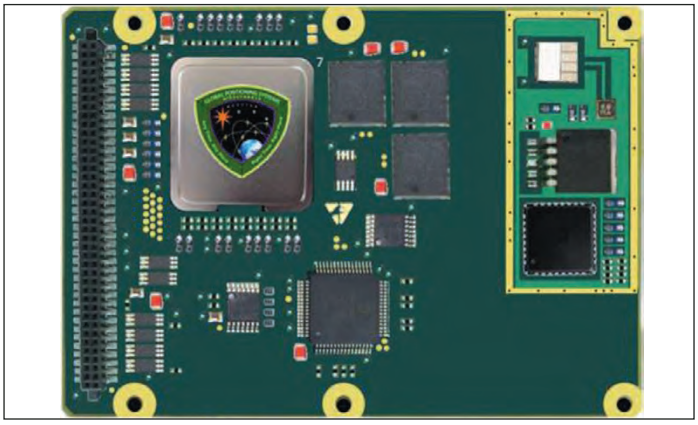
Next Major Program Event: February 2014 construction contract award for exercise site construction.

Program Office Comments: In commenting on a draft of this assessment, the program office provided technical comments, which were incorporated where deemed appropriate.

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Military GPS User Equipment (MGUE), Increment 1

The Air Force's MGUE program plans to develop GPS receivers compatible with the military's next-generation GPS signal, Military-Code. The modernized receivers are to provide U.S. forces with enhanced position, navigation, and time capabilities, while improving resistance to existing and emerging threats, such as jamming. The program is to be completed in two increments. Increment 1, assessed here, leverages technologies from the Modernized User Equipment (MUE) program to develop two variants and begin development of the Common GPS Module.



Source: U.S. Air Force.

Current Status

In April 2012, the Air Force initiated technology development for Increment 1 of MGUE. According to the Air Force, all five critical technologies identified by the Office of the Secretary of Defense—military-code acquisition engine, military-code cryptography, selective availability/anti-spoofing module cryptography, anti-spoofing, and anti-tamper-are currently nearing maturity. The Air Force plans to develop two variants—one each for ground and aviation, as Navy officials believe the aviation variant can support maritime needs. The current approved Increment 1 program leverages technologies from the Modernized User Equipment program to develop two variants and begin development of the Common GPS Module. Increment 2 is not yet approved.

The program's preliminary design review has been delayed 5 months, to June 2014. According to officials, the delay was caused by two factors: sequestration of fiscal year 2013 MGUE funding, which forced the program to limit contractor activity, and a new initiative to reduce complexity within the cryptography required to encrypt and decrypt communications. In last year's assessment, the program reported two main risk areas, ensuring more than one contractor meets design requirements for the application specific integrated circuit (ASIC)—a vital component leveraged from MUE—and software development. According to Air Force officials, progress in manufacturing and testing the ASIC as well as the complexity reduction effort has largely addressed these risk areas. However, the program identified a new risk in obtaining security certification to field GPS receivers in unclassified environments. According to officials, however, neither the delay in the preliminary design review nor the risk areas is expected to delay the program's entry into system development, scheduled for November 2014.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program: TBD
Research and development: $1,658.0 million
Procurement: TBD
Quantity: 124 (development), 550 (production)

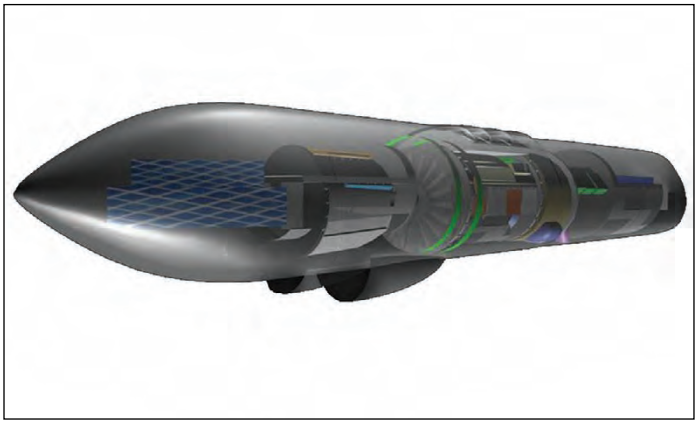
Next Major Program Event: Preliminary design review, April 2014

Program Office Comments: In commenting on a draft of this assessment, the Air Force affirmed that it continues to strive to field military-code GPS receivers as quickly as possible. The service has leveraged previous technology and industry experience to mitigate risk and reduce cost, and seeks additional opportunities to streamline the MGUE acquisition. The program office also provided technical comments, which have been incorporated where appropriate.

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Next Generation Jammer (NGJ)

The Navy's Next Generation Jammer (NGJ) is being developed as an external jamming pod system fitted on carrier-based EA-18G Growler aircraft. It will replace the ALQ-99 jamming pod system and provide enhanced airborne electronic attack capabilities to disrupt and degrade enemy air defense and ground communication systems. The Navy plans to field capabilities in three increments for different radio frequency ranges beginning with Increment 1 (mid-band) in 2020 with Increments 2 and 3 (low- and high-band) to follow. We assessed Increment 1.



Source: U.S. Navy.

Current Status

In July 2013, DOD approved NGJ Increment 1's entry into technology development; however, work was delayed when GAO sustained a protest related to the technology development contract award. Prior to technology development, the Navy completed a 33-month technology maturation phase, during which the Navy selected four contractors to prototype key technologies and subsystems related to their proposed NGJ Increment 1 concept. According to program officials, each contractor chose the technologies to prototype during technology maturation, but they generally aligned with five critical technology areas—power generation and distribution, exciters, beam formers, amplifiers, and apertures. DOD believes that these prototyping activities meet the competitive prototyping requirements of the Weapon Systems Acquisition Reform Act of 2009, which require competitive prototyping for MDAPs before system development unless a waiver is granted. The program office stated it is also planning to use open systems architecture to enhance future competitions and to provide flexibility for upgrades.

Following technology maturation, the Navy awarded a single $280 million contract to Raytheon for technology development with plans to award a sole-source follow-on contract to complete system development for Increment 1. In October 2011, the Navy stated that it expected to save about $641 million by using only one contractor for technology development. In November 2013, GAO sustained portions of BAE Systems' protest of the contract award and recommended that the Navy document a reevaluation of the proposals and a cost/technical tradeoff analysis. In January 2014, the Navy reaffirmed Raytheon's contract award and resumed NGJ's technology development efforts after a 6-month delay, but faces a $100 million funding reduction.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program: $6,336.3 million
Research and development: $2,894.6 million
Procurement: $3,442.7 million
Quantity: 9 (development), 114 (procurement)

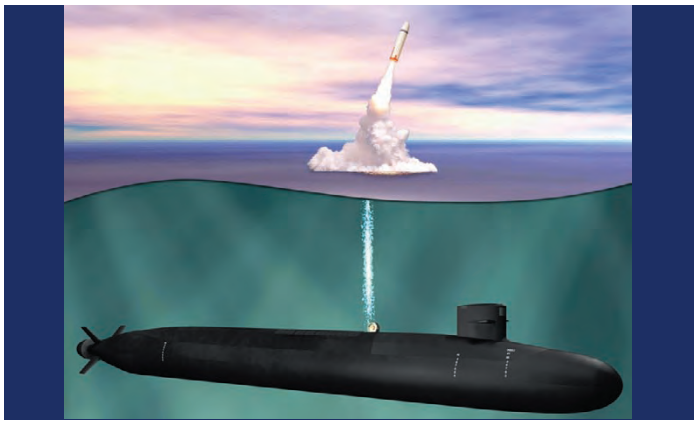
Next Major Program Event: System development start, second quarter fiscal year 2016

Program Office Comments: The NGJ program office provided technical comments, which were incorporated as appropriate. The Navy is reviewing its schedule to identify actions to maintain its fiscal year 2020 fielding date for NGJ Increment 1.

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Ohio-Class Replacement (OR)

The Navy's *Ohio*-class Replacement (OR) will replace the current fleet of *Ohio*-class ballistic missile submarines (SSBNs) as they begin to retire in 2027. The Navy began technology development in January 2011 in order to avoid a gap in sea based nuclear deterrence between the *Ohio*-class's retirement and the production of a replacement. The Navy is working with the United Kingdom to develop a common missile compartment for use on OR and the United Kingdom's replacement SSBN. OR will initially carry the Trident II D5LE missile.



Source: © 2012 General Dynamics Electric Boat.

Current Status

Navy officials stated that they are pursuing design for affordability initiatives and investigating various contracting and acquisition scenarios to reduce average follow-on ship procurement costs from an estimated $5.6 to $4.9 billion (in fiscal year 2010 dollars).The program intends to maximize economic order quantity benefits by leveraging the *Virginia*-class program and the elements common with the United Kingdom's SSBN. Program officials stated the OR and *Virginia*-class programs are aligned to support various contracting scenarios, including procuring the lead OR concurrently in a multi-year procurement with the Block V *Virginia*-class contract. The Navy would develop a legislative proposal in 2017 to support this approach. The lead ship would likely not meet multi-year procurement criteria that require a stable design that has typically completed initial operational test and evaluation. The Navy has set initial configurations for areas including the torpedo room, bow, and stern. In 2014, the program expects to complete initial specifications, set ship length—a major milestone—and start detailed system descriptions and arrangements. The contractor plans to build a notional submarine section to validate the fidelity of its new design tool. The program plans to have 83 percent of design disclosures (including drawings, and material procurement and construction planning information) and 100 percent of arrangements and the three-dimensional product model completed prior to the start of lead ship construction scheduled for fiscal year 2021. Program officials stated that unmitigated, a sequestration of 2014 funds would result in up to a one year delay to the program (potentially creating a gap in sea-based nuclear deterrence), but that they will attempt to mitigate any delays to the fullest extent allowed.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program: $95,103.2 million
Research and development: $11,718.2 million
Procurement: $83,385.0 million
Quantity: 12

Next Major Program Event: System requirements review, fiscal year 2014

Program Office Comments: According to the program office, the OR program multi-year-procurement decision has not been made at this time. The OR program intends to maximize savings from cross-class contracting with the *Virginia*-class and the United Kingdom's *Successor*-class to take advantage of benefits from economic order quantity. The OR program is currently conducting analysis on multi-year-procurement and other contracting scenarios.

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Presidential Aircraft Recapitalization (PAR)

The Air Force's Presidential Aircraft Recapitalization (PAR) program is intended to recapitalize the VC-25A system and support the United States President as Head of State, Chief Executive, and Commander in Chief. PAR's principal mission is to provide the President and his staff air transportation with the same level of security and communications capability available at the White House.

Source: U.S. Air Force.

Current Status

PAR program acquisition strategy development is ongoing with milestone decision authority approval expected in the fourth quarter of fiscal year 2015. According to program officials, the program intends to acquire a large, commercial-derivative aircraft and modify it to meet desired capabilities. The program intends to seek a waiver from the requirement to conduct competitive prototyping prior to entry into engineering and manufacturing development. To ensure some form of competition, the program plans to use open architecture for future upgrades.

Since fiscal year 2012, the PAR program has conducted initial planning activities including assessing risk and systems engineering as well as analysis related to requirements, sustainment, and technology and manufacturing maturity. Risk reduction studies are planned to continue through fiscal year 2014.

The PAR system development start and contract award are expected in the fourth quarter of fiscal year 2015. Program officials reported that at present, the Air Force is still determining the number of aircraft needed to replace the current VC-25A fleet and no decision has been made on PAR fleet size. The first aircraft will be used to support research, development, test, and evaluation. Once the development is completed, the aircraft will be delivered as a fully capable aircraft to support presidential missions in fiscal year 2023. Additional deliveries will commence starting in fiscal year 2025. According to program officials, requirements are being finalized with Air Mobility Command but at the time of our review, critical technologies have not yet been identified. Officials reported that program affordability is under discussion, but no targets for the final program cost have been determined yet.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program: TBD
Research and development (fiscal years 2010 through 2018): $1,075.9 million
Procurement: TBD
Quantity: TBD

Next Major Program Event: Milestone decision authority approval of acquisition strategy, fourth quarter fiscal year 2015.

Program Office Comments: Technical comments were incorporated as appropriate.

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Space Based Infrared Satellite System (SBIRS High)

The Air Force's SBIRS High satellite system is being developed to replace the Defense Support Program and perform a range of missile warning, missile defense, technical intelligence, and battlespace awareness missions. SBIRS High will consist of four satellites in geosynchronous earth orbit (GEO), two sensors on host satellites in highly elliptical orbit (HEO), two replenishment satellites and sensors, and fixed and mobile ground stations. We assessed the space segment and made observations about the ground segment.



Source: © 2007 Lockheed Martin.

Current Status

Both HEO sensors and the first two GEO satellites have been launched. One of two replenishment sensors was delivered to the host this year for integration, and the third and fourth satellites are currently in production. In October 2013, the first GEO satellite was accepted as operational, with previously identified issues resolved. This means that the data returned from the satellite is reliable. The second satellite was accepted for operations in November 2013. Each GEO satellite carries a scanning sensor and a staring sensor, which provide different data to meet program missions. The program launched the first satellite without event recovery software intended to re-establish ground control of the satellite in the event of an unforeseen failure, so that other software issues could be addressed. Given successful recovery software testing on the second GEO satellite, the Air Force plans to upload the software to the first satellite in the fourth quarter of 2014.

The Block 10 software ground system increment is expected to be delivered in March 2016, and is intended to facilitate processing of integrated data from the Defense Support Program satellites, HEO sensors and GEO satellites now on-orbit. According to the program, this software delivery will also provide the capability for fully-tuned starer sensor data, which means that the data returned from the satellites will be cleared of background noise, such as irrelevant light sources. This capability was previously planned for inclusion in a subsequent Block 20 software delivery which is expected to achieve certification in June 2018. The program plans to fully meet operational requirements in 2019 once it has established the full on-orbit constellation of HEO sensors, four GEO satellites, completion of Blocks 10 and 20, and delivery of its mobile ground assets.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total Program: $18,886.4 million
Research & development: $11,805.5 million
Procurement: $6,817.2 million
Quantity: 6

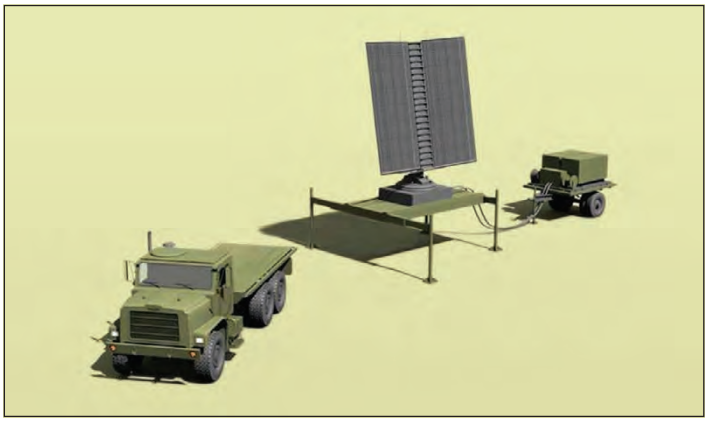
Next Major Program Event: Third GEO satellite available for delivery December 2015

Program Office Comments: In commenting on a draft of this assessment, program officials noted that the first and second satellites are operationally accepted by US Strategic Command. The third is expected early, but will need to be stored. The ground system, and fourth sensor and satellite are on-track. The fifth and sixth satellite production contract is expected fiscal year 2014.

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Three-Dimensional Expeditionary Long-Range Radar (3DELRR)

The Air Force's 3DELRR is being developed as a long-range, ground-based sensor for detecting, identifying, tracking, and reporting aircraft and missiles for the Joint Forces Air Component Commander. It is intended to provide real-time data and support a range of expeditionary operations in all types of weather and terrain. It is being acquired to replace the Air Force's AN/TPS-75 radar systems.



Source: U.S. Air Force.

Current Status

The 3DELRR program entered technology development in May 2009, and these efforts included capability demonstrations of three competing prototypes. The program is scheduled to enter system development in June 2014 after it completes the source selection process for its development and initial production contract. The acquisition strategy for the program has changed in the last year. The program previously planned to award the system development and low-rate initial production contract using full and open competition. However, when the Air Force released the request for proposals for this contract in November 2013, the program limited the competition to the three contractors that had developed full-scale prototypes and completed a preliminary design review—Lockheed Martin, Northrop Grumman, and Raytheon. According to program officials, including other contractors would require more development funding to reach maturity and these costs would not likely be recouped through full and open competition. However, the program plans to take other steps, such as obtaining data rights, to maintain the ability to introduce competition for subsystems and upgrades later. The maximum total ceiling price for the planned contract is $534 million, which includes an option for low-rate initial production.

The 3DELRR program will enter system development with its critical technologies nearing maturity. The program office reported that 3DELRR successfully demonstrated its eight critical technologies and its manufacturing processes in a relevant environment during its technology development efforts. According to the program office, the greatest risk to program execution is budget uncertainty.

Estimated Total Program Cost and Quantity (fiscal year 2014 dollars):
Total Program: $1,531.4 million
Research and development: $543.4 million
Procurement: $988.1 million
Quantities: 35

Next Major Program Event: System development start, June 2014

Program Office Comments: The program office concurred with this assessment.

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Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS) System

The Navy's UCLASS system is expected to address a gap in persistent sea-based intelligence, surveillance, and reconnaissance (ISR) with precision strike capabilities. The system is made up of three key segments an unmanned aerial vehicle, aircraft carrier modifications, and a control system. Working together these segments will provide aircraft carriers with additional ISR as well as targeting and strike capabilities.



Source: U.S. Navy.

Current Status

In June 2013, the Under Secretary of Defense for Acquisition, Technology, and Logistics approved the Navy's plan to invest an estimated $3.7 billion through fiscal year 2020 to develop, produce, and field an initial UCLASS system with up to 24 air vehicles and modify up to four aircraft carriers, to support an early operational capability. The Navy plans to manage UCLASS as a technology development program, and does not plan to hold a formal review to enter system development until after an initial system is fielded in fiscal year 2020. Normally, activities like those planned by the Navy are commensurate with an acquisition program in system development and early production. Using this approach, the Navy is considering seeking approval to bypass a formal system development phase and proceed directly into production in fiscal year 2020 but no formal decision has been made. This approach raises concerns as the Navy could develop, produce, and field a system before undergoing the key oversight mechanisms and reviews that typically govern a program in system development.

In August 2013, the Navy awarded four separate limited source firm fixed-price contracts to develop designs for the air vehicle segment. In fiscal year 2014, the Navy plans to review those preliminary designs, conduct a full and open competition, and award a single contract to complete development and deliver the air vehicles. UCLASS is critically dependent on the development and fielding of the Joint Precision Approach and Landing System (JPALS), a global positioning system that guides aircraft onto an aircraft carrier. Navy officials expect UCLASS to hold a preliminary design review—including the air vehicle, carrier, and control segments—in May 2014 based on JPALS test progress. However, the Navy still considers JPALS one of its top risks for UCLASS.

Estimated Program Cost and Quantity (fiscal year 2014 dollars):
Total program: TBD
Research and development: $3,700 million
Procurement: TBD
Quantity: TBD

Next Major Program Event: Technology development start, 2014

Program Office Comments: According to program officials, the UCLASS program continues to progress toward conducting a milestone A defense acquisition board review in accordance with the program's approved technology development strategy. A milestone B decision will be sought and appropriate documentation submitted for review. The program also provided technical comments, which were incorporated as appropriate.

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Agency Comments and Our Evaluation

DOD provided written comments on a draft of this report. The comments are reprinted in appendix VII. We also received technical comments from DOD, which have been addressed in the report as appropriate.

In its comments, DOD stated that our assessment shows that the Department's commitment to acquisition excellence in the "Better Buying Power" initiatives continues to have a positive impact on the cost, schedule, and performance measures of the programs we assessed. As we note in the report, these initiatives seem to be having a positive effect at least in the near term. This is particularly true for DOD's implementation of "should-cost" reviews which many programs reported were responsible for significant savings. Our assessment also notes that there are still opportunities to find additional savings with two other acquisition reform efforts—affordability constraints and the promotion of competition before and after development start.

Our report also emphasizes that further implementation of knowledge-based best practices are fundamental to containing cost growth and ensuring timely delivery of the capabilities promised to the warfighter in the long term. These include early systems engineering reviews, mature technologies before development start, and the demonstration of mature designs through system-level prototyping.

We are sending copies of this report to appropriate congressional committees; the Secretary of Defense; the Secretaries of the Army, Navy, and Air Force; and the Director of the Office of Management and Budget. In addition, the report will be made available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staff have any questions concerning this report, please contact me at (202) 512-4841. Contact points for our offices of Congressional Relations and Public Affairs may be found on the last page

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of this report. Staff members making key contributions to this report are listed in appendix VIII.



Michael J. Sullivan
Director, Acquisition and Sourcing Management

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List of Committees

The Honorable Carl Levin
Chairman
The Honorable James M. Inhofe
Ranking Member
Committee on Armed Services
United States Senate

The Honorable Richard J. Durbin
Chairman
The Honorable Thad Cochran
Ranking Member
Subcommittee on Defense
Committee on Appropriations
United States Senate

The Honorable Howard P. "Buck" McKeon
Chairman
The Honorable Adam Smith
Ranking Member
Committee on Armed Services
House of Representatives

The Honorable Rodney Frelinghuysen
Chairman
The Honorable Pete Visclosky
Ranking Member
Subcommittee on Defense
Committee on Appropriations
House of Representatives

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Scope and Methodology

Analysis of the Cost Performance of DOD's Portfolio of Major Defense Acquisition Programs

To develop our observations on the overall changes in the size, cost, and cycle time of Department of Defense's portfolio of major defense acquisition programs, we obtained and analyzed cost, quantity, and schedule data from Selected Acquisition Reports (SAR) and other information in the Defense Acquisition Management Information Retrieval (DAMIR) Purview system, referred to as DAMIR.[1] We converted all cost information to fiscal year 2014 dollars using conversion factors from the DOD Comptroller's National Defense Budget Estimates for Fiscal Year 2014 (table 5-9). Data for the total planned investment of major defense acquisition programs were obtained from DAMIR, which we aggregated for all programs using fiscal year 2014 dollars. Through discussions with DOD officials responsible for the database and confirming selected data with program offices, we determined that the SAR data and the information retrieved from DAMIR were sufficiently reliable for our purposes. In general, we refer to the 80 major defense acquisition programs with SARs dated December 2012 as DOD's 2013 or current portfolio and use a similar convention for prior year portfolios. We compared the programs that issued SARs in December 2012 with the list of programs that had issued SARs in December 2011 (2012 portfolio) to identify the programs that exited and entered the current portfolio. The Missile Defense Agency's Ballistic Missile Defense System is excluded from all analyses as the program does not have an integrated long-term baseline which prevents us from assessing the program's cost progress or comparing it to other major defense acquisition programs.

To determine the portfolio trends over the past ten years we collected data from the annual December SARs for the years 2003 (2004 portfolio) through 2012 (2013 portfolio). The 2009 portfolio is excluded because no annual SARs were released for the December 2008 submission date. We then analyzed the data to determine the number of programs in each portfolio year as well as the year-by-year totals for research and development, procurement, and other acquisition funding for each portfolio year as well as the total amount of funding invested or remaining and, in specific cases the amount due to cost growth. We also used DAMIR and SAR data to make a determination of system type for each program to determine the mix of system types in each portfolio year.

[1]DAMIR Purview is an executive information system operated by the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics/Acquisition Resources and Analysis.

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To determine the cost and schedule changes on defense acquisition programs in the current portfolio over the past year, 5 years, and from baseline estimates, we collected data from December 2012, December 2011, and December 2007 SARs; acquisition program baselines; and program offices. For programs less than a year old, we calculated the difference between the December 2012 SAR current estimate and the first full estimate to identify the cost and schedule change over the past year. For programs less than 5 years old, we took a similar approach when calculating the cost and schedule change over the past 5 years. We retrieved data on research, development, test, and evaluation; procurement; total acquisition cost, and schedule estimates for the 80 programs in the 2013 portfolio.[2] In some cases, we divided four programs into two distinct elements, because DOD reports performance data on them separately. As a result some of our analysis reflects a total of 84 programs and sub-elements. We analyzed the data to determine the change in research and development, procurement, and total acquisition costs as well as schedule changes from the first full estimate, generally development start, to the current estimate in the December 2012 SAR. For the programs that did not have a development estimate, we compared the current estimate to the production estimate. Also, for the shipbuilding programs that had a planning estimate, we compared the current estimate to the planning estimate. For programs that began as non–major defense acquisition programs, the first full estimate we used as a baseline may be different than the original baseline disclosed in DOD SARs. We obtained schedule information and calculated the cycle time from program start to initial operational capability and the delay in obtaining initial operational capability. For programs in the current portfolio where schedule data for initial operational capability was not available over the past year, 5 years, and since first full estimates we used the same methodology as used when calculating cost change.

To determine whether programs experienced an increase or decreases in buying power over the past year, we obtained data on program acquisition unit cost to determine whether a program's buying power had increased or decreased. We reviewed SARs for those programs with changes in buying power over the past year to measure the extent to which changes in

[2]We refer to research, development, test, and evaluation costs as research and development or simply as development costs in this report. Total acquisition cost includes research and development and procurement costs as well as acquisition related operation and maintenance and system-specific military construction costs.

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quantity impacted procurement cost changes. When analyzing buying power changes, we also calculated the amount of procurement cost growth attributable to quantity changes, we isolated the change in procurement quantities and the prior-year's acquisition procurement unit cost for programs over the past year. For those programs with a change in procurement quantities, we calculated the amount attributable to quantity changes as the change in quantity multiplied by the average procurement unit cost for the program a year ago. The resulting dollar amount is considered a change due solely to shifts in the number of units procured and may overestimate the amount of change expected when quantities increase and underestimate the expected change when quantities decrease as it does not account for other effects of quantity changes on procurement such as gain or loss of learning in production that could result in changes to unit cost over time or the use or absence of economic orders of material. However, these changes are accounted for as part of the change in cost not due to quantities.

To evaluate program performance against high-risk criteria discussed by DOD, the Office of Management and Budget (OMB), and GAO, we calculated how many programs had less than a 2 percent increase in total acquisition cost over the past year, less than a 10 percent increase over the past 5 years, and less than a 15 percent increase from first full estimates using data from December 2012, December 2011, and December 2007 SARs; acquisition program baselines; and program offices. For programs that began as non–major defense acquisition programs, the first full estimate we used as a baseline may be different than the original baseline contained in DOD SARs. We also compared the performance of the 2013 portfolio in each high-risk category with the performance of the 2012 and 2011 portfolios we reported on in prior years to identify any positive or negative changes. For programs with multiple sub-programs presented in the SARs we calculated the net effect of the sub-programs to reach an aggregate program result.

To discern the cost and schedule performance of the various system types represented in the current portfolio, we first determined each program's system type using DAMIR reported information on commodity type, the program's mission and description summary from the December 2012 SAR, and GAO analyst judgment. The programs were then grouped by system type and cost and schedule change was determined using the cost and schedule changes calculated for the programs in each system type. Development cost change and change in initial operating capability were then calculated for each group as elsewhere in this objective. For change

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in procurement unit cost, a weighted average calculation was used based on the total procurement cost for programs in each system type.

To determine the funding already invested and the funding remaining that is needed to complete the 80 programs in the 2013 portfolio we used funding stream data obtained from DAMIR and the December 2012 SARs. We define funding invested as all funding that has been provided to the programs in fiscal years 2013 and earlier, while funding remaining is all the amounts that will be provided in the fiscal year 2014 and later. To show the amount of additional future funding needed due to cost growth from first full estimates to complete programs in the current portfolio, we compared a funding stream for each program that corresponded to its first full estimate at program start against the funding stream for the current estimate in the program's December 2012 SAR.

Analysis of Selected DOD Programs Using Knowledge-Based Criteria

To collect data from current and future major defense acquisition programs—including cost and schedule estimates, technology maturity, and planned implementation of acquisition reforms—we distributed two electronic questionnaires, one questionnaire for the 38 current programs and a slightly different questionnaire for the 18 future programs. Both of the questionnaires were sent by e-mail in an attached Microsoft Word form that respondents could return electronically. We received responses from all of the programs we assessed from August to November 2013. To ensure the reliability of the data collected through our questionnaires, we took a number of steps to reduce measurement error and non-response error. These steps included conducting three pretests for the future major defense acquisition program questionnaire and three pretests for the major defense acquisition program questionnaire prior to distribution to ensure that our questions were clear, unbiased, and consistently interpreted; reviewing responses to identify obvious errors or inconsistencies; conducting follow-up to clarify responses when needed; and verifying the accuracy of a sample of keypunched questionnaires. Our pretests covered each branch of the military to better ensure that the questionnaires could be understood by officials within each branch.

Our analysis of how well programs are adhering to a knowledge-based acquisition approach focuses on 38 major defense acquisition programs that are mostly in development or the early stages of production. To assess the knowledge attained by key decision points (system development start or detailed design contract award for shipbuilding programs, critical design review or fabrication start for shipbuilding

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programs, and production start), we collected data from program offices about their knowledge at each point. In particular, we focused on the seven programs that crossed these key acquisition points in 2013 and evaluated their adherence to knowledge based practices. We also provide some insight into how much knowledge is obtained at key junctures by other programs we assessed as well. We also included observations on the knowledge that 18 future programs expect to obtain before starting development as well as how much knowledge 14 current programs expect to obtain before reaching their production start. We did not validate the data provided by the program offices, but reviewed the data and performed various checks to determine that they were reliable enough for our purposes. Where we discovered discrepancies, we clarified the data accordingly.

The 56 current and future programs included in our assessment were in various stages of the acquisition cycle, and not all of the programs provided information on knowledge obtained at each point. Programs were not included in our assessments at key decision points if relevant data were not available. For each decision point, we summarized knowledge attainment for the number of programs with data that had reached that knowledge point. Our analysis of knowledge attained at each key point includes factors that we have previously identified as being key to a knowledge-based acquisition approach, including holding early systems engineering reviews, testing an integrated prototype prior to the design review, using a reliability growth curve, planning for manufacturing, and testing a production-representative prototype prior to the making a production decision. Additional information on how we collect these data is found in the product knowledge assessment section of appendix I. See also appendix IV for a list of the practices that are associated with a knowledge-based acquisition approach.

Analysis of Acquisition Initiatives and Program Concurrency

To determine how DOD has begun to implement acquisition reforms, we obtained and analyzed the DOD 5000.02 acquisition instruction in place at the time of our review, the Weapon Systems Acquisition Reform Act of 2009, and the September 14, 2010, Under Secretary of Defense for Acquisition, Technology, and Logistics memorandum on “better buying power” as well as subsequent memorandums clarifying and implementing that guidance, including the “Better Buying Power 2.0” memorandum. In November 2013, DOD released an interim revision of its 5000.02 acquisition instruction with the intention of incorporating the policy changes mandated by the act and “Better Buying Power” memos. As our

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data was collected prior to the release of this revision we did not use the new instruction as criteria for our assessments. To develop our observations, we analyzed questionnaire data received from the 38 current and 18 future major defense acquisition programs in our assessment to determine the extent to which specific acquisition reform issues have been implemented such as establishing affordability constraints, conducting "should-cost" analyses, using competition throughout the acquisition life cycle, and holding configuration steering boards.

To assess program concurrency we identified the programs—among those we included in our assessment—with production start dates. We used the questionnaire responses from those programs to identify the dates for the start and end of developmental testing, compared those dates to the timing of each program's production decision and determined the number of months, if any, of developmental testing done after production start. We then compared the number of overlapping months to the total number of months of developmental testing for each program and calculated the percentage of developmental testing done concurrent with production.

Individual Assessments of Weapon Programs

In total, this report presents individual assessments of 56 weapon programs. A table listing these programs is found in appendix VIII. Out of these programs, 37 are captured in a two-page format discussing technology, design, and manufacturing knowledge obtained and other program issues. Thirty-four of these 37 two-page assessments are of major defense acquisition programs, most of which are in development or early production and 3 assessments are of programs that were projected to become major defense acquisition programs during or soon after our review. The remaining 19 programs are described in a one-page format that describes their current status. Those one-page assessments include 15 future major defense acquisition programs, 2 major defense acquisition program that are well into production, and 2 major defense acquisition programs that were recently restructured or curtailed. Over the past several years, DOD has revised policies governing weapon system acquisitions and changed the terminology used for major acquisition events. To make DOD's acquisition terminology more consistent across the 56 program assessments, we standardized the terminology for key program events. For most individual programs in our assessment, "development start" refers to the initiation of an acquisition program as well as the start of engineering and manufacturing development. This generally coincides with DOD's milestone B. A few programs in our assessment

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have a separate “program start” date, which begins a pre–system development phase for program definition and risk-reduction activities. This “program start” date generally coincides with DOD’s former terminology for milestone I or DOD’s current milestone A. The “production decision” generally refers to the decision to enter the production and deployment phase, typically with low-rate initial production. The “initial capability” refers to the initial operational capability—sometimes called first unit equipped or required asset availability. For shipbuilding programs, the schedule of key program events in relation to acquisition milestones varies for each program. Our work on shipbuilding best practices has identified the detailed design contract award and the start of lead ship fabrication as the points in the acquisition process roughly equivalent to development start and design review for other programs.

For each program we assessed in a two-page format, we present cost, schedule, and quantity data at the program’s first full estimate and an estimate from the latest SAR or the program office reflecting 2013 data where they were available. The first full estimate is generally the cost estimate established at milestone B—development start; however, for a few programs that did not have such an estimate, we used the estimate at milestone C—production start—instead. For shipbuilding programs, we used their planning estimates if those estimates were available. For systems for which a first full estimate was not available, we only present the latest available estimate of cost and quantities. For the other programs assessed in a one-page format, we present the latest available estimate of cost and quantity from the program office.

For each program we assessed, all cost information is presented in fiscal year 2014 dollars. We converted cost information to fiscal year 2014 dollars using conversion factors from the DOD Comptroller’s National Defense Budget Estimates for Fiscal Year 2014 (table 5-9). We have depicted only the program’s main elements of acquisition cost—research and development and procurement. However, the total program cost also includes military construction and acquisition-related operation and maintenance costs. Because of rounding and these additional costs, in some situations, total cost may not match the exact sum of the research and development and procurement costs. The program unit costs are calculated by dividing the total program cost by the total quantities planned. In some instances, the data were not applicable, and we annotate this by using the term “not applicable (NA).” The quantities listed refer to total quantities, including both procurement and development quantities.

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The schedule assessment for each program is based on acquisition cycle time, defined as the number of months between program start and the achievement of initial operational capability or an equivalent fielding date. In some instances the data were not yet available, and we annotate this by using the term “to be determined (TBD)” or “NA.”

The information presented on the “funding needed to complete” is from fiscal year 2014 through completion and, unless otherwise noted, draws on information from SARs or on data from the program office. In some instances, the data were not available, and we annotate this by the term “TBD” or “NA.” The quantities listed refer only to procurement quantities. Satellite programs, in particular, produce a large percentage of their total operational units as development quantities, which are not included in the quantity figure.

The intent of these comparisons is to provide an aggregate, or overall, picture of a program’s history. These assessments represent the sum of the federal government’s actions on a program, not just those of the program manager and the contractor. DOD does a number of detailed analyses of changes that attempt to link specific changes with triggering events or causes. Our analysis does not attempt to make such detailed distinctions.

In this year’s assessment we also reviewed whether individual subcontracting reports from a program’s prime contractor or contractors were accepted on the Electronic Subcontracting Reporting System (eSRS). We reviewed this information for 36 of the major defense acquisition programs included in our assessment using the contract information reported in their December 2012 Selected Acquisition Reports. See appendix VI for a list of the programs we reviewed. The contract numbers for each program’s prime contracts were entered into the eSRS database to determine whether the individual subcontracting reports had been accepted by the government. While we did not assess the reliability of the eSRS database, we took steps to ensure that the data provided by the database was sufficiently reliable for the purpose of our analysis by interviewing defense officials with knowledge of DOD’s process for eSRS and collecting data from program offices on contract reporting. The government uses individual subcontracting reports on eSRS as one method of monitoring small business participation, as the report includes goals for small business subcontracting. Not all prime contracts for major defense acquisition programs are required to submit individual subcontracting reports. For example, some contractors report small

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business participation at a corporate level as opposed to a program level and this data is not captured in the individual subcontracting reports.

Product Knowledge Data on Individual Two-Page Assessments

In our past work examining weapon acquisition issues and best practices for product development, we have found that leading commercial firms pursue an acquisition approach that is anchored in knowledge, whereby high levels of product knowledge are demonstrated by critical points in the acquisition process. On the basis of this work, we have identified three key knowledge points during the acquisition cycle—system development start, critical design review, and production start—at which programs need to demonstrate critical levels of knowledge to proceed. To assess the product development knowledge of each program at these key points, we reviewed data-collection instruments and questionnaires submitted by programs; however, not every program had responses to each element of the data-collection instrument or questionnaire. We also reviewed pertinent program documentation and discussed the information presented on the data-collection instrument and questionnaire with program officials as necessary.

To assess a program's readiness to enter system development, we collected data through the data-collection instrument on critical technologies and early design reviews. To assess technology maturity, we asked program officials to apply a tool, referred to as technology readiness levels (TRL), for our analysis. The National Aeronautics and Space Administration originally developed TRLs, and the Army and Air Force science and technology research organizations use them to determine when technologies are ready to be handed off from science and technology managers to product developers. TRLs are measured on a scale from 1 to 9, beginning with paper studies of a technology's feasibility and culminating with a technology fully integrated into a completed product. See appendix V for TRL definitions. Our best-practices work has shown that a TRL 7—demonstration of a technology in a realistic environment—is the level of technology maturity that constitutes a low risk for starting a product development program.[3] For shipbuilding programs, we have recommended that this level of maturity be achieved by the

[3]GAO, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*, GAO/NSIAD-99-162 (Washington, D.C.: July 30, 1999); and *Best Practices: Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes*, GAO-01-288 (Washington, D.C.: Mar. 8, 2001).

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contract award for detailed design.[4] In our assessment, the technologies that have reached TRL 7, a prototype demonstrated in a realistic environment, are referred to as mature or fully mature. Those technologies that have reached TRL 6, a prototype demonstrated in a relevant environment, are referred to as approaching or nearing maturity. Satellite technologies that have achieved TRL 6 are assessed as fully mature due to the difficulty of demonstrating maturity in a realistic environment—space. In addition, we asked program officials to provide the date of the preliminary design review. We compared this date to the system development start date.

In most cases, we did not validate the program offices' selection of critical technologies or the determination of the demonstrated level of maturity. We sought to clarify the TRLs in those cases where information existed that raised concerns. If we were to conduct a detailed review, we might adjust the critical technologies assessed, their readiness levels demonstrated, or both. It was not always possible to reconstruct the technological maturity of a weapon system at key decision points after the passage of many years. Where practicable, we compared technology assessments provided by the program office to assessments conducted by officials from the Office of the Assistant Secretary of Defense for Research and Engineering.

To assess design stability, we asked program officials to provide the percentage of design drawings completed or projected for completion by the design review, the production decision, and as of our current assessment in the data-collection instrument. In most cases, we did not verify or validate the percentage of engineering drawings provided by the program office. We clarified the percentage of drawings completed in those cases where information that raised concerns existed. Completed drawings were defined as the number of drawings released or deemed releasable to manufacturing that can be considered the "build to" drawings. For shipbuilding programs, we asked program officials to provide the percentage of the three-dimensional product model that had been completed by the start of lead ship fabrication, and as of our current assessment. To gain greater insights into design stability, we also asked program officials to provide the date they planned to first integrate and test all key subsystems and components into a system-level integrated prototype. We compared this date to the date of the design review. We did

[4]GAO, *Best Practices: High Levels of Knowledge at Key Points Differentiate Commercial Shipbuilding from Navy Shipbuilding*, GAO-09-322 (Washington, D.C.: May 13, 2009).

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not assess whether shipbuilding programs had completed integrated prototypes.

To assess production maturity, we asked program officials to identify the number of critical manufacturing processes and, where available, to quantify the extent of statistical control achieved for those processes as a part of our data-collection instrument. In most cases, we did not verify or validate the information provided by the program office. We clarified the number of critical manufacturing processes and the percentage of statistical process control where information existed that raised concerns. We used a standard called the process capability index, a process-performance measurement that quantifies how closely a process is running to its specification limits. The index can be translated into an expected product defect rate, and we have found it to be a best practice. We also used data provided by the program offices on their manufacturing readiness levels (MRL) for process capability and control, a sub-thread tracked as part of the manufacturing readiness assessment process recommended by DOD, to determine production maturity. We assessed programs as having mature manufacturing processes if they reported an MRL 9 for that sub-thread—meaning, that manufacturing processes are stable, adequately controlled, and capable. To gain further insights into production maturity, we asked program officials whether the program planned to demonstrate critical manufacturing processes on a pilot production line before beginning low-rate production. We also asked programs on what date they planned to begin system-level developmental testing of a fully configured, production- representative prototype in its intended environment. We compared this date to the production start date. We did not assess production maturity for shipbuilding programs.

Although the knowledge points provide excellent indicators of potential risks, by themselves they do not cover all elements of risk that a program encounters during development, such as funding instability. Our detailed reviews on individual systems normally provide a more comprehensive assessment of risk elements.

We conducted this performance audit from June 2013 to March 2014, in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

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Current and First Full Estimates for DOD's 2013 Portfolio of Major Defense Acquisition Programs

Table 8 contains the current and first full total acquisition cost estimates (in fiscal year 2013 dollars) for each program or element in the Department of Defense's (DOD) 2013 major defense acquisition program portfolio. For each program we show the percent change in total acquisition cost from the first full estimate, as well as over the past year and 5 years.

Table 8: Current Cost Estimates and First Full Estimates for DOD's 2013 Portfolio of Major Defense Acquisition Programs

Fiscal year 2014 dollars in millions

Program name	Current total acquisition cost	First full estimate total acquisition cost	Change in total acquisition cost from first full estimate (percent)	Change in total acquisition cost within the past year (percent)	Change in total acquisition cost within the past 5 years (percent)
Advanced Extremely High Frequency Satellite (AEHF)	$14,559	$6,700	117.3%	-0.9%	70.2%
AGM-88E Advanced Anti-Radiation Guided Missile (AGM-88E AARGM)	2,062	1,684	22.5	-0.4	15.1
AH-64E Apache New Build (AH-64E New Build)	2,119	2,492	-15.0	2.9	-15.0
AH-64E Apache Remanufacture (AH-64E Remanufacture)	12,499	7,617	64.1	12.9	50.2
AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM)	24,052	11,497	109.2	-0.9	23.3
AIM-9X Block II Air-to-Air Missile (AIM-9X Block II)	3,793	4,202	-9.7	-7.0	-9.7
Airborne and Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS)	3,583	8,576	-58.2	-12.9	-58.2
Airborne Warning and Control System Block 40/45 Upgrade (AWACS Blk 40/45 Upgrade)	2,865	2,936	-2.4	-2.4	-2.4
B-2 Extremely High Frequency SATCOM and Computer Increment 1 (B-2 EHF Inc1)	594	747	-20.5	-2.5	-17.5
B61 Mod 12 Life Extension Program Tailkit Assembly (B61 Mod 12 LEP TKA)	1,369	1,375	-0.5	-0.5	-0.5
C-130J Hercules Transport Aircraft (C-130J)	16,455	998	1548.6	-1.9	22.9
C-5 Reliability Enhancement and Re-engining Program (C-5 RERP)	7,661	11,469	-33.2	-1.1	-30.7
CH-47F Improved Cargo Helicopter (CH-47F)	15,000	3,386	343.0	0.3	8.7
CH-53K Heavy Lift Replacement Helicopter (CH-53K)	24,806	17,414	42.5	4.7	42.0
Chemical Demilitarization-Assembled Chemical Weapons Alternatives (Chem Demil-ACWA)	10,496	2,779	277.7	-0.7	34.5
Cooperative Engagement Capability (CEC)	5,491	3,096	77.4	-1.5	2.8
Gerald R. Ford Class Nuclear Aircraft Carrier (CVN 78)	36,008	37,415	-3.8	-0.8	10.5
DDG 1000 *Zumwalt* Class Destroyer (DDG 1000)	22,000	36,602	-39.9	0.2	-26.8
DDG 51 *Arleigh Burke* Class Guided Missile Destroyer (DDG 51)	107,831	15,974	575.0	2.3	30.5

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Fiscal year 2014 dollars in millions

Program name	Current total acquisition cost	First full estimate total acquisition cost	Change in total acquisition cost from first full estimate (percent)	Change in total acquisition cost within the past year (percent)	Change in total acquisition cost within the past 5 years (percent)
E-2D Advanced Hawkeye Aircraft (E-2D AHE)	19,899	15,516	28.2	-2.3	17.1
EA-18G Growler Aircraft (EA-18G)	13,681	9,440	44.9	16.1	46.5
Evolved Expendable Launch Vehicle (EELV)	63,924	18,276	249.8	78.4	78.8
Excalibur Precision 155mm Projectiles (Excalibur)	1,882	5,024	-62.5	1.0	-25.5
F/A-18E/F Super Hornet Aircraft (F/A-18E/F)	59,674	85,964	-30.6	-1.7	5.8
F-35 Joint Strike Fighter Aircraft (F-35)	332,320	224,775	47.8	-3.4	24.7
Family of Advanced Beyond Line-of-Sight Terminals (FAB-T)	4,618	3,354	37.7	-1.4	22.8
Family of Medium Tactical Vehicles (FMTV)	19,010	10,987	73.0	-0.4	-15.7
Global Broadcast Service (GBS)	1,276	606	110.6	2.8	30.8
Global Positioning System III (GPS III)	4,376	4,145	5.6	1.0	5.6
Ground/Air Task Oriented Radar (G/ATOR)	2,298	1,542	49.1	-26.0	49.1
Guided Multiple Launch Rocket System/Guided Multiple Launch Rocket System Alternative Warhead (GMLRS/GMLRS AW)	6,520	1,860	250.6	2.9	10.0
H-1 Upgrades (4BW/4BN) (H-1 Upgrades)	12,935	3,814	239.1	-1.9	40.3
HC/MC-130 Recapitalization Aircraft (HC/MC-130 Recap)	13,788	8,797	56.7	2.9	56.7
Integrated Air and Missile Defense (IAMD)	5,804	5,289	9.7	-4.2	9.7
Integrated Defensive Electronic Countermeasures (IDECM)	2,582	2,290	12.7	2.8	16.4
IDECM Blocks 2/3	1,720	1,560	10.3	5.5	10.3
IDECM Block 4	862	730	18.0	-2.1	18.0
Joint Air-to-Surface Standoff Missile - JASSM and JASSM-Extended Range (JASSM)	7,223	2,438	196.3	-1.2	16.1
Joint Direct Attack Munition (JDAM)	7,448	3,596	107.1	2.9	18.2
Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS)	2,782	7,011	-60.3	0.6	-61.9
Joint Light Tactical Vehicle (JLTV)	23,651	23,700	-0.2	-0.2	-0.2
Joint Precision Approach and Landing System Increment 1A (JPALS Inc 1A)	1,124	1,065	5.6	8.4	5.6
Joint Primary Aircraft Training System (JPATS)	5,999	3,918	53.1	-0.8	-3.8
Joint Standoff Weapon - Baseline Variant and Unitary Warhead Variant (JSOW)	5,739	8,359	-31.3	-0.6	10.7
JSOW - Baseline Variant	2,353	3,004	-21.7	-0.2	0.1
JSOW - Unitary Variant	3,386	5,354	-36.8	-0.9	19.6
Joint Tactical Networks (JTN)	2,261	1,032	119.1	3.9	2.2

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Fiscal year 2014 dollars in millions

Program name	Current total acquisition cost	First full estimate total acquisition cost	Change in total acquisition cost from first full estimate (percent)	Change in total acquisition cost within the past year (percent)	Change in total acquisition cost within the past 5 years (percent)
Joint Tactical Radio System Handheld, Manpack, and Small Form Fit Radios (JTRS HMS)	8,936	10,557	-15.4	2.1	171.5
KC-130J Transport Aircraft (KC-130J)	9,849	9,975	-1.3	-2.2	-1.3
KC-46 Tanker Modernization Program (KC-46)	44,519	46,090	-3.4	-2.7	-3.4
LHA 6 *America* Class Amphibious Assault Ship	10,110	3,345	202.3	-2.7	182.5
Light Utility Helicopter (LUH), UH-72A Lakota	1,891	1,904	-0.7	-9.3	-10.6
Littoral Combat Ship (LCS)—Seaframes	30,027	2,360	NA	-9.4	NA
LPD 17 *San Antonio* Class Amphibious Transport Dock (LPD 17)	19,424	12,318	57.7	-0.3	23.6
MH-60R Multi-Mission Helicopter (MH-60R)	14,358	5,822	146.6	-5.6	9.5
MH-60S Fleet Combat Support Helicopter (MH-60S)	8,727	3,690	136.5	-1.2	0.7
Mobile User Objective System (MUOS)	7,448	7,069	5.4	0.7	6.7
MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle)	4,951	1,068	363.6	2.1	94.3
MQ-4C Triton Unmanned Aircraft System (MQ-4C Triton)	13,544	13,512	0.2	0.1	0.2
MQ-8 Fire Scout	2,811	2,751	2.2	3.1	29.0
MQ-9 Reaper Unmanned Aircraft System (MQ-9 Reaper)	12,706	2,774	358.1	-0.4	358.1
Multifunctional Information Distribution System (MIDS)	3,809	1,371	177.7	8.2	32.4
National Airspace System (NAS)	1,671	913	82.9	-1.7	-2.1
Navstar Global Positioning System (Navstar GPS)	9,695	7,578	27.9	0.0	-4.1
Navstar GPS Space & Control	8,081	6,538	23.6	-0.1	4.0
Navstar GPS User Equipment	1,614	1,040	55.2	0.8	-30.9
Navy Multiband Terminal Satellite (NMT)	1,937	2,441	-20.7	-0.5	-9.0
Next Generation Operational Control System (GPS OCX)	3,470	3,482	-0.3	-0.3	-0.3
P-8A Poseidon (P-8A)	34,336	32,640	5.2	-0.1	6.4
Paladin Integrated Management (PIM)	6,930	7,033	-1.5	-1.3	-1.5
Patriot Advanced Capability-3 (PAC-3)	13,157	5,482	140.0	1.6	23.6
Patriot/Medium Extended Air Defense System Combined Aggregate Program (Patriot/MEADS CAP)	11,745	28,029	-58.1	-1.0	-56.3
Patriot/MEADS CAP Fire Unit	3,383	20,365	-83.4	-0.5	-82.6
Patriot/MEADS CAP Missile	8,363	7,664	9.1	-1.2	12.6
Remote Minehunting System (RMS)	1,463	1,516	-3.5	-0.5	-8.8
RQ-4A/B Global Hawk Unmanned Aircraft System (RQ-4A/B Global Hawk)	9,874	5,671	74.1	-3.6	-6.5
Ship to Shore Connector (SSC)	4,053	4,158	-2.5	-2.5	-2.5

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Fiscal year 2014 dollars in millions

Program name	Current total acquisition cost	First full estimate total acquisition cost	Change in total acquisition cost from first full estimate (percent)	Change in total acquisition cost within the past year (percent)	Change in total acquisition cost within the past 5 years (percent)
Small Diameter Bomb Increment II (SDB II)	3,839	4,945	-22.4	-2.8	-22.4
Space Based Infrared System High Component (SBIRS High)	19,082	4,835	294.7	-1.0	43.3
SSN 774 *Virginia* Class Submarine (SSN 774)	84,350	63,582	32.7	-2.6	-5.0
Standard Missile-6 (SM-6)	8,943	5,995	49.2	41.9	54.7
Tactical Tomahawk RGM-109E/UGM 109E Missile (Tactical Tomahawk)	7,451	2,226	234.8	-1.5	52.1
Trident II (D-5) Sea-Launched Ballistic Missile UGM 133A (Trident II Missile)	56,419	54,405	3.7	1.1	4.4
UH-60M Black Hawk Helicopter (UH-60M Black Hawk)	24,368	13,641	78.6	-11.1	7.4
V-22 Osprey Joint Services Advanced Vertical Lift Aircraft (V-22)	60,668	42,173	43.9	1.3	0.3
Warfighter Information Network-Tactical Increment 2 (WIN-T Inc 2)	5,046	3,900	29.4	-20.9	29.4
Warfighter Information Network-Tactical Increment 3 (WIN-T Inc 3)	15,414	17,214	-10.5	17.7	-10.5
Wideband Global SATCOM (WGS)	4,154	1,255	230.8	-1.3	84.0

Source: GAO analysis of DOD data.

Notes: Data were obtained from DOD's Selected Acquisition Reports, acquisition program baselines, and, in some cases, program offices. Changes in total acquisition cost for the Littoral Combat Ship—Seaframes over the past 5 years and from its first full estimate are shown as "NA" because DOD reported an incomplete baseline and cost data for the program through 2010.

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Changes in DOD's 2013 Portfolio of Major Defense Acquisition Programs over 5 Years and Since First Full Estimates

Table 9 shows the change in research and development cost, procurement cost, total acquisition cost, and average delay in delivering initial operational capability for those programs in Department of Defense's (DOD) 2013 portfolio over the last 5 years and since their first full cost and schedule estimates.

Table 9: Cost and Schedule Changes for Programs in DOD's 2013 Portfolio

Fiscal year 2014 dollars

	5 year comparison (2008 to 2013)	Since first full estimate (Baseline to 2013)
Change in total research and development cost	$32 billion 12%	$98 billion 51%
Change in total procurement cost	$170 billion 16%	$348 billion 40%
Change in total other acquisition costs[a]	$4 billion 50%	$2 billion 18%
Change in total acquisition cost	$207 billion 16%	$448 billion 42%
Average delay in delivering initial capabilities	12 months 14%	28 months 36%

Source: GAO analysis of DOD data.

Notes: Data were obtained from DOD's SARs and acquisition program baselines. In a few cases data were obtained directly from program offices. Some numbers may not sum due to rounding.

[a]In addition to research and development and procurement costs, total acquisition cost includes acquisition-related operation and maintenance and system-specific military construction costs.

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Knowledge-Based Acquisition Practices

GAO's prior work on best product-development practices found that successful programs take steps to gather knowledge that confirms that their technologies are mature, their designs stable, and their production processes are in control. Successful product developers ensure a high level of knowledge is achieved at key junctures in development. We characterize these junctures as knowledge points. The Related GAO Products section of this report includes references to the body of work that helped us identify these practices and apply them as criteria in weapon system reviews. The following table summarizes these knowledge points and associated key practices.

Table 10: Best Practices for Knowledge-based Acquisitions

Knowledge Point 1: Technologies, time, funding, and other resources match customer needs. Decision to invest in product development
Demonstrate technologies to a high readiness level—Technology Readiness Level 7—to ensure technologies will work in an operational environment[a]
Ensure that requirements for product increment are informed by preliminary design review using systems engineering process (such as prototyping of preliminary design)
Establish cost and schedule estimates for product on the basis of knowledge from preliminary design using systems engineering tools (such as prototyping of preliminary design)
Constrain development phase (5 to 6 years or less) for incremental development
Ensure development phase fully funded (programmed in anticipation of milestone)
Align program manager tenure to complete development phase
Contract strategy that separates system integration and system demonstration activities
Conduct independent cost estimate
Conduct independent program assessment
Conduct major milestone decision review for development start
Knowledge Point 2: Design is stable and performs as expected. Decision to start building and testing production-representative prototypes
Complete system critical design review
Complete 90 percent of engineering design drawing packages
Complete subsystem and system design reviews
Demonstrate with system-level integrated prototype that design meets requirements
Complete the failure modes and effects analysis
Identify key system characteristics
Identify critical manufacturing processes
Establish reliability targets and growth plan on the basis of demonstrated reliability rates of components and subsystems

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Conduct independent cost estimate
Conduct independent program assessment
Conduct major milestone decision review to enter system demonstration
Knowledge Point 3: Production meets cost, schedule, and quality targets. Decision to produce first units for customer
Demonstrate manufacturing processes
Build and test production-representative prototypes to demonstrate product in intended environment
Test production-representative prototypes to achieve reliability goal
Collect statistical process control data
Demonstrate that critical processes are capable and in statistical control
Conduct independent cost estimate
Conduct independent program assessment
Conduct major milestone decision review to begin production

Source: GAO.

Note: DOD considers Technology Readiness Level 6, demonstrations in a relevant environment, to be appropriate for programs entering system development; therefore we have analyzed programs against this measure as well.

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Technology Readiness Levels

Technology readiness level		Description	Hardware/software	Demonstration environment
1.	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties	None (paper studies and analysis)	None
2.	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.	None (paper studies and analysis)	None
3.	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Analytical studies and demonstration of nonscale individual components (pieces of subsystem)	Lab
4.	Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.	Low-fidelity breadboard. Integration of nonscale components to show pieces will work together. Not fully functional or form or fit but representative of technically feasible approach suitable for flight articles.	Lab
5.	Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.	High-fidelity breadboard. Functionally equivalent but not necessarily form and/or fit (size weight, materials, etc). Should be approaching appropriate scale. May include integration of several components with reasonably realistic support elements/subsystems to demonstrate functionality.	Lab demonstrating functionality but not form and fit. May include flight demonstrating breadboard in surrogate aircraft. Technology ready for detailed design studies.

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Technology readiness level		Description	Hardware/software	Demonstration environment
6.	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated realistic environment.	Prototype. Should be very close to form, fit and function. Probably includes the integration of many new components and realistic supporting elements/subsystems if needed to demonstrate full functionality of the subsystem.	High-fidelity lab demonstration or limited/restricted flight demonstration for a relevant environment. Integration of technology is well defined.
7.	System prototype demonstration in a realistic environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in a realistic environment, such as in an aircraft, vehicle or space. Examples include testing the prototype in a test bed aircraft.	Prototype. Should be form, fit and function integrated with other key supporting elements/subsystems to demonstrate full functionality of subsystem.	Flight demonstration in representative realistic environment such as flying test bed or demonstrator aircraft. Technology is well substantiated with test data.
8.	Actual system completed and "flight qualified" through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	Flight-qualified hardware	Developmental Test and Evaluation (DT&E) in the actual system application.
9.	Actual system "flight proven" through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.	Actual system in final form	Operational Test and Evaluation (OT&E) in operational mission conditions.

Source: GAO and its analysis of National Aeronautics and Space Administration data.

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Major Defense Acquisition Programs' Individual Subcontracting Reports in the Electronic Subcontracting Reporting System

Table 11 contains the numbers of individual subcontracting reports from the prime contractor for the programs we assessed that were accepted on the Electronic Subcontracting Reporting System (eSRS). We reviewed this information for the 36 major defense acquisition programs included in our individual program assessments using the prime contracts reported in available Selected Acquisition Reports. The government uses individual subcontracting reports on eSRS as one method of monitoring small business participation, as the report includes goals for small business subcontracting. There are multiple reasons why a program may not have an accepted subcontracting report in eSRS. For example, some programs may have pending or rejected reports within the system as all reports are reviewed prior to acceptance. Not all prime contracts for major defense acquisition programs are required to submit individual subcontracting reports. Instead, some contractors report small business participation at a corporate level as opposed to the program level and this data is not captured in the individual subcontracting reports.[1] Specifically, the F-35 program provided questionnaire data indicating that for the five contracts listed in the December 2012 SAR all report at the comprehensive, contractor level. Similarly for the three contracts listed by JLTV program officials, questionnaire data shows that one of them reports on small business participation at the corporate level with no participation information specific to the JLTV program. Finally, although a program may be required to submit a report it may not yet have done so for the period we reviewed.

[1]Twelve large defense contractors are participants under the Test Program for Negotiation of Comprehensive Small Business Subcontracting Plans created by the National Defense Authorization Act for Fiscal Years 1990 and 1991, Pub. L. No. 101-189, § 834 (1989) and have each established a comprehensive subcontracting plan on a corporate, division or plant-wide basis under which a single summary subcontract report is submitted semi-annually for all covered DOD contracts. The test program has been extended by Congress several times with the current three year extension made by Pub. L. No. 112-81, § 866 (2011) to end on December 31, 2014. Participation in the test program is on a voluntary basis such that the 12 participants may have contracts where they are reporting on an individual basis as well as contracts where they are reporting on a comprehensive basis.

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Table 11: Major Defense Acquisition Programs' Individual Subcontracting Reports in the Electronic Subcontracting Reporting System

Program name	Number of contracts listed in the December 2012 SAR	Contracts with an accepted individual subcontracting report (as of January 2014)
AIM-9X Block II Air-to-Air Missile (AIM-9X Block II)	2	0
Airborne and Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS)	1	0
CH-53K Heavy Lift Replacement Helicopter (CH-53K)	1	0
Gerald R. Ford Class Nuclear Aircraft Carrier (CVN 78)	6	3
DDG 1000 *Zumwalt* Class Destroyer (DDG 1000)	4	3
DDG 51 *Arleigh Burke* Class Guided Missile Destroyer (DDG 51)	4	3
Evolved Expendable Launch Vehicle (EELV)	10	4
Excalibur Precision 155mm Projectiles (Excalibur)	2	0
F-22 Increment 3.2B	2	0
F-35 Lightning II (F-35)	6	0
Family of Advanced Beyond Line-of-Sight Terminals (FAB-T)	2	0
Global Positioning System III (GPS III)	1	0
Ground/Air Task Oriented Radar (G/ATOR)	1	0
Integrated Air and Missile Defense (IAMD)	3	1
Joint Air-to-Surface Standoff Missile-Extended Range (JASSM-ER)	3	0
Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS)	1	0
Joint Light Tactical Vehicle (JLTV)	3	2
Joint Precision Approach and Landing System Increment 1A (JPALS Inc 1A)	1	0
Joint Tactical Radio System Handheld, Manpack, and Small Form Fit Radios (JTRS HMS)	1	0
KC-46 Tanker Modernization Program (KC-46)	1	1
LHA 6 *America* Class Amphibious Assault Ship (LHA 6)	2	2
Littoral Combat Ship (LCS)—Seaframes	3	2
MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle)	6	5
MQ-4C Triton Unmanned Aircraft System (MQ-4C Triton)	1	0
MQ-8 Fire Scout	1	1
MQ-9 Reaper Unmanned Aircraft System (MQ-9 Reaper)	2	0
Mobile User Objective System (MUOS)	1	0
Next Generation Operational Control System (GPS OCX)	1	0
P-8A Poseidon (P-8A)	2	1
Paladin Integrated Management (PIM)	1	1
RQ-4A/B Global Hawk Unmanned Aircraft System (RQ-4A/B Global Hawk)	5	2
Ship to Shore Connector (SSC)	1	1

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Program name	Number of contracts listed in the December 2012 SAR	Contracts with an accepted individual subcontracting report (as of January 2014)
Small Diameter Bomb Increment II (SDB II)	1	0
Space Based Infrared System High Component (SBIRS High)	3	0
Warfighter Information Network-Tactical Increment 2 (WIN-T Inc 2)	1	0
Warfighter Information Network-Tactical Increment 3 (WIN-T Inc 3)	1	0
Total	**87**	**32**

Source: GAO analysis of data from DOD and eSRS.

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Comments from the Department of Defense

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ACQUISITION, TECHNOLOGY AND LOGISTICS

21 MAR 2014

Mr. Michael J. Sullivan
Director, Acquisition and Sourcing Management
U.S. Government Accountability Office
441 G St NW
Washington, DC 20548

Dear Mr. Sullivan,

This is the Department of Defense response to the GAO Draft Report, GAO-14-340SP, "Defense Acquisitions: Assessments of Selected Weapon Programs" dated March 2014 (GAO Code 121144).

The Department is pleased that this year's Draft Report, the 12th annual assessment on the performance of DoD's major acquisition programs, is the most encouraging to date. GAO results indicate that the Department's commitment to acquisition excellence in the Better Buying Power initiatives continue to have a positive impact on cost, schedule, and performance measures of our programs.

The Under Secretary of Defense for Acquisition, Technology, and Logistics will again publish a comprehensive report on the acquisition system in 2014. The 2nd annual report will be a data driven analysis that provides transparent and objective performance measures of our major acquisition programs and contracts. The fiscal environment remains challenging and continues to put downward pressure on investment funding. Continued improvement of the acquisition system will require a more clear understanding of how decisions throughout the process influence performance.

The Department appreciates the opportunity to comment on the Draft Report. My point of contact for this effort is Mr. Joe Beauregard, 703-697-8046.

Sincerely,

Nancy L. Spruill

Nancy L. Spruill
Director
Acquisition Resources & Analysis

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GAO Contact

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Staff Acknowledgments

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The following were responsible for individual programs:

Program name	Primary staff
Current programs	
AIM-9X Block II Air-to-Air Missile (AIM-9X Block II)	Jennifer A. Dougherty, Christopher D. Zbrozek
Air and Missile Defense Radar (AMDR)	George A. Bustamante, C. James Madar, Ioan T. Ifrim
Airborne and Maritime/Fixed Station Joint Tactical Radio System (AMF JTRS)	Aryn C. Ehlow, Nathan A. Tranquilli, Paul G. Williams
CH-53K Heavy Lift Replacement (CH-53K)	Robert K. Miller, Marvin E. Bonner
Gerald R. Ford Class Nuclear Aircraft Carrier (CVN 78)	Burns C. Eckert, Jenny Shinn
DDG 1000 *Zumwalt* Class Destroyer (DDG 1000)	Patrick M. Breiding, Angie Nichols-Friedman
DDG 51 *Arleigh Burke* Class Guided Missile Destroyer (DDG 51)	Greg Campbell, Ioan T. Ifrim
Evolved Expendable Launch Vehicle (EELV)	Desirée E. Cunningham, Maria A. Durant
Excalibur Precision 155mm Projectiles (Excalibur)	Ryan Stott, Carrie W. Rogers
F-22 Increment 3.2B	Robert P. Bullock, Christopher D. Zbrozek, Sean C. Seales
F-35 Lightning II (F-35)	Abby C. Volk, Marvin E. Bonner
Family of Advanced Beyond Line-of-Sight Terminals (FAB-T)	Scott M. Purdy, Alexandra Dew Silva
Global Positioning System III (GPS III)	Laura T. Holliday, Erin R. Cohen
Ground/Air Task Oriented Radar (G/ATOR)	Bonita J. P. Oden, Jonathan Mulcare
Integrated Air and Missile Defense (IAMD)	John M. Ortiz, Carol T. Mebane
Joint Air-to-Surface Standoff Missile Extended Range (JASSM-ER)	Brian A. Tittle, John W. Crawford

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Program name	Primary staff
Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS)	Maria A. Durant, John M. Ortiz
Joint Light Tactical Vehicle (JLTV)	Dayna L. Foster, Andrea M. Bivens
Joint Precision Approach and Landing System Increment 1A (JPALS Inc 1A)	Stephen V. Marchesani, Jared A. Sippel
Joint Tactical Radio System Handheld, Manpack, and Small Form Fit Radios (JTRS HMS)	Nathan A. Tranquilli, Aryn C. Ehlow, Paul G. Williams
KC-46 Tanker Modernization Program (KC-46)	Jeffrey L. Hartnett, Katheryn S. Hubbell
LHA 6 *America* Class Amphibious Assault Ship (LHA 6)	Christopher E. Kunitz, Jenny Chow
Littoral Combat Ship (LCS)—Mission Packages	Laurier R. Fish, Greg Campbell
Littoral Combat Ship (LCS)—Seaframes	Amber N. Keyser, Christopher R. Durbin
Mobile User Objective System (MUOS)	Richard Y. Horiuchi, Desirée E. Cunningham
MQ-1C Unmanned Aircraft System (MQ-1C Gray Eagle)	Deanna Laufer, James S. Kim
MQ-4C Triton Unmanned Aircraft System (MQ-4C Triton)	Tom Twambly, Candice N. Wright, Amanda Parker
MQ-8 Fire Scout	Leigh Ann Haydon, Deanna Laufer
MQ-9 Unmanned Aircraft System Reaper (MQ-9 Reaper)	Megan L. Porter, Laura Jezewski
Next Generation Operational Control System (GPS OCX)	Erin R. Cohen, Jeffrey M. Sanders
P-8A Poseidon (P-8A)	Jocelyn C. Yin, Heather B. Miller
Paladin Integrated Management (PIM)	William C. Allbritton, Marcus C. Ferguson
RQ-4A/B Global Hawk Unmanned Aircraft System (RQ-4A/B Global Hawk)	Laura M. Jezewski, Megan L. Porter
Ship to Shore Connector (SSC)	Matthew Shaffer, Beth Reed Fritts
Small Diameter Bomb Increment II (SDB II)	John W. Crawford, Brian A. Tittle
Space Based Infrared System High Component (SBIRS High)	Claire A. Buck, Maricela Cherveny
Warfighter Information Network-Tactical Increment 2 (WIN-T Inc 2)	James P. Tallon, Andrea Yohe
Warfighter Information Network-Tactical Increment 3 (WIN-T Inc 3)	James P. Tallon, Andrea Yohe
Future Programs	
Amphibious Combat Vehicle (ACV)	MacKenzie H. Cooper, Bonita J. P. Oden
Armored Multi-Purpose Vehicle (AMPV)	Andrea M. Bivens, Dayna L. Foster
B-2 Defensive Management System (DMS) Modernization	Don M. Springman, Matthew B. Lea
Combat Rescue Helicopter (CRH)	J. Andrew Walker, Robert K. Miller
Common Infrared Countermeasures (CIRCM)	Danny G. Owens, Wendy P. Smythe
Enhanced Polar System (EPS)	Bradley L. Terry
F-15 Eagle Passive/Active Warning and Survivability System (F-15 EPAWSS)	Wendell K. Hudson, LeAnna M. Parkey
Ground Combat Vehicle (GCV)	Marcus C. Ferguson, William C. Allbritton
Indirect Fire Protection Capability, Increment 2 (IFPC Inc 2)	Helena Brink, Carol T. Mebane
Joint Air-to-Ground Missile (JAGM)	Wendy P. Smythe, Ryan Stott

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(Continued From Previous Page)

Program name	Primary staff
Military GPS User Equipment (MGUE), Increment 1	Raj C. Chitikila, Andrew H. Redd
Next Generation Jammer (NGJ)	Teakoe S. Coleman, Laura T. Holliday
Ohio Class Replacement (OR)	C. James Madar, Amber N. Keyser
Presidential Aircraft Recapitalization Program (PAR)	LeAnna M. Parkey, Brian Smith
Presidential Helicopter (VXX)	Bonita J. P. Oden, Jerry W. Clark
Space Fence	Laura D. Hook, Jeffrey M. Sanders
Three-Dimensional Expeditionary Long-Range Radar (3DELRR)	Claire Li, Janet L. McKelvey
Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS) System	Julie C. Hadley, Sean D. Merrill

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May 5, 2014

The Honorable Carl Levin
Chairman
The Honorable James M. Inhofe
Ranking Member
Committee on Armed Services
United States Senate

Defense Acquisitions: Military Services Consistently Held Required Configuration Steering Boards That Actively Reviewed Requirements Changes

The Department of Defense (DOD) established Configuration Steering Boards (CSBs) in 2007 as a measure to control requirements changes and associated cost increases on its major defense acquisition programs (MDAPs).[1] These boards are a forum for senior acquisition, funding, and requirement leaders in the Office of the Secretary of Defense, Joint Staff, and the military services to review proposed changes to program requirements or system configurations that have the potential to adversely affect program cost or schedule.[2] Congress has also identified CSBs as a way to control requirements. In the Duncan Hunter National Defense Authorization Act for Fiscal Year 2009, Congress directed DOD to establish and hold annual CSBs for the military services' MDAPs.[3]

In July 2011, we found that the military services held a CSB review for about 77 percent of the MDAPs in 2010, and that programs varied in how they used the boards to control requirements and mitigate cost and schedule risks. [4] In addition, we found that not all of the required officials were invited to participate in the board meetings, particularly in the Navy. We recommended that the Navy amend its policy to ensure that all statutorily required participants are included, and that DOD amend its CSB policy to be consistent with statute and align CSBs with other reviews when possible. Since then, the Navy has updated its guidance to explicitly include the Joint Staff

[1] MDAPs are those estimated by DOD to require an eventual total expenditure for research, development, test, and evaluation of more than $480 million, or for procurement of more than $2.79 billion, in fiscal year 2014 constant dollars.

[2] A requirement is an established need justifying the timely allocation of resources to achieve a capability to accomplish approved military objectives, missions, or tasks. These are often communicated in requirements and other documentation as key performance parameters, key system attributes, or contract specifications. Configuration refers to the functional and physical characteristics of a product.

[3] Pub L. No 110-417, §814 (2008). The Under Secretary of Defense for Acquisition, Technology and Logistics recently directed the military services to employ the Configuration Steering Board construct for all acquisition category levels.

[4] GAO, *Defense Acquisitions: DOD Can Improve Its Management of Configuration Steering Boards,* GAO-11-640 (Washington, D.C.: Jul. 7, 2011).

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and the Office of the Secretary of Defense as CSB participants. In November 2013, DOD amended its CSB policy to ensure that statutorily required participants are included and require annual CSBs for programs in production and sustainment, among other things.[5]

The Senate Report accompanying the National Defense Authorization Act for Fiscal Year 2014 mandated GAO to review DOD's implementation of the CSB process.[6] This report examines the extent to which (1) the military services have held CSBs, and (2) CSBs were approving requirements changes that could impact cost and schedule outcomes.

To conduct this work, we reviewed the Duncan Hunter National Defense Authorization Act for Fiscal Year 2009 and acquisition guidance related to CSBs. Using the Defense Acquisition Management Information Retrieval System, we identified 79 current MDAPs that are required to hold annual CSBs.[7] For each program, we asked the acquisition organization overseeing it—the Air Force, Army, or Navy—to provide the minutes, briefing slides, or other documentation related to the meetings. Specifically, we examined 2013 CSB documentation to determine when the meetings were held; whether requirements and technical configuration increases or decreases were proposed; and if the boards approved the changes. For 12 Navy programs that conducted a CSB in 2013, we were unable to determine if requirements and technical configuration changes were proposed to and approved by the CSB, because the Navy was unable to provide appropriate documentation for these programs. Therefore, we excluded the following programs when determining whether CSBs were approving requirements changes that could impact cost and schedule outcomes: CH-53K Heavy Lift Replacement Helicopter, EA-18G Growler Aircraft, Ground/Air Task Oriented Radar, H-1 Upgrades, Joint Standoff Weapon-Baseline Variant and Unitary Warhead Variant, KC-130J Transport Aircraft, MH-60R Multi-Mission Helicopter, MH-60S Fleet Combat Support Helicopter, Mobile User Objective System, Tactical Tomahawk RGM-109E/UGM-109E Missile, V-22 Osprey Joint Service Advanced Vertical Lift Aircraft, and MQ-8 Vertical Takeoff and Landing Tactical Unmanned Aerial Vehicle Fire Scout.

We also interviewed officials from the Joint Staff, and acquisition and requirements organizations regarding the services' use of CSBs. Finally, we used information gathered from our latest annual weapon acquisition assessment to determine if programs were changing requirements without the approval of a CSB.[8] Our annual weapon acquisition assessment includes a non-generalizable sample of Air Force, Army, and Navy weapon programs in both development and production phases. We assessed program responses to a standard set of questions and identified programs that reported requirements changes in fiscal year 2013. We interviewed program officials to determine whether these requirements changes were presented to the CSB for review.

[5] DOD's Interim Department of Defense Instruction 5000.02, Operation of the Defense Acquisition System (Nov. 25, 2013) contains other modifications to defense acquisition policy which were not relevant for our review.

[6] S. Rep. No. 113-44, at 144 (2013).

[7] We defined current MDAPs as those included in DOD's Defense Acquisition Management Information Retrieval system's official MDAP list. We excluded two programs, the Ballistic Missile Defense System and Chemical Demilitarization-Assembled Chemical Weapons Alternatives, from our analysis because statutory requirements for Configuration Steering Boards only apply to military department major defense acquisition programs. These programs are managed by the Missile Defense Agency and the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense programs, respectively.

[8] GAO, *Defense Acquisitions: Assessments of Selected Weapon Programs,* GAO-14-340SP (Washington, D.C.: Mar. 31, 2014).

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We conducted this performance audit from February 2014 to May 2014 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Results in Brief

In 2013, the military services held a Configuration Steering Board (CSB) for 77 of 79 current MDAPs required to hold one by statute, approximately 97 percent. The Army and Air Force held meetings for all of their programs, while the Navy did not hold a CSB for two of its programs because one program began development in 2013 and the other program had its board cancelled and rescheduled in 2014 in an effort to reduce costs. We also found that the services combined these boards for similar programs or held them in combination with other reviews, although the Navy held some CSB meetings without officials from the Joint Staff and the Office of the Secretary of Defense in attendance.

Based on information the military services were able to provide on 65 of the 77 programs that held a CSB in 2013, the boards actively reviewed and approved requirements or technical configuration changes proposed by eight programs. The boards approved decreases or deferrals for four of the programs, increases for two programs, and both increases and decreases for two programs. The remaining 57 programs that the military services provided information on did not propose any changes to the CSB. However, we found that four programs changed requirements in 2013 without presenting the changes to the CSB for review or approval. In all four instances, the programs deferred, decreased, or modified their requirements.

We are not making recommendations in this report. We provided a draft of this product to DOD for comment. In an e-mail received on May 2, 2014, the Assistant Secretary of Defense for Acquisition stated that the department did not have any comments on the report. However, DOD provided technical comments which were incorporated into the report, as appropriate.

Military Services Consistently Held Annual Configuration Steering Boards

The military services held a CSB in 2013 for nearly all of the current MDAPs as required by statute—77 of 79 programs (approximately 97 percent). Table 1 shows the number of CSBs held in 2013 by military service.

Table 1: Number of Current Programs that Held Configuration Steering Boards in 2013

Military Service	Number of Major Defense Acquisition Programs[a]	Number of Programs that Held a Configuration Steering Board
Air Force	25	25
Army	18	18
Navy	36	34
Total	**79**	**77**

Source: GAO analysis of DOD data.

[a] The 2013 Configuration Steering Boards for the Joint Light Tactical Vehicle and the F-35 Joint Strike Fighter Aircraft were chaired by the Service Acquisition Executive of the Army and Navy, respectively, and were included in the count for each military service.

The Air Force and Army held CSBs for all of their programs in 2013, while the Navy held a CSB for all but two of its MDAPs. One of the Navy's programs, the Air and Missile Defense Radar program began development in October 2013 and is not required to complete the review until

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October 2014. The Navy cancelled its planned November 2013 CSB review of the other program, the Navy Multiband Terminal Satellite, in an effort to reduce costs and rescheduled the review for May 2014.

Each of the services combined CSBs for similar programs or held them in combination with other reviews to increase efficiency; however, this may have led to the Navy excluding required participants. For example, the Air Force and Army typically held boards for multiple similar programs at one time (i.e. aviation programs), while the Navy held boards in conjunction with annual execution or program executive office reviews. According to Navy officials, program executive office reviews were service-led meetings that included representatives from the Navy, but did not include representatives from the Joint Staff or the Office of the Secretary of Defense. Navy officials stated that any changes made during these reviews were to be sent afterwards to the Joint Staff and the Office of the Secretary of Defense for review.

CSBs Were Actively Involved in the Review of Requirements Changes and Cost and Schedule Impacts, but Not All Changes Were Brought to the Boards For Approval

CSBs reviewed and approved requirements or technical configuration changes proposed by eight programs in 2013, based on our analysis. The majority of the changes were for requirements decreases or deferrals; however, CSBs did approve some requirements increases. In addition, four programs reduced, deferred, or modified requirements in 2013 without getting approval by the CSB.

CSBs Approved Few Requirements Increases and Most Programs Identified Cost Impacts

Based on information the military services were able to provide on 65 of the 77 programs that held a CSB in 2013, the boards actively reviewed and approved requirements or technical configuration changes proposed by eight programs. The remaining 57 programs that the military services provided information on did not propose any changes to the board. We found that programs often proposed low-level system requirements changes, such as physical design requirements, as opposed to top-level requirements such as key performance parameters or key system attributes, which are considered to be critical or essential to the operation of the system. Of the eight programs whose proposals were approved by the CSB, four programs decreased or deferred requirements, two programs increased requirements, and two programs both increased and decreased requirements. Table 2 provides additional details about the eight programs whose proposals were approved by the CSB.

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Table 2: Requirements and Technical Configuration Proposals Approved by Configuration Steering Boards

Program	Type of Change	Description of Change
DDG 51 Arleigh Burke Class Guided Missile Destroyer	Deferral	Deferred installing intelligence equipment until ship deployment, resulting in cost savings and minimal schedule delays.
P-8A Poseidon Multi-Mission Maritime Aircraft	Deferral	Deferred targeting and search capabilities to future increments, resulting in design change cost savings.
MQ-1C Gray Eagle Unmanned Aircraft System	Decrease	Decreased requirements for the removal and replacement of system payloads and communications data rate; no cost impacts were identified.
Warfighter Information Network-Tactical Increment 3	Decrease	Decreased key Net-Ready requirement, the ability to exchange information with the "network", and key training requirement as a result of Army budget constraints and program restructure.
AGM-88E Advanced Anti-Radiation Guided Missile	Increase	Added new technology into the system to address obsolescence, resulting in an increase in cost.
LPD 17 San Antonio Class Amphibious Transport Dock (LPD 17)	Increase	Increased security features, including containers, tubing, and locks, resulting in an increase in cost.
F-35 Joint Strike Fighter Aircraft	Increase and Decrease	Increased two requirements and decreased one requirement for allowed contaminant levels based on testing, lessons learned, and safety assessments; no cost impacts were identified.
Littoral Combat Ship	Increase and Decrease	Increased requirements to make habitability modifications and improve satellite communications, and also decreased a requirement for a stabilizing component, resulting in a net increase in cost.

Source: GAO presentation of DOD data.

As described in the table, three programs that increased requirements identified cost impacts as a result of the changes. The board approved the configuration changes and associated costs presented by the Littoral Combat Ship program, and also approved the release of engineering change order funding for the LPD 17 program to cover the cost of the changes. The CSB required the AGM-88E Advanced Anti-Radiation Guided Missile program to formally request the funding for the cost of the technology insertion and include information about the effort's return on investment. According to Navy officials, the funding was released in January 2014. The F-35 program office did not present cost and schedule impacts of its proposed changes to the CSB. According to a program official, the contractor has not yet provided a cost estimate for the changes, but these changes needed to be made for safety reasons.

Four Programs Changed Requirements Without CSB Approval

Although the CSBs were actively involved in reviewing requirements and technical configuration changes that were presented to them, we identified four programs that changed key or system requirements in 2013 without presenting the changes to the CSB for review or approval. Almost all of these changes were for requirements decreases or deferrals. Service acquisition policies allow program managers to request CSBs outside of the annual cycle, if needed, however none of these programs requested this type of meeting in 2013. Officials from most of the programs indicated that they briefed board members about the decreased requirements at the next annual meeting. A brief description of changes made to the programs is provided below.

- **Family of Beyond Line-of-Sight Terminals –** The Air Force program deleted two system-level requirements in 2013, both without CSB approval. The program did not propose these deletions to the board for approval because, according to program officials, the Air Force's requirements council had already approved them. According to program officials, both requirements related to software architecture, and were deleted

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either because the program no longer needed the architecture due to technology developments or because DOD no longer used these legacy interfaces.

- **Paladin Integrated Management –** This Army program modified a key system attribute related to firing accuracy without CSB approval. The program adjusted its minimum and maximum range values upwards and downwards, respectively, based on testing results. Officials stated that the accuracy requirement adjustment did not impact the program's cost or schedule. Program officials further stated that they worked with requirements officials to receive approval for the modification and did not find the need to call special event-driven boards because everyone involved in the CSB process was already involved with the normal requirements change approval process. The program did, however, brief the CSB about the change during its 2013 annual meeting.

- **RQ-4A/B Global Hawk Unmanned Aircraft System –** In 2013, the Air Force's Global Hawk program deferred 15 system-level requirements related to the ground control station and control of the aircraft, among other things. The President's Budget for Fiscal Year 2013 divested the program's Block 30 system and eliminated related funding. Global Hawk officials stated that these deferrals were not proposed during the program's annual CSB review because they were directly related to the termination of the Block 30 aircraft.

- **Warfighter Information Network-Tactical (WIN-T) Increment 2 –** The Army's WIN-T Increment 2 program deleted a key performance parameter related to force protection. According to program officials, the program's final product will be installed on various platforms that did not have the same requirement criteria, and are beyond the program's control. The program sought and received approval for the deletion from the Joint Requirements Oversight Council in August 2013. According to program officials, the program did not propose this deletion to the board for approval because the requirements council had already approved the deletion. Program officials further stated that the program did not consider holding an event-driven CSB because the Joint Requirements Oversight Council is responsible for approving key performance parameter changes. However, program officials stated that they informed the board of the deleted requirement during the annual board meeting.

Agency Comments

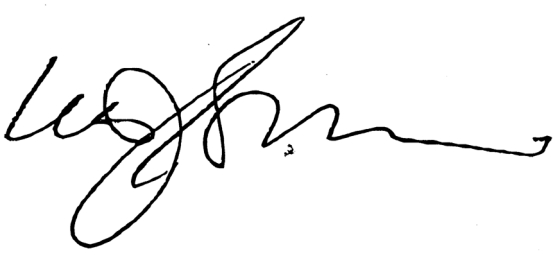
We are not making recommendations in this report. We provided a draft of this product to DOD for comment. In an e-mail received on May 2, 2014, the Assistant Secretary of Defense for Acquisition stated that the department did not have any comments on the report. However, DOD provided technical comments which were incorporated into the report, as appropriate.

- - - - -

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Should you or your staff have questions, please contact me at (202) 512-4841 or sullivanm@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Key contributors to this report were Cheryl Andrew, Assistant Director; Kristine Hassinger; Laura Jezewski; LeAnna Parkey; Brian Smith; Robert Swierczek; and Abby Volk.



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Getting Our Partners Airborne

Training Air Advisors and Their Impact In-Theater

Maj Gen Michael A. Keltz, USAF



Most Americans would be surprised to learn that US Air Force (USAF) members fly Russian-made Mi-17 transport helicopters and that a few have even flown Mi-35 gunships. USAF aircrew and maintenance personnel will also soon fly and maintain the Embraer / Sierra Nevada A-29 Super Tucano light attack aircraft and a special-mission variant of the Pilatus PC-12—and will continue to do so for years to come. The origins of these programs can be traced to 2007, when the Department of Defense (DOD) developed a plan to build airpower capabilities in the Iraqi and Afghan air forces. For Afghanistan, the concept of operations proposed the acquisition of 149

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rotary- and fixed-wing aircraft for training and a variety of operational missions. This proposal identified the need for an initial contingent of 600 USAF personnel—a number that would increase with growing demand in Afghanistan—to train and advise Iraqi and Afghan partners. Accordingly, the directive called for a capability to train USAF personnel in the air-advising mission prior to deployment. Although Air Force Special Operations Command had been providing this type of training for special operations forces (SOF), no such training existed for these conventional General Purpose Forces (GPF) Airmen. Existing ground-centric, predeployment training centers and SOF aviation-related training venues were at capacity. Consequently, in March 2007, the chief of staff of the Air Force directed Air Education and Training Command (AETC) to establish a permanent AETC-led predeployment training detachment, the Air Advisor Academy (AAA), to prepare air advisors to serve in this capacity.[1]



Photo courtesy of Lt Col Scott Voskovitch, USAF

The Iraqi Air Force flies the C-208B as a flying training platform. Modified versions perform special missions. (From "AC-208 Combat Caravan Light Attack Aircraft, Iraq," airforce-technology.com, http://www.airforce-technology.com/projects/ac-208-combat-caravan/.)

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Air Advisor Academy

Since the inception of the AAA in 2007, this AETC schoolhouse has educated and trained more than 4,300 students. Now fully operational at Joint Base McGuire-Dix-Lakehurst in New Jersey, the AAA has the capacity to train up to 1,500 students per year, producing 1,227 graduates in 2013. The school provides education and training in three areas: (1) air-advising core skills; (2) language, region, and culture; and (3) advanced force-protection skills, referred to as "fieldcraft." AETC offers eight different AAA training courses for Airmen deploying to permissive, uncertain, and hostile environments in any region across the globe; furthermore, it can tailor these courses in accordance with particular customer requirements. Airmen preparing to serve as aircrew and maintenance air advisors in Iraq and Afghanistan must complete a five-week hostile-environment course.

Even though this article discusses aircrew and maintenance air advisors, it is important to note that the AAA trains Airmen who will advise foreign partners in nearly every USAF career field. In fact, roughly 75 percent of Airmen who serve as air advisors come from the many other USAF career fields. Similarly, this article focuses on Iraq and Afghanistan, but the school trains Airmen preparing for air-advising activities in every geographic combatant command (GCC). Indeed, AAA education and training are on the rise as the demand for air advisors grows across each GCC. Gen Mark A. Welsh, the USAF chief of staff, explained in a June 2013 interview that "there are lots of other combatant commands that want the things that we offer who haven't gotten them for a while." General Welsh cited "partnership-building capability engagements," among other USAF capabilities, as a requirement across the GCCs that "is not going away; it's just going to shift."[2] Current unconstrained calculations for the next five years indicate that the number of Airmen who need training to perform air-advising and other security-cooperation activities in countries other than Iraq and Afghanistan could meet or even exceed the school's current capacity.[3]

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Projections indicate that the demand for air advisors in Afghanistan will remain long after the planned termination of US and coalition combat operations at the end of 2014. In its July 2013 *Report on Progress toward Security and Stability in Afghanistan* to Congress, the DOD assessed that Afghan National Security Forces (ANSF) will "need continued assistance and combat support through the end of the ISAF [International Security Assistance Force] mandate in December 2014; beyond then it will still require substantial training, advising and assistance—including financial support—to address ongoing shortcomings." The latter include "more complex and technologically advanced capabilities that will be fielded, such as . . . air support." More specifically, the DOD found that "ANSF components responsible for these more complex tasks, particularly air operations, will not be capable of fully independent operations by December 2014," citing long-term challenges in more sophisticated aviation career fields.[4] In a news conference on 30 July 2013 aligned with the release of this report, Dr. Peter Lavoy, acting assistant secretary of defense for Asian and Pacific security affairs, elaborated on this assessment: "We envision that it will take a period of time before they can adequately fully have sovereign ownership of all those skill sets, including well beyond the 2014 date."[5] In the June 2013 interview, General Welsh voiced a similar view, asserting that the Afghan Air Force (AAF) lacks "people who are trained to maintain an air force over time" and offered that the USAF "can help them with that. But it's going to be a few more years before they're there, in our estimation."[6] Accordingly, Kristina Wong projected in a June 2013 *Washington Times* article that most of the 940 coalition advisors currently building the AAF will remain through 2017 and that a smaller number could continue advising Afghans until 2024.[7]

Training for Aircrew and Maintenance Air Advisors

In addition to AAA courses, aircrew and maintenance air advisors must have specific training in the partner nation (PN) aircraft they will operate and maintain. Once trained, aircrew personnel receive formal

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flight evaluations to gain certification in the operation of these platforms. When the PN aircraft is also flown in the USAF, the major command (MAJCOM) responsible for the training typically manages this portion of air-advising training. In the case of non-USAF aircraft, such as the Mi-17, the aircrew and maintenance training is managed by AETC Headquarters' Special Missions Division (HQ AETC/A3Q) in the Directorate of Intelligence, Operations, and Nuclear Integration at Joint Base San Antonio–Randolph in San Antonio, Texas. To execute these responsibilities, the division works with the theater—US Central Command in the case of Iraq and Afghanistan—to establish and validate the associated training requirements. HQ AETC/A3Q then establishes the USAF program that will support this requirement, develops a DOD or contracted training solution, initiates the contracting process when applicable, and—once the contract is awarded—oversees execution of the contracted training. Additionally, the division develops the syllabus that will guide the training, schedules individuals for training, and manages the associated student pipeline. HQ AETC/A3Q also manages standardization/evaluation programs for each of these non-USAF aircraft. Individuals assigned to the division conduct flight evaluations to certify aircrew members in the operation of these aircraft. Bringing these responsibilities full circle, HQ AETC/A3Q performs assessments of the air-advising programs in-theater and uses feedback from these visits to make necessary changes to air-advising education and training.

Furthermore, AETC's Special Missions Division supplies MAJCOM-level management and oversight of GPF air-advising education and training conducted at the AAA. Centrally managing these programs from a single office makes perfect sense because each is inextricably linked to both the air-advising mission and each other. Since AETC is the lead MAJCOM for air-advising education and training, non-USAF aircrew and maintenance training, flying training, technical training, and expeditionary skills training, it's also logical that the AAA and associated aircrew/maintenance training fall under that command. Since the inception of this air-advising aircrew and maintenance training

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program in 2007, AETC—with HQ AETC/A3Q in the lead—has managed the training of a total of 846 aircrew and maintenance professionals in 12 aircraft types at a rate of roughly 150 trainees per year. The program has had a substantial impact in Iraq and Afghanistan and is poised to do even more across the globe in the years ahead.



Photo courtesy MSgt Jay Simmons, USAF

An Afghan Air Force Mi-35 gunship awaits tasking at Kabul International Airport, Afghanistan, on 13 February 2010. Two USAF pilots served as air advisors in Afghan Mi-35s during 2010 and 2011.

Rotary-Wing Air-Advising Programs

After the Soviet-Afghan war in the 1980s, the Soviet Union left the Soviet-backed Afghan government with a fleet of over 400 military aircraft, including a large number of Soviet-made helicopters. Years of

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fighting within Afghanistan during the 1990s and the US response to the terrorist attacks of 11 September 2001 left the AAF in shambles. By 2007 the Afghan military had only 20 aircraft in its inventory, mostly Mi-17s and Mi-35s.[8] As a direct result of US security assistance and US-led air-advising programs in Afghanistan, the AAF now consists of approximately 100 aircraft. The fleet includes 48 Mi-17s, six Mi-35 attack helicopters, 26 Cessna 208B (C-208B) Grand Caravan fixed-wing trainers/airlifters, six Cessna 182 (C-182) fixed-wing trainers, and six MD-530 rotary-wing trainers.[9] Two USAF pilots served as Mi-35 air advisors in 2010 and 2011, helping the AAF further develop this preexisting capability.[10] The AAF had 6,277 personnel in March 2013, and—as C-130Hs, A-29s, PC-12s, and more Mi-17s are added to the fold—projections indicate it will have 140 aircraft and 8,000 personnel by 2016.[11] According to the DOD's *Report on Progress*, "The Afghan Air Force faces a number of challenges—particularly recruiting and training personnel to operate and maintain the fleet—and is not expected to be fully mission capable until at least 2018."[12] To meet this objective, the USAF must have a sustained and fully funded air-advising program during this time frame.

USAF air advisors train, advise, and assist Afghan counterparts in Mi-17 operations and maintenance; moreover, the advisors' duties include combat missions with Afghan crews. Prior to deploying, these USAF crew members and maintainers attend AETC's Mi-17 training courses for aircrew and maintenance air advisors. Concord XXI Inc. provides a two-week Mi-17 simulator training course in Daleville, Alabama, during which pilots and flight engineers complete 40 hours of academics and 10 simulator hours, and the flight engineers undergo an evaluation in the simulator. After finishing the course, pilots attend six weeks of Mi-17 flying training in Destin, Florida, conducted by Vertol Systems Company Inc. This course consists of 40 hours of ground academics, 35 hours of flight training, and two formal flight evaluations. Flight engineers attend a four-week course in Destin that includes 25 flying hours. USAF maintenance personnel preparing to deploy as air advisors attend a three-week US Army Mi-17 maintenance course at

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Fort Rucker, Alabama, that emphasizes general aircraft familiarization and involves 40 hours of academics and 80 hours of hands-on training. Typically, as many as 25 USAF pilots, six flight engineers, and 48 maintenance personnel are trained each year to perform air-advising duties in the Mi-17. Twelve pilots, 17 flight engineers, and 30 maintainers completed training in 2013.

An Mi-17 search and rescue, humanitarian assistance, and disaster-relief mission conducted on 28–29 July 2010 in northeastern Afghanistan demonstrates one impact not often considered in conjunction with air advising. Massive flooding led local Afghan government authorities to request assistance from Brig Gen Muhammed Barat, the AAF's Kabul Air Wing commander, in the early morning of 28 July 2010.[13] Lt Col Greg Roberts, a career USAF rescue helicopter pilot, was serving at the time as General Barat's air advisor and commander of the USAF air-advising squadron in Kabul.[14] General Barat and Lieutenant Colonel Roberts immediately assembled a team of AAF crew members and USAF air advisors to respond to a humanitarian disaster unfolding in one of the most high-threat, insurgent-laden regions of Afghanistan. In just two AAF Mi-17 helicopters, this team rescued an astonishing 2,080 Afghans over the next two days—the largest two-ship helicopter rescue in USAF history.[15] Arming Afghans with the capacity to conduct humanitarian missions of this type across their country will drastically increase the legitimacy of the ANSF and the Afghan government as a whole. Ultimately, helicopter missions saving Afghans will have a far more powerful effect on the hearts and minds of the Afghan people—and the efficacy of the Taliban, for that matter—than any other effect of direct air combat. If a handful of Afghans and air advisors with two Mi-17s can have such an impact in two days, then one can only imagine what a fully trained and operational AAF will be able to do.[16]

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An Afghan Air Force officer who flew on board the Mi-17s rescues a child during the daring two-day operation. (From Lt Col Gregory A. Roberts, "Flight Lead Narrative for Afghan Rescue 705 Flight Operations, 28–29 Jul 2010," 438th Air Expeditionary Wing, 6 August 2010, with updates 24 January 2011 and 1 March 2011.)

As the AAF builds on such experiences, the DOD's *Report on Progress* observed that "the AAF is increasingly capable of carrying out a range of operations" and cited examples of its growing effect.[17] From 15 to 18 November 2012, AAF Mi-17s supported Afghan border police who were providing supplies to local villages in a contested area of southern Afghanistan—"possibly the first time these villages had seen GIRoA [Government of the Islamic Republic of Afghanistan] forces, let alone AAF helicopters, delivering humanitarian aid."[18] In fact, AAF Mi-17 operations have advanced to the point where Afghan crews routinely conduct resupply, casualty evacuation (CASEVAC), and passenger-transport missions across the country without US or coalition air advisors on board.[19] In partnership with coalition and Afghan ground forces, Mi-17s now conduct more sophisticated air-assault operations as well.[20] The same report, however, projected that "the 86 Mi-17 helicopters pro-

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grammed for the post-2014 AAF fleet will meet only minimal operational requirements."[21] USAF air advisors will necessarily continue to assist and advise their Afghan counterparts as the AAF develops its fleet of Mi-17s and builds on this progress.

Fixed-Wing Air-Advising Programs

C-172 and T-6

Beyond the Mi-17 program in Afghanistan, AETC-trained USAF air advisors also offered years of assistance to the Iraqi Air Force (IqAF) in the development of a fixed-wing pilot-training program. At its inception, this program consisted of six months of primary flight training in the C-172 and six months of advanced flight training in the C-208B. USAF air advisors served as instructors in both aircraft. The Beechcraft T-6 Texan II is now used for primary flight training in Iraq, and USAF air advisors advise the IqAF on T-6 maintenance practices. USAF air advisors train and advise foreign counterparts to enable the PN air forces they represent to perform, over time, their roles and responsibilities independent of US assistance. This approach is now mature in Iraq, and if the United States stays the course, the air-advising model can prove successful in Afghanistan as well.

C-182 and C-208B

As in Iraq, pilot training in the AAF consists of two phases: the first in the C-182 and the second in the C-208B. USAF active-duty and contracted air advisors instruct in both aircraft. HQ AETC/A3Q is charged with training the active-duty air advisors involved in these and other non-USAF aircraft programs. The Air Force Security Assistance Training Squadron, assigned to the Headquarters AETC International Affairs Directorate at Joint Base San Antonio–Randolph, manages USAF contracts that deploy civilian instructors who support some of these same programs. To prepare USAF air advisors en route to Afghanistan, the

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Spartan College of Aeronautics and Technology in Tulsa, Oklahoma, provides C-182 and C-208B aircrew and maintenance training. Spartan previously offered the C-172 training as well. The 15-day C-182 air-advisor pilot course consists of approximately 10 hours of ground academics, 10 hours of flight training, and a flight evaluation. The C-208B pilot course lasts 20 days, with 10 hours of ground academics, 12 hours of cockpit procedural training, 20 hours of flight training, and a flight evaluation. Roughly half of the 15-day familiarization training for the maintenance air advisors consists of hands-on experience.

The training that USAF air advisors provide in the various Afghan airframes has begun to bear fruit. Three AAF classes have completed their pilot training in Afghanistan and, on 23 June 2013, the fourth class began the C-208B phase of training.[22] On 20 May 2013, an Afghan C-208B crew flew a badly wounded Afghan soldier from Kandahar to a hospital in Kabul. A USAF air advisor participated in the operation, but this mission marked only the second time that AAF personnel had planned and led a real-world CASEVAC mission.[23] In fact, the AAF has recently reached the point where it has begun flying operational missions without the assistance of air advisors. On 25 June 2013, two Afghan lieutenants trained by USAF air advisors completed the first all-Afghan C-208B operational flight, airlifting 16 passengers—including four local governors.[24]

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Members of the Afghan Air Force's Security Forces Quick Reaction Force of the Kabul Air Wing unload from an Mi-17 and practice insertion procedures during an exercise on 27 March 2013. (From Capt Anastasia Wasem, "Afghan Air Force Conducts Multi-Aircraft, Multi-Capability Exercise," US Air Forces Central Command, 1 April 2013, http://www.afcent.af.mil/news/story.asp?id=123342416.)

Additionally, Afghan forces have begun conducting exercises involving both fixed- and rotary-wing missions. On 27 March 2013, the AAF conducted its first combined training exercise, flying Afghan Mi-35s and Mi-17s in an air-assault capacity and C-208Bs in a CASEVAC role.[25] The Mi-17s inserted and extracted Afghan troops, Mi-35s cleared landing sites and flew armed overwatch, and C-208Bs transported patients. USAF air advisors trained, advised, and assisted the AAF in developing these operational capabilities. These exercises and other ongoing training efforts have stimulated progress on the battlefield. In support of a major Afghan National Army operation in northeastern Afghanistan in the spring of 2013, Mi-17s and C-208Bs flew CASEVAC and battlefield circulation missions.[26] In fact, the AAF increased its CASEVAC mis-

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sions by 34 percent from February to June 2013.[27] Such air operations allow the Afghans to take the lead, reducing the ANSF's dependence on US and coalition forces. As a result of the air-advising effort, the United States has in turn begun reducing a commensurate portion of direct air support to Afghan ground forces. In a very real and measurable way, then, air advising allows US military forces in Afghanistan to implement the Obama administration's plan to transition combat operations to Afghan forces by the end of 2014.[28]



Three Afghan Air Force pilots receive recognition after completing aircraft commander upgrade training. Following a year of flying with USAF air advisors, two of these pilots flew the first all-Afghan C-208B mission on 25 June 2013. (From "Major Milestone Achieved As AAF Aircraft Commanders Are Certified and Fly First All Afghan C-208 Mission at Shindand AB," *NATO Training Mission Afghanistan Storyboard*, 838th Air Expeditionary Advisory Group, 25 June 2013.)

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Aircraft on the Horizon

Even though projections call for the end of US combat operations in less than a year, the air-advising mission will remain necessary for years to come. Three new Afghan aircraft programs that will need an enduring air-advisor mission in Afghanistan—and will ultimately allow the AAF to stand on its own—include the C-130H, the light air support (LAS) A-29 Super Tucano, and the PC-12. The ANSF is currently dependent on US and coalition capabilities such as medium airlift; special-missions support; intelligence, surveillance, and reconnaissance (ISR); and fixed-wing weapons employment. The development of Afghan-appropriate capabilities in each of these areas is critical. The C-130H, A-29, and PC-12 have been selected to perform these roles, thus prompting the need for USAF air advisors and associated preparatory training in all three airframes. HQ AETC/A3Q will play a key role in the development, implementation, and management of USAF A-29 and PC-12 training programs and will assist in preparing C-130H air advisors.

C-130H

To meet a pressing requirement for a medium-airlift capability, Ashton B. Carter, the US deputy secretary of defense, directed the USAF in January 2013 to provide the AAF with four C-130Hs and associated training.[29] The first two aircraft arrived on 9 October 2013, and delivery of the last two is scheduled for November 2014.[30] The first group of Afghan C-130H pilots began training in the United States in May 2013.[31] Assisting the AAF in fully developing this new program will require a USAF air-advising mission in Afghanistan after 2014. According to the DOD's *Report on Progress*, the new C-130Hs "provide an initial capability to do inter-theater lift that will take several years to mature."[32] USAF aircrews/maintainers with prior C-130H experience will comprise the bulk of initial air advisors, and the USAF's Air Mobility Command will likely provide any necessary training for the aircrew and maintenance personnel. On 14 August 2013, the first group of 31

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USAF maintainers preparing to assist the AAF with the new C-130H program completed the necessary predeployment training at the AAA.

A-29

Brazilian Embraer Defense and Security, in cooperation with the US-based Sierra Nevada Corporation, was selected on 27 February 2013 to supply the AAF with 20 A-29 Super Tucanos, training for AAF aircrew and maintenance personnel, and associated logistical support.[33] Sierra Nevada will also train USAF air advisors who will in turn train and advise the AAF. This air-advisor training is scheduled to begin in the fall of 2014. The first A-29s should be available in September 2014, and at that point, plans call for delivering two aircraft per month.[34] The USAF intends to deploy air advisors to Afghanistan to assist Afghan counterparts as they build the organizations and infrastructure required to support this more sophisticated weapons system. The DOD reported that the new A-29 LAS program will "provide the AAF with the capability to conduct air interdiction, armed reconnaissance, air-to-ground support, combat search and rescue, border patrol, and aerial escort missions."[35] To train the AAF to perform these missions adequately, officials project an incremental training approach that includes US aircrew and maintenance air advisors for years to come. In fact, "the full employment of CAS [close air support] capability is not expected until sometime post-2018."[36]

Although this new USAF A-29 LAS program focuses on Afghanistan, it brings with it some extraordinary opportunities elsewhere. Over the past 70 years, the Inter-American Air Forces Academy (IAAFA), located at Joint Base San Antonio–Lackland, has played a central role in USAF security cooperation and engagement efforts across the Western Hemisphere. This AETC organization has trained more than 45,000 Latin Americans in a variety of mission areas, including aircraft operations and maintenance.[37] Meanwhile, the Brazilian-built Super Tucano is rapidly becoming the light attack weapons system of choice across much of Latin America.[38] As the region's air forces transition to the Su-

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per Tucano, it will become increasingly important for IAAFA instructors to gain knowledge and expertise in the operation and maintenance of this airframe—and initial steps have been taken toward that end. During a June 2013 visit to the IAAFA, representatives from Embraer and Sierra Nevada delivered A-29 technical manuals. The IAAFA plans to use these materials to incorporate A-29 checklists and procedures into six of its maintenance courses.[39]

The A-29 air-advising mission allows the IAAFA to further improve this effort. As A-29 aircrew and maintenance air advisors to the AAF, USAF personnel will acquire substantial knowledge of A-29 operations and maintenance. Further, they will gain unique combat-related A-29 experience that will greatly assist the IAAFA and its faculty as the academy continues to engage a region moving decidedly toward the Super Tucano. This tie between Afghanistan and the IAAFA mission is instructive insofar as it demonstrates quite poignantly that air advising and security cooperation are more widely applicable beyond the borders of Iraq and Afghanistan. It also shows the critical role that AETC organizations—such as the Air Force Security Assistance Training Squadron; HQ AETC/A3Q; the AAA; and, potentially, the IAAFA—play in institutionalizing the knowledge and experience acquired in Iraq and Afghanistan for use in other countries and GCCs around the world.

During current military operations in Afghanistan, US and other coalition aircraft flying close air support missions receive targeting information and clearance to expend munitions from US and coalition joint terminal attack controllers (JTAC). Prior to deployment to Afghanistan, US controllers complete a rigorous program that often includes training with actual aircraft that will conduct combat operations in that country. It is also quite valuable for the aircrews flying these aircraft to train with the same JTACs who will direct air-to-ground operations intheater. The aircraft and aircrews, however, have multiple other predeployment training requirements; consequently, aircraft availability for JTAC training is often problematic. Because plans call for A-29 air-advising training to take place in the United States, the pilots of these

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aircraft may be available for JTAC training. If availability and contractual agreements allow, this training would prove mutually beneficial for pilots and JTACs alike as A-29s take flight in Afghanistan. Over time, A-29s will begin combat operations in Afghanistan, and the training that JTACs and air advisors receive stateside could be put to good use downrange.

KA-350/AC-208B/PC-12

In years past, HQ AETC/A3Q managed two air-advising aircrew and maintenance programs supporting the IqAF that demonstrate the capacity for air-advising efforts to reach their desired end state. A military variant of the Hawker Beechcraft King Air 350 light transport aircraft, the KA-350ER-ISR was introduced into the IqAF in July 2008 to serve in an aerial reconnaissance role.[40] Hawker Beechcraft offered KA-350 maintenance-familiarization training in Wichita, Kansas, to support this IqAF advising mission. Pilots received KA-350 simulator training in Orlando, Florida, and then flew US Navy T-44s with a compatible avionics suite at Naval Air Station Kingsville in Corpus Christi, Texas. Similar to the MC-12W Liberty flown by the USAF in Afghanistan, the modified KA-350 gives the IqAF the ISR capabilities necessary to detect and deter insurgent activity.[41] USAF air advisors launched the KA-350 program and, after it matured, transitioned operations and maintenance to full control of the IqAF.

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Photo courtesy Sgt Brandon Bolick, USA

An Iraqi Air Force AC-208B Combat Caravan fires a Hellfire missile on 8 November 2010 and scores a direct hit on an Aziziyah Training Range target south of Baghdad. (From MSgt Mike Edwards, "Iraqi Airmen Demonstrate Operational Capabilities in Hellfire Exercise," *Inside Af.Mil*, 2 December 2010, http://www.af.mil/news/story.asp?id=123233035.)

The same occurred with a special-missions variant of the C-208B. Three of these aircraft, modified to serve in an ISR capacity, were delivered to the IqAF in 2007. The following year, Alliant Techsystems Inc., a defense company in Fort Worth, Texas, began modifying three C-208Bs to carry and employ the AGM-114M/K Hellfire missile.[42] Alliant delivered the first of these aircraft in December 2008 and the last in November 2009. An IqAF AC-208B aircrew first fired a Hellfire missile on a bombing range near Al Asad Air Base on 4 November 2009. The following year, on 8 November, Iraqis fired a second missile in conjunction with the first Iraqi-run live-fire missile-training exercise since the time preceding Operation Iraqi Freedom in 2003.[43] USAF air advisors played an active role in advancing IqAF capabilities to this point. The

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third live employment, on 23 March 2011, further validated the USAF's air-advising mission. An Iraqi special operations forward air controller directed this AC-208B launch, which occurred as part of an increasingly sophisticated scenario.[44] Adding this aircraft to the inventory—and training its crews and maintainers—has enabled the IqAF to better conduct counterinsurgency operations.

These two programs might be considered predecessors of the PC-12 program now on the rise in Afghanistan. An Afghan Special Mission Wing (SMW), established in July 2012, provides air support to the Afghan special forces' counterterrorism and counternarcotics mission.[45] Up to this point, those special forces and the new SMW, together with 30 aging Mi-17s and 180 personnel, have relied heavily on US support to the special operations mission.[46] To enable transition to Afghan air support of special missions, the DOD recently awarded two contracts for a total of 48 new SMW aircraft. Sierra Nevada will supply 18 specially modified PC-12s, and Russian-based Rosoboronexport will deliver 30 new Mi-17s that will replace the existing fleet.[47]

Training and advising Afghan special operations aircrews and maintainers will take time. The new wing plans to have 188 pilots to fly its projected fleet of 48 aircraft; it had 42 pilots as of January 2013. Only seven of them were fully qualified to fly with night vision goggles. The SMW includes a total of 32 crew chiefs / flight engineers but needs 143. Of the 385 Afghan maintenance personnel required, the wing had only 86.[48] Working in conjunction with the theater, HQ AETC/A3Q is developing a plan to help the Afghans fill these personnel shortfalls by training and advising the SMW's aircrew and maintenance force. In addition to the Mi-17 program already discussed, the first USAF aircrew preparing to serve as PC-12 air advisors graduated from training in November and December of 2013. Once again, HQ AETC/A3Q will be responsible for training the active-duty air advisors, and Air Force Security Assistance Training will manage the contracted PC-12 instructors.

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Conclusion / The Way Ahead

Multiple, tangible benefits accrue to these air-advising aircrew and maintenance programs in Iraq and Afghanistan. First, USAF air advisors played an important role in enabling an orderly departure from Iraq at the end of 2011 and will remain central to the Obama administration's plan to transition military operations to Afghan control. Simply stated, a viable air force for Afghanistan depends upon the continued support of USAF air advisors. Without an adequate airpower capability, Afghan ground forces either will not have the capacity to maintain security or will require dedicated US and coalition air support beyond 2014—neither of which seems a practical option at present.

More specifically, without AAA and HQ AETC/A3Q support, the Afghan C-130H, A-29, and PC-12 programs will never get off the ground. Nicole Finch and Lt Col Peter Garretson observed that US engagement strategy "cannot consist simply of selling or giving a partner nation equipment and then leaving. The goal of improving a partner nation's aviation enterprise starts long before any equipment is procured or delivered and continues after any equipment is fielded."[49] Accordingly, cutting short the air-advising mission in Afghanistan would likely leave Afghans with new aircraft they cannot adequately operate and maintain. Additionally, the current Mi-17, C-182, and C-208B programs—which are gaining momentum and beginning to show some measurable results—will likely stall without continued and consistent support from USAF air advisors. Similarly, AAF and SMW missions such as pilot training, mobility, CASEVAC, light attack, and air support for special missions would falter. Continuing the USAF air-advising mission, then, offers the only reasonable USAF method by which Afghan forces can reduce current dependence on US and coalition capabilities and ultimately assume control in each of these areas.

The benefit of air advising is not isolated to Iraq and Afghanistan. With AETC in the lead, the USAF has institutionalized GPF air-advising training for aircrew and maintenance personnel and is now poised to apply that model elsewhere. As previously noted, robust air-advising

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experience and knowledge of A-29 Super Tucano combat operations and maintenance in Afghanistan will posture the service to train and advise PNs at the IAAFA, across Latin America, and wherever these aircraft may be flown. As budgets decrease and sequestration takes full effect, this low-cost alternative to persistent US military presence abroad allows us to further our national security interests around the world and continue to assist our partners, like Afghanistan, with a substantially reduced financial burden and US military footprint. In sum, USAF air advising will allow us to transition responsibility over time to the AAF as we build the airpower capacity of other PNs around the globe. ✪

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11. Ibid.; and Wong, "High Expectations."

12. Department of Defense, *Report on Progress*, 75.

13. Marion with Roberts, "Other Face of Airpower," 23.

14. Lieutenant Colonel Roberts currently serves as deputy division chief of the HQ AETC/A2/3/10's Standardization/Evaluation Division. In this capacity, he works with HQ AETC/A3Q to conduct Mi-17 flight evaluations in support of the USAF's air-advising aircrew training mission.

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38. Dave Lopez, "Bullet Background Paper on Initiatives to Incorporate A-29 Maintenance Concepts in IAAFA Courses," Inter-American Air Forces Academy, 318th Training Squadron, 11 July 2013, 1. The A-29 is currently flown by Brazil, Colombia, Chile, Dominican Republic, and Ecuador. Guatemala will join this group in 2014, and five other Latin American countries have expressed interest in the platform.

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Maj Gen Michael A. Keltz, USAF

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Joint Intelligence, Surveillance, and Reconnaissance in Contested Airspace

Dr. Robert P. Haffa Jr.
Anand Datla



Despite unprecedented success with intelligence, surveillance, and reconnaissance (ISR) networks put in place over Iraq and Afghanistan during the last decade, the joint force has yet to come to grips with the challenges and range of possible options to employ ISR platforms in contested airspace.[1] The Department of Defense ISR Task Force that supported innovations such as Project Liberty and

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the battlefield airborne communications node in countering insurgencies in Southwest Asia and the Middle East has not yet addressed either the new strategic concepts or the operational challenges inherent in an AirSea Battle in the Western Pacific or the Persian Gulf in an antiaccess/area-denial (A2/AD) environment.[2]

This article seeks to define the attributes of a family of airborne ISR systems required to operate in nonpermissive military environments. It assumes that despite solid progress in integrating ISR into uncontested airspace, these systems, for the most part, will not prove adequate in future contingencies in which the adversary contests the airspace over a vital region. To help expand the scope of options for ISR systems to operate effectively under these conditions, the article identifies operational factors in Iraq and Afghanistan that led to an integrated, joint ISR system of systems. In so doing, it becomes apparent that the force mix of platforms and sensors fielded to support these conflicts is unlikely to be the right system for an emerging security environment characterized by problematic access and the denial of key bases, ports, and lines of communication enabling power projection. When force planners analyze the plausible contingencies facing US armed forces in the future, they find that an ISR network designed for operation in permissive airspace will be quickly stretched to failure.

The article first reviews the ISR network that proved so successful in uncontested airspace in terms of platforms, sensors, and integration systems (command, control, communications, and computers used for processing data). It then examines the tasking declared in *Sustaining U.S. Global Leadership: Priorities for 21st Century Defense*, inferring from that document and follow-on joint guidance the requirements for a future ISR family of systems.[3] Finally, the article suggests a course of action through investment in ISR platforms, sensors, and system integration that might successfully underwrite this strategic guidance.

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ISR in Uncontested Airspace: Platforms, Sensors, Integration

Airborne ISR assets deployed to Iraq and Afghanistan had the good fortune to operate in essentially uncontested airspace in support of counterinsurgency and counterterror operations. Much of that airborne ISR network consisted of unmanned aerial vehicles (UAV) because of their long dwell time, improved sensors, enhanced connectivity, and precision strike capability. By using more than a platform-centric approach, however, the United States successfully created a family of systems during these conflicts that integrated sensors and command and control (C2) systems to prosecute the wars against a mobile and clandestine foe.

The principal airborne ISR platforms employed in Iraq and Afghanistan were UAVs that evolved from use of the Predator drone during the North Atlantic Treaty Organization's air war over the Balkans in the late 1990s. Although the Predator brought newfound capability in its ability to persist over an area of interest and relay video to the air component commander, "it couldn't . . . deliver target-quality mensurated coordinates or designate targets for other aircraft to strike."[4] Furthermore, the Predator may have brought with it the second-order consequence of gluing too many humans in the chain of command to the video screen, forming long lines of intelligence analysts waiting for their opportunity to watch the real-time show from the battlefield and, as a result, slowing decision making. For example, the attack on Abu Musab al-Zarqawi, the al-Qaeda leader in Iraq, was said to have taken 600 hours of Predator time and thousands of hours of analyst time to facilitate a strike executed in a matter of minutes. Nevertheless, Predator ushered in a new era in situational awareness (SA) and inspired a revolution in coupling ISR with strike when it and its follow-on, the Reaper, were mated with the Hellfire antitank missile. That unmanned hunter-killer concept is one of the most important of all military capabilities—a lesson identified—that will carry forward as the United States faces more sophisticated adversaries in the future.

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However, Predator and Reaper had relatively narrow fields of view. Therefore, the unmanned, high-flying Global Hawk became particularly valuable to combat commanders owing to its ability to survey large geographic areas from an altitude of 60,000 feet. The United States also deployed in Afghanistan a classified, stealthy remotely piloted aircraft—once referred to as the "Beast of Kandahar"—since identified as the Sentinel, designed and deployed as a tactical reconnaissance asset. Unfortunately, this UAV surrendered its cloak of secrecy when it crash-landed over Iranian territory.[5]

Not all airborne ISR platforms used in Iraq and Afghanistan were unmanned. The MC-12 Liberty, an augmented version of the turbo-propelled King Air 350, was developed and fielded rapidly to focus on improvised explosive devices (IED) in Iraq. By cross-cueing full motion video (FMV), signals intelligence (SIGINT), and backtracking software, the Liberty system could determine not only the location of IEDs but also the events leading to their roadside insertion. Of course, the United States also deployed its more traditional manned ISR platforms to support conventional and counterinsurgency operations in Iraq and Afghanistan, such as the C-135-based capabilities of the Rivet Joint for SIGINT, the Joint Surveillance Target Attack Radar System aircraft for accurate radar imagery, ground-moving target indications and battle management, and the venerable U-2 for photo imagery. These aircraft were unimpeded by enemy air defenses in their ISR operations along and within uncontested airspace.

We should also note the term *nontraditional ISR*, which refers to the use of sensor systems such as targeting pods on manned fighter aircraft that, although not designed for ISR operations, proved very useful in contributing to battlespace awareness in these unconventional campaigns. Examples include F-18s and F-15s collecting imagery with targeting pods, F-16CJs designed for countering surface-to-air missiles collecting SIGINT, and AC-130s using video capabilities to monitor facilities of interest.[6] Such imagery has the advantage of being downloaded and transmitted over data links to the war fighter in near real

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time or simply returned to a bank of stored ISR data for processing and disseminating in a less time-sensitive environment.

Similar to the challenges facing platforms in low-intensity conflict, ISR sensors had to be adapted to concentrate on an unconventional adversary. Perhaps the most innovative—and arguably the most valuable—application was the use of FMV. Coupled with the persistence of platforms that could loiter for long periods of time, FMV could distinguish friend from foe on the ground and avoid collateral damage in the event of an attack. Prominent here were the multispectral targeting systems used by the Predator and Reaper drones, employing automated tracking, color, fused images, and electronic zoom.[7] To enlarge the field of view and allow a single aircraft to provide coverage of multiple targets, the "Gorgon Stare" system was designed to augment the FMV capability by adding 10 separate electro-optical (EO) and infrared (IR) sensors to offer a single wide-area perspective over a four-kilometer-square area. On the Project Liberty MC-12s, an IR pointer allowed the aircrew to designate an object to troops on the ground.

The sensors on these manned and unmanned systems were developed specifically for the unconventional, land-based target set in Iraq and Afghanistan. The Global Hawk, developed originally as a replacement for the manned U-2 in a strategic surveillance role, needed additional modification. Block 20 Global Hawks were equipped primarily for imagery intelligence and were later modified to serve as battlefield communications nodes. Block 30 Global Hawk aircraft acted as multispectral platforms with EO, IR, synthetic aperture radar, and SIGINT sensors. At its high-altitude, over-the-battlefield position and with its long endurance, Global Hawk could cross-cue, verify, and link similar sensors and systems operated by manned standoff ISR platforms.

Other ISR force multipliers included the targeting pods carried on tactical fighters—the so-called nontraditional ISR platforms. These pods contained high-resolution, forward-looking IR sensors displaying an image with a wide-angle search capability and a narrow field of view to acquire battlefield-sized targets. These images could be down-

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linked in streaming video to forward-deployed ground forces in a form of ISR close air support. Because of this innovation, nontraditional ISR was often specified as a fighter's primary task in the daily air tasking order and coordinated with UAV operations to supply long dwell time when needed and rapid reaction as necessary.[8]

Management and integration of these platforms and sensors have evolved over the last decade, and each of these airborne ISR systems has been adapted to facilitate real-time C2 in support of the war fighter. Unfortunately, as is often the case in individual systems, the C2 network put in place is stovepiped from platform and sensor to a specific user and service-specific distributed ground station, thus failing to cross the air, sea, and land domains and include joint customers seeking essential elements of information.

All of these ISR systems shared the objective of informing ground commanders and increasing their SA within a mobile and complex battlespace. As the initial air operations plan for Operation Enduring Freedom unfolded in late 2001, links between the Predator and AC-130U gunships were established using an omnidirectional C-band antenna. That innovation quickly led to sending Predator video to troops on the ground through a Remotely Operated Video Enhanced Receiver system, eventually supporting video feeds from multiple UAVs and downsized to handheld versions carried by troops on the ground.[9]

The object of Task Force Observe, Detect, Identify, and Neutralize (ODIN)—one of the best examples of air-ground ISR integration to come out of the Iraq and Afghanistan wars—was to counter the enemy's IED campaign. Components of the US integrated ISR system included UAVs with FMV and the Liberty King Airs, also equipped with video and SIGINT. In addition to ferreting out IEDs and shortening the decision chain with radio links to Apache helicopters, the ODIN system proved noteworthy for its ability to distribute collected data to common ground stations, cross-cueing human intelligence, imagery, and SIGINT to create "pattern of life" footprints leading to the

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acquisition of high-value targets and the unraveling of complex IED networks.[10]

One concern with the ODIN network had to do with its performance over the rugged and mountainous terrain of Afghanistan compared with that over the relatively flat landscape of Iraq. A solution to this issue involved the use of airborne communications systems to act as a relay to help integrate air and surface operations. The battlefield airborne communications node was developed to overcome these difficulties by allowing air and ground-based units operating far from each other to see the same ISR picture. The node has been deployed on both manned (the E-11A) and unmanned (Global Hawk) platforms to improve system integration, enhance SA, and strengthen beyond-line-of-sight communications.[11]

What might we conclude from this brief description of ISR platforms, sensors, and their integration employed in counterinsurgency and counterterror operations over the last decade? The demand signal was high, and the targets were time-sensitive, resulting in an emphasis on airborne platforms focused on supporting tactical ground operations in complex irregular warfare. Sensor systems deployed to Iraq and Afghanistan were tailored to a target set of IEDs, moving vehicles, and high-value individuals, driving the need for persistence. C2 of these ISR systems tended to emphasize single communications links between sensor and shooter rather than wideband communications conveying SA to the joint force. Clearly, the innovation in ISR brought to this unconventional battlefield was exemplary, from unmanned reconnaissance-strike systems to nontraditional tactics and techniques. Nevertheless, these platforms could operate only within a sanctuary of uncontested airspace. Had air defenses been more robust, these ISR operations might have proved far more difficult—and certainly less successful.

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Priorities for Twenty-First-Century Defense: Implications for ISR

The shift from counterinsurgency to broader strategic engagement in support of US and allied security has a number of implications for ISR. The document *Sustaining U.S. Global Leadership*, mentioned above, generates these requirements, tilting America's strategic focus and force posture toward the Asia-Pacific. To credibly deter and defend in the future, the policy directs the US military to "invest as required to ensure its ability to operate effectively in anti-access and area denial . . . environments."[12]

These requirements stand in stark contrast to present US ISR capabilities that emphasize counterterror and counterinsurgency operations. ISR will now have to provide persistent coverage over a vast area that could come under attack by adversaries, threatening the operations of US and allied armed forces. The guidance further warns that adversaries in these A2/AD areas will present difficult obstacles to US military intervention. In a follow-on document, the Joint Chiefs of Staff have clarified the ISR requirements dictated by this strategic shift. Specifically, the *Joint Operational Access Concept* charges ISR assets to

- Prepare the operational area in advance to facilitate access. . . .
- Exploit advantages in one or more domains to disrupt or destroy enemy anti-access/area-denial capabilities in others.
- Disrupt enemy reconnaissance and surveillance efforts while protecting friendly efforts. . . .
- Attack enemy antiaccess/area-denial defenses in depth rather than rolling back those defenses from the perimeter.
- Maximize surprise through deception, stealth, and ambiguity to complicate enemy targeting.[13]

It further emphasizes that the "reconnaissance/counterreconnaissance fight is a critical multidomain contest in any combat operation to gain operational access, as each combatant attempts to gain better situa-

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tional awareness than the other" and that the joint force will demand a major ISR effort applied aggressively. Finally, it notes that this concept will put a heavy burden on continued operations supported by robust C2: "Characterizing an adversary is a continuous activity, commencing years before hostilities begin and continuing during and after those hostilities. This has implications for steady state sizing, systemic capacity, and analytic technologies of intelligence forces. Specifically, the reconnaissance and surveillance contest is critical to access operations."[14]

In an open forum, we can best judge the requirements levied on airborne ISR assets through development of the nascent AirSea Battle operational concept. According to analysis conducted by the Center for Strategic and Budgetary Assessments (CSBA), a "blinding campaign" or "scouting battle" will be the first and most important military move in an A2/AD confrontation.[15] During this phase of the conflict, each side will seek to attack the other's ISR assets and battle networks to deprive the opponent of the ability to detect, identify, and target approaching forces at range. The CSBA study concludes that achieving the technical and procedural interoperability required for a successful joint AirSea Battle will "be toughest with respect to C2, communications, and ISR, simply because these drive the information and data flows" essential to SA.[16]

When the CSBA studies move beyond the A2/AD scenarios in the Western Pacific and the Persian Gulf, pondering the implementation problems inherent in AirSea Battle, they point to the need for rapid and continuing investment in integrated ISR systems.[17] This family of joint ISR systems necessary to underwrite AirSea Battle will have long lead times because of the complexity of integrating various platforms and sensors. Most challenging will be fully compatible and interoperable joint C2, ISR, and processing, exploitation, and dissemination (PED) architectures. Thus, the CSBA concludes that "early Air Force and Navy agreement on efficient migration paths for these architectures is particularly important."[18]

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ISR in Contested Airspace: Platforms, Sensors, Integration

Two things are clear. First, over the last decade the US military put in place an effective ISR network to prosecute an irregular enemy in relatively uncontested airspace. Second, the United States now needs to replicate that capability in a far more formidable threat environment. In pursuit of this capability, a number of studies are under way that will undoubtedly build on the legacy of effective airborne ISR systems developed and deployed over the last decade. But they are also likely to suggest new approaches in platforms, sensors, and systems to operate effectively in contested airspace.

ISR platforms of the future will need all of the characteristics of those that performed so well over the last decade with one substantial added requirement: survivability in hostile airspace. Although endurance, payload, integration, and connectivity are essential, none of these attributes will be of value if the platform cannot survive in an A2/AD environment. Replacing the Predator and Reaper in the unmanned reconnaissance-strike role will call for new UAVs that can loiter, survive, and attack near and within heavily defended airspace. Most promising here is the unmanned combat air system demonstrator (UCAS-D) undergoing tests by the Navy and the separate but related unmanned carrier-launched airborne surveillance and strike system (UCLASS) program. Whether or not the former is folded into the latter, the unmanned combat aerial vehicle (UCAV) could be designed to carry a suite of sensors and weapons 2,000 nautical miles or more from the carrier without refueling and will have far greater range and persistence if the vehicle can be refueled while airborne. Important to the UAV's survival is its low observability—designed from the start with the stealth to penetrate highly defended airspace. Like its nonstealthy forebears, the UCAV will carry the sensors and weapons to conduct missions of both reconnaissance and precision strike.[19]

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High-altitude, long-endurance UAVs will also play a role but, depending on the enemy's air order of battle, will have to be operated judiciously and equipped with self-defense capability. Global Hawk and the Navy's Broad Area Maritime Surveillance System, the Triton, might need a self-protection suite that includes a laser warning system, radar warning receiver, electronic attack or jamming system, and a towed decoy. The ISR provided by those high-altitude UAVs can be supplemented by the stealthy Sentinel drone at the tactical level—reportedly a key ISR asset in preparing the battlefield for the raid that killed Osama bin Laden.[20] For the longer term, it may make sense for the Air Force to convert its MQ-X UAV program, now on hold, into a land-based version of the vehicle emerging from the Navy's UCAS-D/UCLASS programs.[21]

The F-22's and F-35's low observability could allow them to conduct nontraditional ISR missions in contested airspace. As the number of jointly operated Joint Strike Fighters increases, they will be able to operate in groups—separated at distances so as not to compromise their stealth but close enough to offer mutual support, such as standoff jamming by one flight of fighters while others penetrate. These stealthy aircraft will have impressive sensor suites characterized as "vacuum cleaners"—collecting data about the enemy's posture and feeding it to joint networks. Meanwhile, the F-35's formidable computational power will allow a real-time recalculation of alternative mission routing in response to intelligence regarding enemy air defenses.

Space-based platforms have been major contributors to collecting ISR data over Iraq and Afghanistan, particularly in cueing other platforms to areas and targets of interest. However, due to the strategic nature of their collection missions and the time that elapses between passes over those areas of interest, satellites have not been considered major players in the pursuit of high-value, mobile, tactical targets. Under new tasking that demands greater wide-area surveillance and strategic assessments over the Western Pacific and Persian Gulf, that perception is likely to change. The increased fidelity of satellite-mounted

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sensors such as IR and radar, as well as their significant contributions to communications and C2, will likely place greater priority on space-based ISR systems—including the X-37B reusable space plane—in the future.

The systems of targets and the wide-area surveillance needed for the rebalancing of US military forces to the Pacific will also prompt a shift in sensor focus and capability. Each of the platforms described above must tailor its sensing capabilities toward detecting the A2/AD forces and networks (e.g., antisatellite weapons, long-range ISR systems, and precision-guided conventional land-attack and antiship cruise and ballistic missiles) arrayed against the operation of US and allied assets in the region. The ISR capabilities of UAVs will have much to offer, as long as those platforms remain survivable. Thus, a suite of multi-intelligence (INT) sensors, similar to that carried by Reaper and Global Hawk but improved in terms of range and low observability, will allow a new generation of UAVs to make major contributions to SA. For example, advanced sensors with multispectral imaging and multiwave radars might penetrate structures, exposing anything hidden inside. Just as UAV remote sensor requirements stemmed from past changes in military missions, so will new capability requirements arise from emerging military doctrine, including the need for persistence and penetration of advanced air defenses.

UAV payloads might consist of a modular, open-architecture suite of sensors for collecting reconnaissance from across the electromagnetic spectrum and, in the UCAV version, precision munitions capable of exploiting processed information to target enemies with pinpoint accuracy. The requirement for high-definition FMV with its attendant bandwidth, considered so important over the last decade, may take a backseat to large, strategic UAVs with long-range radar, SIGINT, and EO/IR sensors and multifunction radio-frequency-sensor payloads. For example, the Global Hawk Block 40 aircraft with a high-range resolution sensor will allow precision target measurement and classification from high altitude and longer standoff ranges. Similar sensor payloads

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may let the UCAV find imprecisely located targets on its own, similar to programs such as Tacit Rainbow and the low-cost autonomous attack submunition—abandoned in the past because of uncertainty regarding the unmanned vehicles' reliability for autonomous munitions delivery.

The F-22 and F-35 will also assume ISR roles well beyond the nontraditional role played by fourth-generation fighters with targeting pods over Iraq and Afghanistan. Most notable may be the spherical SA system termed the distributed aperture system developed for the F-35. That system of six EO sensors offers ballistic missile detection and tracking, including launch point detection as well as IR search-and-track functions and day/night navigation. Moreover, both of the fifth-generation stealthy fighters will add ISR capability through their active electronically scanned array (AESA) radars, supplying enhanced target resolution with low probability of intercept and increased resistance to jamming. These aircraft have enhanced defensive sensor suites as well. Just as AESA radar can be used for electronic attack of enemy air defenses, so will the F-35's digital radio-frequency memory capabilities allow the aircraft "to duplicate incoming radar signals, alter them, and send them back to the receiver modified to suggest that the fighter is either not there or is somewhere else."[22]

Given the revived importance of satellites to ISR gathering under the new strategic priorities, space-based sensors must also receive added emphasis. Two capabilities appear particularly significant: space-based radar and IR. The former was an ambitious program initiated a decade ago, designed to provide high-volume, readily available synthetic aperture radar imaging, surface moving-target indications, and high-resolution terrain information to the joint war fighter. Although the program's complexity and cost led to its cancellation, the strategic pivot to A2/AD areas argues for its rebirth. Space radar, which offers coherent change detection to track an enemy order of battle in A2/AD scenarios, has the granularity to detect the launch and track the arc of cruise missiles.

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A new generation of space-based IR satellites will make major contributions to denied-area ISR. Somewhat ironically, the difficulty experienced by the United States in locating the launch of Scud missiles during the 1991 Iraq war led to an improved capability that now has application in more far-flung theaters of operation. The new space-based IR system, in addition to detecting long-range ballistic missile launches, will contribute to SA of theater missile defense, characterize IR event signatures, and provide intelligence to support force protection, strike planning, and other missions conducted in an A2/AD scenario.[23]

The challenge of integrating ISR assets will become even more complex when military forces operate in A2/AD environments. Over Iraq and Afghanistan, the principal issue involved the quantity of ISR data—a complex system of PED moving vast amounts of data around the theater. In A2/AD airspace, we must pay greater attention not only to the joint and interoperable PED processes but also to their security. One of the approaches both to improving security and handling large amounts of data will entail improvements in the PED process at the multiservice distributed common ground/surface system nodes. A major task at hand involves integrating airborne ISR data into these communications centers. The ultimate architecture must create a network that can fuse and interpret data from multiple sources as well as process and disseminate those data to joint users at just the right time. Particularly important here is an integrated presentation of multisensor, multi-INT inputs on a common joint display.

No matter how streamlined and secure the PED process, however, disseminating ISR data to C2 facilities followed by subsequent tasking to a strike platform imposes unavoidable delays and inserts C2 uncertainties. We learned from operations in Afghanistan that sensor-to-shooter links communicated faster than could be supported by a C2 process requiring evaluation and approval at numerous decision levels. Inadequate communications links, incomplete bomb damage assessment, and poor dynamic airspace management all contributed to

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shortfalls in the ISR integration process. In uncontested airspace, the Predators and Reapers with FMV and precision-guided weapons filled this gap nicely. Building on that practice, ISR assets in A2/AD environments will need greater airborne persistence as well as sensor-to-sensor integration and data processing at the point of origin to supply real-time information on time-sensitive targets.[24]

A complex mix of platform, sensor, and integration attributes is required to effectively engage time-sensitive or mobile targets in contested airspace. They include range, endurance, survivability, short reaction time, flexible munitions mixes, network connectivity, and onboard mission planning and targeting.[25] Platforms possessing these attributes in varying degrees of effectiveness include the F-22 and F-35 fighters, an armed UCAV (presuming that strike authority is granted with a human in or on the loop), and the B-2 bomber or its advanced technology replacement now under the cloak of security and in development. As autonomous as these platforms and sensors might be, coordinated tactics and engagement profiles in antiaccess environments will demand that stealthy platforms be able to talk to each other. The multifunction advanced data link with high-data-rate, low-probability-of-intercept, and low-probability-of-detection properties is in development for the F-35, but plans to place the link on the B-2 (or the future bomber) and F-22 may have stalled. To integrate these stealthy ISR and strike systems, we must field this data link or something like it.[26]

Just as space-based sensors and platforms will prove critical to ISR in A2/AD scenarios, so will space-based communications prove essential to ISR integration. Replenishment of the Global Positioning System, now under way, is needed for the timing and positioning of ISR assets and required for the guidance of air-launched precision weapons. The jam-resistant and nuclear-hardened Milstar communication satellite constellation is being replaced by the advanced extremely high frequency (AEHF) satellite system, which will provide enhanced capacity and clarity-enabling ISR asset integration at both the strategic and tactical levels. The next generation of satellite terminals, known as the

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Family of Advanced Beyond-Line-of-Sight Terminals, is also necessary to facilitate communications between airborne ISR assets and AEHF satellites.[27] We can also protect satellite communication by restarting the laser-based transformational satellite system, once abandoned but now strengthened by a broadened industrial base and mature technology readiness.[28] Finally, self-defense will also be necessary for space-based assets in A2/AD scenarios.[29]

Conclusion

In directing a strategic shift away from a decade's emphasis on large-scale counterterror, counterinsurgency, and prolonged stability operations, the nation's defense leaders have issued a powerful challenge to the airborne ISR enterprise. Because of the uncontested environment for the operation of an ISR family of systems over Iraq and Afghanistan, the platforms, supporting sensors, and C2 connections cannot simply be lifted and relocated to a new theater of operations. Nevertheless, the joint force can still profit from years of effort in establishing tactics, techniques, and procedures that replaced the ponderous practice of transferring actionable intelligence to the operator, which so often had the counterproductive effect of disrupting the relationship among sensor, decider, and shooter.

Force planners with an airborne ISR portfolio can also profit from the joint "family of systems" approach adopted by their colleagues who deliberate future platforms, sensors, and integration for long-range strike.[30] As comparisons are drawn across different scenarios, the worth of these individual systems varies markedly. Penetrating deeply into defended territory, surveilling targets from long range, loitering and tracking time-sensitive targets, and surviving in defended airspace with integrated ISR and strike capabilities can all lead to differing solutions. Given this range of requirements, a family-of-systems approach that offers diverse ISR platforms, sensors, and integration options appears prudent in a security environment populated by emerging ad-

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versaries who present differing antiaccess challenges. But this family of systems must be connected across the armed services.

More work remains, and several studies exploring ISR in contested airspace are under way. Lessons identified from recent wars continue to stress the power of ISR integration for effective C2 while the challenges of operating in contested airspace will place a premium on varying approaches to survivability. In any scenario, the issue of ISR in A2/AD environments will involve getting the right information to the right person at the right time to make the right decision. We should use studies and war games to adapt the effective ISR network put in place over the last decade to more stressful conditions, and we should identify the investments needed, particularly when a long lead time is necessary to gain a desired ISR capability. To ensure that the prowess so ably demonstrated by airborne ISR systems in uncontested airspace does not atrophy in the face of increasingly nonpermissive environments, we must accelerate those studies and provide the needed investment. ✪

Notes

1. Joint Publication 2-01, *Joint and National Intelligence Support to Military Operations*, 5 January 2012, defines ISR as "an activity that synchronizes and integrates the planning and operation of sensors, assets, and processing, exploitation, and dissemination systems in direct support of current and future operations" (GL-12).

2. The battlefield airborne communications node is an airborne communications relay system mounted on manned and unmanned aircraft to link air and ground forces with a common ISR picture. See Adm Jonathan W. Greenert, USN, and Gen Norton A. Schwartz, USAF, "Air-Sea Battle," 20 February 2012, http://www.the-american-interest.com/articles/2012/02/20/air-sea-battle/.

3. Department of Defense, *Sustaining U.S. Global Leadership: Priorities for 21st Century Defense* (Washington, DC: Department of Defense, January 2012). For reinforcing guidance, see Department of Defense, *Quadrennial Defense Review 2014* (Washington, DC: Department of Defense, 2014), http://www.defense.gov/pubs/2014_Quadrennial_Defense_Review.pdf.

4. Richard Whittle, *Predator's Big Safari*, Mitchell Paper 7 (Washington, DC: Mitchell Institute for Airpower Studies, August 2011), 4.

5. The conditions surrounding the crash landing of the RQ-170 drone in Iran in December 2011 remain murky, and the competing claims on both sides are unlikely to be resolved

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conclusively. Regardless, the United States lost a valuable ISR asset in defended airspace. See Robert Haffa and Anand Datla, "6 Ways to Improve UAVs," *C4ISR Journal* 11, no. 2 (March 2012): 30–31.

6. See Curtis E. LeMay Center for Doctrine Development and Education, "Annex 2-0, Global Integrated Intelligence, Surveillance and Reconnaissance Operations," 6 January 2012, https://doctrine.af.mil/DTM/dtmisroperations.htm.

7. "Raytheon Nets $31.4 Million Contract for MTS-A on MH-60, Predator," Space War, 28 September 2005, http://www.spacewar.com/news/uav-05zzzzl.html.

8. John A. Tirpak, "Eyes of the Fighter," *Air Force Magazine* 89, no. 1 (January 2006): 40–44.

9. Whittle, *Predator's Big Safari*, 28.

10. Jon W. Glass, "Taking Aim in Afghanistan," *DefenseNews*, 5 February 2009, http://defensenews.com/article/20090205/C4ISR02.

11. See "USAF Continues to Grow, Strengthen Its BACN Fleet with New E-11A Buy," InsideDefense.com, 30 August 2012.

12. Department of Defense, *Sustaining U.S. Global Leadership*, 4–5.

13. Department of Defense, *Joint Operational Access Concept*, Version 1.0 (Washington, DC: Department of Defense, 17 January 2012), iii.

14. Ibid., 22–23, 29. See also Joint Chiefs of Staff, *Capstone Concept for Joint Operations: Joint Force 2020* (Washington, DC: Joint Chiefs of Staff, 10 September 2012).

15. Jan van Tol et al., *AirSea Battle: A Point of Departure Operational Concept* (Washington, DC: Center for Strategic and Budgetary Assessments, 2010), xiii, 56.

16. Ibid., 112.

17. See also Mark Gunzinger with Chris Dougherty, *Outside-In: Operating from Range to Defeat Iran's Anti-access and Area-Denial Threats* (Washington, DC: Center for Strategic and Budgetary Assessments, 2011).

18. Van Tol et al., *AirSea Battle*, 122.

19. See Thomas P. Ehrhard, PhD, and Robert O. Work, *Range, Persistence, Stealth and Networking: The Case for a Carrier-Based Unmanned Combat Air System* (Washington, DC: Center for Strategic and Budgetary Assessments, 2008).

20. See "RQ-170 Unmanned Aerial Vehicle, United States of America," airforce-technology.com, accessed 7 March 2014, http://www.airforce-technology.com.

21. However, the Air Force may have another solution to conduct ISR in contested airspace—the RQ-180. See Amy Butler and Bill Sweetman, "Return of the Penetrator," *Aviation Week and Space Technology* 175, no. 42 (9 December 2013): 20.

22. John A. Tirpak, "A New Revolution in Military Affairs," *Air Force Magazine* 94, no. 7 (July 2011): 10, http://www.airforcemag.com/MagazineArchive/Pages/2011/July%202011/0711watch.aspx. See also Barry D. Watts, *The Maturing Revolution in Military Affairs* (Washington, DC: Center for Strategic and Budgetary Assessments, 2011), 29.

23. "Space Based Infrared System (SBIRS)," Lockheed Martin, accessed 7 March 2014, http://www.lockheedmartin.com/us/products/sbirs.html.

24. David Deptula, "Integration Nation," *C4ISR Journal* 11, no. 3 (April 2012): 32.

25. See Christopher J. Bowie, *Destroying Mobile Ground Targets in an Anti-access Environment*, Analysis Center Papers (Washington, DC: Northrop Grumman, December 2001).

26. The Air Force and its industry partners are working this problem. See Amy Butler, "Cross Talk," *Aviation Week and Space Technology* 176, no. 7 (3 March 2014): 24.

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27. Amy Svitak and Amy Butler, "Fabulous Opportunity," *Aviation Week and Space Technology* 174, no. 26 (23 July 2012): 41.

28. See Stew Magnuson, "Military Space Communications Lacks Direction, Critics Say," *National Defense*, January 2013, http://www.nationaldefensemagazine.org/archive/2013/January/Pages/MilitarySpaceCommunicationsLacksDirection,CriticsSay.aspx.

29. See Robert P. Haffa Jr., *Full-Spectrum Air Power: Building the Air Force America Needs*, Special Report no. 122 (Washington, DC: Heritage Foundation, 12 October 2012), 18, http://thf_media.s3.amazonaws.com/2012/pdf/SR122.pdf.

30. See Robert P. Haffa Jr., and Michael W. Isherwood, "Long-Range Conventional Strike: A Joint Family of Systems," *Joint Force Quarterly* 60 (1st Quarter 2011): 102–7.



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Nightfall

Machine Autonomy in Air-to-Air Combat

Capt Michael W. Byrnes, USAF*



Although one finds no shortage of professional and academic conversation about remotely piloted aircraft (RPA) and potential unmanned combat aerial vehicles (UCAV), there is a distinct lack of forecasting of their futures on the basis of a tight fusion of tactics, technology, and the enduring truths of air combat. This article claims that a tactically autonomous, machine-piloted aircraft whose

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design capitalizes on John Boyd's observe, orient, decide, act (OODA) loop and energy-maneuverability constructs will bring new and unmatched lethality to air-to-air combat. It submits that the machine's combined advantages applied to the nature of the tasks would make the idea of human-inhabited platforms that challenge it resemble the mismatch depicted in *The Charge of the Light Brigade*. A convergence of new technologies indicates the earliest stages of emergence of a tactically game-changing approach to air warfare, but the institutional Air Force appears skeptical—perhaps since this theory of air dominance begins life in an environment resistant and rightfully cautious toward its development.[1] To date, a credible RPA optimized for air combat has not been developed, and the nation and service face severe fiscal austerity, increasing risk aversion.[2] Furthermore, the idea of a machine outflying the world's best fighter pilots may frustrate and unsettle conventional wisdom, inviting political contention.

However, if logic proves the dominance of this theory of machine autonomy in airpower and if the technology to execute it emerges, then making the emotional decision to reject it places our forces at strategic risk. To show that such claims are reasonable, the article presents a notional UCAV termed *FQ-X* to provide a guided tour through emerging real-world technologies and to show their tactical implications in an engagement. The discussion shifts to assessing briefly how these tactical effects ripple into the operational and strategic and then closely examines autonomous decision making in the context of the OODA loop before taking a deep dive into the technologies behind machine pilotage. Finally, the article counters prominent objections to the machine pilot in the arenas of cyber defensibility and the ethics of killing by a proxy weapon capable of making its own decisions. It wraps up with an assessment of the tactical and cultural integration challenges that lie ahead for the Air Force at the appearance of these novel systems.

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FQ-X Design and Features

The form of a machine like FQ-X, whose purpose is to find and destroy enemy aircraft, will favor small size and weight, great speed, low detectability, and unprecedented accuracy. The design exploits cutting-edge metamaterials that complement radar-absorptive materials to generate specific tactical advantages. Metamaterials are synthetic structures that demonstrate effects previously thought physically impossible. Specifically, negative-index-of-refraction metamaterials are capable of refracting electromagnetic energy in a way that "bends" it around (rather than bounces it off) an object, rendering it invisible in a particular region of the spectrum. Researchers proved techniques to do so as early as 2001 and less than 10 years later in the visual and infrared spectra.[3] By 2012 a team had even devised methods to overcome geometry and polarization limits, which were showstoppers for the use of metamaterials to hide a large object like an aircraft.[4] The implication for airpower is that a new generation of extremely stealthy materials is emerging, and the military does not have the luxury of keeping them a secret. Their utility in a variety of civil and military applications may also lead to their relatively cheap and plentiful manufacture. Although no stealth technique is flawless, metamaterial layers within a dielectric composite skin of FQ-X severely hamper current detection and identification methods. Preventing an enemy missile lock on an FQ-X is an excellent return on investment, but the overriding reason for stealth is that FQ-X focuses religiously on the OODA loop. The priorities are to defeat the operator's decision cycle first and missile-guidance systems second. When the aircraft is successful at both, it sidesteps a staple of modern air combat, undermining a multibillion-dollar national security investment.[5] When a scenario does not permit slipping past the allowable weapons-employment zone of air-to-air missiles, existing countermeasures and emerging directed-energy point defenses are excellent options for an aircraft with millisecond reaction times.[6]

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Defensive capabilities are of limited value if not paired with tools to find, fix, identify, and target hostile aircraft. Radar technology has evolved to the point that superficial assumptions about its capabilities are no longer accurate. For example, it would be natural to think that if a transmitting aircraft sends out a pulse of energy to detect an opponent, then that opponent (who was just hit with that energy) should be able to notice and respond. However, modern radars with low-probability-of-intercept technologies transmit at power levels below the receiving aircraft's detection threshold, working across multiple frequencies and across time to integrate the collection of weaker returns into a coherent signal.[7] Modulation techniques applied to active electronically-scanned-array antennas allow for multiple beams, which translates to multiple target acquisition and engagement.[8] The key to all of these fantastic capabilities is the capacity for digital signal processing.[9] The principle of "first look, first kill" belongs to the aircraft with the most processing power and the best software to leverage it. F-22 processing power is on the order of 5 billion decimal operations per second.[10] Modern graphics processing units can execute digital signal processing for radar applications at 10 to 100 times that speed and are available as affordable commercial off-the-shelf hardware.[11] FQ-X uses arrays of graphics processing units to showcase how much the "find and fix" stage of air combat is really a battle for computing power, which it leverages from general-purpose hardware, shifting task specialization into software to reduce cost and increase flexibility.

Today's predominant use of guided missiles is already an implicit admission of reliance on automation, and if the machine pilot can outperform human processing in the most allegedly artistic piece of air combat, simpler ones also likely favor the machine. To demonstrate, FQ-X collapses to gun range to outmaneuver the modern human-inhabited fighter, exploiting both positive and negative G choices. FQ-X's options are flexible, thanks to carbon nanotube composite structures and the absence of a human inside. Carbon nanotubes are microscopic structures formed in 1952 lab experiments that did not reach broad awareness in the Western scientific community until 1991.[12] In 2012 re-

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searchers at North Carolina State University demonstrated fabrication of large-scale carbon nanotube materials that showed a remarkable 30 percent improvement in specific strength over the world's best-engineered composites.[13]

Once positioned to attack, FQ-X needs to deliver hyperprecise effects to maximize use of a comparatively lean arsenal that a small craft is likely to contain. To that end, it has a nearly all-aspect targeting system accurate enough to pick a particular spot on an opposing aircraft to place a high-explosive round or directed-energy burst. To positively identify the target and hit the desired spot, FQ-X must have integrated multispectral optics and computer vision software. One of the largest commercial drivers of this object detection software is Google (which pursues the technology for image-based search engines).[14] However, open-source projects like OpenCV, containing more than 2,500 optimized detection and recognition algorithms, are also rapidly advancing application of the science.[15] Computer vision frameworks such as OpenCV also take advantage of graphics processing units to speed processing functions five to 100 times faster than traditional computer hardware.[16] Figure 1 depicts an engagement approaching this endgame state from FQ-X's computer vision perspective, first from a notional US system's display and then from a hypothetical competing foreign version.

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Figure 1. Dealer's choice: Mock-up graphics of computer vision for a sixth-generation approach. (USAF stock image of F-35A in flight and author's rendered image of J-20 using royalty-free 3D model purchased at TurboSquid, http://www.turbosquid.com/FullPreview/Index.cfm/ID/745460. The author edited both images to illustrate basic object detection, recognition, and tracking principles inherent in the field of computer vision.)

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With clearance to engage, it fires an armor-piercing high-explosive incendiary round into a critical system like the first compressor stage of an engine, rapidly ending the engagement with little opportunity for the adversary to adapt. FQ-X, on the other hand, learns from every detail of the encounter with real-time machine learning. It can pass lessons to other UCAVs, making partnered aircraft smarter by every engagement. Besides direct aircraft-to-aircraft sharing, the FQ-X air vehicle can send its telemetry to a ground control station (GCS). In the event an air vehicle is destroyed, its last moments may be stored on a secure network via the GCS. The implication may not seem obvious at first, but contrasted to the loss of a human-inhabited fighter, the difference is staggering. Losing a human pilot is a tragedy, and in cold but factual terms that a commander must face, it means the loss of an enormous investment of time and money in training and operational experience. If a veteran pilot falls in combat, then a young rookie has to take his or her place, starting a cycle of development all over again. The machine pilot, however, learns from death and in near real time commits adaptations to other UCAVs in the fight. Opponents may find that the same tactic never works twice against these systems.

Implications: Ripping into the Operational and Strategic

If machine-controlled maneuvering and accuracy make every cannon round a "golden BB," then left unchecked a single FQ-X with a few hundred rounds of ammunition and sufficient fuel reserves is enough to wipe out an entire fleet.[17] The economics of this approach are similarly stunning to consider and require examination with a global airpower perspective. The Russian-Indian jointly developed FGFA (PAK-FA derivative) is still several years from reaching initial operational capability and seems subject to the same delays and cost spirals of any highly complex development program.[18] Conservatively, current estimates are about $100 million per copy and likely to rise.[19] On the US side of the equation, each Raptor has a flyaway cost of $148 million, each F-35 in low-rate initial production was $153 million during 2011,

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and a fighter pilot costs an estimated $2.6 million.[20] An AIM-9X missile is approximately $300,000.[21] If the aircraft and crew are fixed setup costs and their weapons are marginal costs of engaging a target, then the FQ-X system is poised to become substantially more affordable than the fifth-generation fighters it is engineered to overcome. FQ-X has a high percentage of commercial off-the-shelf hardware, small size, and no need for a one-to-one crew-to-aircraft ratio. The marginal cost for two stabilized cannon rounds fired at close range is a mere $20.[22] A rechargeable directed-energy weapon's cost to employ would depend on maintenance required per 100 firing cycles but would be inexpensive in a mature design.

Any compromise of defensive counterair ability jeopardizes high-value airborne assets, tanker and mobility aircraft, and the Airmen aboard them, opening the possibility for losses on a scale that our own service has not endured since its bombers attempted daylight raids in the 1940s.[23] The difference between then and now, of course, is that our industrial production base and budget are not configured to replenish such high attrition. In our efforts to become an effects-based force, we redefined mass by concentrating more capabilities in fewer physical assets, and that strategic choice has trade-offs.[24] Europe, Russia, India, and China have followed us into the game of big, high-tech fighter projects as well, thus framing a global problem-solving mind-set about how nations build airpower.[25] With so much depending on the current paradigm, an aggressor FQ-X performing as advertised in a US Air Force Weapons School event would become an inflection point in airpower history. Assuming that sixth-generation systems will simply be refinements of their fifth-generation predecessors falls well short of positively revolutionizing lethality, economy, and capability of airpower, and it invites increased risk to our current assets.[26] The path forward to continued assurance of air dominance starts by redefining our most basic understanding of what an airplane is and continues by applying well-established truths about air combat to new technological opportunities.

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Flying Machines: Heart of the OODA Loop

Aviators instinctively see the airplane as a machine whose purpose is to fly rather than a machine that flies to serve its purpose.[27] However, if the Boyd cycle lies at the heart of describing success in air combat, then it makes sense to give priority to the elements of an aircraft most responsible for supporting speed and accuracy in the OODA loop and call all others secondary. RPAs and UCAVs are computers with airframes strapped to them, not the other way around. Flight-control actuators, avionics, radios, sensors, and even weapons are like plug-and-play peripherals for this platform, just as one might plug in printers, scanners, or cameras to a personal computer. This view reveals an opportunity to affect the flexibility and affordability of sixth-generation airpower. Decades ago, open architecture of IBM PC clones enabled massive proliferation of computing technology.[28] Similarly, pursuing plug-and-play standards, commercial off-the-shelf hardware, and common operating systems for autonomous aircraft and their GCSs supports proliferation and cost reduction that help to accelerate the pace of research, development, testing, and operational use. A tactically autonomous aircraft like FQ-X need not seek science-fiction-like self-awareness; within the scope of air-to-air combat, it is an airborne computer that executes the underlying mathematical truths of what human combat pilots do in the cockpit, doing so more quickly and with more precision.

Boyd's OODA loop implicitly reveals that the "art of flying" is actually a cyclical processing activity. It includes sensory data acquisition, reconciliation against known information to derive meaning, selection of a response from a known repository of possible choices or synthesis of a new option when none is satisfactory, and execution of the choice. Machine-learning algorithms address these tasks in two modes: supervised (designers train the software by telling it right from wrong) and unsupervised (it determines if a new action is right or wrong by experimentation and by extension of what it already knows).[29] A machine pilot with appropriate sensors and multiple computing cores can ac-

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quire and integrate information from diverse sources more quickly and reliably than a human.[30] With a trained artificial intelligence (AI), it can also draw clearer interpretation from data without human psychological biases. Humans average 200–300 milliseconds to react to simple stimuli, but machines can select or synthesize and execute maneuvers, making millions of corrections in that same quarter of a second.[31] Every step in OODA that we can do, they will do better. Although Boyd's hypothesis is a cornerstone of fighter aviation, an inadvertent consequence of its logic in this evolving context is that machines will inevitably outfly human pilots. Furthermore, machine pilots do not have continuation-training requirements or currencies to maintain.[32] Unlike humans, whose skills regress without reinforcement, tactically autonomous aircraft can "sit on a shelf" for extended periods of time and remain exactly as sharp as they were the day they were pulled from service. Budget sequestration grounded 17 squadrons and did long-term damage to combat readiness—an effect that autonomous airpower would not suffer from. That $591 million cut represents an overhead cost which simply would never have existed in the first place with machine pilots.[33]

Tactical Autonomy Today

A common objection to this application of the OODA loop claims that the machine will not be able to do one or more of these tasks at the same level as human cognition, particularly the "orient" and "decide" steps. One author concludes that "the information required to make such a decision [to fire weapons] comes from so many sources and could be so easily spoofed or jammed by the enemy, that the validity of that computerized decision could never be fully trusted."[34] Unfortunately, he presents no discussion of the specific technical challenges and solutions, instead generalizing to conclude that "what separates men from machines is the ability to see opportunity and use it creatively."[35] In fairness, that author's point was not "anti-unmanned aerial vehicle (UAV)" but a wise call for caution about how much faith

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we put in these yet immature aircraft. Still, reconciling his perspective against recent technical developments reveals that his viewpoint does not anticipate the direction in which machine pilotage is evolving.

In 2012 the Defense Science Board released a study on the role of autonomy in Department of Defense systems, finding significant opportunity for RPAs to further leverage existing computer vision, AI, and machine-learning technologies to add value through onboard autonomy.[36] To get a sense of how underexploited existing AI really is, consider that in 2008 an MIT researcher (and former F-15C pilot) successfully executed machine-learned, real-time, basic fighter maneuvering using a neurodynamic programming technique in a flight-test lab.[37] The software adapted rapidly and learned to maneuver into a weapons-employment zone by discovery rather than by being taught exemplar tactics (fig. 2). The MIT work shows that the basis for autonomous unmanned fighters exists in building blocks and that future maturation would add sophistication to take the technology beyond the lab and into complex flight environments.[38] In another compelling development that would facilitate machine pilotage, researchers in the AI subdiscipline of neuroinformatics recently constructed "neuromorphic" chips that behave like synthetic neurons on silicon substrate, imitating brain function and allowing incorporation of complex cognitive abilities in electronic systems.[39] A University of Zurich team presented a design capable of performing complex sensorimotor tasks that, in an organic brain, require short-term memory and context-dependent decision making.[40]

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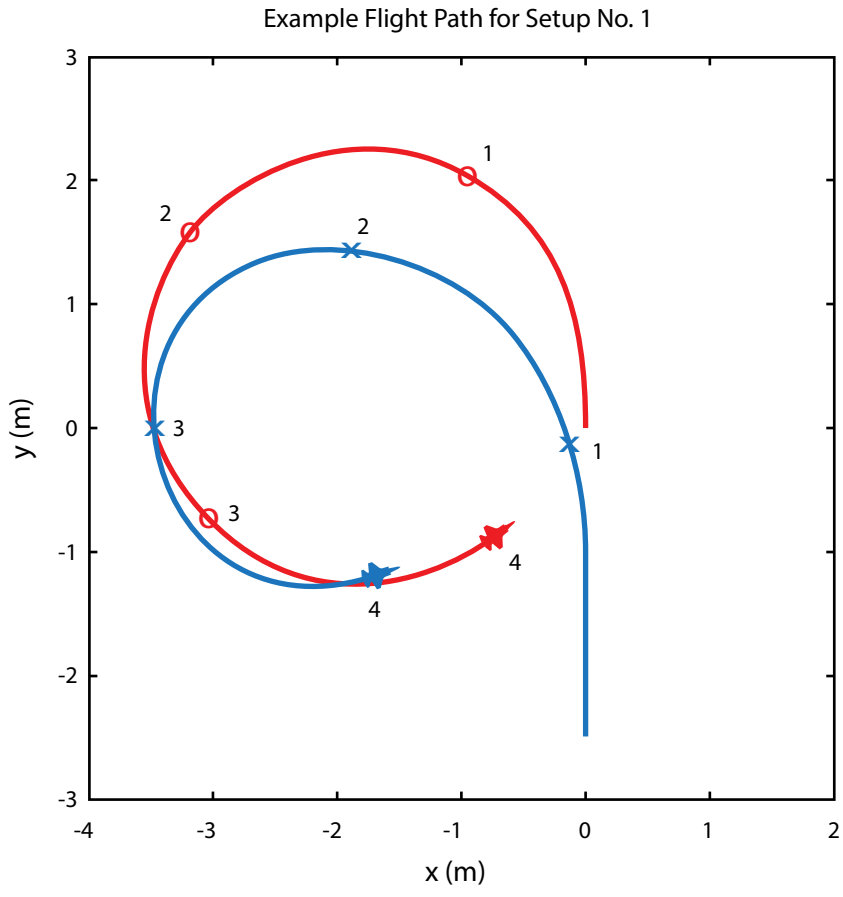


Figure 2. UAVs learning basic fighter maneuvering from a perch setup. (Adapted from James S. McGrew et al., "Air-Combat Strategy Using Approximate Dynamic Programming," *Journal of Guidance, Control, and Dynamics* 33, no. 5 [September–October 2010]: 649. Reprinted with permission from James S. McGrew.)

An applied information technology perspective and increasingly evolved AI technologies suggest that new UAVs will thrive when granted tactical autonomy. These machines cause us to revisit the notion of "centralized control, decentralized execution." This codified Air Corps doctrine, born in a world without real-time video feeds, taught that commanders of an air campaign had to grant crews a high degree of autonomy, entrusting them to accomplish a mission.[41] Later, real-time connectivity to the cockpit (or a GCS in control of a remote air-

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craft) allowed commanders to be as tactically hands-on or -off as they saw fit.[42] With FQ-X, autonomy for the conduct of the engagement would return to the air vehicle to take advantage of its superior processing speed and reaction times. The Defense Science Board study, however, points out that a machine's autonomy to perform tasks does not preclude its adherence to rules of engagement or suggest that it is totally absent of human supervision.[43] Human decision making at a higher level is crucial to bridge the tactical to the operational, but these machine-pilotage technologies suggest that stick-and-rudder skills might not be an Airman's central value proposition.

Hacking the Mission

Reliability of the machine pilot is a natural concern. Potential defects in the design are more likely than computer hacking and are most effectively abated through comprehensive testing demanded by the best practices of software engineering. The fear of cyber attack relies on the belief that any computer system can be hacked.[44] A more accurate answer, however, is that breaching the security of an information technology system *requires the defender of that system to make a mistake in design or operation*. In highly complex systems, that fact leads to a cycle of vulnerability discovery, analysis, and repair or mitigation. It is therefore critically important to engage in thorough testing and security reviews at every step of the system's design and to keep the authorized user's opportunities to commit an unsafe act to a minimum through excellent design of human-computer interaction.[45] All "cyber" attacks are attempts to negatively affect the confidentiality, integrity, or availability of a system.[46] Like their counterparts in the kinetic realm, they are observable, repeatable tactical actions that one can study and counteract.

The intersection of classically kinetic air combat and more novel cyber activities paints a fascinating picture of the potential employment methodologies and skill sets demanded of crews that operate assets like FQ-X. From a cyber-defense perspective, for example, shooting

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down the air vehicle falls under the category of a physically based attack against system availability.[47] A fighter pilot would simply say, "You lost and got shot down," analyze the tactical reasons in a debriefing, and teach how to win next time. Both perspectives are simultaneously valid, and both mind-sets extend from common points of overlap in different directions: one toward a very kinetic, visceral, tactical set of problem-solving skills, and the other toward analytically preventing exploitation of a computer system. A design like FQ-X is subject to the rules of both worlds and needs those employing it to operate in a unified framework that addresses both air combat and cyber-defense concerns. The cyber defender is unlikely to be able to look at an air battle and integrate tactical- and operational-level concerns to prosecute a war. The fighter pilot is unlikely to be able to detect and counter an enemy's attempt to launch a complex exploit against the UCAV's operational flight program. The good news for the US Air Force is that it has a rich heritage of expertise at all levels of air warfare and is actively developing capability in the cyber realm.[48]

Ethics of Autonomy

As frequently as skeptics cite hacking as a potential weakness of unmanned flight, consideration of the ethics of autonomous weapons employment captures far more public apprehension. The discussion sits amidst a much larger and more ambiguous debate about remote and robotically enabled warfare. A search on Amazon for "drone warfare" books revealed nearly 30 promising titles and almost 200 total results. A Google Scholar search for the same topic returned 14,800 results. A third of the *Routledge Handbook of Ethics and War* is dedicated to drone and cyber topics, and the entire cover image depicts an armed MQ-1B.[49] *Jus in bello* (the justice of conduct in war) arguments regarding the use of RPAs focus much of their contention on targeting criteria, collateral damage, and debates about the wisdom of overreliance on military instruments of power. Those issues are important national discussions, but to cut through the noise of so many conversa-

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tions and emphasize the ethics of truly tactically autonomous combat calls for a scholarly work like Armin Krishnan's *Killer Robots*.[50]

Krishnan clearly delineates between the types of robotic systems involved in the military's trade, and the FQ-X concept intersects his definitions of the terms *unmanned aerial vehicle* and *autonomous weapon*.[51] He raises the concern that once an advanced machine demonstrates capability and offers the economy of not having to pay health care or retirement benefits, the military and its political masters will become fixated on the efficiency and convenience of replacing humans on the battlefield. If they do so, perhaps also seeking the political convenience of minimizing casualties, they will fail to consider the qualitative, long-term consequences of that choice.[52] The irony of a pure, unbridled quest for combat efficiency, as political-military strategist Thomas K. Adams points out, is that sooner or later the inventors realize that humans are always the weakest link in a system. They optimize human operators and then human decision makers out of the equation to replace them with another machine. As an argument to the extreme, he suggests that the cycle repeats until the tactical level of war involves no humans at all, rendering the whole activity a pointless waste of resources that fails to resolve the human needs that triggered it in the first place.[53] A government must respect the ethics of its civilization and consider what statecraft and warfare communicate to the world about its people. In the case of FQ-X, the most pressing question concerns whom to hold responsible for the conduct of a proxy weapon that makes its own decisions.

If the device functions as intended, the ethics are simple: the UCAV is an extension of the will of the person who commanded it, and the chain of responsibility traces from the operator up the kill chain of the command and control structure. If, however, the system deviates and kills people the operator never intended to harm, then assignment of blame becomes more complicated, calling into question the degree of autonomy one can grant a machine and how much human supervision must remain in the kill chain.[54] The Air Force encountered a parallel

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situation in which a complex system broke down during the 1994 Blackhawk incident. Skilled Airmen working across multiple platforms to control airspace utterly failed, and 26 people died unnecessarily as a result. That system was defined by people, policies, practices, training, technologies, and rules of engagement. In the end, not one person went to jail because of the incident.[55] Systems like FQ-X will similarly employ procedural guidance to reflect a combatant commander's intent, though translated into a digital form subject to error checking and closer scrutiny. Regardless of analog or digital means, however, an enduring takeaway of the Blackhawk incident appears to be that attaining the satisfaction of justice becomes difficult when responsibility is diffused in complex systems. We must deliberately plan how to take responsibility for the things we intend to create; otherwise, we will have no more satisfying answers than we did in 1994—or in any friendly-fire or civilian-casualty event before or since.

Ethical debates guide the implementation of any new means of war fighting, making a technology either admired or monstrous before the court of public opinion. Autonomous weapons must reconcile a tactical desire to exploit the benefits of their independence—for example, reducing signatures by disabling data links during an engagement—with our moral need to limit the diffusion of responsibility to nonhuman actors in a system. One solution is to break the autonomous air-to-air engagement into five phases—searching, stalking, closure, capture, and kill—and then assign discrete levels of autonomy and operator interaction per phase.[56] This approach would allow the UCAV to maximize its time under autonomous, low-detectability conditions and reach back to its human operator at key junctures where moral questions trump the tactical risk. Another method would authorize firing freely on enemy unmanned systems but require operator consent to take a human life. Such techniques are merely extensions of existing methods of managing lethal autonomy.[57] Joint terminal attack controllers call for close air support in one of three types, and each type allows the pilot (a semiautonomous entity to the controller on the ground) different degrees of freedom.[58] Just as air forces build the

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ground component's trust in airpower, so must UCAV designers progressively prove new systems—as one author suggested might be appropriate in pursuit of an optionally manned design for the Air Force's next long-range bomber.[59] This line of thinking is consistent with the Defense Science Board's study on the role of machine autonomy.[60]

Integration and Cultural Issues

Air forces that have an ecosystem of aircraft specialized in distinct tasks succeed over those with aircraft designs burdened by divergent workloads. L'Armée de l'Air learned that lesson disastrously at the hands of the Luftwaffe in 1940.[61] Systems with the capacity for tactical autonomy, like FQ-X, will not go to war alone and will need to integrate their capabilities with dissimilar UAVs and human-inhabited vehicles. Autonomous aerial refueling, for example, may manifest from follow-on work after the Defense Advanced Research Projects Agency's KQ-X project or the Navy's unmanned combat air system demonstrator.[62] If so, KC-46 acquisition just beginning in the midst of UAV advances suggests a long period of overlap with both manned and unmanned platforms providing global reach. The exact pattern of integration—which assets will be autonomous, remotely piloted, or human inhabited—will have as much to do with availability of assets that can do the job as with the combatant commander's vision, preferences, and comfort level. Certainly, a strong need will exist for deep, pervasive integration across all available air assets in order to maximize the utility of every platform in the ecosystem of an air force.

Recent discussion of how to fit future autonomous and remotely piloted systems into an air order of battle and into the cultural fabric of the service has been lively in *Air and Space Power Journal*. The prevailing theme is that semiautonomous UCAVs will serve as wingmen while the manned fighter remains the centerpiece of air warfare. The most disturbing thing about this notion is that it attempts to serve two masters: avoiding saying anything upsetting while also trying to advance the development of UAVs. It is also strictly "forward pass" think-

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ing, as if chair-flying an ideal sortie without simulating enemy responses in a "backward pass" through the concept.[63] Its assumptions are that (1) force multiplication is all we require of UAVs and (2) in air combat, none of these platforms can defeat manned fighters directly. One author even states that they "will not replace the manned fighter aircraft—we cannot build a control system to replicate the sensing and processing ability of trained aircrews."[64] That article offers neither technical nor research data to qualify its indefinite, unrestricted claim. In light of the research evidence in favor of machine pilotage, that statement is suspect.

In another article from the same release of the *Journal*, Maj David Blair and Capt Nick Helms suggest that manned-remote fusion represents the future of airpower and argue that the principal hindrance to realization of that future lies within Air Force culture rather than technology.[65] Their analysis seeks to reconcile the roles of these two breeds of airpower and their accommodation within the Air Force's operational culture. However, it also envisions the fusion of manned assets and UAVs whereby human-inhabited assets unquestioningly lead the fight into contested airspace. It never stops to ask whether the application of Boyd's words to this emerging technology would actually render such a future improbable. As a competing construct, FQ-X pushes OODA to nanosecond resolution and argues that the air-to-air decision-making cycle of a human pilot, at its best, could never logically win a direct contest with pure machine autonomy—meaning that competition for primacy does in fact exist.

Still, they believe that

> the true conversation does not deal with competition between humans and machines. Instead, it concerns the nature of cooperation between them. . . .
>
> . . . The fear that pilots are replaceable is best answered by using the lens of technology to amplify the things truly irreplaceable about them. Technology then ceases to be a threat, allowing us to magnify our distinctively human capacities of judgment, reasoning, and situational awareness across the battlespace.[66]

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These authors seek the inclusion of RPA operators into the larger fold of pilots, emphasizing the Air Force's chosen *RPA* term, to demonstrate that pilotage is more than sitting in the cockpit.[67] Conversely, thinkers such as Houston Cantwell recommend dropping the pilot terminology, along with the stick and rudder, to allow these aircraft to come into their own and realize a potential separate and distinct from that of manned aircraft.[68] He also exposes a hurdle to Blair and Helms's seemingly reasonable approach in that many pilots have wrapped their personal identities so tightly around the act of flying that they will not give it up if asked politely. In fact, one-third surveyed would rather leave the service than fly RPAs.[69] Cantwell, Blair, and Helms would all agree, however, that a concentration on inputs (the stick and rudder) rather than outputs (combat effects) reflects twentieth-century thinking that will not advance airpower.[70]

Regardless of the terminology or approach selected, these cultural issues drive organizational priorities that affect how, when, and even if the Air Force chooses to invest in autonomous technologies. Research on organizational core competencies published in the *McKinsey Quarterly* reveals that "the company's power structure cannot be driven by several functions at once. . . . A world-class competence must steer the power structure in a company. The keeper of the skill drives all the company's major decisions, even in unrelated functions."[71] Although the Air Force espouses three core competencies that enable six distinctive capabilities, in practice it cannot escape the interplay of core competency and power structure.[72] The apparent skill driver in the Air Force is the successful execution of air-to-air combat. Recent commentary from Lawrence Spinetta highlights that leaders in the fighter enterprise have the opportunity to command at 26 wings whereas the RPA enterprise has only one.[73] His interest in the discussion is not about emotive perceptions of fairness; rather, it hangs on Stephen Rosen's observation that the pace of innovation in the military is restricted by the speed at which officers (who, in retrospect, possessed the innovation) rise to consequential levels of the command structure.[74] The concern articulated by Spinetta is that hanging on to fight-

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ers so tightly as to slight RPAs (or UCAVs) discards opportunities to preserve the nation's technological edge. Choosing not to respond to FQ-X on the basis of perpetuating the service's power structure could actually nullify the value that structure delivers.

Conclusions

The technological landscape is replete with advances heralding profound change for the means of success in air combat. Nevertheless, certain long-standing discoveries about the nature of airpower itself endure—namely, Boyd's OODA loop and the value of an aircraft's autonomy, whether or not a human is physically aboard. Hyperstealthy metamaterials, carbon nanotube composites, sophisticated computer vision, and advanced AI work in concert to open the door to a new generation of aircraft. These technologies can improve the survivability of human-inhabited vehicles, but combined application in a tactically autonomous system is key to unlocking new levels of performance and economy in air combat. Consideration of cyber and ethical dimensions remains a responsibility of exploring this new potential. Integration with other assets and primacy in the battlespace will prove contentious, particularly since today's RPAs exhibit such constrained performance; however, the notion that all such aircraft will be mere force multipliers for manned fighters represents a potentially tragic underestimation of the capability, efficiency, and lethality of machine pilotage. Functional and subsequent political displacement of the fighter pilot may be an emotionally charged idea, but our developmental priorities must reflect the need to preserve our Airmen, fleet, and sovereignty. Being second to market with tactically autonomous UAVs adds risk. Whether the technology reaches viability next year or in 30 years, its present-day versions prompt us to analyze the logic of their potential. If the machine pilot can usurp the organic one's most prized art form, then that ability raises the question of why any nation would seek a human-inhabited sixth-generation fighter—even if both options were similarly priced.

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Aviators may dislike it, the public will question it, science fiction imagines harbingers of the Cylon apocalypse, and we are uncertain about how to best utilize it within the context of a larger Air Force.[75] Nevertheless, the FQ-X concept is too dangerous to our current thinking to ignore forever. The standard rules of the arms race apply: if a rival succeeds first, then our failure would be judged by the words of our own airpower theorists. Just as air superiority is a prerequisite for combined-arms victory, so will tactically autonomous UCAVs (or a novel measure to counter them) become a prerequisite for the survival of fleets of human-inhabited air vehicles. In a technology-dependent service, the cycle of invention, skepticism, resistance, and adaptation continues—all of this has happened before, and all of it will happen again. This particular time, however, it may not matter how undesirable the Air Force culture finds it. Key enabling technologies are evolving outside the military's control. Much of the maturation of unmanned systems occurs with commercial capital to meet civilian business objectives across multiple industries.[76] Creating legal controls is precarious for dual-use technologies that serve principally civil purposes and simultaneously underpin devastating capabilities like FQ-X. Common technical standards obscure the line, and increased computing power raises the stakes for what these systems can accomplish. Ubiquitous dual-use, however, is an opportunity for cost reduction in the development of these aircraft.

Deliberately ignoring tactical machine autonomy may do little to slow its arrival, and for the Air Force, the most proximate threat to resistance may not come from foreign entities but from within the joint team. The US Navy, whose institutional future is tied to its ships rather than what flies off their decks, has outshined its sister services in advancing UAV technology. Common GCS designs, X-47B, and recently opened competition for the unmanned carrier-launched air surveillance and strike system (that awarded four $15 million contracts) show that the Navy is incrementally maturing the technology and concepts.[77] That service will soon have far more impressive UAVs than the Air Force. We might find ourselves right back in the days of acquiesc-

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ing to the purchase and rebranding of a Navy plane, as with the F-4.[78] ✪

Notes

1. Air Combat Command's (ACC) strategic plan for 2012 omits the terms *UAV*, *UCAV*, *RPA*, or *unmanned* and includes only a single picture of an RQ-4 amidst a collage of other aircraft. Whatever the long-term intent, exclusion in the document reveals that this enterprise is not a first-order priority although the plan clearly states that ACC maintains lead integration responsibilities for global intelligence, surveillance, and reconnaissance and actively seeks to invest in recapitalization, a "Next-Gen fighter," and "a holistic set of game-changing capabilities and cross-cutting technologies" (12). The overall impression communicated is that ACC desires new technology, but it does not convey that remotely piloted systems represent the kind it seeks to develop. Air Combat Command, *2012 Air Combat Command Strategic Plan: Securing the High Ground* (Joint Base Langley–Eustis, VA: Air Combat Command, 2012), especially 3–15, http://www.acc.af.mil/shared/media/document/afd-120319-025.pdf.

2. The Air Force armed the RQ-1 with an AIM-92 Stinger missile in 2002 and fired on an Iraqi MiG that crossed into the no-fly zone but did not win the engagement. Allegedly, a guidance error within the missile prevented it from hitting the MiG. Bootie Cosgrove-Mather, "Pilotless Warriors Soar to Success," *CBS News*, 25 April 2003, http://www.cbsnews.com/news/pilotless-warriors-soar-to-success/.

3. R. A. Shelby, D. R. Smith, and S. Schultz, "Experimental Verification of a Negative Index of Refraction," *Science* 292, no. 5514 (6 April 2001): 77–79, http://www.sciencemag.org/content/292/5514/77; C. G. Parazzoli et al., "Experimental Verification and Simulation of Negative Index of Refraction Using Snell's Law," *Physical Review Letters* 90, no. 10 (14 March 2003): 1–4, http://prl.aps.org/abstract/PRL/v90/i10/e107401; Henri J. Lezec, Jennifer A. Dionne, and Harry A. Atwater, "Negative Refraction at Visible Frequencies," *Science* 316, no. 5823 (20 April 2007): 430–32, http://www.sciencemag.org/content/316/5823/430.abstract; and Debashis Chanda et al., "Large-Area Flexible 3D Optical Negative Index Metamaterial Formed by Nanotransfer Printing," *Nature Nanotechnology* 6, no. 7 (July 2011): 402–7, http://www.nature.com/nnano/journal/v6/n7/full/nnano.2011.82.html.

4. T. Xu et al., "Perfect Invisibility Cloaking by Isotropic Media," *Physical Review A* 86, no. 4-B (October 2012): 1–5, http://link.aps.org/doi/10.1103/PhysRevA.86.043827.

5. AIM-9X (acknowledged) contracts commit to delivery of 10,142 missiles at a cost of $3 billion. "AIM-9X Sidewinder," Deagel.com, 13 November 2013, http://www.deagel.com/Air-to-Air-Missiles/AIM-9X-Sidewinder_a001166003.aspx. AIM-120 AMRAAM program costs exceed $20 billion. "AIM-120D AMRAAM," Deagel.com, 13 November 2013, http://www.deagel.com/Air-to-Air-Missiles/AIM-120D-AMRAAM_a001164006.aspx. Legacy AIM-7 missiles have an advertised unit cost of $125,000. "AIM-7 Sparrow," fact sheet, US Air Force, 1 October 2003, http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104575/aim-7-sparrow.aspx.

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6. "High Energy Liquid Laser Area Defense System (HELLADS)," Defense Advanced Research Projects Agency (DARPA) Strategic Technology Office, accessed 24 August 2013, http://www.darpa.mil/Our_Work/STO/Programs/High_Energy_Liquid_Laser_Area_Defense_System_(HELLADS).aspx.

7. George W. Stimson, *Introduction to Airborne Radar*, 2nd ed. (Mendham, NJ: SciTech Publishing, 1998), 525–34.

8. Ibid., 503.

9. Ibid., 535.

10. Ibid.

11. "CUFFT [CUDA Fast Fourier Transform Library]," nVidia Corporation, accessed 8 August 2013, https://developer.nvidia.com/cufft; and Jimmy Pettersson and Ian Wainwright, *Radar Signal Processing with Graphics Processors (GPUs)* (Uppsala: Uppsala Universitet, February 2010), http://uu.diva-portal.org/smash/get/diva2:292558/FULLTEXT01.pdf.

12. Marc Monthioux and Vladimir L. Kuznetsov, "Who Should Be Given the Credit for the Discovery of Carbon Nanotubes?," *Carbon* 44, no. 9 (19 March 2006): 1621–23, http://nanotube.msu.edu/HSS/2006/1/2006-1.pdf.

13. X. Wang et al., "Ultrastrong, Stiff and Multifunctional Carbon Nanotube Composites," *Materials Research Letters* 1, no. 1 (2013): 19–25, http://www.tandfonline.com/doi/pdf/10.1080/21663831.2012.686586.

14. Josh Lowensohn, "Google Snaps Up Object Recognition Startup DNNresearch," CNet, 12 March 2013, http://news.cnet.com/8301-1023_3-57573953-93/google-snaps-up-object-recognition-startup-dnnresearch/.

15. "About," OpenCV, accessed 24 July 2013, http://opencv.org/about.html.

16. "OpenCV," nVidia Developer Zone, accessed 4 August 2013, https://developer.nvidia.com/opencv.

17. The kind of gun targeting system proposed herein would represent the most difficult design challenge after the core artificial intelligence (AI), and it would represent the highest risk item to project success. If the AI fails to meet expectations, the technology might still be transferrable for other less-challenging projects. However, if high-resolution air-to-air gun targeting proves too difficult a problem to solve, then the entire asset must be redesigned to accommodate a different operational construct (e.g., small short-range missiles or a return to conventional radar-guided missiles already in inventory), which may still offer value or may diminish the value proposition substantially. Lessons learned from the software-engineering industry suggest tackling the highest-risk segments of software-intensive systems first through controlled experiments rather than launching into a project via the easiest tasks and later becoming stuck at a point where costs and pressure on the industry team begin to mount. Anthony J. Lattanze, "Architecture Centric Design Method: A Practical Architectural Design Method for Software Intensive Systems," Carnegie Mellon University, Institute for Software Research, accessed 18 January 2014, http://anthonylattanze.com/acdm.php.

18. Gulshan Luthra, "IAF Decides on 144 Fifth Generation Fighters," India Strategic, October 2012, http://www.indiastrategic.in/topstories1766_IAF_decides_144_fifth_generation_fighters.htm.

19. Ajai Shukla, "Delays and Challenges for Indo-Russian Fighter," *Business Standard*, 15 May 2012, http://www.business-standard.com/article/economy-policy/delays-and-challenges-for-indo-russian-fighter-112051502009_1.html.

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20. Department of the Air Force, *United States Air Force FY 2011 Budget Estimates,* vol. 1, *Air Force Procurement, Air Force* (Washington, DC: Department of the Air Force, February 2010), 1–15, http://www.saffm.hq.af.mil/shared/media/document/AFD-100128-072.pdf; and Michael Hoffman, "UAV Pilot Career Field Could Save $1.5B," *Air Force Times*, 1 March 2009, http://www.airforcetimes.com/article/20090301/NEWS/903010326/UAV-pilot-career-field-could-save-1-5B.

21. Three billion dollars divided by 10,142 missiles equals approximately $300,000. "AIM-9X Sidewinder."

22. The cost estimate of $9.39 per unit for the PGU-28/B 20 mm semi-armor-piercing high-explosive incendiary round is derived from contract lot size and reported costs. "PGU-27A/B TP/ PGU-28A/B SAPHEI / PGU-30A/B TP-T," GlobalSecurity.org, accessed 31 July 2013, http://www.globalsecurity.org/military/systems/munitions/pgu-28.htm.

23. *The United States Strategic Bombing Surveys (European War) (Pacific War)* (30 September 1945, 1 July 1946; repr. Maxwell AFB, AL: Air University Press, October 1987), 6, 68, http://aupress.au.af.mil/digital/pdf/book/b_0020_spangrud_strategic_bombing_surveys.pdf.

24. Briefing, Col Gary Crowder, subject: Effects-Based Operations, slide 4, "Precision Redefines the Concept of Mass," 19 March 2003, http://www.au.af.mil/au/awc/awcgate/dod/ebo_slides/ebo_slides.htm. In light of deep defense-budget cuts, Hon. Chuck Hagel, the current secretary of defense, observed that the Department of Defense stands again at a crossroads in terms of selecting a small, lean, high-tech force or a larger one that could not afford modernization. Secretary of Defense Chuck Hagel, "Statement on Strategic Choices and Management Review" (speech, Pentagon Press Briefing Room, 31 July 2013), http://www.defense.gov/speeches/speech.aspx?speechid=1798.

25. Richard Fisher, "Deterring China's Fighter Buildup," *Defense News*, 19 November 2012, http://www.defensenews.com/article/20121119/DEFFEAT05/311190005/Deterring-China-8217-s-Fighter-Buildup.

26. John A. Tirpak, "The Sixth Generation Fighter," *Air Force Magazine* 92, no. 10 (October 2009): 38–42, http://www.airforcemag.com/MagazineArchive/Documents/2009/October%202009/1009fighter.pdf.

27. Maj Houston Cantwell analyzed the attitudes of Air Force pilots toward RPAs, finding a significant negative stigma surrounding them. Many pilots appear to love the act of flying more than the leveraging of aircraft to produce military effects. Maj Houston Cantwell, "Beyond Butterflies: Predator and the Evolution of Unmanned Aerial Vehicles in Air Force Culture" (thesis, School of Advanced Air and Space Studies, Maxwell AFB, AL, 2007), 81–85.

28. Corey Sandler, "IBM: Colossus of Armonk," *Creative Computing* 10, no. 11 (November 1984): 298, http://www.atarimagazines.com/creative/v10n11/298_IBM_colossus_of_Armonk.php.

29. Stuart J. Russell and Peter Norvig, *Artificial Intelligence: A Modern Approach*, 3rd ed. (Upper Saddle River, NJ: Prentice Hall, 2010), 695.

30. This article restricts the discussion to air-to-air applications because they present an extremely sterile environment compared to the air-to-ground (surface attack) domain. Acquiring and processing sensor data against a relatively empty background are far simpler than doing so against a cluttered backdrop of Earth's surface and all of the natural and man-made objects layered upon it. Surface attack is also extremely context dependent whereas air-to-air combat follows a more streamlined set of rules regarding electronic and visual identification measures and reconciliation against published rules of engagement. Christo-

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32. During refinement of the concept for this article, Capt Steve Christopher contributed this thought about the sharp contrast between machine preservation of capability and a human's natural tendency to get out of practice without perpetual reinforcement and challenge.

33. Brian Everstine and Marcus Weisgerber, "Reduced Flying Hours Forces [*sic*] Grounding of 17 USAF Combat Air Squadrons," *Air Force Times*, 8 April 2013, http://www.airforcetimes.com/article/20130408/NEWS/304080035/Reduced-flying-hours-forces-grounding-17-USAF-combat-air-squadrons.

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35. Ibid.

36. Defense Science Board, *Task Force Report: The Role of Autonomy in DoD Systems* (Washington DC: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, July 2012), 33–45, http://www.acq.osd.mil/dsb/reports/AutonomyReport.pdf.

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38. The current level of maturity supports a Department of Defense Technology Readiness Level (TRL) of three. Assistant Secretary of Defense for Research and Engineering, *Technology Readiness Assessment (TRA) Guidance* (Washington, DC: Assistant Secretary of Defense for Research and Engineering, April 2011), 2–13, http://www.acq.osd.mil/chieftechnologist/publications/docs/TRA2011.pdf.

39. "Microchips That Mimic the Brain: Novel Microchips Imitate the Brain's Information Processing in Real Time," *Science Daily*, 22 July 2013, http://www.sciencedaily.com/releases/2013/07/130722152705.htm.

40. Emre Neftci et al., "Synthesizing Cognition in Neuromorphic Electronic Systems," *Proceedings of the National Academy of Sciences of the United States of America*, 22 July 2013, http://www.pnas.org/content/early/2013/07/17/1212083110.

41. Maj Rene F. Romero, "The Origin of Centralized Control and Decentralized Execution" (thesis, US Army Command and General Staff College, 2003), 58–84, http://www.au.af.mil/au/awc/awcgate/army/romero.pdf.

42. From the author's personal experience and the experience of numerous RPA pilots. Flying the Predator and having the combined force air component commander relay direction to the crew via text chat occurred repeatedly during Operation Unified Protector.

43. Defense Science Board, *Task Force Report*, 1–3.

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44. For an article that exemplifies this viewpoint, see Brian E. Finch, "Anything and Everything Can Be Hacked," *Huffington Post*, 15 August 2013, http://www.huffingtonpost.com/brian-e-finch/caveat-cyber-emptor_b_3748602.html.

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47. Ibid., 559.

48. Warren Strobel and Deborah Charles, "U.S. on Offense in Cyber War: Building Command Center, Hiring Warriors," *Insurance Journal*, 7 June 2013, http://www.insurancejournal.com/news/national/2013/06/07/294731.htm.

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57. During refinement of the concept for this article, Capt Jon Kinsey contributed this thought about air vehicle autonomy through the eyes of a terminal attack controller.

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59. Caitlin H. Lee, "Embracing Autonomy: The Key to Developing a New Generation of Remotely Piloted Aircraft for Operations in Contested Air Environments," *Air and Space Power Journal* 25, no. 4 (Winter 2011): 85–86, http://www.airpower.maxwell.af.mil/airchronicles/apj/2011/2011-4/2011_4.asp.

60. Defense Science Board, *Task Force Report*, 1–7.

61. Anthony C. Cain, "L'Armée de l'Air, 1933–1940: Drifting toward Defeat," in *Why Air Forces Fail: The Anatomy of Defeat*, ed. Robin Higham and Stephen J. Harris (Lexington: University Press of Kentucky 2006), 54.

62. "Making Connections at 45,000 Feet: Future UAVs May Fuel Up in Flight," Defense Advanced Research Projects Agency (DARPA), 5 October 2012, http://www.darpa.mil/NewsEvents/Releases/2012/10/05.aspx. Budget constraints prompted the Navy to use manned surrogates to test the data-link system for autonomous air-to-air refueling; however,

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that service believes it will get the same level of technology maturation through the reduced-cost approach. Graham Warwick, "X-47B Unmanned Aerial Refueling Demo Victim of Cuts," *Aviation Week*, 15 April 2013, http://www.aviationweek.com/Article.aspx?id=/article-xml/asd_04_15_2013_p03-01-568738.xml.

63. Chair flying is a practice among pilots to study and prepare for a flight whereby they mentally rehearse and visualize the sequence of events that they expect to happen during the actual flight.

64. Col Michael W. Pietrucha, "The Next Lightweight Fighter: Not Your Grandfather's Combat Aircraft," *Air and Space Power Journal* 27, no. 4 (July–August 2013): 40, http://www.airpower.au.af.mil/digital/pdf/issues/2013/ASPJ-Jul-Aug-2013.pdf.

65. Maj David J. Blair and Capt Nick Helms, "The Swarm, the Cloud, and the Importance of Getting There First: What's at Stake in the Remote Aviation Culture Debate," *Air and Space Power Journal* 27, no. 4 (July–August 2013): 18, http://www.airpower.au.af.mil/digital/pdf/issues/2013/ASPJ-Jul-Aug-2013.pdf.

66. Ibid., 22, 23.

67. Ibid., 29.

68. Cantwell, "Beyond Butterflies," 115.

69. Ibid., 86.

70. This perspective of focusing on effects is also central to former Air Force chief of staff Gen John P. Jumper's vision of future RPA concepts of operations. Gen John P. Jumper, USAF, retired, "Next Generation Remotely Piloted Vehicle Concept of Operations" (unpublished), 14 March 2011, provided via e-mail by Capt Curt Wilson, USAF.

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73. Lt Col Lawrence Spinetta, "The Glass Ceiling for Remotely Piloted Aircraft," *Air and Space Power Journal* 27, no. 4 (July–August 2013): 107, http://www.airpower.au.af.mil/digital/pdf/issues/2013/ASPJ-Jul-Aug-2013.pdf.

74. Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military* (Ithaca, NY: Cornell University Press, 1991), 105.

75. In Glen A. Larson's 1978 television series *Battlestar Galactica*, later remade in 2003 by Ronald D. Moore and David Eick, Cylons were intelligent machines that achieved self-awareness and rebelled against humanity; they were the antagonists of the story line.

76. For example, the Association of Unmanned Vehicle Systems International's 2013 Unmanned Systems Conference and Exhibit enjoyed 75 percent commercial/industrial attendees versus 16 percent military. "Why Attend?," AUVSI's Unmanned Systems 2013, accessed 22 August 2013, http://www.auvsishow.org/auvsi13/public/Content.aspx?ID=1242.

77. Michael Cooney, "When Open Source and Drones Mix: US Navy Better Than Army and Air Force," *Network World*, 8 August 2013, http://www.networkworld.com/community/node/83576; and Tamir Eshel, "US Navy Awards UCLASS Studies amid Debate on Performance," *Defense Update*, 21 August 2013, http://defense-update.com/20130821_us-navy-awards-uclas-contracts-amid-debate.html.

78. "F-4 Phantom II Fighter," Boeing Corporation, accessed 23 August 2013, http://www.boeing.com/boeing/history/mdc/phantomII.page; and Capt Curt Wilson, personal e-mail

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correspondence, 18 August 2013. Captain Wilson predicts that the Air Force, strained by severe budget limitations and frustrated in its attempts to innovate amidst high operations tempo, will likely accept the US Navy's lead on RPAs in the short term.



Capt Michael W. Byrnes, USAF

Captain Byrnes (USAFA; MS, Carnegie Mellon University) recently arrived at the 29th Attack Squadron, Holloman AFB, New Mexico, to serve as an MQ-9 Formal Training Unit instructor pilot. Previously, he was a dual-qualified MQ-1B pilot and an MQ-9 instructor pilot working in the weapons and tactics section of his last squadron at Creech AFB, Nevada. He has flown more than 2,000 hours of diverse mission sets in the MQ-1 and MQ-9 in support of worldwide contingency operations. A graduate of the Euro-NATO Joint Jet Pilot Training Program and a distinguished graduate of the Air Force Academy, Captain Byrnes served as an enlisted avionics-sensor-maintenance journeyman prior to commissioning.

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"Finnishing" the Force

Achieving True Flexibility for the Joint Force Commander

Lt Col Matt J. Martin, USAF
CDR Brian Rivera, USNR
Maj Jussi Toivanen, Finnish Army

As opposed to finding independent solutions, we are trying to find joint, collaborative solutions that best support the joint warfighter in any spectrum of war.

—Gen John Corley, USAF, Retired
Commander, Air Combat Command



The US military has never been more capable. In the past, we found sophisticated jammers, sensors, and command and control (C2) systems only at the operational level of war (typically

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as part of the air or maritime components). Today they appear in the backpacks and vehicles of frontline troops. Similarly, although the highest-end capabilities were once tasked only against strategic objectives, today's C2 and data-distribution systems allow operational-level capabilities to provide direct support to ground troops. Even though these capabilities permit unprecedented joint flexibility and recent changes in joint doctrine make possible the joint tasking of tactical assets, many of the latest capabilities remain organized and controlled as if they can support merely a single component.[1] Key examples include ground-based signals intelligence sensors and organic airborne reconnaissance assets not organized, trained, or equipped for independent availability to the joint force. As we will see below, such assets as the Army's MQ-1C Gray Eagle or man-portable electronic jammers are intended to deploy as part of a larger single-component force, with little consideration given to their overall joint utility.

But what if things were different? What if the joint force commander (JFC) had not only knowledge—based on the expertise and experience of joint planners—of the capabilities of all our tactical and operational systems but also the tasking tools and authority to incorporate specific capabilities into the operational design of a joint campaign? Conversely, what if tactical commanders enjoyed the same fidelity of tactical control over joint assets as they do with their own organic assets? (The joint assets would include not just traditional, direct-support assets such as close air support [CAS] but the full range of joint capabilities.)

We face a future of severe fiscal constraints, rapidly emerging regional conflicts (consisting of both asymmetric and near-peer foes), and the likely need for both joint and coalition partnerships in any operation. Consequently, professional joint planners must seek new ways to take advantage of all existing US capabilities—regardless of echelon or service—and increase flexibility for the JFC. Many smaller Western nations are familiar with this problem, one born of limited forces that must fill multiple joint requirements. Finland is one such country, and Finnish operational thinking may prove instructive. This

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article uses the Finnish model as a case study to support three key reforms to traditional US force presentation towards a more capable joint task force (JTF): (1) enabling JTF planners to take a capabilities-based approach to requesting forces, (2) making it possible to separate traditionally organic forces from their parent units for small-scale deployment and employment, and (3) increasing the flexibility of joint-relevant forces (the use of both operational forces that do not normally provide direct support to tactical units and traditionally tactical units as operational assets) by increasing their connectivity to make them more supportive of and responsive to the full spectrum of joint C2.

The Joint Relevance of New Tactical Capabilities

Recent years have seen a tremendous increase in sophisticated capabilities fielded at the tactical level. Take, for example, the ITT Electronic Systems Counter Radio-Controlled IED [improvised explosive device] Electronic Warfare (CREW) 2.1 vehicle-mounted jammer (up to 25,000 of which are on contract for purchase by the US Army). It uses a digitally controlled, 30-watt transmitter that can cover the entire HF/VHF/UHF spectrum, jam multiple frequencies simultaneously, and cover both broad areas and spot targets.[2] In situations involving asymmetric targets near a border or those in which the JFC possesses insufficient electronic warfare (EW) capability at the joint level to attain the desired effects, these types of systems could act as key gap-fillers in a joint operational plan. They also pose problems for joint planners in terms of electronic deconfliction and fratricide.

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Marine carrying a Thor II backpack-mounted counter IED jammer. (Reprinted from "Marine Corps Photos," US Marine Corps, 13 February 2012, http://www.marines.mil/Photos.aspx?igphoto=768.)

Tactical intelligence, surveillance, and reconnaissance (ISR) has also seen huge advances in miniaturized capabilities. For instance, the AN/MLQ-40 vehicle-borne multisensor signals intelligence system can "detect, monitor, identify and selectively exploit Radio Frequency (RF) Signals for Intelligence information providing situational awareness and potential targets for Tactical Commanders. The exploited signal data can be relayed via voice or data through the organic Wideband Beyond Line of Sight (WBLOS) SATCOM communications system."[3] With both wide-area coverage and the ability to distribute data to joint exploitation centers, these ground-based sensors could significantly add to the JFC's collection capabilities. The joint use of such a system, however, would require distribution of ISR data to the joint and opera-

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tional levels as well as the traditional tactical level. Operational C2 mechanisms must also be in place to task these systems as joint assets.



US Army photo

AN/MLQ-40 Prophet

Perhaps the most capable system fielded at the tactical level is the US Army's MQ-1C Gray Eagle. A variant of the General Atomics MQ-1 Predator, the Gray Eagle is a 3,600-pound airplane with a 56-foot wingspan, a 25,000-foot service ceiling, and a payload of up to 400 pounds of external stores. The Army has a long-term plan to equip each of its divisions with a company of 12 Gray Eagles.[4] Ultimately, these aircraft achieve a true multirole operational capability, including air-to-ground fires, ISR, and EW.[5] The Army plans to procure and field this capability as an aviation support element for use as an organic asset. Despite efforts to make this platform available for joint use (see the section on Task no. 11, below), it is not yet available to the JFC as a separate, taskable capability. Since the Gray Eagle flies above the coordinating altitude in joint airspace, we already face the problem of incorporating it into the joint airspace planning process. Tasking the Gray Eagle as a joint operational asset will require putting in place the same type of tasking and C2 tools that already exist for Marine Corps and Navy aviation (more on that later).

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US Army photo

MQ-1C Gray Eagle

Recent Conflicts and the Need for Joint Flexibility

The recent operation in Libya or the ongoing North Atlantic Treaty Organization (NATO) operations in Afghanistan are the types of scenarios in which these capabilities could prove useful at the joint level. In Operation Unified Protector, for example, during enforcement of the no-fly zone over Libya, the US Navy and other NATO maritime forces supported the air component even as they carried out their own maritime tasks. This support included supplying C2 for tactical air assets and conducting surveillance missions with tactical unmanned aircraft.[6] However, since neither US nor NATO doctrine specifies a mechanism for either the JTF headquarters or a supported component to incorporate these capabilities into joint-level plans, key joint tasks tend to go to components that will address them with single-domain solutions.[7] Although a few areas of traditional joint integration (such as CAS and tactical mobility) have mature tactics, techniques, and procedures (TTP) and liaison structures for effective integration, other areas such

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as ISR, EW, and multiechelon communications do not. Therefore, joint support at the tactical level in these areas tends to occur on an ad hoc basis with less-than-optimal coordination. Opportunities to plan for joint cross-cue, provide a mechanism for dynamic joint retasking, or simply synchronize joint operations and increase efficiency can be lost.

Another example of the need for greater joint flexibility at the tactical level took place during surge operations in Operation Iraqi Freedom. This period focused on classic counterinsurgency operations instead of corps-level planning. Every battalion commander needed the ability to plan and execute operations independently—tasks that often depended on the predictable availability of operational-level capabilities, regardless of the priority of that particular action in the overall scheme of maneuver.[8] Maintaining the integrity of tactical-level operations and ensuring that joint-level assets promised during the planning phase remain available for execution, regardless of changes in the operational picture, were more important to the overall success of a counterinsurgency campaign than constantly shifting assets to meet perceived operational priorities. Future counterinsurgency JFCs might therefore be willing to risk inefficiency at the operational level rather than pull promised joint assets from tactical commanders just when they need them most.

Thus, in Iraqi Freedom, the traditional model was inappropriate to the new fight. Not only did tactical commanders have difficulty planning their operations 72 hours or more in advance (to comply with the doctrinal 72-hour air tasking order [ATO] cycle) but also the sudden removal of a capability in favor of higher priorities could make it impossible for tactical commanders to carry out their operations.[9] Ad hoc solutions were created to overcome doctrinal deficiencies in Operations Iraqi Freedom and Enduring Freedom, but the doctrinal model remains the same. Moreover, since the joint force air component commander (JFACC) had no visibility on the operations conducted at the battalion level—and no mechanism to understand the real-time ISR

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needs of tactical commanders—he could not respond to emerging ISR requirements.[10] The traditional liaison elements in place (e.g., air liaison officers [ALO], an air component coordinating element at the corps level, and a battlefield coordination detachment at the combined air and space operations center [CAOC]) concentrate for the most part on translating apportionment into allocation—primarily to provide CAS to the Army. They are neither set up nor intended to offer real-time coordination of joint ISR, EW, and C2.

Similarly, the fact that tactical commanders had no real-time visibility on the status of operational ISR assets, even when those assets were in the local area, meant that they would have no warning prior to reallocation and no way to fill that gap with other available assets. Joint doctrine gives tactical commanders a means of accessing the full range of joint fires, but for ISR, communications relay, and EW, a doctrinal or procedural solution remains elusive although ad hoc solutions were devised during Iraqi Freedom (see the section on intelligence liaison officers [ILO], below).

Expanding Traditional Joint Air Tasking to Include New Tactical Capabilities

In traditional joint operations, during which a component commander has organic air assets not needed for organic tasking, those assets are typically made available to the JFC. In fact, according to Joint Publication 3-30, *Command and Control for Joint Air Operations*, the JFC has the authority to make available components' organic air forces for joint tasking. To determine which ones to provide for joint air operations, the JFC will consult with component commanders and identify excess air capabilities. Typically, the commander of Air Force forces is designated the JFACC and becomes the supported commander for strategic attack, air interdiction, and airborne ISR.[11] For instance, carrier strike group F-18s that belong to the joint force maritime component commander (JFMCC) would typically be "retained for employment in

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support of the assigned joint maritime missions."[12] When the JFMCC has excess capabilities—F-18s not required for assigned joint missions or for fleet defense—he or she will give them to the JFACC via the joint air tasking process.[13]

The primary mission of the organic air capabilities of the Marine air-ground task force's (MAGTF) aviation combat element (ACE) is to support the task force's ground combat element. During joint operations, the MAGTF's aviation assets normally support its mission requirements, and these organic air requirements in support of subordinate elements within the task force are prioritized and scheduling conflicts are resolved by the MAGTF commander.[14] In the unlikely event the MAGTF has excess air capabilities, those assets will be given to the JFACC for theater air tasking, including air defense, long-range interdiction, and long-range reconnaissance.[15]

Once the components identify and provide excess air capabilities (including unmanned aircraft systems [UAS], typically identified as an ISR asset) to the JFC, the JFACC becomes the component responsible for planning, coordinating, allocating, and tasking. In accordance with JP 3-30, "the JAOC [joint air operations center] should request ISR support from the JFC or another component if available assets cannot fulfill specific airborne ISR requirements. It is imperative [that] the JFACC remains aware of all surveillance and reconnaissance capabilities that can be integrated into joint air operations."[16] But this does not necessarily mean that all resources are pooled for maximizing the JFC's theater-wide surveillance and reconnaissance effects. In the case of Marine UASs (as well as Army UASs), these are considered organic ISR assets—even if their parent unit is neither tasked nor deployed.[17] Indeed, given the existence of an identified best practice of pooling and optimizing the use of organic UASs to support Marine operations, the Marines do not extend this practice to the joint level. This is true even when Marine capability is present in a joint operations area but Marine ground operations have not yet commenced.[18] That is, even

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though the MAGTF contains highly capable ISR assets, if it has not yet begun ground operations, those assets will sit idle.

Once operations begin, though, the Marine unmanned aerial vehicle squadron (VMU)—a UAS unit attached to the MAGTF—will provide, through the MAGTF's ACE, the task force commander with UAS capability in either a general or direct-support role. Under general support, the ACE commander will supply UASs to the force as a whole, ensuring that all MAGTF elements have the best access and that "priority of support to subordinate elements will likely go to the unit that is the main effort."[19] When the ACE and VMU operate in a direct-support role, UASs support a specific, designated unit.[20]

The Marines of the I Marine Expeditionary Force (Forward), for example, became both the MAGTF and Regional Command–Southwest during Enduring Freedom and faced an ISR resource-management challenge. The problem involved optimizing the use of ISR capabilities against coalition and NATO requirements. The solution included making organic aviation assets available to the priorities of required mission sets. Essentially, the Marines integrated air reconnaissance UASs in concert with other functions of aviation.[21]

Integrating Operational Capabilities at the Tactical Level—ALOs and ILOs

Another instance of increased flexibility came in the form of the ILO in Iraqi Freedom and Enduring Freedom. Beginning in 2006, the US Air Force began to deploy experienced ISR officers and noncommissioned officers to divisions and regional commands in Iraq and Afghanistan as part of the ALO contingents. Their purpose, although not yet enshrined in a joint doctrine document or tactics manual, was to improve the integration of the Air Force's ISR capabilities into Army and Marine tactical operations, assist with the planning of the use of those assets in ground operations, and optimize their employment

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when tasked to provide direct support. According to Lt Gen David Deptula, former USAF/A2, this partnering brought about

> better understanding and results for the collection requirements of ground commanders; improved partnering between ground force intelligence staffs, CAOC ISR division analysts, and . . . [distributed] analysts to work time-sensitive analytical questions pertaining to current operations; and exceptional situational awareness for ISR crews regarding the details of current operations in which they will participate.[22]

During Iraqi Freedom and now in Afghanistan, the Air Force embedded ILOs within each deployed division as well as at key nodes such as the JTF headquarters and special operations forces headquarters—and with maneuver units engaged in high-priority operations. Typically, they were embedded in ground units as a means of better synchronizing operational ISR support with maneuver and fires. They also took advantage of the inherent ISR capabilities of joint-fires assets such as fighters with advanced targeting pods, incorporating them into the tactical-collection plans of ground units. This type of capability, which has come to be known as nontraditional ISR, supplied a key gap-filler for units engaged in ISR-intensive counterinsurgency operations.[23] However, the use of ILOs was never added to joint doctrine or sourced as part of ALO unit-manning plans. The utilization of ILOs in Iraqi Freedom and Enduring Freedom demonstrates that adding new capabilities is not enough to increase joint flexibility and effectiveness. Rather, we need a means—typically operator-centric—of planning for the use of these capabilities, leveraging them in complementary ways with other capabilities, and integrating them into dynamic operations.

The Finnish Model: An Example of Joint Flexibility

The main points in strategy for transformation of the Defense Forces are that the size of the Armed Forces must be equal with the tasks and budget, they must develop equal effectiveness with fewer resources, and they must build cooperation within the nation.

—Gen Ari Puheloinen
Commander, Finnish Defense Forces

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In recent years, the Finnish Defense Forces (FDF) have faced wide structural transformation because of aging equipment, the high cost of modernization, and the expensive nature of crisis-management operations. To counter these issues, the FDF is making joint flexibility a primary consideration in the acquisition process, with the goal of moving away from dedicated service capabilities towards more commonality and better cost-effectiveness. In fact, joint operations have been at the heart of Finnish operational thinking since World War II. Central to the FDF are terms like "service shared operations" or "service shared fire."[24] Thus, "key areas of Finland are secured in all circumstances, aggression is defied and if needed combatted in a JOINT operation in order to accomplish the end state."[25] Figure 1 shows the C2 structure of the FDF along with the level of joint organization.[26]

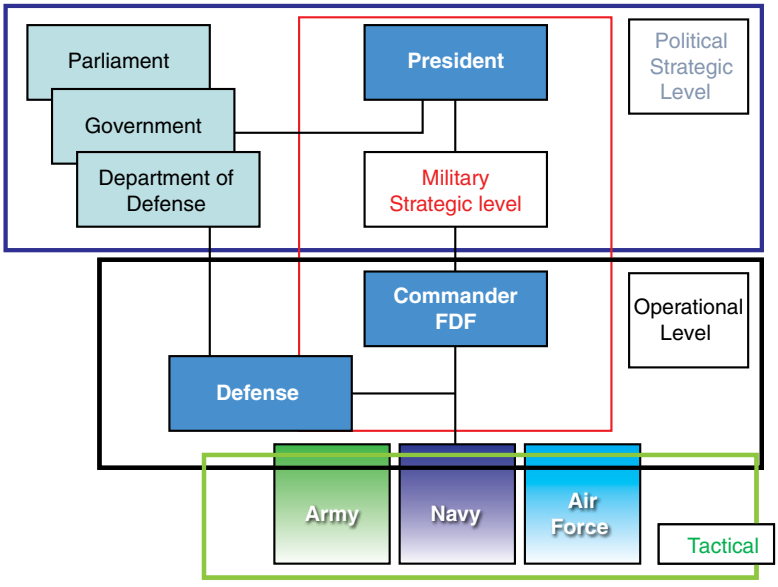


Figure 1. FDF structure. (From Col Pasi Kesseli, "Use of Common Capabilities in the Winter and Continuation War" [lecture presented at the Finnish National Defense University, 5 November 2012].)

The FDF leverages capabilities from the Army, Navy, and Air Force, as well as from a set common capabilities (fig. 2). These capabilities

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(mainly joint fires, ISR, and EW), organized along component lines and considered common to joint operations, constitute the bulk of the FDF.

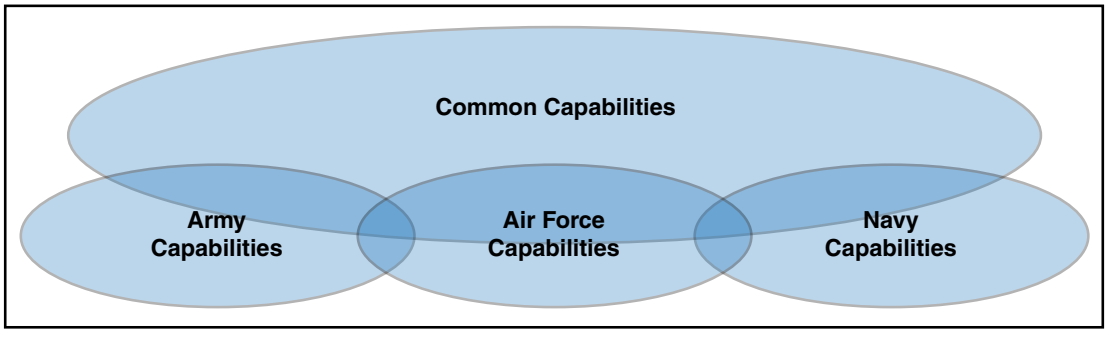


Figure 2. FDF capability organization. (From Kenttäohjesääntö, Yleinen osa, *Puolustusjärjestelmän Toiminnan Perusteet* [Field Manual, General Part, *Basic Structure of the Defense System*], 30.)

Common capabilities are allocated and assigned at the joint level, and the Defense Command plans their use—including service capabilities for use by the commander. Along with key enablers, the Finnish model prescribes joint integration based on a set of common principles for acquisition, training, and organization.[27] The key difference here between the US and the Finnish model is that although Finnish planners can reach down to the tactical level to pluck needed capabilities from larger parent units, the US planner cannot tap into something like the MQ-1C without tasking the entire division to which it belongs.

The Finnish service chiefs are generally responsible for planning the independent use of service (noncommon) forces. However, even these forces will be allocated to the Defense Command when needed. This would include any operation to "defend Finland and will be led by the Defense Command using the capabilities of the Army, the Navy and Air Force in addition to the common capabilities."[28]

Defense Command prioritizes the use of common capabilities in national/joint operations and returns any excess to the services or to the regional commands. In some cases, the command can delegate a task

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to a service.[29] During joint operations, Defense Command will ensure a high level of situational awareness for all players by integrating the recognized air, land, and maritime pictures into a common operating picture (COP). The command will then either act as the JTF headquarters or allocate capabilities to operations led by the services. Doing so enables the FDF to mass Finland's limited combat power and concentrate it against the aggressor's most critical vulnerability or center of gravity. Defense Command will also use centralized control with a flat command structure to make decisions more rapidly than the aggressor and operate inside his decision-making cycle. Finnish joint operations are therefore task-oriented, using only those capabilities needed to reach culmination. Other capabilities are then returned to the supporting services.[30] In all cases, though, Defense Command will own and distribute the real-time COP and coordinate all operations.

A common Finnish scenario involves the need to move land forces along the coastline to assume an advantageous defensive position. In this case, Defense Command will delegate operational control to Army headquarters. In case of major maneuver, the command will use forces with common capabilities to support the maneuver and may also assume operational control of supporting forces (such as the Navy or Air Force) to support the Army. These would typically be key enablers such as joint fires, information warfare, or ISR.[31]

Admittedly, Finland is a small country with limited resources, and many people might argue that almost any organizational structure would work. However, since future Department of Defense (DOD) budgets will probably continue a downward trend, it is informative to examine smaller militaries and the way they maximize capability with limited resources. This is the primary driver behind the creation of joint "common capabilities." Strategically, Finland must be able to build up and employ joint forces rapidly against single tasks—even if those forces are normally organized at the tactical level or are otherwise organic to the service. Like Finland's Defense Command, the US DOD faces increasingly constrained budgets, smaller force structures,

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and the need to organize joint and coalition task forces quickly to respond to small and often asymmetric crises. Thus, a JFC's ability to tap directly into tactical-level units—particularly when they possess key enabling capabilities such as C2, ISR, and EW—could be of key importance. The DOD may benefit greatly from the lessons of the Finnish model. In fact, the Army and Air Force have already given some thought to this type of arrangement for unmanned aircraft.

Task No. 11 and the Use of Organic Unmanned Aircraft Systems

On 30 June 2008, Gen John Corley, commander of US Air Combat Command, and Gen William Wallace, commander of US Army Training and Doctrine Command, agreed to a new concept for the employment of theater-capable multirole unmanned aircraft. This concept grew from an earlier task (no. 11) from the Army–Air Force Warfighters talks in which the chairman of the Joint Chiefs of Staff gave the two services the task of finding a better way to employ these highly capable systems in joint operations.[32] The concept called for doctrine, organization, and training, as well as material, leadership, and personnel changes to the Air Force MQ-1/MQ-9 and the Army MQ-1C programs. The goal called for all three platforms to function seamlessly as joint air assets controlled by the JFACC (when deemed necessary by the JFC) and as "near organic" systems when the JFC determined that a ground commander should receive direct support. Figure 3 identifies the data, TTPs, and C2 links needed to execute the concept.

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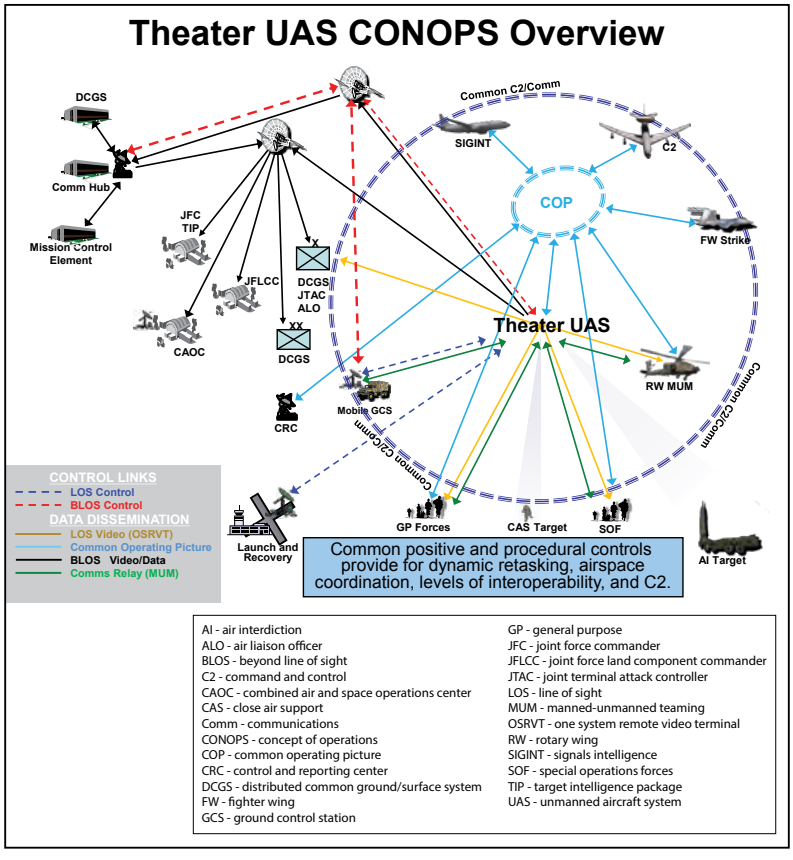


Figure 3. Task no. 11 operational view. (Reprinted from Air Combat Command and Training and Doctrine Command, *The Multi-Role, Theater-Capable, UAS Enabling Concept* [Hampton, VA: Air Combat Command, 2008], 4.)

The idea behind the concept entails building the maximum possible flexibility into these systems by ensuring that the ISR data they produce is compatible with both Army and Air Force ISR exploitation systems as well as Link-16 and Blue Force Tracker tactical data links. The systems should also be able to distribute their ISR data both locally and beyond line of sight. They should respond to both tactical and operational echelons of C2. Task no. 11 requires that operators of these systems be well versed in the joint TTPs and terminology needed for both joint and component integration.

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The US Army and Air Force have since taken steps to implement the concept by making adjustments to their organize/train/equip efforts. Changes have been made to joint doctrine and TTPs (e.g., the procedures needed to incorporate Army assets into the JFACC ATO in the same manner as Navy and Marine air assets).[33] The Air Force has also taken advantage of this work to improve support provided to ground units in Afghanistan through habitual association with supported units as well as better visibility and understanding of tactical ground operations. The Army, however, has not yet had the opportunity to demonstrate joint integration of the MQ-1C and, therefore, has been able to test the concept only through war gaming.[34]

Recommendations: A Scheme for Greater Joint Flexibility (Plug and Play)

Obviously, the US military is much bigger and has much greater capacity than the FDF. Consequently, under what circumstances would the JFC need to tap into tactical capabilities? Consider the following three vignettes:

1. *A small, regional conflict that threatens a nonvital interest of the United States or its allies but for political reasons requires US involvement*. Operation Unified Protector in Libya offers one such example. In this case, it was politically unacceptable for the United States to take the lead with offensive forces or to introduce ground troops directly into the conflict, despite the fact that a US commander directed the main effort and that the vast majority of key enabling capabilities came from America.[35] According to Lt Gen Ralph Jodice, JFACC for Unified Protector, his operation suffered from gaps in ISR and EW due to the lack of the capacity of forces normally available in a large US operation (e.g., U-2s or RQ-4s). In the future, when high-level ISR assets are not available, having access to mitigating organic maritime or land-based capabilities for direct joint tasking could prove decisive.[36]

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2. *The deterrence phase of what is expected to be a major US operation*. In this case, the United States may need to rapidly demonstrate its ability to respond to regional aggression with flexible deterrence operations while awaiting a larger deployed force. There simply may not be time for a JTF commander to wait for high-end operational capabilities to arrive on station. The JTF, therefore, would need to take maximum advantage of any capabilities that might already be in-theater to produce a decisive deterrent effect. As it stands, organic capability resident within a nontasked or not-yet-active parent unit is not directly available to the JFC.
3. *Simultaneous conflicts breaking out in different areas of responsibility*. In this case, one of the operations may have a lower priority and thus cannot gain access to a significant number of operational capabilities. As in vignette no. 2, the JTF commander of the lower-priority conflict would have to make the best use possible of whatever capabilities are on hand—such as tapping into tactical-level ISR or EW without tasking the parent unit.

To ease the leveraging of tactical capabilities to satisfy operational-level needs in these vignettes, one would have to make significant changes to joint planning doctrine, joint operational doctrine, and the manner in which those forces are made available to the JFC for tasking.

Reform No. 1: Capabilities-Based Planning

Currently, forces are identified for apportionment through their primary maneuver echelon. For example, a JTF planning staff might learn that a brigade combat team is on the apportionment list, but without amplifying information on the internal capabilities of that team, the JFC would have to rely on the knowledge and experience of the planning staff. That would work fine if an Army officer with appropriate experience happens to be on the team. If no such person is available, then those capabilities would remain invisible to the JTF planning staff. To correct this situation, we need to identify joint capabilities as part of their parent maneuver units during the apportion-

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ment process. Thus, when a JTF's J-5 staff is planning an operation and receives global force management appendices with a list of apportioned forces, the appendix could be expanded to include detailed information about joint capabilities. This addition might take the form of another column with the relevant information (see the table below). J-5 planners would also need more training so they will understand the nature of these capabilities and include them in their plans.

Table. Hypothetical global force management appendix identifying joint capability

APPENDIX 1 (U.S. Army Apportionment Tables) to Section IV (Apportionment of Forces) to Global Force Management										
Service/Unit Type/Capability	Bin A			FMID	Bin B			FMID	Joint Capes	Notes
	Units	Eqmt	RLD		Units	Eqmt	RLD			
HQ's										
Corps HQ	1		N+4	5A1	1		N+4	5A2		
Division HQs	1		N+3	5A4	1		N+3	5A5		
	1		S+49	5A7	1		S+51	5A6		
BCT's										
Armored Brigade Combat Team (ABCT)	6		N+2	5B1	4		N+2	5B4	SIGINT	
			N+3	5B2			N+4	5B5	Electronic Attack	
			N+5	5B3			S+48	5BC		
			N+5	5B7			S+54	5BD		
			S+47	5BA						
			S+52	5BB						
Infantry BCT (IBCT)	5		N+2	5C2	4		N+2	5C1	FMV	One IBCT (5C1) is embarked on the Army Preposition ships along with a sustainment brigade, two Eng BN's, an early medical support element, and JTF-PO (SPOD) package
			N+2	5C3			S+43	5CC		
			N+4	5C4			S+44	5CD		
			S+44	5CA			S+47	5CE		
			S+45	5CB						
Infantry BCT (Air Assault [AASLT])	1		N+14	5C6	1		N+4	5C5		
Infantry BCT (Airborne [ABN])	1		N+1	5C8	1		N+2	5C7		
Striker BCT (SBCT)	1		S+44	5BF	1		N+3	5BE		
Tactical Combat Force (TCF) (BN)	2		S+20		1		S+20			These units are only infantry Bn's and cannot be combined into a IBCT.
			S+30							
Afloat Preposition Units										
										Unit includes equipment for an IBCT, sustainment Bde, 2 eng Bn's, 1 earmy medical support element, a JTF-PO package,

FMID - force management identifiers
FMV - full-motion video
JTF-PO (SPOD) - joint task force port opening seaport of debarkation
RLD - ready-to-load date

Reform No. 2: Independent Presentation of Small, Traditionally Organic Units

Currently, submaneuver units (i.e., those not presented as independently maneuverable) are bundled with their higher-echelon main-

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maneuver unit. Consequently, a company equipped with tactical jammers would be presented only as part of a larger unit (brigade or division). If the JTF needs access just to the company equipped with jammers, then the force provider may have no mechanism to mobilize and deploy it independently of the parent unit. (This may be the case even though the company will not be called upon to maneuver independently of a larger force—if, for example, the company is needed at a coalition base on a border.) Since we routinely deploy and task small units with operational capabilities from all four services, this should simply be a matter of extending this ability to units that do not traditionally deploy on their own.

This would constitute a "plug-and-play" approach to joint capabilities. In the example of an infantry company with backpack jammers, the JFC will need to access that unit via the time-phased force and deployment data sourcing process in order to include it in the operational plan for purposes of C2, sustainment, and so forth. Then, as the JFC designs the overall C2 structure, the unit could be aligned with the appropriate tactical C2, basing, and sustainment elements—and included in the support plans of the units responsible for those basing locations.

Reform No. 3: Flat and Flexible Joint Command and Control

For maritime capabilities, we can expect a maritime component commander with associated tactical C2 of maritime forces. The maritime component, therefore, can assume the task of using maritime organic capability as a joint asset. But the JFACC should be able to control air assets normally organic to the land component—or do so in the absence of land forces that would exercise tactical C2. For example, as part of Task no. 11, the enabling concept specifies the need for an MQ-1C company to interface with a CAOC, integrate into the ATO and master air attack plan process, and receive those ATO instructions. The air component's tactical C2 elements would then control that company.[37] This process drives training and equipment as Gray Eagle companies take on the task of preparing to function as joint air assets.

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For small land units that will deploy without their higher-echelon tactical C2, the issue becomes a bit trickier. They must either interface directly with the JTF headquarters or attach themselves to another component (perhaps special operations or the JFACC for ISR). In either case, they would need the connectivity to interface with the appropriate C2 network as well as training in the appropriate joint TTPs. In most cases, though, the TTPs already exist (e.g., joint CAS). So the main task amounts to training for units not previously trained to function as joint assets.

A practice of providing the JFC with daily status reports of high-demand, low-density organic assets already exists. For instance, each day the US Navy reports the status of SM-3 and Tomahawk land-attack missiles within the fleet to the Joint Staff and to the geographical combatant commanders. Without integrated solutions, this data has to be sent via PowerPoint briefs or Excel spreadsheets.[38] The commanders, therefore, are aware of the numbers and types of SM-3s and missiles aboard ships operating in their area of responsibility and have the means to task those weapons, but the information sharing is less than optimal. We need a better solution—the ability to inject data into the COP—to allow better JFC tracking and tasking.

For the converse problem of better support to the tactical commander, the effectiveness of ILOs embedded with ground units has been well documented. We should expand this liaison presence to mirror the CAS approach, with liaisons at every echelon from division to battalion. These ILOs not only should be experts on operational ISR capabilities (both airborne and within other domains) but also should have the training and authority to match tactical ISR desired effects to available sensors and exploitation elements—and even exercise tactical (but not terminal) control over operational sensors, just as forward air controllers exercise tactical control over CAS assets. However, we would not expect ILOs to exercise air traffic control, as we do with forward air controllers.

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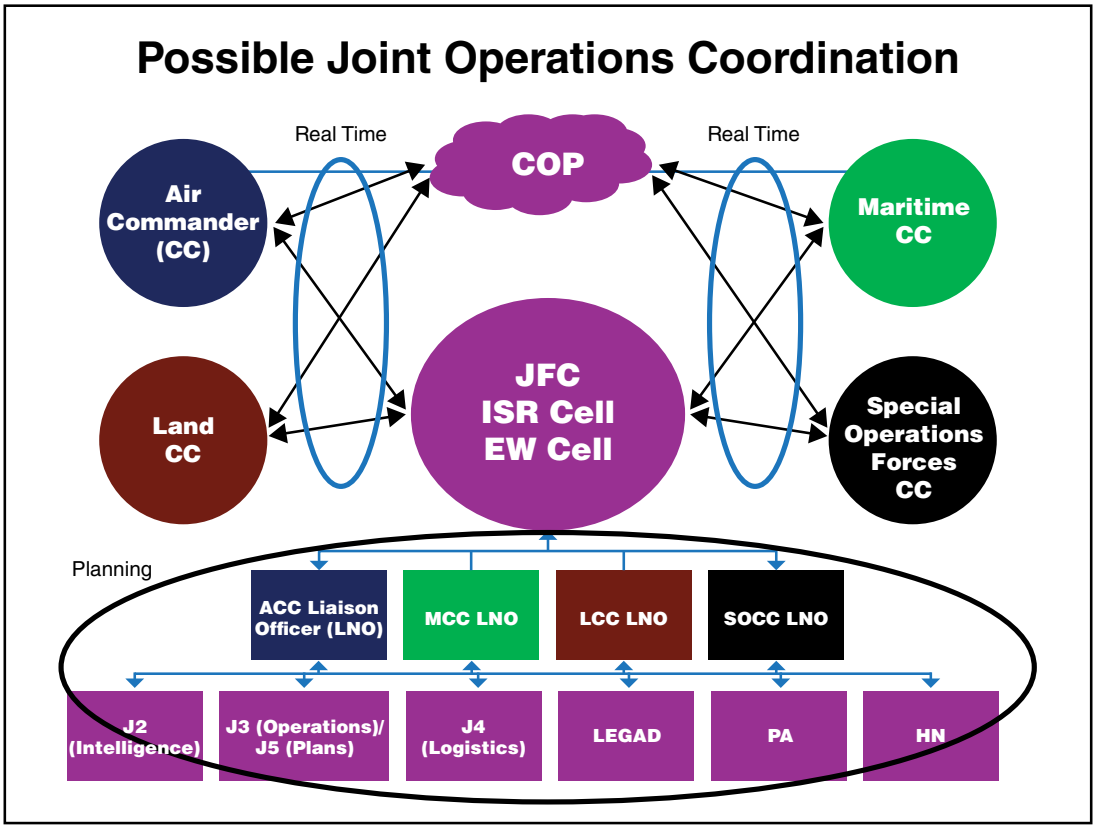
If manning restrictions prevent the training and deployment of more ILOs, then the role of the joint terminal attack controller should be expanded to include ILO and EW liaison duties. Doing so would require both additional training and improved connectivity with ISR/EW collection platforms and their associated exploitation elements. These elements (i.e., the distributed common ground/surface systems) could then be leveraged to provide greater ISR fusion and analysis (as well as knowledge of sensor and platform capabilities) to the controllers in order to ease their burden and increase their capabilities. Finally, we need real-time coordination at the joint level in the form of ISR and EW coordination cells that perform a number of functions:

- Provide real-time joint coordination to mass joint sensors and jammers on specific objectives.
- Facilitate cross-cueing of joint ISR and EW.
- Offer real-time guidance to components to change the weight of effort against dynamic targets inside the execution phase.
- Analyze component ISR products to arrive at fused, joint intelligence assessments and feed the decision-making process.
- Ensure that all players tasked against joint objectives maintain and facilitate a high level of situational awareness.
- Assist the J-3 and J-5 staffs with planning for the use of joint capabilities.

Figure 4 shows a possible coordination scheme among joint-level execution, planning, and the various components. We should note that coordination cells at the joint level will not act as tactical C2 agencies, nor will they provide guidance directly to tactical units. The components will still fill those roles. Rather, joint cells will coordinate with ISR and EW cells within the component headquarters to conduct the above functions. Similarly, large-scale operations with sufficient forces to obviate the need to tap into tactical-level forces for joint tasks may not need these cells. For smaller-scale operations described in the three vignettes, however, small coordination cells on the JTF level will

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be in the best position to derive maximum efficiency and flexibility of joint forces.



ACC - air component command
HN - host nation
LCC - land component command
LEGAD - legal adviser
MCC - maritime component command
PA - public affairs
SOCC - special operations component command

Figure 4. A possible scheme for small JTF coordination

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The Life You Save Could Be Your Own

The United States and its allies face uncertain times—those marked by pop-up regional conflicts, shrinking defense budgets, and insufficient forces to carry out assigned tasks. We may no longer be able to afford the luxury of retaining our most sophisticated capabilities as organic elements of a component or maneuver unit. At times, for reasons of politics, finances, or simple priority, a JTF commander will need access (i.e., visibility during the planning process, the ability to task tactical units independently of their parent maneuver units, and operational C2 of traditionally tactical assets) to the full capabilities of all assigned forces. As a steward of our national resources, the joint force would be remiss if it did not explore every possibility to provide just that. As a result, joint capabilities must be available not only for joint planning purposes but also for joint tasking, even in the absence of their parent maneuver units in a traditional C2 architecture.

At the same time, we must make sure that the tactical commander has access to the most sophisticated operational capabilities when appropriate and available. Doing so will involve not only simple connectivity but also liaisons and forward controllers who are experts in the application of joint military power—individuals who have the visibility and authority to leverage high-end joint capabilities to great tactical effect. Perhaps we cannot predict the next conflict, but we can build maximum flexibility within the joint force to fight it. ✪

Notes

1. For example, according to the latest version of Joint Publication (JP) 3-30, *Command and Control of Joint Air Operations*, 10 February 2014, http://www.dtic.mil/doctrine/new_pubs/jp3_30.pdf, "Theater-capable UASs . . . can be used to support the JFC" (III-32). Furthermore, JP 3-32, *Command and Control for Joint Maritime Operations*, 7 August 2013, http://www.dtic.mil/doctrine/new_pubs/jp3_32.pdf, notes that "the JFMCC [joint force maritime component commander] provides a unique complement of sensors and sensor fusion capability to support joint requirements and advocates for the use of other component and national assets to provide optimum support to maritime operations. Sonar capabilities and the

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ability to relocate surveillance and reconnaissance assets may provide additional options to the JFC. Close coordination with other component commanders and the communications system directorate of a joint staff (J-6) early in joint planning is essential to aligning architectures with platform and sensor employment plans to optimize intelligence, surveillance, reconnaissance, and associated processing, exploitation, and dissemination systems throughout the joint force" (II-7).

2. "JCREW: ITT Wins Contracts for Land Mine Jammers," *Defense Industry Daily*, 3 October 2011, http://www.defenseindustrydaily.com/edo-wins-88m-contract-for-land-mine-jammers-03196/; and "CREW Vehicle Receiver/Jammer (CVRJ): Roadmap to Capabilities," Exelis, accessed 2 June 2013, http://www.exelisinc.com/solutions/CREW-Vehicle-Receiver-Jammer/Pages/default.aspx.

3. "AN/MLQ-40(V)4 Prophet Spiral 1+," L-3 Communications, Linkabit Division, n.d., accessed 21 May 2013, http://www2.l-3com.com/linkabit/products/.

4. Kris Osborn, "Army Expanding, Upgrading Gray Eagle Fleet," US Army, 28 June 2012, http://www.army.mil/article/82790.

5. "ER/MP Gray Eagle: Enhanced MQ-1C Predators for the Army," *Defense Industry Daily*, 16 December 2013, https://www.defenseindustrydaily.com/warrior-ermp-an-enhanced-predator-for-the-army-03056/.

6. "Insitu ScanEagle Works with NATO on Libyan Missions," *Defense Daily* 251, no. 32 (16 August 2011), http://www.defensedaily.com/Assets/File/txt/DD_2011-08-15_17-31.txt.

7. "The JFC should attempt to meet the organic needs of the component commanders, while ensuring the JFACC has the assets available to execute JFC assigned JOA [joint operations area]-wide operations. These decisions will typically change as the phase of an operation changes. As with any joint capable asset, the JFC retains the authority to use any UAS asset to meet the needs of the JFC mission. How theater-capable UAS operations are managed and planned will vary based on the type and phase of an operation." JP 3-30, *Command and Control of Joint Air Operations*, III-32. Also, "sensor capability resident in the joint maritime force may support the joint force collection plan and may be integrated into the joint data network. Sensor tasking procedures, allocation of collection assets, and product dissemination should be determined early in the planning process." JP 3-32, *Command and Control for Joint Maritime Operations*, III-11. The following guidance is provided to joint-level collection managers with regard to tasking joint ISR assets: "The list of viable collection disciplines, systems, and sensors is reviewed for current availability (to include estimated downtime if not available) and the addition or deletion of capabilities. Coordination with adjacent and higher HQ and national agencies will determine the availability of theater and national resources." JP 2-01, *Joint and National Intelligence Support to Military Operations*, 5 January 2012, III-24, http://www.dtic.mil/doctrine/new_pubs/jp2_01.pdf. Typically, joint-level collection managers constrain themselves to operational-level ISR assets to collect against joint targets rather than trying to task an organic asset directly.

8. Lt Col Michael L. Downs, "Rethinking the Combined Force Air Component Commander's Intelligence, Surveillance, and Reconnaissance Approach to Counterinsurgency," *Air and Space Power Journal* 22, no. 3 (Fall 2008): 70.

9. Ibid., 72.

10. Col James M. Waring, Lt Col Carl L. Giles, and CW3 John A. Robinson, "The 19th BCD in Counterinsurgency Operations," *Field Artillery*, July–August 2005, 17.

11. JP 3-30, *Command and Control of Joint Air Operations*, II-2.

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12. Ibid., II-17.
13. Ibid.
14. Marine Corps Warfighting Publication (MCWP) 3-42.1, *Unmanned Aerial Vehicle Operations*, 14 August 2003, 2-2, http://www.marines.mil/Portals/59/Publications/MCWP%203-42.1%20Unmanned%20Aerial%20Vehicle%20Operations.pdf.
15. JP 3-30, *Command and Control of Joint Air Operations*, II-16.
16. Ibid., III-27.
17. Anthony C. Bolden, Lt Col George J. David, and Brian R. Mahoney, "Airborne ISR: A New Way to Command and Control Organic Assets," *Marine Corps Gazette* issue 95, no. 8 (August 2011): 45–48.
18. Ibid., 46, 47.
19. MCWP 3-42.1, *Unmanned Aerial Vehicle Operations*, 2-2.
20. Ibid.
21. Bolden, David, and Mahoney, "Airborne ISR," 47.
22. David A. Deptula and James R. Marrs, "Global Distributed ISR Operations: The Changing Face of Warfare," *Joint Force Quarterly* 54 (3rd Quarter 2009): 113.
23. Capt Kevin Pratte, "Sensor Packaging—Making the Most of NTISR," *Air Land and Sea Bulletin* issue 2007-03 (September 2007): 13.
24. Lt Cdr Ville Vanska, "JOINT Operations in Finnish Operational Art" (predoctoral thesis, Finnish National Defense University, 2011), 2.
25. Translated from Kenttäohjesääntö, Yleinen osa, *Puolustusjärjestelmän Toiminnan Perusteet* (Helsinki: Suunnitteluosasto, Pääesikunta, Edita Prima Oy, 2008), 73, 95. [Field Manual, General Part, *Basic Structure of the Defense System*, J-5 Defence Command.]
26. Col Pasi Kesseli, "Use of Common Capabilities in the Winter and Continuation War" (lecture presented at the Finnish National Defense University, 5 November 2012).
27. Kenttäohjesääntö, Yleinen osa, *Puolustusjärjestelmän Toiminnan Perusteet*, 31.
28. Ibid., 109.
29. Ibid., 29–32, 35–36, 38.
30. Vanska, "JOINT Operations," 16.
31. Ibid., 72.
32. Paul Boyce, "Air Force, Army Leaders Discuss New UAS Concept of Operations," US Army, 2 July 2008, http://www.army.mil/article/10570/Air_Force__Army_leaders_discuss_new_UAS_concept_of_operations/.
33. See JP 3-30, *Command and Control of Joint Air Operations*, III-32 through III-34.
34. Mr. Anthony Parlati (formerly of the Air Combat Command Predator/Reaper Operations Branch), telephone interview by Lt Col Matt Martin, 30 May 2013.
35. Ian Brzezinski, "Lesson from Libya: NATO Alliance Remains Relevant," *National Defense Magazine*, November 2011, http://www.nationaldefensemagazine.org/archive/2011/November/Pages/LessonFromLibyaNATOAllianceRemainsRelevant.aspx.
36. Lt Gen Ralph Jodice, Skype interview by Lt Col Matt Martin, 29 May 2013.
37. See USAF Air Combat Command and USA Training and Doctrine Command, "The Army–Air Force Multi-Role, Theater-Capable, UAS Enabling Concept," USAF Air Combat Command and USA Training and Doctrine Command, 2008.
38. Based on the authors' experience.

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Lt Col Matt J. Martin, USAF

Lieutenant Colonel Martin (BA, Purdue University; MA, University of Denver) is a special projects officer assigned to the 28th Bomb Wing, Ellsworth AFB, South Dakota. He is responsible for integrating new and joint-urgent capabilities into the wing's MQ-9 combat operations as well as improving the realistic training of its MQ-9 crews. Lieutenant Colonel Martin is an MQ-9 pilot with more than 2,000 hours of combat experience in Iraq and Afghanistan. Previous assignments include chief of MQ-1/9 operations, Headquarters Air Combat Command; chief of airborne reconnaissance and electronic warfare, NATO Headquarters Air Command Izmir, Turkey; wing chief of safety and 16th Training Squadron director of operations, 49th Wing, Holloman AFB, New Mexico; and commander, 46th Expeditionary Squadron, Balad AB, Iraq. Lieutenant Colonel Martin is a graduate of Squadron Officer School, Air Command and Staff College, Air War College, and the Joint and Combined Warfighting School.



CDR Brian Rivera, USNR

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Major Toivanen is a staff officer in the J-5 Plans and Policy Division of the Finnish Defense Command in Helsinki, Finland, responsible for developing operational plans for the Finnish Defense Forces. He was commissioned through the Finnish National Defense College in June 1999. Major Toivanen is a tank officer who has served as a tank company and mechanized task force executive officer and as head of the Armored Reserve Officer School Course in the Armored Brigade, previously serving as director of the Operations Division Intelligence Center, Army Western Command Headquarters. He is a graduate of the Finnish National Defense College; Senior Staff Officer Course, Finnish National Defense University; General Staff Officer Course, Finnish National Defense University; and the Joint and Combined Warfighting School, Norfolk, Virginia. A former complementary student in the Department of Political Science, University of Tampere, Major Toivanen has also completed the Company Commander (Mechanized) Course, Battalion Commander (Mechanized) Course, and Nordic United Nations Military Observer Course

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The Air Force and Diversity

The Awkward Embrace

Col Suzanne M. Streeter, USAF*

We don't just celebrate diversity. . . . We embrace it!

—Gen Mark A. Welsh
Chief of Staff, US Air Force



The Air Force is pursuing diversity as a mission imperative, recognizing that individuals who think alike might not resolve future complex problem sets. These challenges range from unrav-

*The author profusely thanks Dr. Kimberly Hudson; Ms. Kimberly Streeter; Col Jill Singleton; COL Gene Kamena, USA, retired; Lt Col John Yourse; and Dr. Elizabeth Woodworth for their reviews, edits, and frank discussions on this topic. Thanks also to Ms. Kimberly Streeter for her inspiration on the title.

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eling an intelligence problem at the tactical level, through developing a campaign plan against a near-peer competitor at the operational level, to creating policies at the strategic level. Recent efforts have attempted to integrate diversity measures into Air Force culture, including Air Force instructions to codify "diversity [as] a military necessity."[1] Most Airmen, however, are more likely to view "diversity" as another top-down initiative accompanied by computer-based training, checklists, and rules-based compliance rather than recognizing it as a game changer for the Air Force. Even those who discern that diversity is important for the mission are often unable to articulate why this is so. The few who realize its importance or recognize groupthink in their inner circle often do so late in their careers.[2]

Discordance exists between Air Force intentions vis-à-vis diversity and any effective programs and policies to retain and develop a diverse cadre of senior leadership. Issues lie ahead for the service, from retaining key demographic populations to inculcating diversity's importance to mission success. This article addresses such a key demographic—active duty women officers—as an exemplar of the Air Force's retention challenges with diverse groups. Nevertheless, the data reflects that many of the conclusions are equally valid or comparable for other minority groups. Even though the service has initiated formal diversity efforts, recommended policy and development programs may help develop and retain competent officers across the board. Ultimately, building a diverse Air Force leadership team—including retention of its female officers—must be a persistent leadership effort.

The Air Force's Diversity Challenge

Groupthink is the worst thing you can have when you have a problem. . . . If there are all male Caucasians sitting around the table, you have groupthink.

—Gen Philip M. Breedlove, USAF

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The Air Force proudly touts its diversity numbers, including the fact that 18.9 percent of the overall active duty force consists of women and that about 27 percent of its members derive from minority populations.[3] However, its long-term retention of minorities remains problematic; retaining female junior officers is emblematic of this systemic issue (see figs. 1–4). As of 2008, the Air Force's retention rate for women officers was about 50 percent around the seven-year mark, whereas the men met this milestone at about the 12-year mark; after 12 years of service, women's attrition rate was 70 percent (fig. 1).[4] Male officers do not reach this level of attrition until the 21-year mark. Female line-officer O-6s are conspicuously small in number (figs. 2 and 3) (line officers are the backbone of the Air Force's cadre of senior leadership as group and wing commanders, center directors, and general officers). The numbers are not that much better when combined with the non-line-officers (fig. 4). Finally, as of 2008, 85 percent of all general officers were white males (fig. 2).[5] These diversity imbalances in terms of gender and minorities at the senior leadership level have implications for the Air Force's long-term operational and overarching organizational success, as discussed later.

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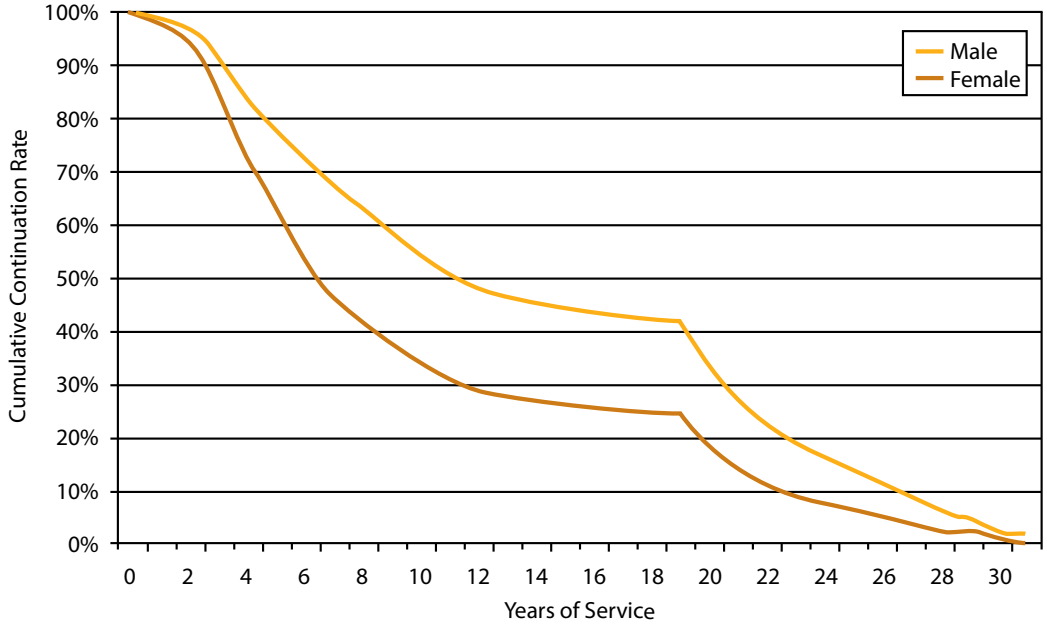


Figure 1. Attrition of Air Force officers. (Reprinted from Military Leadership Diversity Commission, *Officer Retention Rates across the Services by Gender and Race/Ethnicity*, Issue Paper no. 24 [Arlington, VA: Military Leadership Diversity Commission, March 2010], 4, http://www.hsdl.org/?view&did=716147.)

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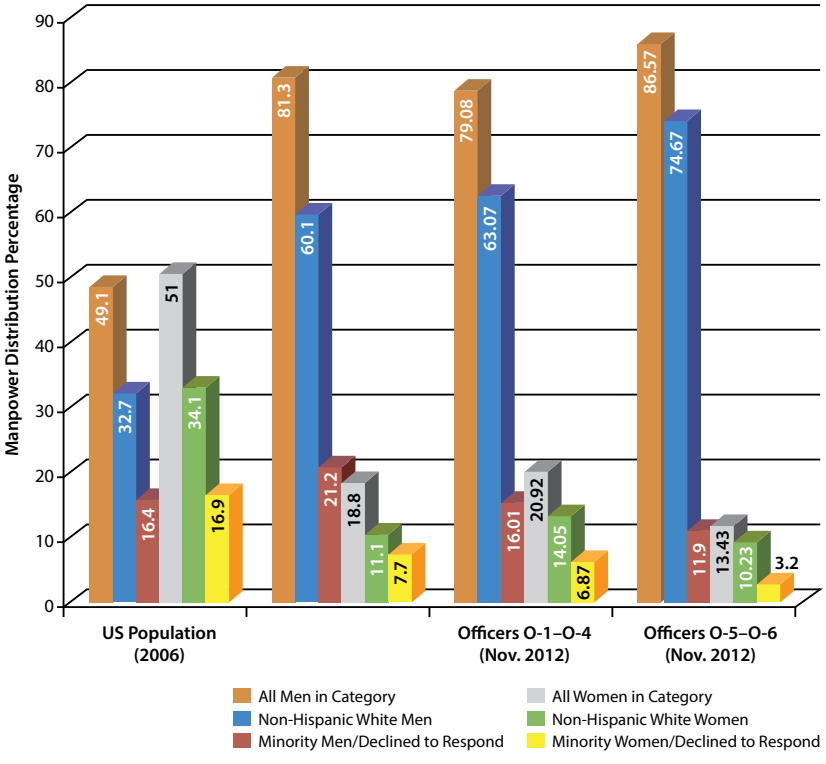


Figure 2. Gender and minority status distribution versus 85 percent of Air Force general officers as non-Hispanic white men. (Adapted from US Census Bureau, "Women and Men Population in the United States: 2006," accessed 10 December 2012, http://www.census.gov/population/www/socdemo/men_women_2006.html; and the author's compilation of data from the Air Force Personnel Center [AFPC] Interactive Demographic Analysis System [IDEAS] application, November 2012.)

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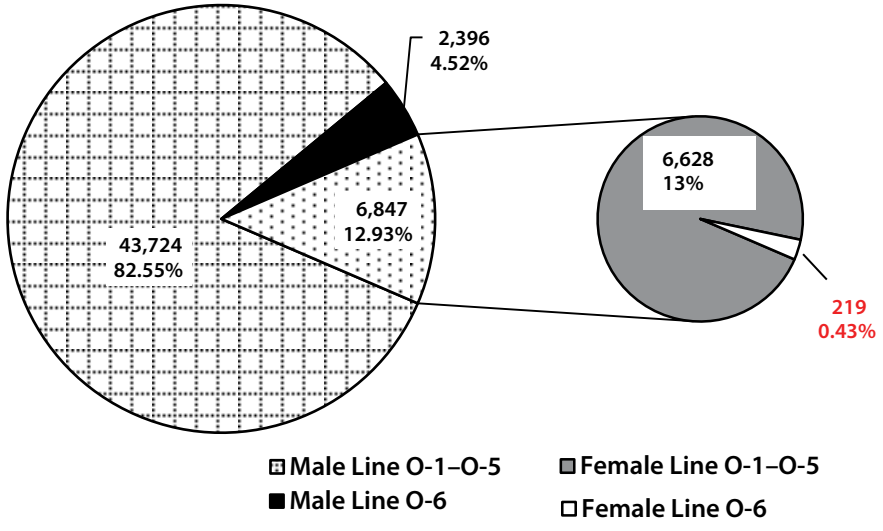


Figure 3. Line officers by gender (November 2012). (From the author's compilation of data from the AFPC IDEAS application, November 2012, end-of-month data extracted 11 December 2012.)

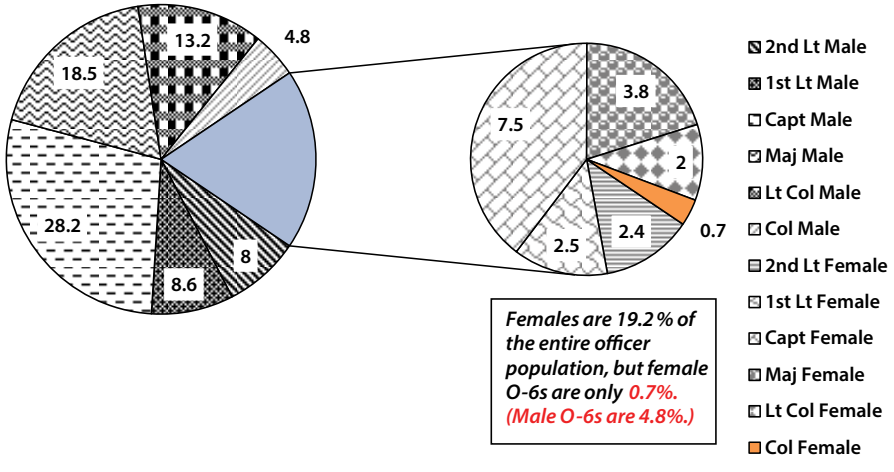


Figure 4. Percentage of the entire officer population (line/nonline) by rank and gender (September 2011 data). (Adapted from "The Air Force in Facts and Figures: 2012 Almanac," *Air Force Magazine* 95, no. 5 [May 2012]: 40, http://www.airforce-magazine.com/MagazineArchive/Magazine%20Documents/2012/May%202012/0512facts_figs.pdf.)

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Diversity: Meaning and Importance

The Air Force has designated diversity as an institutional competency; in other words, it is "expected of all Airmen, throughout their careers, and will be . . . needed to operate successfully in the constantly changing environment in which they function."[6] This particular institutional competency is defined as "a composite of . . . personal life experiences, geographic background, socioeconomic background, cultural knowledge, educational background, work background, language abilities, physical abilities, philosophical/spiritual perspectives, age, race, ethnicity, and gender."[7] In July 2012, the Air Force acknowledged that "diversity is a leadership issue" and that leaders should develop "Airmen with different backgrounds and perspectives so [that] they continue to grow and thrive in the Air Force" because diversity "enhances mission readiness and is a national security imperative."[8] In July 2011, Gen Norton Schwartz, former chief of staff of the Air Force, asserted that "diversity should not be an end unto itself, but rather one of the means toward our broader desired state of enhanced effectiveness as an Air Force."[9] In spite of these strategic words, the service has not presented a clear case for how diversity improves mission readiness and national security, nor has it addressed how those at the operational and tactical levels should leverage diversity to enhance their mission success. Diversity is important to mission readiness and national security in terms of demographically representative leadership, enhanced civil-military relations with a diverse civil society, and the leveraging of diversity as a demographic mission necessity.

Representative Leadership

The Military Leadership Diversity Commission found that "officers were generally less demographically diverse than both the enlisted troops they led and the civilian population they served."[10] This situation could lead to "invisible privilege"—a condition in which a dominant group cannot comprehend those who do not fit the "norm" of that culture. A relatively homogeneous senior leadership cadre can

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become prone to "blind spots" in their dealings with the diverse enlisted corps and relatively diverse junior officer corps—not fully understanding what will resonate with these populations.[11] For example, current efforts to develop retention policies for women that emphasize monetary carrots do not necessarily reflect measures that will entice them to stay. In fact, in a 2002 survey, "only 4 percent of the women said pay and allowances were a critical factor in their decision to separate from the active duty Air Force"; other reasons honed in on family and leadership issues.[12] The military is one of the few US workplaces where women receive the same compensation as their male counterparts for doing identical jobs.[13] This equal-pay factor might not cross the minds of senior leaders who focus primarily on fiscally oriented retention efforts.[14]

Civil-Military Relations

Relative homogeneity in the senior officer corps also has implications for civil-military relations with respect to political leadership and the broader civilian society. As former House Armed Services Committee chairman Ike Skelton (D-MO) warned, "Those who protect us are psychologically divorced from those who are being protected."[15] Throughout history, tension has existed between military and civilian leadership. Increasing divergence in the attitudes of the Air Force and political leadership is foreseeable if the service's senior leadership cadre stays mostly homogeneous (given the continuation of a reduced presence of lawmakers who are military veterans). This trend has ramifications not only for garnering support for Air Force program requirements within Congress but also for resonating with the general public when the Air Force articulates its raison d'être.

Diversity and Military Necessity

Diverse teams are better than homogeneous ones at solving complex problem sets and thus can lead to mission success.[16] Indeed, cognitive diversity—thinking differently—has enabled "diverse groups of prob-

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lem solvers . . . [to have] consistently outperformed groups of the best and brightest."[17] Several studies of the civilian workforce suggest that gender diversity at the senior levels helps companies during a recession. One 2012 report that studied 2,360 worldwide companies from 2005 to 2011 demonstrated that "large-cap stock" companies (those making $10 billion annually) with at least one woman on their boards "outperformed those without women board members by 26%." It attributed this success to wide-ranging characteristics from "better mix of leadership skills" to "risk aversion," especially in a volatile market.[18] The benefits or success of gender diversity can be undermined by institutional biases or poorly implemented diversity programs.[19]

The military has no wide-range studies that examine whether diverse teams resolve complex problem sets better than nondiverse teams.[20] However, by concentrating on one segment of diversity—gender—one could make the case that women are increasingly necessary to conduct military missions. For example, male military personnel could not interact with Afghan women without violating cultural taboos. Marine Corps female engagement teams and special forces cultural support teams established in response to this matter produced unexpected benefits and valuable intelligence, including expanded impact since women "have considerable influence on their husbands, children and their community as a whole."[21] Gen Martin Dempsey, chairman of the Joint Chiefs of Staff, recognized this fact in January 2013 when he pushed for the lifting of the women's combat ban, assessing that "ultimately, we're acting to strengthen the joint force."[22] Not only have women been increasingly integrated in operations downrange but also a need exists for them to fill positions since fewer young people are available to meet military requirements. Specifically, only 15 percent of the US "youth population . . . is [eligible and] available to serve in the military."[23]

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Moving toward Leadership Diversity

In her book *The Loudest Duck*, Laura Liswood asserts that "we need to get beyond the bricks and mortar of diversity as we know it—the committees, the employee networks, and the trainings. . . . These are all necessary, but not sufficient." She astutely observes that "diverse organizations require more sophisticated leadership . . . to reap the benefits of what true diversity can provide" and describes most corporations' approach to diversity as one of "Noah's Ark," whereby accession is the principal means of measuring diversity's success. However, there are often no effective programs to retain these minorities; even designed training can become counterproductive and the "unconscious handling of diversity can lead to diverse groups leaving."[24] As demonstrated below, this is the case for the Air Force as well.

The Air Force has directed much of its effort on gaining diversity via accession. In the case of gender diversity, female officer accession rates have averaged 24 percent (fiscal years 1997–2011).[25] However, the average percentage of females in the overall officer corps over the same time frame remained at 17.83 percent.[26] Disparities between accession and overall officer corps percentages for other minorities also exist. Given these facts, the article examines the Air Force's diversity efforts beyond accession, including three of the five priorities of the 2013 *United States Air Force Diversity Strategic Roadmap* that address the development and retention of a diverse force: "institutionalize diversity as necessary to mission success"; "develop a high-quality, talented and diverse total force (active duty, Guard, Reserve, and civilians)"; and "retain a high-quality, talented and diverse total force."[27] The planned actions to execute these goals have not gone far enough to ensure that Airmen understand how and why diversity is a critical part of solving complex problem sets.

The first priority is to "institutionalize diversity as necessary to mission success"—a multiyear and complex effort requiring persistent leadership efforts to communicate basic awareness (fig. 5). The next steps of influencing attitudes and changing beliefs—thereby evolving

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Air Force culture—will call for even more dedicated attention and time. Efforts should include reviewing and changing policies to ensure the Air Force does not run "the risk of perpetuating the idea that organization members must always adjust to the organization, rather than the organization at non-mission-essential times adjusting to the diverse needs of its members."[28]

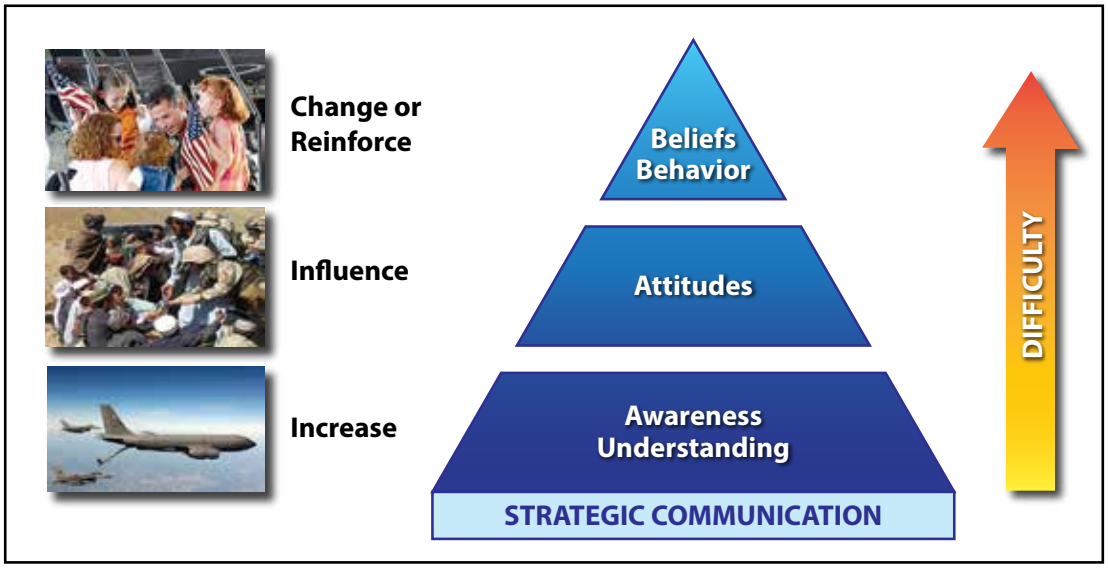


Figure 5. Desired effects of strategic communication. (Reprinted from USAF Public Affairs Center of Excellence, 2012.)

Current goals and actions mostly deal with Airmen feeling included instead of institutionalizing why and how diversity is necessary to mission success.[29] These actions include creating the Air Force Diversity Committee, major command–level diversity focus groups, and Air Force–wide guidance via the latest Air Force Instruction (AFI) 36-7001, *Diversity*, 20 July 2012.[30] Inclusion is important because "without an awareness of the cultural diversity of one's organization and the needs of different cultural groups, it is difficult to achieve an inclusive culture where members feel like they belong and believe they can succeed" (and stay).[31] Nevertheless, a backlash might emerge from the

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dominant population if the Air Force overemphasizes inclusion rather than diversity's importance since "framing social inequalities only in the context of the disadvantaged outgroup encourages prejudicial attitudes by privileged group members."[32] Several examples of this kind of reaction within the Air Force fall under the realm of the Equal Opportunity (EO) Office.[33] If diversity is to succeed, it must "complement, but remain separate and distinct from, Air Force Equal Opportunity compliance programs and activities," as noted by AFI 36-7001.[34] Most people regard the EO office as a resource to use when inclusion (or one might say, "tolerance") fails; therefore, relating diversity to an office associated with social ills would inhibit its evolution into a value completely embraced by the Air Force.[35]

Regarding the 2013 *Air Force Diversity Strategic Roadmap*'s second priority of "develop[ing] a high-quality, talented and diverse total force (active duty, Guard, Reserve, and civilians)," that plan has the right view of assuring the infusion of diversity and inclusion into many avenues of training and education. As mentioned previously, diversity cannot be reduced to computer-based ancillary training that involves individuals quickly clicking through to obtain their annual certificate. Headquarters Air Force Global Diversity Division is researching ways to implement a new learning framework following the 70-20-10 model created by the Center for Creative Leadership and adapted by Princeton University.[36] This model proposes that only 10 percent of students learn from "formal training," that 70 percent learn "from real life and on-the-job experiences, tasks and problem solving," and that about 20 percent learn "from feedback and from observing and working with role models."[37] Squadron Officer College's Leadership Department is implementing a 70-20-10 approach via a leadership elective that leverages Second Life, an online avatar-based program that virtually immerses students in historical leadership situations, allowing them to better grasp leadership styles.[38] Avatar-based scenarios like this one should be expanded to realistic diversity education and training insofar as no Air Force professional education offerings for officers have fully developed diversity education programs based on the 70-20-10 model.[39]

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The 2013 *Air Force Diversity Strategic Roadmap* advocates mentoring as a path to "effectively operate in a global environment."[40] The online mentoring program that the service has had since 2009 could be a significant complementary tool because it allows mentors to see their protégés' official personnel records but presupposes that mentors have access to the Air Force Portal and that protégés are comfortable asking a senior officer to serve as a mentor.[41] A 2011 report by Women in International Security observes a "direct correlation between mentorship and professional advancement" but indicates that most government agencies "do not devote enough resources toward ensuring that existing programs are effective."[42] Instead, the Air Force could consider something like the OfficerWomen eMentor Program, which develops female officers and veterans.[43] In this program, a female officer can seek out a specific mentor or join a forum to discuss such issues as dual-military couples, efficiently regaining flight qualifications after giving birth, lactation in the workplace, or general career advice.[44] OfficerWomen eMentor has produced measurable results with a sister service. The Navy contracted with AcademyWomen, the program's sponsor, for a three-year pilot eMentor program for all uniformed female Sailors (officers and enlisted). Eighty-two percent of survey participants who reached a retention decision while in the program elected to remain in uniform, and 67 percent of these retained members reported that program participation "positively impacted their decision" to stay in the service.[45] This latter group represented 45 enlisted and 15 female officers in the program who elected to stay, translating to an estimated savings of $4.35 million to the Navy.[46]

Informal mentoring is the more traditional route, whether at work or at events like the "Women in the Air Force" Symposium mentioned in the *Air Force Diversity Strategic Roadmap* of 2010.[47] Low-cost mentoring opportunities include women-specific quarterly lunches or webinars with senior Air Force women leaders; webinars are already an avenue for certain development teams to convey data to their career fields, so the foundation is already in place. Finally, the Air Force could include training for senior officers who mentor junior officers of different

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races and genders. This training would not only address various approaches for interacting with and developing different personalities, genders, orientations, and cultures but also examine concerns that "those in the dominant group often fear that they will have to be politically correct, avoid giving critical feedback . . . [and] accept compromised performance."[48]

Regarding the third relevant priority of "retain[ing] a high-quality, talented and diverse total force," the service has taken concrete steps since the inaugural 2010 *Air Force Diversity Strategic Roadmap* to realize this goal.[49] Nevertheless, efforts to "achieve an inclusive environment that provides the total force with the opportunity to realize their full potential" should extend beyond surveys and tracking of quantitative performance measures.[50] It should also expand the Air Force culture to guarantee a well-rounded, mission-competent, diverse force, including a diverse senior leader cadre. The road map still contains too few measurable goals to indicate whether the Air Force is succeeding in this endeavor.[51] Indeed, as Steven Samuels and Dena Samuels point out,

> Even with the best of intentions, it is common to make surface-level, often cosmetic, changes in the hope of alleviating the problem. . . . Since leaders do not believe there is any underlying problem in situations like these, they see no need to make any underlying changes. Thus, they may release public statements pointing to successes they have accomplished in these domains, add a statement about being an equal-opportunity employer in their recruitment advertisements, or put women and people of color into their training films.[52]

The Air Force will stagnate in its diversity efforts without an in-depth review and overhaul of personnel policies and systems. Both the following recommendations and those mentioned above in the *Air Force Diversity Strategic Roadmap* indicate ways of making this document's aspirations a reality: policy transformation and program development leading to a stronger force.

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Recommendations

Change Policy

Previous policy recommendations to mitigate issues concerning the retention of female officers include home basing, sabbatical programs, and a more flexible continuum of service (see the table below).[53] These recommendations, which remain valid, can be applied to a range of demographics, including men and women from the millennial generation, who tend to follow less linear career paths. However, the Air Force has not fully implemented these recommendations; they require action by the chief of staff of the Air Force and Congress. These programs would not only retain women but also promote key skill sets and cognitive diversity across the force.

Table. Reasons for leaving the Air Force (2002 data)

Reasons for Leaving the Air Force	*% Critical/Significant Factor*	*% Not a Factor*
Start a family	24	60
Stay home with children	27	61
Spend more time with family	41	40
Child care	8	80
Civilian jobs (more money)	12	67
Civilian jobs (more fulfilling work)	20	61
Civilian jobs (move ahead)	12	72
Civilian jobs (better cultural climate)	11	70
Geographic stability	41	42
Dissatisfied with Air Force leadership	27	42

Reprinted from Lt Col Laura A. H. DiSilverio, *Winning the Retention Wars: The Air Force, Women Officers, and the Need for Transformation*, Fairchild Paper (Maxwell AFB, AL: Air University Press, August 2003), 30.

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The first proposed solution instituted home basing as an option, defined as "assigning a military member to the same base or location for an extended period of time."[54] In August 2001, the Government Accounting Office pointed out that more time between moves led to more likelihood of retention across the board—60–64 percent for three-plus-year tours as opposed to 46 percent for two-to-three-year tours (the average was two-year tours).[55] The Air Force slashed the number of moves in 2006 to conserve funds by keeping individuals on station for an average of four years (saving about $134 million annually).[56] An unimplemented proposal included more extensive home basing for officers—up to eight to 10 years. This initiative allowed junior officers "to develop roots in a community and a support network," minimizing the disruption of frequent moves.[57] Today a viable option entails expanding the current policy regarding permanent change of station, which allows selected enlisted members to volunteer for hard-to-fill spots via the Voluntary Stabilized Base Assignment Program for five years at a time.[58] For officers, a home-basing program is easier to implement in locations like Colorado Springs, San Antonio, or Washington, DC, because of the greater number of lateral and vertical openings. This initiative could retain individuals who otherwise would separate for reasons of geographic stability as well as reduce moving costs in this era of austerity. The AFPC would have to gauge the size of the program, but it could be lottery-based to keep the numbers at a manageable level and account for mission needs.

A second recommendation included a "non-punitive break in service option as a retention tool."[59] Earlier proposed, unimplemented solutions were a "one-year paid sabbatical" and a one-to-five-year unpaid break in service; each option would allow personnel to return as valued assets to the Air Force, saving training funds in the long run.[60] The National Defense Authorization Act (NDAA) of 2009 authorized each service to "carry out pilot programs under which officers and enlisted members of the regular components of the Armed Forces . . . may be inactivated from active duty in order to meet personal or professional needs and returned to active duty."[61] Congress authorized "20 officers

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and 20 enlisted members of each Armed Force" per year, for a maximum of three years.[62] In the 2012 NDAA, Congress extended the program to the end of calendar year 2015.[63] However, the Navy has been the only Department of Defense service to take advantage of the Career Intermission Pilot Program, a once-in-a career initiative that includes full health care and a small stipend for participants.[64] The Air Force should follow the Navy's lead in establishing a career-intermission pilot program of its own. It is within the secretary of the Air Force's power to establish this program; in the long run, it would not be overly expensive to implement. The Air Force could also examine the Coast Guard's temporary separation program, activated since fiscal year 2001.[65] That service rededicated support to the program in September 2012 as a "retention tool" and an option for personnel making life-changing decisions.[66] Although the Coast Guard falls under Title 14 and as such is not bound by NDAA restrictions, the Air Force could still benchmark from some practices. If well integrated, a break in service would not prove punitive to an individual's career. There is no reason why a program participant should not attain senior officer status since his or her "outside" experience could inject even more cognitive diversity.[67]

A third recommendation includes increasing the "permeability of [the] active-reserve barrier."[68] This kind of policy change is needed more than ever. The Air Force designed the 3-1 Integration Plan to allow the three components of the Air Force to combine their personnel systems, thus allowing for a true continuum of service, but it was shelved for reasons unknown to the author.[69] The fact that the Army initiated its continuum of service program in 2012, though, shows great promise. According to the *Army Reserve 2012 Posture Statement*, the goal is to "inspire Soldiers to a lifetime of military service, which includes seamless transitions between active and Reserve statuses."[70] If the plan unfolds as intended, a Soldier could take several paths, including a mix of reserve status and active-reserve.[71] It behooves the Air Force to track the outcome of the Army program and reconsider the shelved 3-1 Integration Plan.

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Develop a Diverse Force

The Air Force should create solid development programs to inculcate diversity as a force multiplier; pursuing surface-level diversity can be counterproductive. If women and minorities are put into key positions based solely on gender or their minority status rather than on training or competence, they may be more likely to fail and either create or reinforce negative perceptions. Furthermore, these individuals would not receive the critical feedback they need to grow as leaders. Action plans should be sensitive to these factors and prepare leaders to develop their entire officer corps's core competencies so that, when chosen, everyone can step up confidently to leadership positions.

Intervention to inculcate diversity into the Air Force culture should be implemented incrementally. One approach to the 2013 *Air Force Diversity Strategic Roadmap*'s institutionalization priority involves linking diversity to mission effectiveness at every turn in the field. This reinforcement could be woven into opportunities found in mentoring, professional development sessions for officers, and wingman days. An initial focus, for example, would call for Airmen to uncover their own misperceptions or implicit biases about women officers (or minorities).[72] Free surveys are available, such as the Harvard Implicit Association Test, which measures subconscious biases via a simple online test.[73] Other activities could leverage case studies from free websites like the Stanford Graduate School of Business's "Leadership in Focus."[74] These programs could include a concerted effort to develop technical and leadership competencies in all Airmen.[75]

Conduct Surveys

The Air Force is on the right track with future survey topics, such as an upcoming one concerning women's reasons for leaving active duty.[76] However, this effort could expand to include crowdsourcing techniques. That is, instead of obtaining a snapshot of quantitative data, the Air Force could opt for a living source in which members provide reasons that women officers leave as well as possible solutions.

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Not all reasons would be actionable, but the information would widen the aperture for senior leadership to develop better retention policies.

Additional data snapshots would also prove useful, such as expanding the 2013 *Air Force Diversity Strategic Roadmap*'s performance measurement of "track[ing] the number/percentage of supervisory total force personnel who indicate . . . they are serving as a mentor" to include questions about who they are mentoring and why.[77] The survey could include a hyperlink to mentoring resources. Another method for capturing the incorporation of diversity into the culture might entail using questions on diversity as it relates to mission effectiveness in unit climate-assessment surveys since current questions dealing with interrelationships tend to emphasize EO-related issues. The Air Force should also consider publicly tracking attrition rates of stressed career fields such as intelligence or cyber. At this time, the service publishes a thorough analysis of the attrition rates of pilots, navigators, and air battle managers only in its annual analysis of rated officer retention; it is difficult to understand why individuals are leaving if the numbers are not analyzed and published.

Use Avatars

The work started by the Squadron Officer College's use of avatars could grow to introduce diversity in a way that reaches the younger generation. Imagine a simulation in which an officer role-plays a minority or a woman via an online avatar, encountering some of the implicit biases or challenges. This will not necessarily change attitudes immediately but could plant some seeds of empathy. Another option with this technology would involve developing scenarios in which players encounter realistic, complex problems that can be solved only by a diverse virtual team.[78]

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Conclusions and Areas for Future Research

This article has addressed the Air Force's recognition of diversity as a critical mission element and has expanded upon why and how divergence exists between policy and reality when it comes to the retention of women officers. First, many Air Force people do not consider diversity as a factor when they create operational teams or solve complex problems, no matter the findings of surveys regarding how Airmen recognize the importance of diversity.[79] Second, current personnel policies are not necessarily conducive to retention. The 2013 *Air Force Diversity Strategic Roadmap* recognizes this fact and has outlined actions to accommodate these values. Third, although the service has created groups to discuss diversity, programs that develop a diverse force are limited, especially in the education and mentoring fields. The Air Force should consider strategic-level tracks to close this gap in the retention of women officers—first, by pursuing policy changes at the Headquarters Air Force and congressional levels and second (and probably more time consuming and leadership intensive), by moving beyond rhetoric and a culture in which women-officer leaders are a normative part of achieving mission success.

Headquarters Air Force Global Diversity Division, charged with developing diversity policy and programs, is committed to resolving the aforementioned challenges. However, a small office of five permanent-party members is not enough to turn the tide of Air Force culture. Its personnel need assistance both from the service's senior leadership and from the field to create excitement about diversity.

Developing effective programs needs the most research and work. The objective is to move the Air Force beyond the guidance, talking points, and static websites, all of which operate via a pull versus a push methodology. Furthermore, it is not clear how the numerous speeches by senior leaders to niche audiences like the National Association for the Advancement of Colored People or Congress are translated to action. These programs should not only focus on those in the field but also reiterate the lessons at every educational opportunity,

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from accession programs to professional military education. Another area for further research, the introduction of leadership from the middle, would train a specific cadre of individuals on diversity to develop a peer cadre—much like the Air Force does now for resiliency.[80] Finally, as Samuels and Samuels recommend, "a framework is needed to help leaders become more culturally aware of other organizational members' experiences and needs . . . to highlight the manner in which the statuses of leaders might serve as blinders and even inhibitors to creating a diverse and inclusive workplace."[81]

Transforming culture is a difficult endeavor. Although the Air Force has taken great strides to initiate this change, it will require at least a generation of consistent involvement on the part of senior leadership as well as purposeful policies and programs to make diversity a true Air Force competency. The steps that the service takes in the next few years will make all the difference for the retention and development of diverse individuals. More important, however, is the goal of changing the attitude of the entire force to truly embrace diversity as a force multiplier in dealing with increasingly complex problems. ✪

Notes

1. Air Force Instruction (AFI) 1-1, Air *Force Culture*, 7 August 2012, 11, http://static.e-publishing.af.mil/production/1/af_cc/publication/afi1-1/afi1-1.pdf.

2. The 2011 report of the Military Leadership Diversity Commission (MLDC) stated that "there are potential perceptual barriers that prevent racial/ethnic minorities and women from obtaining key assignments, such as command. In particular, . . . [they] may lack sufficient knowledge about key assignment opportunities, perhaps because . . . [they] do not receive the same counseling or mentoring about key assignments as their white male counterparts." MLDC, *From Representation to Inclusion: Diversity Leadership for the 21st-Century; Final Report* (Arlington, VA: MLDC, March 2011), 68, http://diversity.defense.gov/Portals/51/Documents/Special%20Feature/MLDC_Final_Report.pdf.

3. "Air Force Personnel Demographics," Air Force Personnel Center, accessed 28 October 2012, http://www.afpc.af.mil/library/airforcepersonneldemographics.asp.

4. MLDC, *Officer Retention Rates across the Services by Gender and Race/Ethnicity*, Issue Paper no. 24 (Arlington, VA: MLDC, March 2010), 4, http://www.hsdl.rg/?view&did=716147.

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5. The MLDC's report makes this particular point via its charts. Military Leadership Diversity Commission, *From Representation to Inclusion*, 43.

6. Air Force Policy Directive 36-26, *Total Force Development*, 27 September 2011, 9, http://static.e-publishing.af.mil/production/1/af_a1/publication/afpd36-26/afpd_36-26.pdf; and Col Harry Lane, chief, Headquarters Air Force Global Diversity Division, Pentagon, to the author, e-mail, 10 October 2012.

7. "Air Force Diversity," US Air Force, accessed 25 September 2012, http://www.af.mil/Diversity.aspx.

8. Air Force Document (AFD) 120716-024, "US Air Force Key Talking Points, June 2012 Special Edition: Diversity," 16 July 2012, http://www.af.mil/Portals/1/documents/diversity/2012-diversity-talking-points.pdf.

9. Gen Norton Schwartz (remarks, 102nd NAACP Annual Convention Military Awards Dinner, 26 July 2011).

10. MLDC, *From Representation to Inclusion*, 44.

11. Within the Air Force Academy, for example, the normative population is comprised of white Christian males. Anybody who does not fit into that category is not necessarily viewed as inherently belonging to that institution and often has to go above and beyond simply to justify his or her membership. Without conscious effort or education, dominant groups simply do not realize that others have a different experience or outlook than their own. As Steven Samuels and Dena Samuels remark, "When privilege is normalized, those in dominant positions tend not to see themselves as privileged and thus run the risk of ignoring their own role in perpetuating inequalities" or inadvertently "distance themselves from their goals." Steven M. Samuels and Dena R. Samuels, "Incorporating the Concept of Privilege into Policy and Practice," in *Attitudes Aren't Free: Thinking Deeply about Diversity in the US Armed Forces*, ed. James E. Parco and David Levy (Maxwell AFB, AL: Air University Press, February 2010), 326.

12. Lt Col Laura A. H. DiSilverio, *Winning the Retention Wars: The Air Force, Women Officers, and the Need for Transformation*, Fairchild Paper (Maxwell AFB, AL: Air University Press, August 2003), 36. In 2002 Lieutenant Colonel DiSilverio conducted a survey for her Air War College research paper that included this data. She observed that "the Air Force can focus its retention efforts on decreasing the conflict between having/caring for families and fulfilling military duties rather than on making the military look attractive in comparison to civilian opportunities. The Air Force has historically been focused on the latter" (ibid.).

13. This is not to say that women are promoted at the same rate. The MLDC made clear the existence of a gap, especially in the Coast Guard and Navy, due to any number of potential reasons. The latter include performance reports that are not competitively written and assignment matching. Promotion boards are not necessarily one of the reasons because they work under very clear direction regarding what is expected. MLDC, *From Representation to Inclusion*, 76–78.

14. With the millennial generation forming the junior officer ranks, monetary reasons are not necessarily incentives to stay. A 2011 survey of 250 junior officers (mostly Marines and Army and 86 percent male) noted that 75 percent of those surveyed claimed "personnel management issues" and that 57 percent cited "the limited ability to control their own careers" as reasons for leaving the military. Though only 4 percent of them were in the Air Force, the generational tendencies are probably similar. Sayce Falk and Sasha Rogers, "Ju-

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nior Military Officer Retention: Challenges & Opportunities" (master's thesis, John F. Kennedy School of Government, March 2011), 11, 53.

15. Philip Ewing, "Defense Leaders Fear Military-Civilian 'Disconnect,'" Politico.com, 20 February 2011, http://www.politico.com/news/stories/0211/49838.html.

16. Several examples exist in the civilian world, such as computer gamers who mapped the complex molecular structure of a retrovirus enzyme that perplexed trained scientists for years. University of Washington, "Gamers Succeed Where Scientists Fail: Molecular Structure of Retrovirus Enzyme Solved, Doors Open to New AIDS Drug Design," *ScienceDaily*, 19 September 2011, http://www.sciencedaily.com/releases/2011/09/110918144955.htm.

17. Scott E. Page, *The Difference: How the Power of Diversity Creates Better Groups, Firms, Schools, and Societies* (Princeton, NJ: Princeton University Press, 2007), xxv. For this article, cognitive diversity includes identity diversity. That is, the socialization of US society (especially the military) fits firmly into the masculine quadrant of any chart made by Geert Hofstede, Gert Jan Hofstede, and Michael Minkov. In a masculine society, male and female "emotional gender roles are clearly distinct"; masculine values such as work earnings and recognition are more esteemed than values found in feminine society, such as the importance of "relationships and quality of life." Due to this typical socialization in American society, women also tend to be cognitively diverse (they think differently) due to their identity diversity. Geert Hofstede, Gert Jan Hofstede, and Michael Minkov, *Cultures and Organizations: Software of the Mind* (New York: McGraw Hill, 2010), 140–41,151–52, 155. Alluding to organizational theorist I. D. Steiner, Dr. Scott Page notes that diversity is necessary for "*conjunctive tasks*, those in which everyone's contribution is critical" (emphasis in original). He also remarks that although identity diversity does not automatically translate to success, when it is linked to cognitive diversity and issues that require diverse thought, "identity diversity produces better outcomes indirectly." One could argue that this holds especially true in the case of the military since its leaders and many junior officers are tasked to resolve complex problems that need innovative solutions. Page, *Difference*, xv, xxv–xxvi, 13.

18. Credit Suisse Research, *Gender Diversity and Corporate Performance* (Zurich: Credit Suisse, August 2012), 12, 18, 19.

19. According to Frank Dobbin and Jiwook Jung, "The fact that board diversity has no effect on profits, but a negative effect on stock price, lends support to our thesis that institutional investors may sell the stock of firms that appoint women to their boards—not because profits suffer, but because they are biased against women." Frank Dobbin and Jiwook Jung, "Corporate Board Gender Diversity and Stock Performance: The Competence Gap or Institutional Investor Bias?," *North Carolina Law Review* 89, no. 3 (March 2011): 828, http://www.wjh.harvard.edu/~dobbin/cv/articles/2011_NCLR_Dobbin_Jung.pdf. The MLDC notes that "if it is not managed effectively, diversity . . . can actually reduce capability, most frequently through the decreased communication and/or increased conflict that result when some people are (or feel) excluded." MLDC, *Decision Paper no. 6: Diversity Leadership* (Arlington, VA: MLDC, February 2011), 6.

20. This topic should be considered for future research.

21. Sgt Christopher McCullough, "Female Engagement Teams: Who They Are and Why They Do It," *Defense Video & Imagery Distribution System*, 1 August 2012, http://www.dvidshub.net/news/92477/female-engagement-teams-who-they-and-why-they-do#.UI3rBYbuhTw#ixzz2AeSqGXsr. See also "About the Cultural Support Program," US

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Army John F. Kennedy Special Warfare Center and School, accessed 4 February 2013, http://www.soc.mil/swcs/cst/about.html.

22. Cheryl Pellerin, "Dempsey: Allowing Women in Combat Strengthens Joint Force," US Department of Defense, 24 January 2013, http://www.defense.gov/news/newsarticle.aspx?id=119100.

23. US Department of Defense, *Population Representation in the Military Services: Fiscal Year 2011* (Washington, DC: Office of the Under Secretary of Defense [Personnel and Readiness], 2011), 2.

24. Laura Liswood, *The Loudest Duck: Moving beyond Diversity While Embracing Differences to Achieve Success at Work* (Hoboken, NJ: John Wiley & Sons, 2010), xix–xx, xxvii, 1–2, 4, 82.

25. This 15-year average raises the question as to why overall female accession rates have hovered at 24 percent (with many ups and downs). We need further research on expanding the Air Force message to attract more women for the health of the force.

26. Department of Defense, *Population Representation*, D-20, 23.

27. Air Force Global Diversity Division, *United States Air Force Diversity Strategic Roadmap* (Washington, DC: Air Force Global Diversity Division, AF/A1DV, 12 March 2013), 9, 14, 15, http://www.af.mil/Portals/1/documents/diversity/diversity-strategic-roadmap.pdf.

28. Samuels and Samuels, "Incorporating the Concept of Privilege," 322.

29. Air Force Global Diversity Division, *Diversity Strategic Roadmap*, 9–10.

30. Air Force Diversity Operations, *United States Air Force Diversity Strategic Roadmap: A Journey to Excellence* (Washington, DC: Air Force Diversity Operations, AF/A1DV, 19 October 2010), 5, 7, http://www.af.mil/shared/media/document/AFD-101117-010.pdf; Lane to the author, e-mail; and Lt Col John Yourse, Headquarters Air Force Global Diversity Division, Pentagon, to the author, e-mail, 5 November 2012.

31. Samuels and Samuels, "Incorporating the Concept of Privilege," 322.

32. Ibid., 327.

33. The most recent example occurred when General Welsh, the chief of staff of the Air Force, issued an edict to conduct "health and welfare" checks in December 2012 to ensure that workspaces were professional. These checks were depicted as a "witch hunt" against the fighter pilot culture. General Welsh countered vehemently, stating that certain traditions had no place in today's Air Force. Nevertheless, discussions regarding witch hunts are still alive in the blogosphere and workspaces. Gen Mark A. Welsh III, "CSAF January Letter to Airmen—Happy New Year," 2 January 2013, http://www.301fw.afrc.af.mil/news/story.asp?id=123331351.

34. AFI 36-7001, *Diversity*, 20 July 2012, 4.

35. Regarding the repeal of the "Don't Ask, Don't Tell" policy, Steven Samuels and Col Gary Packard declared in February 2012 that "our Oath of Office demands that we support our nation's laws; thus, under repeal, toleration is the minimum behavioral expectation of every service member. However, military strength is not built on toleration. Strength requires acceptance and, ultimately, respect and inclusiveness for all who volunteer to serve. We must value our colleagues for who they are and not who we want them to be." Steven M. Samuels and Col Gary A. Packard, "Repeal of DADT Makes the Military Stronger," *Air Force Times*, 6 February 2012, 24; and Dr. Steven Samuels (USAFA professor, Department of Behavioral Sciences and Leadership), interview by the author, 17 November 2012.

36. Yourse to the author, e-mail.

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37. "Learning Philosophy," Princeton University Office of Human Resources, 21 June 2011, http://www.princeton.edu/hr/learning/philosophy/. From the Center for Creative Leadership, this model is "a research-based, time-tested guideline for developing managers [that] proposes engaging them with three clusters of experience, using a 70-20-10 ratio: challenging assignments (70%), developmental relationships (20%), and coursework and training (10%). Despite the popularity of the 70-20-10 rule, most organizations are still not systematic or intentional about using a synergistic combination of assignments-relationships-coursework to groom future leaders." Meena Surie Wilson et al., *Grooming Top Leaders: Cultural Perspectives from China, India, Singapore and the United States* (Greensboro, NC: Center for Creative Leadership, September 2011), 4, http://www.ccl.org/leadership/pdf/research/GroomingTopLeaders.pdf.

38. Dr. Fil J. Arenas (associate professor, Organizational Leadership Studies, Squadron Officer College), interviews by the author, 11 October 2012 and 14 December 2012.

39. Training and education are included as key parts of the development priority mentioned in the 2013 *Air Force Diversity Strategic Roadmap*. Work remains, despite the progress made in introducing diversity at various levels of accession and professional military education (PME) programs. Training and education should go beyond these efforts and should be emphasized at every opportunity to link with mission needs. Increasing awareness and influencing attitudes vis-à-vis diversity starts with officer accession programs. Solid efforts have begun at the Jeanne M. Holm Center for Officer Accessions and Citizen Development, which oversees all officer accession programs with the exception of those at the United States Air Force Academy (USAFA). The Holm Center introduces the diversity concept to its cadets and officer trainees, specifically via a two-hour lesson entitled "Managing Diversity," which utilizes team-building exercises to cover the elements and challenges of leading a diverse force. The USAFA has been most holistic and dedicated in its approach to diversity. Though the academy's focus remains on accessing a more diverse force, it has recognized the need to develop solid action plans not only to diversify its teaching cadre but also to train it, expand opportunities for retention, and put resources behind its efforts. Of the three main Air Force officer PME programs, the one geared toward junior officers (Squadron Officer School) has the most developed program to comply with the Air Staff's direction. A 50-minute in-class course introduces the Air Force's emphasis on diversity, and a 90-minute team-building exercise touches on diversity as a consideration for building a team. The Air Command and Staff College, geared toward majors, has some diversity elements in its curricula, including an elective historical survey of women in the military; however, only 12 of 485 students were enrolled in this particular course. At this time, the Air War College does not have any topics on diversity in its curricula. Nevertheless, the Leadership Department is looking into ways to interweave diversity into its Joint Strategic Leadership course as well as its 360 leadership survey for Annual Year 2014's class; this effort would include administrating the Harvard Implicit Bias test. See Air Force Global Diversity Division, *Air Force Diversity Strategic Roadmap* (2013), 14; Dr. Charles Nath III (director of curriculum, Holm Center), interview by the author, 19 October 2012; *USAFA Diversity Plan* (Colorado Springs, CO: USAFA Diversity Office, June 2009), 2–3, 14, http://www.usafa.edu/superintendent/diversityoffice/links/AFD-110316-012.pdf; Arenas, interview, 11 October 2012; Dr. Mary N. Hampton (associate dean for academics, Air Command and Staff College / DEA), interview by the author, 1 November 2012; and COL Gene Kamena, USAF, retired (former deputy department

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chair, Air War College Department of Leadership and Warfighting), interview by the author, 5 November 2012.

40. Air Force Global Diversity Division, *Air Force Diversity Strategic Roadmap* (2013), 14.

41. The mentoring programs can be found on the MyEDP, MyODP, or MyCDP, via the Air Force Portal. AFI 36-3401, *Air Force Mentoring*, 1 June 2000, took 13 years to replace; Air Force Manual 36-2643, *Air Force Mentoring Program*, was issued on 1 May 2013.

42. Jolynn Shoemaker and Jennifer Park, *Progress Report on Women in Peace & Security Careers: US Executive Branch*, WIIS Leadership Series (Washington, DC: Women in International Security, [2011]), 4, http://csis.org/files/publication/110726_WIIS_ProgressReport_ExecBranch_fnl.pdf.

43. In the interest of full disclosure, note that the author is a board member of AcademyWomen, the sponsoring vehicle. AcademyWomen also sponsors e-Mentoring leadership programs for female cadets and midshipmen, male and female veterans, and military spouses.

44. These individuals meet virtually, via telephone/e-mail/Skype or in person. At this time, the program is mostly restricted to women mentoring women with some inclusion of senior male mentors (O-4 commanders and above). "Our eMentor Programs," E-Mentor, accessed 12 November 2012, http://www.ementorprogram.org/pages/programs; and Stefanie Goebel, eMentor Leadership Program director, to the author, e-mail, 27 November 2012.

45. *NavyWomen eMentor Leadership Program: Year 3; Year End Assessment Report, 2010–2011* (Washington, DC: Department of the Navy, n.d.), 8. Data prepared by Magnolia, Inc., as a third-party evaluation of AcademyWomen services, AcademyWomen Archives.

46. When extrapolated to the entire population of program participants, the 12 individuals who stated in the survey that the program "positively impacted their decision to remain in uniform" represent 60 program participants. Retaining these 60 members would translate to a total $4.35 million return on investment (the program costs approximately $200,000) when one considers replacement costs such as recruitment and training. *NavyWomen eMentor Leadership Program*, 22, 27; and Stefanie Goebel, eMentor Leadership Program director, to the author, e-mail, 29 January 2013.

47. Air Force Diversity Operations, *Air Force Diversity Strategic Roadmap* (2010), 14.

48. Liswood, *Loudest Duck*, 27.

49. The Air Force Diversity Committee formed in December 2010. A quarterly session is cochaired by the secretary of the Air Force and the chief of the Air Force's human resources staffs to "offer advice on major diversity policy issues and long-term strategic oversight and perspectives." Lane to the author, e-mail. Further, a chief diversity officer was hired at the US Air Force Academy in early 2011, and several surveys have been conducted or planned, including an Air Force Personnel Center (AFPC) Career Decision Survey in November 2011 to better understand why individuals leave/remain in the Air Force (results are pending) and a planned joint Air Force Public Affairs and AFPC survey to examine the specific issue of retaining women. Finally, in 2012 official guidance in the form of AFI 36-7001, *Diversity*, and AFI 1-1, *Air Force Culture*, was issued in summer 2012. Lane to the author, e-mail.

50. Air Force Global Diversity Division, *Air Force Diversity Strategic Roadmap* (2013), 15.

51. Air Force leaders should remain vigilant to the problem set of increasing diversity because resting on one's laurels could trigger inadvertent backsliding. Yourse, interview.

52. Samuels and Samuels, "Incorporating the Concept of Privilege," 323.

53. Lieutenant Colonel DiSilverio addressed three policy recommendations, including values identified by women, in her Fairchild Paper *Winning the Retention Wars*.

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54. Ibid., 42.

55. US General Accounting Office, *Military Personnel: Longer Time between Moves Related to Higher Satisfaction and Retention*, GAO 01-841 (Washington, DC: US General Accounting Office, August 2001), 2, 17, http://www.gao.gov/new.items/d01841.pdf.

56. Erik Holmes, "Slowing PCS—Fewer Moves Will Save Millions, Boost Unit Efficiency, Leaders Say," *Air Force Times*, 23 October 2006.

57. DiSilverio, *Winning the Retention Wars*, 43. According to DiSilverio, "Of 3,795 officers completing a 1999 AFPC survey about home basing, 83 percent overwhelmingly liked the concept. The majority of personnel (76 percent of officers) would want to remain at a home-base location for 5–12 years" (ibid.).

58. AFI 36-2110, *Assignments*, 22 September 2009, 343.

59. DiSilverio, *Winning the Retention Wars*, 45.

60. Ibid., 46.

61. *Duncan Hunter National Defense Authorization Act for Fiscal Year 2009*, Public Law 110-417, 110th Cong., 2nd sess., 14 October 2008, sec. 533(a)(1).

62. Ibid., sec. 533(c).

63. *National Defense Authorization Act for Fiscal Year 2012*, Public Law 112–81, 112th Cong., 1st sess., 31 December 2011, sec. 531.

64. Specifically, the Navy indicated that "during the period of inactive duty in the IRR [Individual Ready Reserve], the member is provided full active duty TRICARE health benefits for themselves [*sic*] and their dependents, a monthly stipend of 2 times 1/30th of their basic pay, and a one-time move to a CONUS [continental United States] location of their choice for the duration of their participation in the pilot program. All program participants will return to active duty at the end of the period prescribed and will incur a two-month for every one-month of program participation obligated service (OBLISERVE) in addition to any existing OBLISERVE owed to the Navy." NAVADMIN 089/12, "Career Intermission Pilot Program Extension," 16 March 2012, http://www.public.navy.mil/bupers-npc/reference/messages/Documents/NAVADMINS/NAV2012/NAV12089.txt.

65. The Coast Guard program is open to men and women, officers and enlisted. Individuals can leave twice during their career for 24 months at a time without pay. These individuals choose either to affiliate with the Reserve or not affiliate, and returning to duty is a rather straightforward process. Initially a once-in-a-career opportunity, it was modified in 2009 to become available twice in a career. ALCOAST 299/09, "Update to Temporary Separation and Care of Newborn Children Policy," 19 May 2009, http://www.uscg.mil/announcements/ALCOAST/alcoast299-09.txt; and US Coast Guard, Commandant Instruction M1000.4, *Military Separations*, September 2011, 1-177–1-179.

66. About 407 Coast Guard officers (7.4 percent of the force) separate each year. Of these, about 125 are eligible for temporary separation (30.7 percent), and 59 of them (47.2 percent) took part. Neither the return rates for this program (about 17 percent of approximately 44 officer participants) nor the promotion rates have been high thus far, but the Coast Guard remains dedicated since even a small return rate offers a way to retain quality individuals. TempSepStats Excel Spreadsheet, LCDR Micah Acree, US Coast Guard Workforce Forecasting and Analysis (CG-12A) Officer Team, Washington, DC, to the author, e-mails, 23 and 25 October 2012.

67. Yourse, interview.

68. DiSilverio, *Winning the Retention Wars*, 49.

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69. Michael Donley, secretary of the Air Force, "Rebalancing the Total Force: Leveraging Reserve Strengths for Changing Global Realities" (remarks at the 2011 AFRC Senior Leaders Conference, Washington, DC, 16 May 2011), http://european-security.com/n_index.php?id=6082.

70. US House and Senate, *The United States Army Reserve 2012 Posture Statement: An Enduring Operational Army Reserve; Providing Indispensable Capabilities to the Total Force*, 112th Cong., 2nd sess., March 2012, ii.

71. Ibid., 13.

72. Unconscious bias or "mind bugs" may influence the judgment of even the most well-intentioned officers. As psychologist Roger Shepard observes, "The intellect is completely powerless" when it comes to the fact that "unconscious judgments, may often be in error" in dealing with diversity. Corydon Ireland, "Mahzarin Banaji Looks at Biology of Bias," *Harvard Gazette*, 11 October 2007, http://news.harvard.edu/gazette/story/2007/10/mahzarin-banaji-looks-at-biology-of-bias/.

73. "Project Implicit," Harvard University, accessed 6 October 2012, https://implicit.harvard.edu/implicit/.

74. "Bringing Leadership Lessons to the Classroom . . . and the Boardroom," Stanford Graduate School of Business, accessed 6 October 2012, http://www.gsb.stanford.edu/cldr/teaching/leadershipinfocus.html.

75. Part of developing competency is ensuring that leaders are gender-neutral when it comes to selecting individuals for certain positions. One finds a powerful example of this principle enjoying success in the civilian world. For several decades now, orchestra audition panels have gone to great lengths to overcome gender bias. Panels considering future players will do so without initially seeing the candidates. They will go to such lengths as having men escort women candidates so that the candidate sounds like a man walking. Having leveled the playing field, the panel focuses solely on the quality of the music. According to the study, "Estimates based on the roster sample indicate that blind auditions may account for 25 percent of the increase in the percentage of orchestra musicians who are female." Claudia Goldin and Cecilia Rouse, "Orchestrating Impartiality: The Impact of 'Blind' Auditions on Female Musicians," *American Economic Review* 90, no. 4 (September 2000): 715–41.

76. Lane to author, e-mail.

77. Air Force Global Diversity Division, *Air Force Diversity Strategic Roadmap* (2013), 14.

78. Arenas, interview, 11 October 2012.

79. The "January 2012 Internal Communication Assessment Group Diversity Survey of Airmen [revealed that]: 86% believe the Air Force is doing a good/excellent job creating diversity throughout the Total Force; 75% agree that it is important for the Air Force to attract, recruit, develop and retain a diverse workforce; 61% think Air Force senior leaders are committed to improving diversity." The surveys do not demonstrate how the questions were framed, but more telling of the author's personal experience are the following statistics: "[Sixty-one percent] have not read or heard diversity initiatives discussed by senior leaders; 40% understand the Air Force definition of diversity." AFD 120716-024, "US Air Force Key Talking Points."

80. Many thanks to Kimberly Streeter for this idea.

81. Samuels and Samuels, "Incorporating the Concept of Privilege," 323.

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Colonel Streeter (USAFA; MA, Middlebury College; MA, Naval Postgraduate School; MA, Air University) is currently assigned to the US Cyber Command Joint Intelligence Operations Center as the division chief of Intelligence Plans and Exercises. This division serves as the driving force behind intelligence planning support to deliberate and real-world contingency planning of cyber operations. Colonel Streeter is a master intelligence officer with 18 years of operational intelligence experience at all levels of the Air Force, including staff experience at Headquarters Air Force. She was most recently a student at the Air War College. Previously, she was deputy commander of the 548th Intelligence, Surveillance, and Reconnaissance Group, Beale AFB, California, which included 1,200 Airmen and civilian personnel engaged in the rapid processing, analysis, fusion, and reporting of intelligence information collected by U-2, RQ-4, MC-12, MQ-1, and MQ-9 reconnaissance aircraft supporting tactical military forces, regional commanders, and national priorities worldwide. She has also been a director of operations and squadron commander. Deployments include translator for Operation Decisive Endeavor, officer in charge of the Cryptologic Services Group at the combined air and space operations center, and officer in charge of setting up the Air Force's first in-country expeditionary intelligence-exploitation squadron in support of Operation Enduring Freedom.

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The Comanche and the Albatross

About Our Neck Was Hung

Col Michael W. Pietrucha, USAF

F-35. We have no other choice.

—Gen Mark A. Welsh III
Chief of Staff, US Air Force



The Air Force intended eventually to replace much of the post-Vietnam fighter fleet with the F-35A. This stealthy aircraft possessed advanced technology and was no more expensive than the aircraft it was designed to supplant. The Air Force sought to buy 1,763 F-35As—the number required to replace every F-16, A-10, and F-117 in service in 2001. Envisioned after the resounding success of the

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F-117 in the Gulf War, the program placed high emphasis on the utility of low radar observability. Designed to provide combat aircraft for the Air Force, Navy, and Marine Corps as well as a host of allies worldwide, the Joint Strike Fighter (JSF) would usher in a revolutionary improvement in American airpower.

Instead, the program has been troubled, characterized by the Pentagon's acquisition chief as "acquisition malpractice," and finds itself well behind schedule and over budget.[1] Rather than an affordable, capable fighter aircraft, operational in large numbers by 2015, the F-35 continues to arrive late and cost more than anticipated.[2] Program delays, unmet performance requirements, and spiraling costs have recently run full tilt into an austere budgetary environment dictated by the Budget Control Act of 2011.[3] More significantly, the program emerged from decades of North Atlantic Treaty Organization (NATO)–centric Cold War experience; furthermore, the Air Force did not envision it either for the Pacific theater or for an adversary with China's air defense capabilities. In this light and despite more than a decade of development invested in the program, budgetary realities should serve as an impetus to reexamine the Air Force's participation in the F-35 program and the future of the fighter force.

We have choices—if we are willing to entertain them. The Army's treatment of the Comanche program offers an example of a bold move in aviation that allowed that service to both modernize and recapitalize. This example shows a potential way forward and should remind Airmen that the Air Force is essential for national security, that no individual aircraft has ever proven indispensable to national security, and that we should be wary of risking national airpower capabilities in our pursuit of a single type of platform. This article presents an alternative future structure designed to preserve the combat air forces (CAF) as an agile and combat-ready multipurpose force, restoring the "high-low" mix that the Air Force essentially abandoned in the 1990s.[4] It offers a future force, called here the "alternate force"—one more broadly capable and affordable than the force that the current path will produce.

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The Comanche

At the heart of any JSF discussion lies the belief that the program cannot be cancelled—that any attempt is doomed to failure because of the spread of the program structure in the United States and internationally. Despite any great unwillingness to end the program, doing so is certainly not impossible. Clearly, the Army's experience with the Comanche is instructive.

In 2004 the RAH-66 Comanche had been in development for 22 years, most of that time as a major defense acquisition program. Two prototypes had been built, and the program was healthy. Yet, the Army terminated it due to questionable utility, expected unaffordability, and the presence of a credible alternative. Acting secretary of the Army Les Brownlee, along with Gen Peter Schoomaker, the Army chief of staff, announced the termination, explaining that

> we've examined closely our resourcing plans for aviation and concluded that some of the capabilities those funds would provide are no longer consistent with the changed operational environment. Therefore, General Schoomaker and I have recommended that the Comanche helicopter program be terminated and those resources reallocated to restructuring and revitalizing Army aviation. With the approval of the president and the Secretary of Defense, we began briefing key members of Congress this morning.[5]

Key to the arrangement that terminated the Comanche was repurposing of the programmed money entirely into Army aviation with Joint Staff and congressional consent. Today, the average age of the Army's rotary wing fleet is less than it was in 2004, the AH-64E is poised for the production line, the Army flies remotely piloted vehicles that it did not possess eight years ago, and the rotary transport fleet has been largely recapitalized—even in the Army Guard. In 2004 the Army courageously euthanized the program, and, despite fighting two wars in that time frame, its aviation arm benefited more than one would have expected had the Comanche continued in 2004.[6] The Army managed the termination so astutely that it became a nonevent,

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both politically and financially. Redirected into other Army aviation programs, the money largely went to the same contractors in the same districts that would have received the Comanche funding.

Admittedly, the parallels go only so far. The JSF program, which is much larger and currently produces aircraft, involves a number of international partners who have invested in the program at varying levels. However, the rationale for terminating the F-35 programming to allow a redesign of the tactical air (TACAIR) enterprise remains the same: s*ome of the capabilities those funds would provide are no longer consistent with the changed operational environment, and it does not serve either the United States or our partner nations to continue on the current path*.

The Challenges

Even if funding were unlimited, reasons might still exist for terminating the F-35. Specifically, its performance has not met initial requirements, its payload is low, its range is short, and espionage efforts by the People's Republic of China (PRC) may have compromised the aircraft long in advance of its introduction.[7] Our assumptions about the operational environment, made more than a decade ago, do not match current reality with respect to either the threat (worse) or the potential adversaries (more diverse). The mission of the aircraft—to penetrate the most advanced air defenses and drop precision-guided munitions on critical targets of a peer adversary—remains questionable at best, especially if that peer is located in the Indo-Asia-Pacific region, where basing is limited, ranges are long, and potential adversaries have logistical advantages. Despite official pronouncements in support of the F-35 program, the Air Force must remember that its contribution to the nation is fundamentally more about *airpower* than about any particular aircraft. In a resource-constrained environment, commitment to the F-35 must be considered secondary in importance to the joint requirement for TACAIR.

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A number of related challenges are associated with the future of the CAF. These problems are not limited to insufficient training resources; rather, they derive from a force-structure shrinkage that has continued for two decades. Financial imperatives that led to a force-structure drawdown in the first place have not gone away, leaving us with a number of critical hurdles to clear before the end of the decade:

1. The Air Force's capability for suppression of enemy air defenses (SEAD) has dwindled in the almost 20 years since retirement of the EF-111A and F-4G. The Air Force has not replaced either the aircraft or, critically, the trained aircrews (unlike the Navy, which has a growing force of EA-18G Growlers). The F-22, F-35, and B-2 are shorn of support capabilities that might enhance their effectiveness and must rely on Navy support.
2. The Air Force possesses no affordable, deployable light attack / armed reconnaissance capability that it can use for irregular warfare. Particularly limiting is the fact that, with the sole exception of the A-10, the service has no capability to operate fighter/attack aircraft from airfields that are too short or rough to handle fast jets. This liability has become a problem of global reach in that the Air Force cannot provide persistent air cover with TACAIR to large portions of the globe, even with tanker support. Without a carrier air wing available to provide short-term coverage, there are few remaining options for CAF support to far-flung forces. Had the Soviets not built large airfields in both Iraq and Afghanistan, we might have faced this problem a decade ago.
3. Basing opportunities are limited, and the vast majority of airfields worldwide remain incapable of supporting legacy or future fighters. The Air Force is neither prepared nor equipped to operate small force packages from very austere bases by using thin logistical pipelines and relying on local support. Distributing single squadrons of easily supportable aircraft over multiple airfields could well deliver a very effective combat capability difficult to counter, particularly in South America, Africa, and the Pacific. In

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the Asia-Pacific, the ability to operate from fields 6,000 feet long more than doubles the potential basing and provides opportunities on island bases that cannot accommodate a longer strip.

4. The lack of absorbable cockpits has already drawn the Air Force's inventory of fighter aviators to a point where demand exceeds inventory and is projected to do so well past 2024. Even this date may be a product of the width of the chart and not the result of a plan to make the demand and inventory lines congruent again. Without a rapid infusion of hardware and an increase in the pilot-training pipeline, we will not have the fighter/attack aviators necessary to fill the squadrons and carry out all of the associated tasks, including conducting tests, training pilots, attending professional military education institutions, and filling the rated staff.[8]
5. The Air Force has no practical ability to supply combat aircraft to the air forces of partner nations that cannot afford the F-16—a deficiency that poses particular difficulties in building or rebuilding such air forces, particularly in Asia and Africa. The significant obstacle of procuring light air support aircraft for the Afghan Air Force will be further compounded by the lack of tactics manuals; established tactics, techniques, and procedures; or experienced aircrews to train Afghan pilots.
6. The Air Force has spent significant time and effort over the last 10 years improving both its own ability and that of our NATO partners with respect to close air support (CAS). Given a shrinking pool of ground attack aircraft and the increasing cost to operate them, the service already has insufficient sorties available to support CAS training for joint terminal attack controllers.
7. Regarding homeland defense, no armed platform occupies a niche between Customs and Border Patrol / Coast Guard helicopters and fast jets, posing a mismatch of capabilities any time we need to intercept slow-moving aircraft.

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8. The use of costly, aging F-15 and F-16 aircraft for air sovereignty alert (ASA) roles remains an expensive overmatch in capabilities that a modern, less expensive airframe could relieve. This challenge is particularly acute for the Air National Guard, which has faced continuous loss of frontline combat capability as legacy fighters and A-10s are removed from the force.

Commitment to the F-35 makes every one of these issues worse, not only because the aircraft itself will not fill these gaps but also because the required funding effectively deprives the Air Force of the resources demanded to address them. At the heart of the disconnect lie two decades of vision that emphasizes the "all-fifth-generation" fighter force that consists solely of advanced low-observable fighter aircraft.[9] This approach, which concentrates a notional future conflict against a peer adversary, relies heavily on the assumption that a fighter force designed for the most intense conflicts is automatically suitable for any contingency. The pursuit of this vision comes at a very high opportunity cost and invites a great deal of risk, both programmatic and operational.

Evaluating the Need for a Course Change

Pursuit of the full F-35 buy of 1,763 aircraft remains the articulated Air Force strategy—a plan that inflicts significant damage on the existing TACAIR fleet. Putting aside the impending loss of the newly upgraded A-10, the service has been engaging in an unprecedented force-structure drawdown throughout the total force, reducing fighter and attack strength across the board. In 2013, 17 fighter squadrons were grounded for lack of flying hours while the Air Force simultaneously attempted to increase the production rate of the F-35.[10] The drive for large numbers of increasingly expensive F-35s has taken its toll on flying hours and upgrades for both the legacy fleet and the F-22. Hours for fighter aviators are roughly half of what they were in the Gulf War, placing the service's aircrews in the unenviable position of flying less than the Chinese and some European allies.[11]

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The "fighter redux" has severely affected the inventory of the Air National Guard and Air Force Reserve, with some fighter and attack units transitioning from the A-10/F-16 to airlift or remotely piloted aircraft and others losing their flying roles entirely.[12] Although it garners short-term savings, this approach alters the role of the Air Reserve Component (ARC) as a strategic reserve and as a second chance to "capture" active duty aviators and maintainers who are leaving the regular Air Force. The ARC should be postured to regain a broad spectrum of aviation capabilities, reequip for the ASA mission, and capitalize on existing locations in proximity to Army and Marine Corps bases and training areas. A recapitalized ARC would include the full range of capabilities from the upgraded fourth-generation fighters through the OA-X and FT-X.[13]

Even a reduced buy of F-35s is problematic because of the high cost of supporting a JSF fleet of any size, given the doubling of unit costs since 2001.[14] The test program for the aircraft remains about one-third complete, leaving the Air Force with quite limited visibility into the platform's actual costs and capabilities. At this writing, the aircraft has only recently employed its first weapons on a test range. In many respects, the F-35 is a difficult aircraft to argue against because its potential remains largely unknown and discussions tend to address what the aircraft "can" do despite the absence of operational test data that actually determines how an aircraft performs. In this context, what the aircraft "should" be able to do or "might" accomplish is treated as established fact despite the lack of either testing or verification.

The Air Force has proven consistent in the pursuit of "fifth generation" fighters as an essential war-fighting requirement. One of the key shortcomings of this presumption is that it is largely "faith-based" in two respects. Firstly, despite the history of the F-35 program, it presumes that the capabilities we expect will be delivered. Secondly, it is based on a belief that radar low observability will remain effective against future air defense threats. Notably, that presumption of stealthiness rests on shaky ground. Although true for the F-117 against Iraq's

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Kari system in 1991, stealthiness is unlikely to remain so against an adversary that has two decades to prepare for US stealth fighters, which have much higher infrared, visual, and emitter signatures than did the F-117.[15] Only eight years later, the latter aircraft proved vulnerable to a surface-to-air-missile system that had reached initial operational capability in 1959, and we should not presume that Russian and Chinese radar developers have wasted the intervening decades since the Gulf War.

The argument for the F-35 rests heavily on a threat environment that is far from global. In reality only Russia and China can pose the kind of antiaccess, area denial (A2AD) environment that justifies a massive investment in stealth. Air Force leadership is rightly considering other possible adversary capabilities of the future, but in reality only one operator of a true stealth fighter exists—and that is the US Air Force.[16] That service has remained the sole operator of stealth fighters since the late 1980s. Even a decade from now, the F-22 inventory alone will likely outnumber all other models of foreign fifth-generation fighters combined.

The Air Force has not lost a plane to a hostile aircraft since the Vietnam War. The ground-based air defense threat has advanced significantly in the past two decades, but even though some extremely capable systems are available to potential adversaries, the number of nations able to purchase and operate them is quite limited. Outside China and Russia, no massive threat from an advanced integrated air defense system exists. Moreover, China is a poor example of a threat to cite if someone is trying to justify a short-ranged fighter with limited payload flown from island bases within range of overwhelming missile attack.

These facts make the risk calculation involved with prioritizing stealth over performance, range, and weapons loadout inherently suspect—and the F-35 might well be the first modern fighter to have substantially less performance than its predecessors. Admittedly, the classified status of many of its capabilities prevents full disclosure or public debate regarding this point. However, if we prioritize radar low observability as the primary consideration at the cost of many other at-

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tributes necessary in a fighter, the stealth-based paths become stealth-limited paths. This priority may indeed sacrifice readiness, force size, magazine depth (ammunition supply), and other force structure to build and maintain a fleet of aircraft that has limited utility against the majority of TACAIR challenges worldwide, not to mention questionable capability in the A2AD environment of the Western Pacific.

A strategy based on the presumed ability to penetrate advanced air defenses is viable only if it does not prevent the pursuit of other strategies. If the force design is instead a niche capability usable only against certain adversaries under favorable conditions and only if that strategy is pursued, then we have significantly reduced our flexibility and have taken immediate airpower options off the table for the promise of a single new capability that is still more than a decade away. Pursuit of an expensive, modern, cutting-edge force has already cost us in terms of force size, structure, flying hours, and entire areas of expertise that we no longer have. In its quest of the F-22 and now the F-35, the Air Force has traded away its dedicated electronic warfare (EW) fighters, the training programs that supported them, and the EW-savvy crews who manned them, leaving fighter EW the purview of the Navy and Marine Corps. In light of the A-10's impending retirement, CAS is primed to go the same way as EW.

The Alternative

It is easy to criticize a developmental program; in fact, all advanced fighter programs endure robust criticism throughout their developmental lives. The strengths of any particular criticism are irrelevant in the absence of a genuine alternative. Unwillingness to investigate an alternative is not the same as not having one. The alternate force postulated here represents an attempt to illustrate that alternatives not only exist but also may present a more robust defense for the nation and its interests.

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The fundamental objective of this force structure construct involves making a trade-off between a TACAIR force of limited numbers and narrow depth for a larger, more broadly useful one designed to tackle all of the Air Force's institutional challenges highlighted above. It does not entirely eliminate the F-35 force, given that we already have more of them than we ever had F-117s, but it effectively terminates the Air Force's participation in the program after fiscal year (FY) 2014. The objectives of this proposal are to

- maintain a limited number of F-35As (those already purchased) as a replacement for the capabilities lost upon retirement of the F-117;
- create a modernized TACAIR fleet consisting of a high-low mix of modernized legacy fighters, light attack aircraft, and multipurpose jet trainer / attack aircraft;
- recover some "sunk cost" of the F-35 program by using advanced systems to modernize older fighters, in effect fielding fifth-generation systems in fourth-generation airframes;
- restore the Air Force's SEAD/EW fighters and crews;
- expand the service's global reach capabilities by providing deployable TACAIR assets that can operate from short, rough airstrips on a logistical shoestring;
- increase the number of absorbable cockpits to the point where the Air Force can augment the inventory of fighter/attack aviators to meet requirements;
- invest in affordable, exportable "light combat aircraft" derived from Air Education and Training Command's T-X program;
- allow the Air Guard to maintain its position as the operational reserve and "relief valve" for experienced fighter/attack aviators while recapitalizing its portion of the CAF; and
- build a TACAIR force that can meet the nation's demands for airpower capabilities even in the face of increasing fuel costs and decreasing budgets.

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This force design effectively captures sensors and systems intended for the F-35 and places them into new-build and refitted F-16s and F-15Es. To a great extent, this process is already occurring but without full funding. Such a realignment of future force structure terminates the F-35 in favor of advanced fourth-generation fighters, electing to defer stealth to a later generation. It involves a strong investment in improved fourth-generation aircraft, retains the A-10, and adds hundreds of OA-X, FT-X, and AT-X platforms.

Certain assumptions about the global context are necessary:

1. The most capable potential adversary remains the PRC with Iran and the Democratic People's Republic of Korea (DPRK) posing challenges of their own.
2. No significant change occurs in overseas permanent basing.
3. Air Force funding drops to sequester levels until at least 2024.
4. The PRC maintains its current spending levels and development of both combat aviation and theater ballistic missiles. No fundamental change occurs in governance of the PRC, Islamic Republic of Iran, or DPRK.
5. Continuous fighter presence remains a requirement in US Central Command's and/or US Africa Command's area of responsibility.
6. The existing B-2 and B-52 force is unaltered.
7. Fuel costs continue to increase.[17]

The force design reflects the reality that since Vietnam, the United States has been involved in far more irregular-style conflicts than regular ones—but that giving up a force designed to achieve coercive effects against a peer adversary amounts to an unwarranted risk. It expands upon the high-low mix model that gave us the F-16 and F-15 and builds a high-medium-low mix of TACAIR capabilities.[18]

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Force Design

The existing F-22 fleet anchors the "high" end of the TACAIR mix. One oversize F-35 wing, modeled on the 37th Tactical Fighter Wing at Tonopah Test Range, Nevada, will fill the stealth fighter gap left by the F-117. The bulk of the high end will consist of upgraded F-15C, F-15E, and F-16C/D/F aircraft. Many of the upgrades to the fourth-generation fleet will be "harvested" from the JSF program, whereby advanced subsystems from the F-35/F-22 that are ready for fielding will be retrofitted into older fighter designs. In effect, this process is already happening with the F-15E and F-15C to some extent; upgrades of sensors and EW gear should be spread as far as possible throughout the force, including the B-52, not otherwise addressed by this article. The Air Force should purchase a limited number of new aircraft, with 60 F-15Gs and 72 two-seat Block 70 F-16Fs as the baseline. Such purchases are only partially additive. The Block 70 squadrons will be an in-place upgrade of Block 40 squadrons while the F-15G Strike Weasels are added to the force to replace the long-lost F-4G/EF-111A and the critical expertise that came with them.[19] When economically feasible, existing fourth-generation airframes with significant service life remaining should be upgraded to a common standard.

The middle of the TACAIR mix will include the A-10 and combat variants of the T-X—the FT-X and AT-X. The A-10 is facing its own fatigue problems, and the introduction of the OA-X (see below) may allow the Air Force to reduce the A-10 inventory to a number that can credibly support operations on the Korean Peninsula. The service should procure the F-X, envisioned as a T-38 replacement, in three variants. The base airframe—T-X, essentially a modernized T-38 equivalent purchased off the shelf—would constitute the most numerous aircraft (400). The AT-X would take the form of an all-weather, combat-capable, multirole T-X with air-to-ground capability including guns, rockets, and precision-guided munitions. The FT-X would be a fully capable light fighter with a modern air-intercept radar and air-to-air-missile capability comparable to that of the F-16C. The FT-X is intended as a good fit for the Air

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National Guard's ASA mission and for use as an aggressor. As such it might replace the Guard's F-16s that have reached the end of their service lives. Both aircraft would also serve as relatively low-cost, dual-role, exportable fighters/trainers (similar to the F-5A/E). The low end of the manned TACAIR spectrum is occupied by the OA-X, Air Combat Command's concept of a modern turboprop light attack aircraft—intended to be additive over and above existing TACAIR numbers except when A-10 units are upgraded directly. The OA-X will assume the burden of irregular warfare and counterterrorism deployments as well as provide ASA alert on demand.[20]

The following offers a quick look at the future CAF without the JSF. In April of last year, members of Headquarters US Air Force / A8 ran a series of cost projections to 2023, using a tradespace analysis tool against the expected funding of the service's air superiority (AS) and global persistent attack (GPA) portfolios.[21] This reality-based assessment used a budget baseline that locked in spending levels expected from the Budget Control Act of 2011, with a real defense budget growth of a paltry 0.3 percent. All F-35 procurement funds from FY 2014 to FY 2023 were redirected within the AS and GPA portfolios, which do not include the MQ-9, B-52, or B-2 aircraft.[22] F-35 research, development, test, and evaluation funds are left intact for systems migration and maintenance of the aircraft already purchased although doing so will never be cost effective. The "sand charts" supporting this plan include sustainment as well as procurement costs. Table 1 reflects the recapitalized fighter/attack (plus B-1) total active inventory (TAI). The last two columns represent an increase in aircraft and cockpits compared to the FY 2013 programmed force extended (PFE) (1,763 F-35s). In some respects, this comparison is unfair. That is, the FY 2013 PFE overshoots the projected budget line (particularly beyond five years) by 10s of billions of dollars even before sequester while this alternate force stays within the sequester limits, with no gimmicks such as expected efficiency improvements or transfers from other portfolios.

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Table 1. Alternate fighter/attack aircraft, TAI 2023

Mission Design Series	*Source*	*Regular AF*	*ARC*	*Total*	*Aircraft Delta*	*Cockpit Delta*
F-22	Existing	167	20	187	0	0
F-35	Existing	56	0	56	0	0
F-15C/D	Upgraded[a]	113	116	233	-16	-16
F-15E	Upgraded[b]	218	0	218	0	0
F-15G[c]	New Build[d]	60	0	60	+ 60	+120
F-16C/D	Upgraded[e]	377	361	738	-282	-282
F-16F	New Build[f]	54	18	72	+72	+144
AT-X	New Build	38	18	56	+56	+112
A-10C	Existing	60	90	150	-133	-133
FT-X	New Build	36	58	94	+94	+188
OA-X	New Build	132	108	240	+240	+480
Total Fighter/ Attack		1,311	789	2,100	+91	+613

[a] F-15C/D upgrades included infrared search and track, active electronically scanned array radars (APG-63v3), and the Eagle passive/active warning and survivability system (EPAWSS) upgrade to EW systems.

[b] F-15E upgrades included APG-82 and EPAWSS.

[c] The F-15G (called EF-15E by Boeing) moves the EW systems from the EA-18G to the F-15E+.

[d] New-build aircraft were priced for both purchase and operation and maintenance in accordance with existing examples. F-15Gs were priced at $110 million each, with the F-16F at $70 million. The baseline for the AT-X was the Royal Air Force's Hawk T2, priced at $33 million in adjusted dollars; the FT-X was priced at $35 million. The OA-X was priced at the light attack / armed reconnaissance + 20 percent price at $12 million each.

[e] F-16C/D upgrades, which were largely applied to Block 40/42/50/52 aircraft, consist of the combat avionics programmed extension suite radar / EW upgrade plus a service-life extension.

[f] The F-16F is a Block 70 F-16 modeled after the Israel Defense Force's two-seat, medium-range F-16I Sufa.

Under this projection, the fighter/attack force in 2023 includes 2,100 TAI aircraft, 91 more than the unconstrained PFE, with a concurrent increase in cockpits because every new aircraft is a two-seater.[23] Table 1 does not account for all of the money spent; B-1Bs were reduced (table 2).

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Table 2. Alternate bomber aircraft, TAI 2013

Mission Design Series	*Source*	*Regular AF*	*ARC*	*Total*	*Aircraft Delta*	*Cockpit Delta*
B-1B	Existing	20	0	20	-18	-72

By 2023 the complete plan divests 18 B-1Bs, A-10s that have not already been rewinged, and the oldest F-16s in favor of 540 brand-new F-15Gs, F-16Fs, OA-Xs, AT-Xs, and FT-Xs. The Air Force's long-dormant EW fighters return, reducing dependence on the short-range EA-18G. Included in the reallocation are the entire GPA/AS sequester bill and munitions funding to 80 percent of desired war reserve as well as legacy modernization and upgrade. No training or range funds were raided. In the target year, production lines for the light combat aircraft (OA-X, FT-X, and AT-X) remain open, allowing for future purchases after the "bow wave" of expenditures subsides and for development of the long range strike bomber as well as the sixth-generation F-X. An alternative not only exists but also restores long-dormant capabilities and increases the size of the force.

Strategic Risk Management

The viability of the alternate force cannot be divorced from a discussion of force structure, which itself addresses expectations for twenty-first-century airpower. It is reasonable to assume that any conflict which involves the joint force also involves airpower application; consequently, we should give careful thought to what airpower brings to the fight.

Categorizing potential conflicts as "most likely" through "most threatening" and then making the case that the most threatening is of primary importance has become habitual. For the wars in Iraq and Afghanistan, the Air Force followed this approach—one that had the unfortunate effect of placing a heavy burden on legacy jet fighters that used only a fraction of their capabilities in these two wars. The ser-

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vice's preferred structure emphasizes the most threatening conflict—often the descriptor for major combat operations with the established military forces of a peer or peer-like state.

The fifth-generation fighter is held up as a hedge against the most threatening scenario, as if we must use this particular aircraft to fight a peer nation. This attitude is typical of a cultural belief that superior technology will lead to American victory and that if we lack the most technologically advanced aircraft, we cannot prevail in war. This hardware-based, strategy-independent assumption fails to consider the possibilities inherent in an approach that encompasses a broad range of airpower capabilities in favor of a very specific niche capability. It is also demonstrably false. Clearly, we had a technological edge in Vietnam, rough parity in Korea, and, arguably, technological inferiority against the Luftwaffe. Yet, the outcomes of those conflicts did not align with the associated aircraft technological advantage.

Under the approach that has prevailed since 2001, any possible conflict other than the most threatening one is a lesser-included case that a stealthy niche force can handle effectively. In effect, the F-35 in particular is presented as having broad applicability that makes it inherently well suited to any form of conflict simply because it can handle the so-called high end, when in reality the data does not support this conclusion. Using Afghanistan as an example, we simply could not have afforded to deploy or employ F-35s in the fashion that we employed F-16s and F-15Es—based on the operation and maintenance (O&M) costs or the fuel consumption, to say nothing of the decremented airframe life.[24] The use of existing fourth-generation aircraft in Iraq and Afghanistan was itself far more costly than a comparable strategy pursued with modern light attack aircraft, making the "lesser included case" path very hard on equipment, logistics, and personnel.[25]

Realistically, irregular conflicts are the most likely to occur, given that this has been the case throughout recorded Western military history.[26] Withdrawal from Iraq and eventual withdrawal from Afghanistan will not presage the end of US involvement in irregular warfare.

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America is currently involved in Mali, the Philippines, Afghanistan, Pakistan, Yemen, Jordan, Uganda, and the Horn of Africa; Libya is a fading memory; and Syria remains a possibility. A very fuzzy dividing line also exists—a conflict with China over Taiwan might not prove most threatening to the United States if it remained a conventional battle. Further, a collection of irregular challenges might very well aggregate to provide a most threatening scenario, especially if it involved the collapse of a nuclear state or loss of access to critical resources, territory, or aspects of the global commons.

Making the "lesser-included" argument particularly weak is the assumption that forces constructed for a less intense, broader challenge are inherently inferior. Capabilities such as endurance, ordnance diversity, weapons payload, maneuverability, fuel economy, range, and rough field capability are not considered worthwhile in the face of a binary classification—stealthy / not stealthy. The environment in which a conflict occurs is one of the defining aspects of any war, unquestionably having an impact on the flavor of airpower capabilities that can be brought to bear. If all environments, strategies, and adversaries are lesser-included cases of the "stealth only" option, then large numbers of F-35s would make sense—if they are affordable. However, if that is not true, then we ignore the consequences of being unable to fight proliferating and widespread "most likely" scenarios—or the obvious consequences of treating irregular warfare challenges as a lesser-included case and flying the wings off our fast-jet TACAIR, despite a decade of hard data on the effect of this approach.

The all-fifth-generation force also ignores the wide applicability and deterrence value of having a flexible force that can do more than one thing well, particularly under uncertain conditions in a rapidly developing crisis. There is always value in deploying combat aviation forward if we can accept the risk. Such risk has nothing to do with an aircraft's stealthiness but everything to do with how fast we can deploy airpower into austere conditions, with limited manpower, to conduct combat operations shorn of a fixed, preplanned basing structure. It

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would be a much easier decision to deploy OA-Xs or AT-Xs into Ukraine today, even knowing that we risked their loss on the ground, than to accomplish the same task with F-35s. If US Air Forces in Europe currently possessed light combat aircraft (OA-Xs, AT-Xs, and FT-Xs) capable of operating on a logistical shoestring from Ukrainian airfields in poor condition, then the supreme allied commander, Europe, would no doubt sleep more soundly in the face of a Russian irregular threat—which by itself was enough to secure Crimea.

The battle between the most threatening and most likely scenarios leads to an infertile discussion of false trade-offs. The force structure built solely for the most threatening scenario is fundamentally flawed because it relies on a false assumption that the A2AD challenge can be mitigated solely by fifth-generation fighters—in particular, a short-range, long-runway fleet shorn of EW/SEAD support. A force structure that discards some tailored capability for most likely conflicts may be unable to meet the needs of the nation because it relies on a faulty assumption that such a force cannot provide coercive effects against a peer and is therefore of little value.[27] Both of these scenarios ignore basic lessons in the art of war. If we have more employment options from more places, then we have more opportunities to gain leverage against an enemy. If we intentionally minimize our list of possible options, then we allow our adversaries the luxury of building and training a force designed to counter a limited US Air Force.

End State

The broad approach taken in the design of this proposed alternate force results in an increase in the number of fighter/attack squadrons and a significant increase in the number of absorbable cockpits while reducing O&M costs over the PFE.[28] It recognizes that one of the primary drivers of readiness problems is the high rotational burden on the fast-jet fleet and creates a force structure that drives the vast majority of the rotational burden to the lowest-cost aircraft with the lowest O&M and lowest fuel consumption. The approach also backs up the global-

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reach tenet with aircraft that can fight from unimproved airstrips. The capability to counter advanced air defenses is retained, but it returns to an approach proven in Vietnam and Operation Desert Storm—specialized aircraft with well-trained crews flying dedicated missions in support of strike aircraft. The current Air Force approach, which has relied entirely on the Navy for jamming support for 16 years, is reversed with a combined Weasel/Jammer capability in the F-15G. The F-35s already purchased are retained, and advanced capabilities will be available to satisfy commitments made to partner nations.

Collateral effects include the shifting of the burden of expensive low-observable fighter programs to the PRC, which cannot effectively use them to project power far beyond the mainland. Although none of the aircraft numbers lost in the fighter reductions of the last decade are regained, the average age of the fleet is slightly reduced. Inclusion of the F-16F adds a medium-range F-16 variant better suited to the Pacific theater. Adding combat aircraft types that are less expensive than the heavier fighters better positions the Air Force to engage effectively with emerging partner air forces, expanding our influence and opening up opportunities for burden sharing. Critically, with most purchases complete in 2023, it frees multiple billions of dollars for development and procurement of the long range strike bomber and/or a next-generation fighter program (F-X) after 2023—a bonus that the PFE never comes close to providing.

Climbing Out of the Readiness Pit

Money gained through termination of the JSF cannot be entirely dedicated to aircraft purchase and upgrade, particularly in a case such as this in which TACAIR TAI actually increases. Some aircraft programs, such as the F-X and OA-X, are designed to "make money" by meeting current demands with an O&M cost low enough that the procurement is eventually paid for in O&M savings. Adding fuel cost increases into the sustainment calculation is difficult and not attempted,

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but this construct is more forgiving of that expense than the PFE because of lower fuel consumption.

The effectiveness of TACAIR depends upon giving particular attention to several other areas—readiness, for instance.[29] Having used readiness funds to pay for hardware bills, we must now restore the resulting decrease in readiness with funds dedicated to the TACAIR enterprise. The point of F-35 divestiture includes avoiding a permanent low-readiness state that is an extension of our current condition. The second area is magazine depth. Having temporarily given up the (presumed) capability to bring aircraft into the worst of enemy air defenses, we should not entirely relinquish the capability to hold defended targets at risk. This means additional investment in standoff weapons, including AGM-158 joint air-to-surface standoff and antiradiation missiles. It also entails an increase in improved air-to-air missile inventories and development of weapons that need not trade away performance and capabilities in order to fit into a JSF weapons bay. Finally, restoration of long-dormant anti-surface-warfare weaponry is a critical capability for the Pacific region. In the third element—systems, particularly sensors and communications—the fruits of F-35 development can be practically harvested without continuing the program itself by fielding and deploying the advanced radar, EW gear, and data links from the JSF program onto fighters and conventional bombers.

Conclusion

It is time for a rational discussion of the F-35. Such a dialogue would have to be free from the vacuum of a notional volume of contested airspace and consider the context of the complete CAF enterprise and its application across the globe. The F-35 program has long since passed the point where we can expect it to provide a substantial improvement in a broad war-fighting context over its predecessors. Designed for a European conflict that did not occur and a threat environment less advanced than the present one, the F-35 program offers little improvement over its predecessors and demands vast resources from diminishing funds.

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Following the example of the Comanche program, we should consider cancelling the F-35 in favor of a robust, modernized CAF that emphasizes broad capabilities rather than occupying the short-range stealthy niche. Facing a decade of reduced budgetary authority, we must follow a prudent path towards recovery after more than 20 years of continuous combat operations. Doing so will help address a number of collateral issues, including force readiness, global reach, and the inventory of fighter/attack aircrews. Viable alternatives to the F-35 exist if we have the courage to examine them. ✪

Notes

1. Dave Majumdar, "Kendall: Early F-35 Production 'Acquisition Malpractice,'" *DefenseNews*, 6 February 2012, http://www.defensenews.com/article/20120206/DEFREG02/302060003/.

2. Government Accountability Office, *Joint Strike Fighter: DOD Actions Needed to Further Enhance Restructuring and Address Affordability Risks*, GAO-12-437 (Washington, DC: Government Accountability Office, June 2012), http://www.gao.gov/assets/600/591608.pdf.

3. General Accounting Office, *Defense Aircraft Investments: Major Program Commitments Based on Optimistic Budget Projections*, GAO/T-NSIAD-97-103 (Washington, DC: General Accounting Office, 5 March 1997), http://www.gao.gov/assets/110/106735.pdf.

4. The high-low mix was the rationale for the procurement numbers of the F-15 and F-16. The F-15 was the high end, procured in limited numbers, and the F-16 the low end, procured in much larger numbers. The intent was to maintain a broadly capable force under post-Vietnam budget constraints.

5. Acting Secretary of the Army Les Brownlee, "Briefing on the Restructure and Revitalization of Army Aviation," Department of Defense, 23 February 2004, http://www.defense.gov/transcripts/transcript.aspx?transcriptid=2122.

6. Julien Demotes-Mainard, "RAH-66 Comanche—the Self-Inflicted Termination: Exploring the Dynamics of Change in Weapons Procurement," *Defense Acquisition Research Journal* 19, no. 2 (April 2012): 183–208, http://www.dau.mil/pubscats/PubsCats/AR%20Journal/arj62/Demotes-Mainard_ARJ62.pdf.

7. David Alexander, "Theft of F-35 Design Data Is Helping U.S. Adversaries—Pentagon," Reuters, 19 June 2013, http://www.reuters.com/article/2013/06/19/usa-fighter-hacking-idUSL2N0EV0T320130619.

8. "Aircrew Summit 2012, 21 June General Officer Steering Group VTC Brief," v7 (Washington, DC: Headquarters US Air Force / A30, 21 June 2012).

9. The imprecise term *fifth generation* is used generically to apply to modern fighter aircraft that have radar low observability as one of their primary design characteristics. Typically, it includes the F-22, F-35, Russian PAK-FA prototype, and J-20. The F-15, F-16, and F-18 are fourth-generation aircraft.

10. Brian Everstine and Marcus Weisgerber, "Reduced Flying Hours Forces USAF to Ground 17 Combat Air Squadrons," *DefenseNews*, 8 April 2013, http://www.defensenews

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.com/article/20130408/DEFREG02/304080011/Reduced-Flying-Hours-Forces-USAF-Ground-17-Combat-Air-Squadrons.

11. Julian E. Barnes, "Warning Sounded on Cuts to Pilot Training: Air Force Responds to Cost Concerns by Reducing Flight Hours to 120 Hours or Less, Fewer Than Those of Allies—and China," *Wall Street Journal*, 19 December 2013, http://online.wsj.com/news/articles/SB10001424052702304773104579268651994849572.

12. The series of fighter force-strength reductions in the last decade has been collectively referred to as the "fighter redux" or "CAF redux." At least two major strength reductions have occurred, bringing the planned total fighter strength below 2,000.

13. The OA-X is Air Combat Command's proposal for a turboprop light attack aircraft similar to the Embraer A-29 Super Tucano or the Beechcraft AT-6B. The FT-X (sometimes the AT-X) is the proposed combat variant of Air Education and Training Command's T-38 replacement—the T-X.

14. Government Accountability Office, *F-35 Joint Strike Fighter*: *Current Outlook Is Improved, but Long-Term Affordability Is a Major Concern* (Washington, DC: Government Accountability Office, March 2013), 5, table 1, http://www.gao.gov/assets/660/652948.pdf.

15. Kari (*Irak* spelled backwards) was the French-built integrated air defense system possessed by the Iraqis prior to Desert Storm. It was only partially reconstituted after the Gulf War. The F-117A had no radar, data link, afterburner, or EW gear; in fact, it did not even use radio after crossing a hostile border.

16. Gen Mike Hostage (speech, Air Force Association, 17 September 2013), http://www.af.mil/Portals/1/documents/af%20events/17SeptAFAGen%20HostageCOMACCSpeech.pdf.

17. The global assumptions are based on current trends. Like any other set of assumptions, a radical event such as a new revolution in Iran or the fall of the regime in the DPRK is an unpredictable occurrence that would alter the list substantially. Internal US trends are perhaps easier to predict—congressional resistance to reducing the B-1 fleet is well established, the 2011 Budget Control Act is law, and fuel costs have been on a steady, upward trend for two decades (arguably four) despite increased worldwide production.

18. When the terms *high*, *medium*, and *low* are used in this context, they refer to their cost and to the intensity of the conflict for which they are optimized. "High-end" aircraft are expensive because of the advanced sensors, weapons, and communications required to conduct missions in contested airspace; "low-end" aircraft are less costly and designed for the parts of a campaign that do not demand operations in hostile airspace.

19. The F-15G is a modified F-15E+. Its EW systems are migrated from the EA-18G Growler, just as the migration of EA-6B systems to the F-111 Aardvark created the EF-111A Raven.

20. The MQ-9, funded from the intelligence, surveillance, and reconnaissance (ISR) portfolio, is left alone since it does not compete for funds directly with other TACAIR.

21. We did not utilize any funding from the ISR portfolio, which covers the MQ-9, or the global strike portfolio, which covers the B-52 and B-2.

22. The tradespace analysis tool includes not only purchase costs but also sustainment costs.

23. The two-seat fighter squadron is more expensive than its single-seat counterpart for obvious reasons. However, in an environment where we have insufficient cockpits to go around, the two-seat fighter squadrons double the number of absorbable cockpits without a concurrent doubling of costs.

24. Estimated O&M costs for the F-35 currently hover around $32,000 per flying hour compared to the F-16's $19,000; the A-10's $18,000; and the F-15E's $28,000 (Air Force Total

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Ownership Cost database, FY 2013). By comparison, the Air National Guard's AT-6B test program operated for two years with an hourly flying cost of less than $1,500.

25. For detailed discussions of the potential impact of a light attack aircraft on Air Force operations in Operation Iraqi Freedom and Operation Enduring Freedom, see Michael Pietrucha and J. David Torres-Laboy, "Making the Case for OA-X," *Air Land Sea Bulletin* 2010-1 (January 2010): 15–18; and Michael Pietrucha, "Logistical Fratricide," *Armed Forces Journal* 149, no. 6 (January/February 2012): 14–37.

26. Although the term *guerrilla warfare* derives from the Peninsular War in Spain against the Emperor Napoleon, historical examples of irregular warfare are legion. The Romans, for example, fought far more irregular conflicts than classical major combat operations such as the Punic Wars and had an adaptable military structure that varied by time and place, depending greatly on the nature of their adversaries.

27. A fifth-generation penetrating force is not necessary to produce coercive effects against a large, maritime-dependent nation. Approaches used against Japan in early and mid-World War II are but one example of an effective strategy that can be conducted with airpower and operated at a distance without the need for mass penetration of air defenses.

28. Absorbable cockpits—operational flying positions filled by fighter/attack aircrews—are a measure of the ability to develop and season aircrews.

29. Given this article's focus on TACAIR and the necessity of neglecting the bombers, it must be noted that readiness, system upgrades, and magazine depth are bomber issues as well.



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Religion in Military Society

Reconciling Establishment and Free Exercise

Chaplain, Maj Robert A. Sugg, USAF



The First Amendment of the US Constitution's Bill of Rights declares that "Congress shall make no law respecting an establishment of religion, or prohibiting the free exercise thereof." In military society, a unique collision of "rights" between nonestablishment and religious freedom requires an equally unique accommodation of religious practices—that is, *an agreement that allows people, groups, and so forth, to work together*. Many recent news reports indicate that our commanders and senior leadership lack clear guidance for

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parsing the complicated ground that separates "church and state." Because both the (non) Establishment and Free Exercise Clauses of our Constitution have equal weight, the government may not become "entangled" in religion or show it hostility.[1] By examining military society through both lenses—(non) establishment and free exercise—commanders can more clearly understand their responsibilities to service members as they carry out the mission. This article addresses establishment and free exercise in light of constitutional case law, offering four simple tools for making better decisions.

The Military Community

Military installations are isolated communities of culturally diverse people whose right of freedom of religion has been limited for the sake of the mission. Service members are American citizens protected by the Constitution and are on loan from 50 sovereign states while they continue to advocate for their legal and social preferences through the voting booth. In civilian communities, social and cultural standards found in laws and policies differ from town to town and state to state; they are established from the bottom up. For example, a Christian community will tend toward Christian standards; a Jewish community, Jewish standards; a progressive community, progressive standards; or a family community, family standards. In local politics, the religious and the secular all have equal access to the voting booth. In contrast, on military installations, all religious institutions have been fenced out, and political interaction between religious communities and elected officials does not exist. On fenced military communities, commanders are expected to maintain the constitutional balance of (non) establishment and free exercise. To do so, they have both a judge advocate general (JAG) and a chaplain to advise them.

To make things more difficult, military installations are a public-private hybrid consisting of government mission and family life. For instance, an aircraft hangar may be used for maintenance in the morning and a school-sponsored event in the afternoon. Funding options

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are equally confusing. Taxpayer dollars are limited to direct mission requirements that include mandatory funding for chaplain salaries, chapel buildings, and religious worship services while chapel tithes and offerings from the collection plate are also used to fund unit-focused programs such as barbecues in the dormitories and work centers. Commanders must understand that simply scrubbing the religious from military installations or restricting it to the interfaith chapel is not what the writers of our Constitution intended. Consequently, the provision of the right of free exercise through religious accommodation is a direct mission requirement.[2] From the assembly of the Continental Army onward, citizen Soldiers, Sailors, Airmen, and Marines are primarily religious people with religious families, holding religious ethics and living religious lives on government property.

Establishment and Free Exercise: A Condition of Respect

The US Constitution ensures that religion in the public square does not end on military installations. Some people believe that neutrality toward church and state equates to the absence of the religious on government property and in government operations. By using constitutional case law, we will see that this position is emphatically false. The court of *Lemon v. Kurtzman* observes that "judicial caveats against (government entanglement in religion) must recognize that the line of separation, far from being a 'wall,' is a blurred, indistinct, and variable barrier depending on all the circumstances of a particular relationship."[3] Additionally, *Lynch v. Donnelly* notes that

> no significant segment of our society, and no institution within it, can exist in a vacuum or in total or absolute isolation from all the other parts, much less from government. "It has never been thought either possible or desirable to enforce a regime of total separation." . . . Nor does the Constitution require complete separation of church and state; it affirmatively mandates accommodation, not merely tolerance, of all religions, and forbids hostility toward any. . . . Anything less would require the "callous indifference" we have said was never intended by the Establishment Clause. . . . Indeed, we have observed, such hostility would bring us into "war

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> with our national tradition as embodied in the First Amendment's guaranty of the free exercise of religion."[4]

Thomas Jefferson used the term *wall of separation*, writing to religious people in 1802 for the express purpose of allaying the churches' fears that the government would attempt to control their religion. Jefferson stated, "Believing with you that religion is a matter which lies solely between Man & his God . . . I contemplate with sovereign reverence that act of the whole American people which declared that their legislature should 'make no law respecting an establishment of religion, or prohibiting the free exercise thereof,' thus building a wall of separation between Church & State."[5] Jefferson intended the exact opposite of humanists' use of the phrase today in their attempt to keep religion out of government. In fact,

> in 1962, [Supreme Court] Justice Potter Stewart complained that jurisprudence was not "aided by the uncritical invocation of metaphors like the 'wall of separation,' a phrase nowhere to be found in the Constitution." Addressing the issue in 1985, Chief Justice William H. Rehnquist lamented that "unfortunately the Establishment Clause has been expressly freighted with Jefferson's misleading metaphor for nearly 40 years."[6]

Far from banning religion in the public square, the (non) Establishment and Free Exercise Clauses were drafted in a way that allowed people of all faiths—and none—to equally live out their lives on common ground. The founding fathers intended to require American citizens to maintain a condition of mutual respect while they shared the same space. A much better metaphor than "separation of church and state" is "a level playing field for all political issues to be heard equally."[7] Americans cannot choose one of two paths to arrive at common ground. The nonreligious cannot walk the road of (non) establishment and arrive at free exercise. In the same way, the religious cannot walk the road of free exercise and arrive at (non) establishment. Common ground is a level playing field upon which both parties must agree to live as coequals. Respectfully sharing space on a level playing field involves four constitutional principles.

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Hostility toward Religion Is Not Neutrality

On military installations, some of what passes as neutrality toward religion is actually hostility—the primary concern of the religious majority on military installations today. We have already examined the Supreme Court statement that the Constitution "affirmatively mandates accommodation, not merely tolerance, of all religions, and forbids hostility toward any." Additionally the court of *Rubin v. City of Lancaster* cautions that "the danger that such efforts to secure religious 'neutrality' may produce 'a brooding and pervasive devotion to the secular and a passive, or even active, hostility to the religious.'"[8] A recent survey of Air Force chaplains included the statement "I believe Airmen are free to practice their religion except where military necessity dictates otherwise."[9] The chaplains were asked to agree or disagree on a scale of one to four. A subsequent memorandum from the chief of chaplains notes that 82 percent of chaplains believe that Airmen can practice their religion freely.[10] The corollary holds that, of approximately 500 active duty chaplains, 90 believe that Airmen cannot practice their religion freely. An additional concern is that the survey did not measure the ethos—the atmosphere of free exercise. In other words, is there a pervasive institutional bias against the religious that causes religious people or military leadership to "walk on eggshells"? To walk on eggshells in the matter of religion is not evidence of neutrality but of hostility.

God Is Presupposed on Government Property

Lynch v. Donnelly affirms that "there is an unbroken history of official acknowledgment by all three branches of government of the role of religion in American life from at least 1789" and that "we are a religious people whose institutions presuppose a Supreme Being."[11] The courts imply that because our government as a whole presupposes a supreme being, each department of our government must also presuppose a supreme being. The Department of Defense (DOD) is not free to banish God from the public square. In principle, the writers of the

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Constitution clearly expressed that God is not confined to the chapel but walks the parade ground, the maintenance bay, and the flight line.

For example, with regard to paintings, sculpture, and other displays, *Lynch v. Donnelly* affirms the propriety of nonproselytizing religious art in public places:

> Art galleries supported by public revenues display religious paintings of the 15th and 16th centuries, predominantly inspired by one religious faith. The National Gallery in Washington, maintained with Government support, for example, has long exhibited masterpieces with religious messages, notably the Last Supper, and paintings depicting the Birth of Christ, the Crucifixion, and the Resurrection, among many others with explicit Christian themes and messages. The very chamber in which oral arguments on this case were heard is decorated with a notable and permanent—not seasonal—symbol of religion.[12]

The walls of many DOD headquarters buildings, dining facilities, and other common areas are adorned with art and sculpture of many kinds. Art and sculpture with religious overtones are not, on their face, subject to removal or limitation. Regarding symbols of religion, *Lynch v. Donnelly* affirms the constitutionality of the National Day of Prayer, paid federal holidays of religious origin, the phrase "one nation under God" in our pledge of allegiance, the phrase "in God we trust" on our currency, and Christmas crèches owned and displayed by the government for secular purposes.[13] Religion is welcomed to pervade the public square, and it is the commander's constitutional duty to ensure that religion is welcome on military installations.[14]

God May Be Invoked and Welcomed during Government Business

Whether from a military chaplain or a volunteer from a local house of worship, prayer at government events is constitutional.[15] *Marsh v. Chambers* affirms the propriety of prayers during government assemblies.[16] These prayers are, and have always been, religious in nature and not simply ceremonial.

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Regarding religious practitioners with whom he disagreed, founding father Samuel Adams said that "he was no bigot, and could hear a prayer from a gentleman of piety and virtue, who was at the same time a friend to his country."[17] According to *Lynch v. Donnelly*, "It is clear that neither the 17 draftsmen of the Constitution who were Members of the First Congress, nor the Congress of 1789, saw any establishment problem in the employment of congressional Chaplains to offer daily prayers in the Congress, a practice that has continued for nearly two centuries. It would be difficult to identify a more striking example of the accommodation of religious belief intended by the Framers."[18] Religious invocations at government events are an acknowledgement that people of faith have an allegiance to "the Supreme Judge of the world," who is higher than any law of humankind.[19] If we use the level playing field analogy, then providing a respectful presence for a religious prayer is no different than doing so for another nation's national anthem.[20] One does not have to agree with all members of a diverse population to be respectful.

The Threat of Litigation Cannot Be Grounds for Marginalizing the Religious

Lynch v. Donnelly affirms that "a litigant cannot, by the very act of commencing a lawsuit, however, create the appearance of divisiveness and then exploit it as evidence of entanglement."[21] Ethical leaders must be concerned about good order and discipline.[22] However, the principle of good order and discipline cannot be used as a carte blanche to bulldoze all traces of the constitutional rights of a vulnerable class of citizens. Balance is critical! On the one hand, we must not violate the Establishment Clause by offending the nonreligious with the appearance of a government-endorsed religion. On the other hand, we must not violate the Free Exercise Clause by demonstrating hostility to religion through the systematic purging of everything with a religious overtone. Angry agitators, religious or atheist, must not be the determining factor for leadership decisions. The courts have provided much guidance for walking this tightrope and have supplied the

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groundwork for ethical decision making in a military context. In partnership, the JAG and Chaplain Corps must revisit the US Constitution and case law to move forward *collaboratively*, crafting policies and using explicit language that describes a level playing field on which respectful people may agree to disagree. In all cases, DOD policies must clearly define and prohibit hostility toward religion.

Four Tools for Parsing Establishment and Free Exercise

In the past few years, installation commanders in a number of reported incidents have apparently been advised to focus exclusively on the Establishment Clause in an attempt to secure religious neutrality. Unfortunately, in some cases their intended defensive action for (non) establishment was rightfully perceived as offensive to free exercise. In the same way we use 3-D movie glasses, commanders must intentionally look through both lenses of (non) establishment and free exercise to see the constitutional picture clearly. The following four simple tools for discerning the line between the Establishment and Free Exercise Clauses use court decisions as a guide. These court decisions are few, readily available, and easily read.

Historic Practice

Marsh v. Chambers tells us that the constitutionality of government-paid chaplaincy and legislative-type prayer is not found in any "test" but in historic practice.[23] Responding to a suit in which a complainant objected to a government-paid chaplain for the Nebraska Legislature, the Supreme Court held that

> the Nebraska Legislature's chaplaincy practice does not violate the Establishment Clause. . . . The practice of opening sessions of Congress with prayer has continued without interruption for almost 200 years, ever since the First Congress drafted the First Amendment, and a similar practice has been followed for more than a century in Nebraska and many other states. . . . Standing alone, historical patterns, cannot justify contemporary violations of constitutional guarantees, but there is far more here

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> than simply historical patterns. In this context, historical evidence sheds light not only on what the draftsmen intended the Establishment Clause to mean, but also on how they thought that Clause applied to the practice authorized by the First Congress—their actions reveal their intent.[24]

The court of *Marsh v. Chambers* appeals to the contemporary practices of those who actually penned the law. The writers of the Constitution did not forbid what they themselves permitted.[25] When confronted with questions about the scope and practice of chaplains and public prayer, one should employ the first tool to determine if historic practice exists.

Context

Lynch v. Donnelly upheld the constitutionality of a private association to erect a Christmas display on public property on the basis of context:

> The Court has recognized that "total separation is not possible in an absolute sense. Some relationship between government and religious organizations is inevitable." . . . The narrow question is whether there is a secular purpose for Pawtucket's display of the creche. . . . Here, whatever benefit there is to one faith or religion or to all religions, is indirect, remote, and incidental; display of the creche is no more an advancement or endorsement of religion than the Congressional and Executive recognition of the origins of the Holiday itself as "Christ's Mass," or the exhibition of literally hundreds of religious paintings in governmentally supported museums.[26]

Another case, *County of Allegheny v. American Civil Liberties Union*, concerns the constitutionality of a crèche placed on the "Grand Staircase" of a county courthouse. The crèche was part of a larger holiday display dispersed throughout the grounds. The court found that the *location* of the crèche was unconstitutional, based on the context:

> The creche sits on the Grand Staircase, the "main" and "most beautiful part" of the building that is the seat of county government. . . . No viewer could reasonably think that it occupies this location without the support and approval of the government. Thus, by permitting the "display of the creche in this particular physical setting," . . . the county sends an unmistakable message that it supports and promotes the Christian praise to God that is the creche's religious message.[27]

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This case tells us that discerning the line between "a secular purpose" and promoting a religion involves not the religious presence or practice but the context in which it is found. A frontline supervisor, for example, may be religious and live his or her religious life at work. A supervisor, however, must not live this religious life in such a way that it would give *reasonable* people the appearance of favoring the religious over the nonreligious or others of differing faiths. It is a difficult line, but simply "playing it safe" and sanitizing the area violates the supervisor's constitutional rights. When confronted with an object or practice with religious overtones, one should use the second tool to observe the context.

The Lemon Test

> *In the absence of precisely stated constitutional prohibitions, we must draw lines with reference to the three main evils against which the Establishment Clause was intended to afford protection: "sponsorship, financial support, and active involvement of the sovereign in religious activity."*
>
> *—Lemon v. Kurtzman*

This three-point litmus test, also known as the "*Lemon* test," determines the dividing line between free exercise and establishment.[28] A more recent case, *Lynch v. Donnelly* (1984), offers additional clarification for application: "In the line-drawing process, we have often found it useful to inquire whether the challenged law or conduct has a secular purpose, whether its principal or primary effect is to advance or inhibit religion, and whether it creates an excessive entanglement of government with religion."[29] The descriptions and examples below are brief. Commanders and senior leadership would benefit greatly by reading the court decision for themselves.

The first point of the *Lemon* test evaluates for the legitimacy of a secular purpose. The question at hand is, Does the mere presence of a religious symbol or practice on government property imply government *sponsorship* for a specific religion or religion over nonreligion?

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The *Lynch v. Donnelly* court addresses the often misused metaphor of a "wall" of separation between church and state, observing that the "metaphor itself is not a wholly accurate description of the practical aspects of the relationship that in fact exists between church and state" and that "total separation is not possible in an absolute sense."[30] Religious symbols and celebrations may be found on government property for secular reasons and are not, in themselves, evidence of government sponsorship.

The second point of the *Lemon* test evaluates whether or not a symbol or practice's primary effect advances or inhibits religion. This is assessed through context. Regarding the City of Pawtucket's practice of including a crèche in its larger holiday display, the court found that, as mentioned above, "whatever benefit there is to one faith or religion or to all religions, is indirect, remote, and incidental; display of the crèche is no more an advancement or endorsement of religion than the Congressional and Executive recognition of the origins of the Holiday itself as 'Christ's Mass,' or the exhibition of literally hundreds of religious paintings in governmentally supported museums." Again the issue is context. Whether we are looking at a holiday scene or viewing a picture on a wall, the government's question should be, In the eyes of a reasonable person, does this act or display give the appearance of government advancement or inhibition of a particular religion or religion over nonreligion?

The third point of the *Lemon* test evaluates unnecessary government entanglement. In other words, if we go down this road, will the government have to spend significant resources in policing and monitoring to ensure that secular-religious lines are not crossed or that no significant amount of manpower and funding is expended? The court found that

> entanglement is a question of kind and degree. . . . There is no evidence of contact with church authorities concerning the content or design of the exhibit prior to or since Pawtucket's purchase of the creche. No expenditures for maintenance of the creche have been necessary; and since the city owns the creche, now valued at $200, the tangible material it contrib-

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> utes is *de minimis*. In many respects, the display requires far less ongoing, day-to-day interaction between church and state than religious paintings in public galleries.[31]

Allowing the religious time and space in the public square is not government entanglement with religion. Even the government purchase and maintenance of religious items for secular purposes do not constitute entanglement with religion.

Let us examine three recent examples of DOD intervention in religious issues and apply the *Lemon* test to each one. Again, the three questions are as follows: (1) Does the mere existence of a religious symbol or practice on government property imply government sponsorship for a specific religion or religion over nonreligion? (2) Does the context of a religious symbol or practice on government property advance or inhibit a specific religion or religion over nonreligion? (3) Will the religious symbol or practice be an entanglement to the government due to significant amounts of monitoring, funding, or manpower?

The first example comes from a June 2013 news story reporting that "an Air Force video saluting first sergeants—produced by an Air Force Chaplain—was removed by order of the Pentagon because it mentions the word 'God,' even though it was never intended as required viewing."[32] The video was produced in conjunction with a number of first sergeants and intended as a humorous parody of a Super Bowl commercial. In directing the removal of the video, "the Chief of the Air Force News Service Division stated incorrectly, . . . 'Proliferation of religion is not allowed in the Air Force or military. How would an Agnostic, Atheist or Muslim serving in the military take this video?'"[33] Applying the *Lemon* test, we ask, Does the video have a secular purpose? Yes. Is the video's primary effect to advance or inhibit religion? No. Does the video foster excessive government entanglement? No. If all the facts are as stated, then the Pentagon's actions appear to violate the Constitution's First Amendment by favoring nonreligion over religion and evidence of hostility toward religion. Additionally, the Penta-

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gon's position was eventually reversed. No evidence of malice exists—only the lack of clear, objective written guidance from our most senior policy makers.

The second example is from a news report that the Air Force's Rapid Capabilities Office (RCO) removed the Latin name *Dei* (God) from its logo after objections by the Military Association of Atheists and Freethinkers: the "RCO patch logo previously included the motto 'Opus Dei Cum Pecunia Alienum Efficemus' (Doing God's Work with Other People's Money), an inside joke among RCO members. Caucus members say it was changed to 'Miraculi Cum Pecunia Alienum Efficemus' (Doing Miracles with Other People's Money)."[34] Applying the *Lemon* test, we ask, Does the logo have a secular purpose? Yes. Is the logo's primary effect to advance or inhibit religion? No. Does the logo foster excessive government entanglement? No. If all the facts are as stated, then the Pentagon's actions appear to violate the Constitution's First Amendment by favoring nonreligion over religion and evidence of hostility toward religion. Additionally, atheist groups have petitioned our courts for years to remove the phrase "in God we trust" from our monetary notes and coins.[35] The courts have repeatedly and emphatically rejected their argument: "In dismissing the suit, U.S. District Judge Harold Baer, Jr., wrote that 'the Supreme Court has repeatedly assumed the motto's secular purpose and effect' and that federal appeals courts 'have found no constitutional violation in the motto's inclusion on currency.' He added that while the plaintiffs might feel offended, they suffered no 'substantial burden.'"[36]

The third example involves the removal of religious artwork from a dining facility. A painting entitled *Blessed Are the Peacemakers*, a 9-11 memorial gift to the installation, had long been displayed on a dining facility's wall. An atheist organization petitioned for and was granted the removal. A news report also relates that the wing commander said that "he will be ordering another inspection to rid his base of anything else like what had been hanging in the dining hall."[37] Applying the *Lemon* test, we ask, Does the artwork have a secular purpose? Yes. Is

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the artwork's primary effect to advance or inhibit religion? No. Does the artwork foster excessive government entanglement? No. If all the facts are as stated, then the commander's actions appear to violate the Constitution's First Amendment by favoring nonreligion over religion and evidence of hostility toward religion. Another report indicated that the commander maintained that "the painting violated military regulations governing the free exercise of religion" and that "the . . . [regulation] states that we will remain officially neutral regarding religious beliefs—neither officially endorsing nor disapproving any faith belief or absence of belief."[38] The commander cited the regulation correctly, but his interpretation was faulty. He had no "test" available to determine the ground between neutrality and hostility.

The three-part *Lemon* test is a simple tool for items with religious content. Each point of this test involves some subjectivity. Thus, it is critical that *both* the JAG, arguably representing (non) establishment, and the chaplain, representing free exercise, have equal input into a commander's decision process. We must use the 3-D glasses! When faced with an object or practice with religious overtones, ethical leaders should utilize a respectful, methodical, and equitable process to find the balanced position. The third tool in the box is the *Lemon* test.

Bottom-Up Consensus

Commanders at all levels are unelected stewards who have limited legal authority to constrain constitutional rights to accomplish their missions. Primary drivers for poor command decisions include haste, misinformation, or personal bias. Regarding removal of the artwork from the dining facility, for instance, a report noted that the non-DOD complainant "gave the Air Force an hour to take action" and that the subsequent removal took place in 56 minutes.[39] This was a top-down decision. When dealing with social issues, religious or otherwise, the community must be consulted from the bottom up and must take time to contact the JAG, chaplain, senior leadership, and the installation's private organizations. The Air Force's integrated delivery system

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should have an opportunity to broker a peaceful settlement among organizations. Any *appearance* of the imposition of a commander's personal preference for cultural and religious standards that exceed those necessary for the mission may be construed as social engineering and must be seen as a catastrophic moral violation of professional ethics. Commanders must never use their positions to impose any religious or cultural standard, whether Christian, Jewish, Muslim, Wiccan, atheist, conservative, or progressive. In social issues within a closed community, "good order and discipline" is not a top-down affair.[40] Ethical commanders allow members of their community to speak to one another, advocate for their positions, and, most of all, be respected. Then and only then do ethical commanders make command decisions. The fourth tool is bottom-up consensus.

Legal "Tests" or Historic Practice?

In 2007 the *Air Force Law Review* published an article entitled "Religion in the Military: Navigating the Channel between the Religion Clauses."[41] For seven years, it has remained a significant "think piece" for making Air Force policy; indeed, the article is listed as a reference in the current Air Force JAG publication *The Military Commander and the Law*.[42] The legal assessments and conclusions of the authors—Maj David E. Fitzkee, USA, retired, and Capt Linell A. Letendre, USAF—regarding the Chaplain Corps's scope and practice and the provision of public prayer are horribly wrong.

Referring to *Marsh v. Chambers* (1983), Fitzkee and Letendre correctly remark that "the court has upheld an opening prayer for a legislative session relying on the historical exception but has denied a moment of silence in public schools using the *Lemon* analysis."[43] The authors clearly delineate between historically sanctioned prayers at a historically rooted, adult-dominant event from prayers at a child-dominant public school event. Then, inexplicably, they choose to argue the validity of historical prayer in military settings (*Marsh* language) from the same category as prayer at school graduations and

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football games (*Lemon* language).[44] In short, they switch from historical precedent to "tests." Fitzkee and Letendre complete their conversion with the following statement: "When facing the challenging question of prayer at an official military function, one must navigate through the array of legal opinions deliberately and with full understanding of the particular context in which the prayer will be given."[45] Absolutely not! In a legislative or military setting, prayer is found constitutional through historic practice; context is irrelevant. Worse, they end their analysis by declaring,

> Unlike a school environment, where students can vote on whether or not to have a message and decide what the content of the message should be, the military does not put to a vote whether to have an "opening message" at a change-of-command or a dining-in. Instead, a commander typically decides that there will be an invocation and routinely asks a chaplain to perform this duty. This overt government involvement, both in the decision making and delivery of an invocation, results in clear government speech, thereby compelling Establishment Clause analysis.[46]

Do Fitzkee and Letendre really believe that the framers of our Constitution held that military commanders who request chaplain invocations at change-of-command ceremonies are guilty of violating the Establishment Clause? The Supreme Court does not agree.[47] To examine the constitutionality of the Chaplain Corps's scope and practice, one must consult the best court ruling—*Marsh v. Chambers* (historic practice).

A Word about Ceremonial Deism

At the time of this writing, in *Town of Greece v. Galloway*, the Supreme Court is deliberating the consequences of a relatively new artificial construct called "ceremonial deism."[48] At issue is "whether the court of appeals erred in holding that a legislative prayer practice violates the Establishment Clause."[49] In other words, is a prayer at a government event really a prayer? To understand the debate, one must grasp the origins of ceremonial deism. The original term comes from an unpublished 1962 lecture at Brown University given by Yale Law

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School dean Eugene Rostow in which he proposed that "certain types of religious speech, which he called 'ceremonial deism,' were 'so conventional and uncontroversial as to be constitutional.'"[50] Reflecting on this reference in 1984, Justice William Brennan offered his dissenting opinion in *Lynch v. Donnelly*:

> While I remain uncertain about these questions, I would suggest that such practices as the designation of "In God We Trust" as our national motto, or the references to God contained in the Pledge of Allegiance to the flag can best be understood, in Dean Rostow's apt phrase, as a form of "ceremonial deism," protected from Establishment Clause scrutiny chiefly because they have lost through rote repetition any significant religious content.[51]

In his ponderings of uncertainty, Justice Brennan implies that he personally finds that these religious references have no "significant religious content." The original intent of the authors is lost on him.

In 1989 Justice Brennan's thoughts became a legal player through the majority opinion of *County of Allegheny v. American Civil Liberties Union*:

> The concurrence, in contrast, harmonized the result in *Marsh* with the endorsement principle in a rigorous way, explaining that legislative prayer (like the invocation that commences each session of this Court) is a form of acknowledgment of religion that "serve[s], in the only wa[y] reasonably possible in our culture, the legitimate secular purposes of solemnizing public occasions, expressing confidence in the future, and encouraging the recognition of what is worthy of appreciation in society." . . . The function and history of this form of ceremonial deism suggest that "those practices are not understood as conveying government approval of particular religious beliefs."[52]

With regard to legislative prayer, the justices chose not to refute *Marsh*'s historic-practice argument and so added a new proposition on top of it. The *County of Allegheny* court stated that it has "harmonized" *Marsh* with "this form of ceremonial deism" so that legislative prayer should be viewed as a method of "solemnizing public occasions, expressing confidence in the future, and encouraging the recognition of what is worthy of appreciation in society" (see above). But by artifi-

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cially separating the act of prayer from its religious content, the Supreme Court has created additional confusion. The decision of *Town of Greece v. Galloway* may be intended as clarification. Will the Supreme Court uphold the original intent of the framers of the Constitution, meaning that public prayer is an example of free exercise, or will it overturn *Marsh* and pursue ceremonial deism in the name of (non) establishment? It is doubtful that the Supreme Court would overturn *Marsh*. However, it is almost certain that it will also continue to "harmonize" the founders' religious intent with antireligious ceremonial deism.

In the foreseeable future, regardless of *Town of Greece v. Galloway*, the American people should expect that the painting *The Baptism of Pocahontas* will remain on the Capitol Rotunda wall and that the National Gallery of Art will continue to display *Rabbi* and fund the maintenance of the *The Sacrament of the Last Supper*.[53] The Senate chaplain will continue his or her duties, ensuring that "all sessions of the Senate have been opened with prayer, strongly affirming the Senate's faith in God as Sovereign Lord of our Nation."[54] Each of these long-standing government practices provides examples of how our commanders should manage religion on their installations.

Conclusion

In the twenty-first century, US military society has entered a new era of cultural change, and we have been given few tools to make the transition. Indeed, we have not even framed the questions. Military leaders have sworn to support and defend the Constitution of the United States, and service members depend upon those in authority to act honorably. Leaders must be concerned about good order and discipline but must never use this as an easy excuse to sanitize religion. We can neither endorse religion nor show it hostility. We should use the four tools for discerning the line between establishment and free exercise. The only way to determine constitutionality in matters of religion is to look through both the 3-D lenses of (non) establishment and free

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exercise. In practice, the JAG office represents the commander and has given the appearance of advocating for the institution over the rights of the individual. The scale has tipped in favor of (non) establishment. The scale must now be balanced to include the weight of free exercise. It is most critical that the Chaplain Corps "get smart" on constitutional law. Our JAGs and Chaplain Corps should transparently work together to restore First Amendment balance throughout the DOD. Constitutional free exercise must always remain a positive principle to be celebrated and not simply the dark side of (non) establishment. ✪

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Chaplain, Maj Robert A. Sugg, USAF

Chaplain Sugg (MDiv, Seminary of the East; BS, Charter Oak State College; MS, Tarleton State University) is the staff chaplain for the USAF Expeditionary Center, Joint Base McGuire-Dix-Lakehurst, New Jersey. As course director and academic instructor, he developed and delivered cutting-edge education and training for Chaplain Corps personnel deploying to high-risk environments. As staff chaplain, he provides pastoral care and counseling to a staff of 400 and a student population of 24,000 while advising Expeditionary Center leaders on matters of religious accommodation, ethics, and morale. Chaplain Sugg assists the joint base's Chaplain Corps to ensure free exercise of religion and to provide pastoral care, counseling, worship, rites, and sacraments to joint base personnel and their families. He is a credentialed pastoral counselor with over 4,000 hours of client counseling, 870 hours of clinical supervision, and 8 units of Clinical Pastoral Counseling. Chaplain Sugg has been the senior pastor for 12 congregations, including military communities in South Korea, Kuwait, and Saudi Arabia.

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Cataclysm: General Hap Arnold and the Defeat of Japan by Herman S. Wolk. University of North Texas Press (http://untpress.unt.edu/), 1155 Union Circle no. 311336, Denton, Texas 76203-5017, 2012, 352 pages, $24.95 (hardcover), ISBN 1-574412-81-7; $19.95 (softcover), ISBN 1-574414-73-9.

In *Cataclysm* Herman S. Wolk argues that Gen Hap Arnold counted upon the B-29 campaign as a means to an end (i.e., the continued future of the Army Air Forces [AAF] and the effort to make it an independent service). The author does not indicate that Arnold himself ever openly promoted strategic bombing as the decisive tool for victory and, thus, a proof of concept. However, he does convincingly present the case—through Arnold's actions—that privately he thought that the strategy of air bombardment and the AAF's participation in creating a sea blockade could bring about the war's end without a costly ground invasion of the Japanese home islands.

The book includes an introduction and seven chapters, the introduction and last chapter acting as bookends. In the introduction, Wolk identifies his goal of uniquely examining the interconnected roles that General Arnold played in the development and deployment of the B-29 and the establishment of Twentieth Air Force as well as the strategies and policies of an air campaign whose design could have ultimately led to the defeat of Japan. He also notes that his study draws on a source little used in the examination of that defeat—the wartime accounts of the Japanese themselves, a source that gives particular credence to his thesis. In the final chapter, "Who Was Hap Arnold?," Wolk addresses the impact of Arnold's determination to bring about an independent Air Force, including his futurist vision of a radically different aviation technology. The central chapters cover the general's career from his early days in aviation to the period immediately following the Second World War. Each chapter develops the unfolding story of policy, strategy, and command that emerged from the debate about whether an air cam-

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paign and naval blockade could bring about a Japanese surrender or whether a ground invasion was necessary. Of course, the successful use of the atomic bombs rendered that debate moot.

Within the central chapters, Wolk details Arnold's relationship with President Franklin Roosevelt and his cabinet members, such as Harry Hopkins; his struggle to ready the B-29 for operational deployment in spite of numerous technological problems; and his successful establishment of Twentieth Air Force as an independent command under his direct leadership. The general's willingness to replace the Twentieth's operational commanders when he felt they were not producing the desired results demonstrates his emphasis on the success of the Pacific air campaign. In Gen Curtis LeMay, Arnold found a commander who would lead the XI Bomber Command and produce those results. LeMay's shift from high-altitude precision bombing to low-altitude area incendiary bombing brought about the destruction of Japan's dispersed urban industries and, Wolk maintains, the collapse of its will to continue prosecuting the war. Though not *the* factor that brought about surrender, Wolk convincingly argues that strategic bombing and the AAF's involvement in the sea mine campaign were key elements in setting the stage for Japan's capitulation when confronted with the destructiveness of the atomic bombs.

I found this book repetitive at times, particularly in its first half, but I also found it an enlightening and enjoyable read. As the author observes in the introduction, this study is not an operational history but an examination of policy, strategy, and command. As such, Wolk's narrative of Arnold impressed me. The general's impact on the air campaign in the Pacific theater and the interconnected drive to maintain operational independence for Twentieth Air Force laid the foundation for the creation of an independent postwar Air Force. *Cataclysm* is a welcome addition to literature on the air campaign in the Pacific, the debate over the effectiveness of a strategic air campaign, and Arnold's vision of how—through the contributions of a wartime campaign—the AAF could transform itself into a coequal service.

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War over the Trenches: Air Power and the Western Front Campaigns, 1916–1918 by E. R. Hooton. Ian Allan Publishing (http://www.ianallanpublishing.com), 12 Ethel Street, Birmingham B2 4BG, UK, 2010, 352 pages, $18.79 (hardcover), ISBN 9780711034150.

The impetus for the rise of American airpower does not begin with Billy Mitchell in the interwar years but within the Anglo-German competition for aerial dominance during World War I. That is just one of the themes that emerges from E. R. Hooton's superbly researched volume *War over the Trenches: Air Power and the Western Front Campaigns, 1916–1918*. The author provides the reader with what may be the first detailed study of the contributions of airpower during the war.

Most airpower studies tend to gloss over World War I, focusing on airpower theory and its development afterward but rarely addressing the actual use of airpower in that conflict. One sees the same tendency in the Air Force's professional military education for officers, resulting in a fairly superficial view of airpower's contributions. Hooton seeks to fill this gap in historical research by giving the reader comprehensive descriptions (both quantitative and qualitative) of the employment of airpower on the Western Front from 1916 to 1918.

The author chronicles the evolution of airpower at this time by dividing the book into separate periods by chapter. In each, analysis first addresses the campaign from the perspective of the ground commander before discussing the contributions of airpower. Intertwined with the historical accounts is considerable detail about tactical- and operational-level air operations, which Hooton uses to explore the beginnings of many of today's airpower roles.

For example, he examines the Allied successful campaign in the Somme from June to November 1916, describing the static form of warfare that killed hundreds of thousands of troops in the process of taking small stretches of ground (p. 91). Airpower relieved much of the

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stalemate. During this battle, British airmen under Marshal of the Royal Air Force Hugh Trenchard flew more than 21,400 combat sorties (p. 124). Regarding the Somme, Hooton documents one of the first realizations of the split between tactical- and operational-level air operations: "Trenchard believed this outer air battle both on the main battle front and on its periphery was the key to success in the Tactical Level inner air battle to keep the enemy air force at arm's length" (p. 97). Additionally, he notes the emphasis on strategic bombing (a concept applied emphatically in World War II): "Sustained bombing was the other plank of Trenchard's strategy, the aim being to inflict material damage, to divert enemy resources and to dilute enemy air power on the main battlefront" (p. 113). Between 1916 and 1918, aircraft dropped 25,000–30,000 tons of bombs on the Western Front (p. 77). Compared to the tonnage dropped during the next war, these totals may seem insignificant, but in the context of World War I, they are noteworthy, given the fact that bombing began early in the war with pilots releasing hand-grenade-size explosives directly from the cockpit.

In *War over the Trenches,* the author offers the reader unparalleled information about air operations on the Western Front in World War I. That said, the reader should buckle in and brace for 65 detailed tables and an impressive list of sources in multiple languages. Clearly, Hooton addresses a fundamental gap in airpower history, having produced a body of knowledge that should be an asset to both the researcher and recreational reader. For today's airmen, this book makes for a very interesting read—indeed, a must-read for any instructor who needs the context to talk intelligently about the contributions of airpower during World War I, much less the origins of many airpower roles that modern air forces perform today. Even though the author's extensive research may at times overwhelm the reader with detail, the concepts related in the book will appeal to any airpower professional or enthusiast.

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Internal Security Services in Liberalizing States: Transitions, Turmoil, and (In)Security by Joseph L. Derdzinski. Ashgate Publishing (http://www.ashgate.com), Wey Court East, Union Road, Farnham, Surrey GU9 7PT, UK, 2009, 180 pages, $114.95 (hardcover), ISBN 978-0-7546-7504-4.

In a short, scholarly monograph that serves as a cross-cultural case study examining the security regimes and stalled democratic transition between Morocco and Indonesia, Prof. Joseph L. Derdzinski of the US Air Force Academy clearly demonstrates the work done in these two nations (and, more broadly and less deeply, the rest of the developed world). He also addresses the effort that remains, seeking to fill the niche of examining the critical role of internal security systems (like the police, intelligence services, and related institutions) in the process of democratization throughout the world. The study is very technical (but accessible to readers familiar with political science and international relations), meticulously researched, and filled with explanatory footnotes and charts that organize information efficiently.

From the outset, it is clear that *Internal Security Services* assumes the realist perspective, from its approving quotation of Machiavelli that "security for man is impossible unless it be conjoined with power" (p. 3) to its rigorous, detailed examination of the challenges of both Morocco and Indonesia in increased liberalization, given the state of elite power and interests within both countries and the presence of continued terrorist and separatist violence. The introduction examines the state of the literature and identifies the case study's goal of filling a gap by considering the neglected role of internal security forces as a measure of the success of liberalization within a nation. The author then explains his principal approaches and findings. He accounts for the strong focus on two countries by seeking to build a broader conceptual framework for ways that third-party nations and international organizations can effectively encourage liberalization and engender greater respect for personal freedom and human rights as well as leave behind an authoritarian past. Derdzinski offers a detailed assessment of the history and role

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of internal security forces in Morocco (a nominally constitutional Islamic monarchy) and Indonesia (a nominally secular Islamic democracy with a lengthy history of brutal and corrupt dictatorship) before closing with findings and recommendations for reforming the security sectors of liberalizing nations. These suggestions emphasize enforcement and justice rather than merely legal structure. They also encourage rooting out corruption (through providing a living wage for workers and discouraging moonlighting for police and intelligence officials) and developing a robust civil culture that demands accountability and answerability from security forces for any human-rights violations they commit after the transition from authoritarian rule.

Among the many strengths of this book are its awareness of relevant research, including interviews, periodicals, monographs, and reports about human rights conditions from nongovernmental organizations and the US State Department. The study's concentration on two nations and its broader comparative analysis at the end benefit from both its depth and breadth of approach. The scholarly, technical language may prove a barrier to a general audience, but readers equipped with an understanding of the professional language of political science and international relations will find the book's insights immensely rewarding if they are sympathetic to the realist perspective. The author makes numerous practical recommendations for nations of the West regarding how they might best help other countries in the difficult process of liberalizing and moving beyond "partly free" status. Specifically, he suggests that they honestly wrestle with tensions that arise from the need for truth and accountability from internal security forces and the need for some secrecy and freedom of action on their part to conduct necessary tasks. The latter include preserving the security of the state from threats like secession movements as well as domestic and international terrorism—threats by no means unique to the developing world.

The author's research and findings are of the highest quality and apply to a range of nations far beyond the two cases examined. Derdzinski refers to his own experience in Bosnia as an officer with the North

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Atlantic Treaty Organization, and this reviewer has relevant expertise that confirms the validity of the findings of this research to the nations of Chile and Thailand as well. Clearly, the author's findings and conclusions apply to many nations with stalled democratization in the face of separatist violence, concerns about terrorism, and a lack of commitment to broad-based societal and institutional change that threatens their privileged status and could bring them to justice for past wrongs. The United States has engaged and may yet engage in the process of nation building in several countries across the Muslim regions of the world (e.g., Iraq, Afghanistan, Libya, and Syria). Consequently, the subject of this monograph has considerable relevance to individuals interested and involved in present American military policy as it relates to the Muslim world, especially in light of the democratization of states after the Arab Spring. Well written and exceedingly applicable to our times, *Internal Security Services* offers a scholarly approach to an often-neglected and vitally important aspect of ensuring that postauthoritarian regimes can successfully conform to civilized and democratic norms of behavior. It deserves a wide audience and a fair hearing for its policy recommendations.

Nathan Albright
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Freedom's Forge: How American Business Produced Victory in World War II by Arthur Herman. Random House (http://www.randomhouse.com/), 1745 Broadway, New York, New York 10019, 2012, 346 pages, $28.00 (hardcover), ISBN 978-1-4000-6964-4.

Admittedly, the B-29 fuselage on the cover of *Freedom's Forge: How American Business Produced Victory in World War II* by Arthur Herman caught my eye and led me to scan the first few pages. Thank goodness for slick-looking dust jackets because Herman's book is a page-turner. It is 1939, and Hitler attacks Poland. Soon Britain stands alone. Far away the United States struggles out of the Great Depression. President Franklin D. Roosevelt (FDR) knows that the ocean cannot forever

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protect America from the chaos engulfing Europe. He decides to prepare via US industrial might, but industry is not all that mighty in the late 1930s. What to do?

The "greatest generation" story of how US industry ramped up to build liberty ships in record time and crank out bombers by the hundreds is probably familiar, at least vaguely, to most people. Herman's book goes deep to tell the story of the men behind that production, shining light on names like Henry Kaiser and others perhaps unfamiliar to Airmen. Wisely, FDR summons and corrals these men, relying on their peacetime métier to make that wartime industrial miracle happen.

And what men they are—the best in their fields: Bill Knudsen and mass production, the aforementioned Henry Kaiser and big construction, and "Cast-Iron Charlie" Sorensen and Ford Auto, to name just a few. Herman explains where these individuals came from and how their American industrial backgrounds—successes and failures—position them to foment brilliant recommendations and tough decisions to get US industry in high gear. It will not be easy; the state of many US industries is dismal. Further, these individuals are human; some simply do not like each other. We witness big egos at play. They clash, on occasion, even to the point of physical violence.

Airpower advocates will find that the book has a certain appeal, simply from the standpoint of how all the airframes such as B-24s and P-51s begin coming out of car factories. Yes, car factories. But be advised that the book focuses on masters of industry as opposed to masters of the air. If one is researching the machinations of, say, Hap Arnold or Jimmy Doolittle in this tale, he or she should note that Herman covers them only slightly. General Arnold's classic book *Global Mission* is the best go-to source for how *A Few Great Captains* played their roles, as described by DeWitt S. Copp in *his* classic work of the same name.

However, one military person does stand out—and rightfully so—albeit briefly. In May 1940 as German tanks traverse France like so many bumper cars, an epochal scene occurs at the White House. Gen

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George C. Marshall asks FDR if he can have the famous three minutes to give, as Herman appropriately describes it, "the speech of his life" (p. 10). Once FDR grants Marshall the time, the president then receives a stern remonstration to rearm America, and quickly. This is classic "cometh the hour, cometh the man" stuff. Herman captures, perhaps unknowingly, the real pivotal moment that saves America. There is, however, a slight variance with Herman's timing of the event and that of other sources: the author indicates that an urgent telegram from Churchill to FDR, after the fall of France, triggers that meeting; FDR's historical calendar, however, shows Churchill's telegram arriving a day later. This discrepancy, however, is not a detractor. Those, but only a few, lie elsewhere.

For instance, when it comes to the production numbers of tanks, planes, machine guns, and so forth, the book contains a good deal of data—actually, an *incredible* amount of data. The before-and-after numbers are staggering, and a reader may become desensitized to them. Nevertheless, the numbers do work to convey the magnitude of production; they do add to the story's coherence. Also, the creative modular construction of the liberty ships is fascinating, but to a nonengineer, the processes described might be difficult to follow. Readers may need to google terms such as *retractor conveyor* (p. 186) to get a visual idea of this assembly line. A diagram or graphic would have been helpful here. And Herman does not narrate the industrial experts' histories on one timeline. He covers the prominent characters in significant detail, appropriately dedicating a chapter to each. However, readers will have to backtrack to establish who is meeting whom—and when—as their careers intertwine.

Finally, a warning is in order for anyone enamored of FDR and his New Deal. Herman takes aim in an almost iconoclastic way. True enough, prescient FDR eventually brings America's industrial know-it-all men together. But as they undertake the business of industrial conversion for war, they constantly clash with skeptical administration New Dealers who persistently watch, hover, and probe to ensure that big business does not profit too much—never mind that America's sur-

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vival is at stake. Bill Knudsen, in particular, constantly brushes away inimical bureaucrats as a struggling farmer swats away gnats while racing to finish a harvest ahead of an approaching hailstorm.

Interestingly, one aspect of this saga is not mentioned but inferred. As automakers, dam builders, and clothing manufacturers struggle to accelerate production, they do so without computers, PowerPoint, or any other type of modern cyber convenience. One can almost hear the typewriters clattering away in the background and the screaming into 1930s telephones as monumental problems of factory locations, contracts, material shortages, and worker strikes are sorted out. Perhaps this is instructive for us today: could the United States meet this type of challenge without our modern communications, let alone make it happen *at all*?

No plot spoiler here. History shows that US production capability eventually wins the wars in Europe and the Pacific. Still, Herman writes of these men, their challenges, the obstacles, and crushing deadlines in a way that makes the heart pound.

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Hero of the Air: Glenn Curtiss and the Birth of Naval Aviation
by William F. Trimble. Naval Institute Press (http://www.usni.org/navalinstitutepress), 291 Wood Road, Annapolis, Maryland 21402, 2010, 304 pages, $37.95 (hardcover), ISBN 9781591148791.

Hero of the air? Dr. William Trimble's exhaustive biography of aviation pioneer Glenn Curtiss certainly drives the reader to that conclusion. The author offers a thorough study of the aviation pioneer's flying life and his predominant role in the early days of naval aviation. The book is more than the subtitle implies, pointing out that although the Wright brothers were the first to fly, "Curtiss was instrumental in [flight's] development or innovation phase" (p. xiv). As is his practice, Trimble has extensively researched the personal papers of the key

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players of aviation, official naval documents, period newspaper accounts, and a myriad of secondary sources.

Accompanying the central theme of Curtiss's overall contribution to aviation are several secondary themes, one of which examines the strong partnership between Curtiss and the US Navy: "Early on, advocates of aviation in the Navy, chief among them Capt. Washington I. Chambers, recognized that the Navy had special requirements for airplanes and their operations, and for aviators and their training" (p. xv). Trimble affirms the well-supported position that Chambers utilized Curtiss's unique ability to "design and develop" aircraft along with his experience in experimentation to "meet the Navy's special requirements" (p. xv).

This partnership leads to another secondary theme—that the Navy didn't resist aviation; rather, "the Navy's leadership and bureaucracy adjusted well to aviation and other changes" (p. xv). To support this point, the book discusses at length the Navy's efforts to embrace new technologies, such as long-distance flying, and highlights its desire to conduct the first flight across the Atlantic Ocean, which did in fact occur in 1919. Clearly, the Curtiss-Navy partnership helped add aviation to the Navy's capabilities.

Professor Trimble tells Curtiss's story chronologically, beginning with his family's move to western New York and ending with the death of the aviation pioneer at the age of 52. He portrays Curtiss as an innovative and enterprising man who used a "cut and try" approach rather than a scientific or engineering-based method with everything from bicycles to motorcycles to airplanes. His detailed, almost weekly, accounting effectively relates Curtiss's activities and numerous aviation firsts. Understanding the importance of the often-hostile relationship between Curtiss and the Wright brothers, Trimble includes the substory of their legal battles over aviation patents and their desire to protect their respective business interests.

The author does not place his subject on a throne as the infallible creator of naval aircraft. Rather, he notes that Curtiss's "slack and inef-

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ficient 'shop' organization had been a source of frustration" to the Navy (p. 189). Throughout, Trimble clearly articulates the negative effect of the cut-and-try approach to aircraft design and Curtiss's lack of an engineering background. Readers learn that after the Navy's successful flight across the Atlantic Ocean in the Curtiss-built NC-4, Curtiss had the "good sense to walk away" from an aviation industry that had outgrown his aeronautical abilities (p. 214). Rather than offer a whitewashed, glossy characterization, this inclusion of the man's shortfalls helps the reader assess his effect on aviation.

As with Trimble's book *Admiral William A. Moffett: Architect of Naval Aviation* (Smithsonian Institution Press, 1994), readers who seek insight into the subject's family life will be disappointed. This is no "there I was" study. Instead, *Hero of the Air* gives us an in-depth look at a key aviation pioneer who had an immense impact on aviation in general and naval aviation in particular. Although Glenn Curtiss was not the first to fly, one cannot deny his critical role in the early days of flight. William Trimble's biography is a must-read for both aviation and naval historians.

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The Royal Air Force in Texas: Training British Pilots in Terrell during World War II by Tom Killebrew. University of North Texas Press (http://www.unt.edu/untpress), 1155 Union Circle no. 311336, Denton, Texas 76203-5017, 2009, 208 pages, $26.95 (hardcover), ISBN 978-1-57441-169-0; $19.95 (softcover), ISBN 978-1-57441-272-7.

In his contribution to the University of North Texas Press's War and the Southwest series, author Tom Killebrew examines a little-known element of the vital and historic "special relationship" forged between the American and British governments during the Second World War. The monograph opens with varied accounts of British wartime hardships and endurance in the face of the widening Nazi political and military advance across Europe. As continental nations fell to Nazi expansion,

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Hermann Göring's Luftwaffe set its sights on Britain during the summer and fall of 1940, subjecting it to the oft-accounted aerial punishment of the Battle of Britain. Although "the Few" of the Royal Air Force (RAF) valiantly halted the German onslaught, flight schools in the British Isles and across the Commonwealth states could not effectively meet the operational demand for pilots in the expanding war. Airspace congestion, notoriously dismal and uncertain isle weather, and austere operational conditions at overseas training locations prevented them from doing so. Given the ever-present risk of raiding German fighter and bomber formations further compounding the problem of fielding effective daily flight training, the RAF had to find a better solution.

The end of 1940 found British military forces girding themselves to repulse the later-abandoned German invasion across the English Channel. Filling the ranks of the RAF took on even more importance during this time since the subject of flight training beyond the confines of the British Empire had become a topic of conversation during the lend-lease discussions held in Washington, DC, in early 1941. Maneuvering around the fading façade of American neutrality, flag-officer luminaries of the US Army Air Forces, US Navy, and a British delegation agreed to host a four-element training scheme for British student pilots in the United States. One of these elements involved the pairing of British training detachments with existing civilian flying-training facilities throughout the American South and Southwest. Thus, the British Flying Training Schools (BFTS) scheme was born, with No. 1 BFTS taking root at the Kaufman County Airport in Terrell, Texas, in 1941.

The Royal Air Force in Texas relates the four-year history of the No. 1 BFTS in meticulous detail, thoroughly describing the school's early days, including site selection, the administrative trials of standing up the new unit, and the logistical challenges of keeping aircraft and pilots flying over foreign soil. The thorough treatment of these subtle contextual details—one of Killebrew's demonstrated strengths as a researcher and author—greatly enhances the story. His inclusion of considerable primary source material enlivens the tale with such comic details as cold-weather flying gear mistakenly provided to initial classes for use

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during the Texas summer, together with illustrative descriptions of the British cadets' most frequented establishments in downtown Terrell. However, most fascinating are the author's accounts of the nuances of the odd yet very functional command relationship between the on-site British officer cadre and host civilian flight school. Although many individuals in senior RAF circles feared that the cultural and professional divide would make for complications in the execution of vital military training, Killebrew notes the mutual respect and resolve demonstrated by both American and Briton alike. This understanding between aviators became the hallmark of an extremely successful effort to produce top-quality aviators for Britain's first line of defense.

Although the book offers impressive details about the administrative and structural attributes of the No. 1 BFTS, it gives less consideration to the crucial account of the British aviation cadets as individuals. Throughout, Killebrew effectively captures student issues with individual aircraft types, the comedy and tragedy of in-flight incidents, and favored off-duty activities, among other details. For all its strengths, however, *The Royal Air Force in Texas* would have benefited greatly from deeper exploration of the motivations, fears, and personal struggles of the British cadets as they left their loved ones to confront wartime hardships during their rigorous six-month training regimen. That said, Killebrew does not ignore the personal dimension entirely, in that his story includes accounts of cadet interactions at social functions and hospitality visits with Terrell residents, descriptions of the distinctive characters among the 26 total classes of the No. 1 BFTS, and praise of selected graduates' wartime heroics. Further, one must acknowledge that recounting the individual hopes and fears of British cadets was likely hindered by the sheer passage of time, incomplete record keeping by the US government during wartime, and contested claims that structural fires consumed school records in the postwar years.

Despite its isolated shortcomings, *The Royal Air Force in Texas* is an impressive and effective account of the interaction of two seemingly opposite worlds brought together in the name of liberty and embody-

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ing the greatest tradition of Anglo-American cooperation. By documenting and recounting the events of over 70 years past, Killebrew vividly reminds us of the "special relationship" that still endures, perhaps best captured on the No. 1 BFTS patch: *Mare nos dividit, Set Caela Conjungunt* (what the sea divides, the skies unite).

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Liberty's Fallen Generals: Leadership and Sacrifice in the American War of Independence by Steven E. Siry. Potomac Books (http://www.potomacbooksinc.com/), 22841 Quicksilver Drive, Dulles, Virginia 20166, 2012, 184 pages, $15.96 (hardcover), ISBN 978-1-59797-792-0.

Liberty's Fallen Generals is a detailed historical look at a group of generals who gave their lives to the cause of independence during the American Revolutionary War, a conflict laced with stories of the Founding Fathers and other larger-than-life figures. Author Steven Siry paints a picture of these lesser-known martyrs to the cause and shines the light of history onto the significance of their actions and sacrifice. He outlines his purpose in the preface as "a study of generalship, valor, and death" (p. xi) of the 10 men who died in combat from 1775 to 1781, introducing the reader to each general's military background, personal information, and the action that led to his death. Such a method may seem rather mundane, but Siry uses it artfully and masterfully.

His study represents an excellent resource for any serious student of America's foundations. This diverse, interesting group of generals spans the demographic spectrum of the colonies at the time. By presenting each man in chronological order of his death, Siry effectively clarifies the timeline of events—much more so than would a condensation of their lives into an overall history. The index makes the book a useful desk reference while the notes and bibliography lend it authority as they elaborate on general points. Clear citations and the aca-

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demic source material add to the study's appeal as an important part of any library on the Revolutionary War.

Unfortunately, one finds a significant amount of overlap in the background material for Siry's 10 subjects. Initially, he points out that many of these men were present at the same actions or came from similar origins. Given the set structure used for each of the chapters, reoccurring events appear in multiple sections, increasing the probability of confusing the subjects with each other or, worse, of becoming boring. This practice creates irregularity in the book and abruptness between chapters, making it seem more like a collection of essays on a single subject than an organized study. Nevertheless, *Liberty's Fallen Generals* is a well-done examination of an overlooked but fascinating topic.

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The Insurgents: David Petraeus and the Plot to Change the American Way of War by Fred Kaplan. Simon & Schuster (http://www.simonandschuster.com/), 1230 Avenue of the Americas, New York, New York 10020, 2013, 432 pages, $28.00 (hardcover), ISBN 978-1-4516-4263-6; 2014, 432 pages, $16.00 (trade paperback), ISBN 978-1-4516-4265-0.

Fred Kaplan's *The Insurgents*, a *New York Times* best seller, is the most comprehensive account yet of the reframing of American military strategy in Iraq and Afghanistan as counterinsurgency (COIN) campaigns. A masterful storyteller, Pulitzer prize–winning journalist, columnist for *Slate*, and an MIT PhD, the author is well versed in security studies, and in this case he has created a real page-turner. His previous publications include *The Wizards of Armageddon* (Simon & Schuster, 1983), a classic study of nuclear strategists and their theories.

Kaplan argues that David Petraeus and his fellow insurgents succeeded in changing the Army from an institution focused on fighting Cold War–style air-land battles against conventionally equipped uni-

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formed opponents to a more flexible force prepared to conduct wars among the people. The larger context is an Army that turned its back on COIN after Vietnam even though the United States engaged almost continuously throughout the 1990s in such places as northern and southern Iraq, Somalia, Haiti, Bosnia, and Kosovo. These engagements were euphemistically called military operations other than war (MOOTW). The prevailing ethos among top Army generals about such conflicts was that "real men don't do MOOTW," attributed to Gen John Shalikashvili, USA, chairman of the Joint Chiefs of Staff (p. 45).

Because of this prevailing ethos against MOOTW and Secretary of Defense Donald Rumsfeld's policy of transitioning responsibility as quickly as possible to the Iraqis, the revival of COIN thinking required a revolutionary movement or insurgency within the Army. Its center of gravity was a network of Soldier-scholars who, as captains and majors, had taught in either the Department of Social Sciences ("Sosh") or History at West Point. These officers kept alive the lessons of Vietnam and revolutionary warfare through their teachings. More importantly, they also developed bonds among themselves that would later enable them to become a critical mass for changing how the Army fought in Iraq and Afghanistan.

Authors David Cloud and Greg Jaffe advanced a similar thesis in *The Fourth Star: Four Generals and the Epic Struggle for the Future of the United States Army* (Three Rivers Press, 2009), which featured Gen Peter Chiarelli and Gen David Petraeus as Sosh alums spearheading a more enlightened strategy in Iraq, compared to that of Gen John Abizaid and Gen George Casey, who supported Secretary's Rumsfeld's policy of rapid transition. Kaplan's work picks up on this Sosh connection and expands it to tell a completer story about how the United States changed its strategy in Iraq and Afghanistan.

Kaplan's heroes are the network of warrior-scholars who taught at West Point. They include John Nagl, Petraeus's protégé, who earned a PhD at Oxford where he wrote *Learning to Eat Soup with a Knife: Counterinsurgency Lessons from Malaysia and Vietnam* (University of Chicago

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Press, 2005). His book was widely distributed by the Department of Defense and Army officials as things turned south in Iraq. Nagl would coauthor Field Manual (FM) 3-24, *Counterinsurgency*, 2006, the new COIN manual. H. R. McMaster, another Sosh alum, studied for his PhD at the University of North Carolina where he wrote *Dereliction of Duty: Lyndon Johnson, Robert McNamara, the Joint Chiefs of Staff, and the Lies That Led to Vietnam* (HarperCollins, 1997). The chairman of the Joint Chiefs of Staff, Gen Hugh Shelton, ordered all of the service chiefs to read it. Several other Sosh alums with PhDs, including some with equally impressive publications to their credit, constituted the movement's core.

Kaplan's study shows that the Army's program of sending promising captains to graduate school to earn PhDs followed by instructor duty at West Point has proven a wise investment. The Army seems to have broken the code on how to get these young officers back to qualifying operational assignments so that at least some—Petraeus is a case in point—progress to the top ranks and affect the course of events for the better.

Kaplan portrays Petraeus as a master at bureaucratic politics, which he learned from previous mentors. He adeptly exploited and expanded the Sosh network to include like-minded civilian academics, think tanks, and policy wonks as he orchestrated development of the new COIN doctrine. They became known as "COINdinistas." Kaplan does a remarkable job of tracing their influence as they build momentum for a new campaign strategy. As a result, efforts converge from different quarters supporting the appointment of Petraeus to implement it.

A strength of this work is Kaplan's ability to relate the richness and complexity of the historical case without overwhelming the reader. To his credit, he shows that COIN strategies were already being implemented in Iraq before the troop surge of 2007 and the publication of FM 3-24. McMaster's pacification of Tal Afar demonstrated this fact and set in motion a chain of events that would lead to the Anbar Awakening. The difference when Petraeus took charge, however, was a *campaign* establishing unity of effort on the COIN strategy throughout Iraq.

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Kaplan's identification of the central paradox of COIN campaigns is an important insight. The illegitimacy of the ruling elite causes insurgencies to exist in the first place. Yet, successful COIN campaigns require a legitimate host whose interests coincide with those of the intervener. Although the COIN approach produced stunning results in parts of Iraq and Afghanistan, the goal of stable, legitimate governments has not been achieved. The lesson is that COIN will probably not prove effective when the insurgents are out of reach, the government is too corrupt, or the intervening nation is unwilling to commit resources to a lengthy campaign.

Students of the art of war develop themselves by analyzing cases of challenge and response as well as the relationship between military theory and practice. Kaplan has a writer's knack for crafting these themes in a gripping way. Change begins with ideas and is therefore an intellectual endeavor. As Jimmy Doolittle said, "If we should have to fight, we should be prepared to do so from the neck up instead of from the neck down." *The Insurgents* is an excellent case study about the relationship among theory, doctrine, and institutional change.

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Building Toward an Unmanned Aircraft System Training Strategy

Bernard D. Rostker, Charles Nemfakos, Henry A. Leonard, Elliot Axelband, Abby Doll, Kimberly N. Hale, Brian McInnis, Richard Mesic, Daniel Tremblay, Roland J. Yardley, Stephanie Young

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NATIONAL SECURITY RESEARCH DIVISION

Building Toward an Unmanned Aircraft System Training Strategy

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Preface

During the most recent rounds of Base Closure and Realignment Commission activities in 2005, a significant number of training bases were closed. In light of the introduction of new technologies and the great expansion of unmanned aircraft systems (UASs) in the force, Department of Defense planners and some in Congress have become concerned that the existing training infrastructure—bases and their training support facilities—may not be adequate to train UAS air and ground components and the ground forces that use such equipment to capitalize fully on their capabilities. Accordingly, the Deputy Director, Readiness and Training Policy and Programs in the Office of the Under Secretary of Defense for Personnel and Readiness (OUSD [P&R]) asked the RAND Corporation to assess the adequacy of UAS training to support current and future requirements. In addition, the House Armed Services Committee report accompanying the Fiscal Year 2013 National Defense Appropriations Act raised a number of questions concerning training strategies with particular reference to the use of simulators to facilitate training.[1]

This report considers three issues: (1) the development of a general concept for UAS training in the context of current and anticipated future UAS inventories, (2) the development of an appropriate framework based on the general concept to address UAS training requirements, including the appropriate use of simulators, and (3) the airspace requirements necessary for UAS training. The research reported on here covers UASs in the Army, Navy, Air Force, and Marine Corps as fielded and plans as they existed during 2012. A RAND team carried out extensive field visits to understand the current ability of the services to conduct (1) service-specific training and (2) joint training at both home station and joint training facilities. The research will be of interest to those concerned with UAS programs and operations; joint training; or more generally, the incorporation of disruptive technologies into Department of Defense programs and operations.

This research was sponsored by the OUSD (P&R) Directorate for Training and Readiness Policy and Programs, in coordination with the Joint Forces Command's Joint Warfighting Center and the Joint Unmanned Aircraft Systems Center of Excellence. The research was conducted within the Forces and Resources Policy Center of the RAND National Defense Research Institute (NDRI), a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the Defense Intelligence Community. For

[1] House Armed Services Committee, *Conference Report Accompanying the Fiscal Year 2013 National Defense Appropriations Act*, 112th Cong., 2nd Sess., December 17, 2012, p. 136.

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Summary

Unmanned aircraft systems (UASs) have become increasingly prevalent in and important to U.S. military operations. The number of systems has surged, as has the slice of the defense budget allocated to them. Roles have also changed. Initially employed only as reconnaissance or intelligence platforms, they now carry out other missions, including attacking enemy forces. Successful operational tests and demonstrations of the expanded range of UAS capabilities have led to rapid fielding of new systems, often placing unanticipated demands on logistics and training systems and on field commanders to employ new systems effectively. UASs must now be integrated into the training programs of the services. Building a responsive, effective, and efficient UAS training program is a challenge during times of reduced budgets. Any new program must be based on a review of existing training capabilities and new investments across the services.

Focus of this Research

The Deputy Director, Readiness and Training Policy and Programs, in the Office of the Under Secretary of Defense for Personnel and Readiness (OUSD [P&R]) asked the RAND National Defense Research Institute (NDRI) to assess the adequacy of UAS training to support current and future requirements. Proposals to resolve service and joint UAS training issues must be informed by a clear understanding of current problems, opportunities for correction, and associated costs and benefits of the corrections. In this report, we address a number of issues, including (1) a general concept for UAS training; (2) an appropriate framework to address UAS training requirements, including the use of simulators; and (3) the limitations of the infrastructure to accommodate UAS training, including those due to national airspace restrictions. The research considers UASs in the Army, Navy, Air Force, and Marine Corps, both those that are currently fielded and those that were planned to be fielded as of 2012.

Disruptive Technologies and Acquisition Processes

In 1995, Clayton Christensen introduced the term *disruptive technology*, distinguishing it from what he termed *sustaining technology*. In his nomenclature, a sustaining technology improves the performance of an existing system and does not require significant structural adjustments to processes, organizations, or operational paradigms. Disruptive technologies, however, change the way a business operates. The UAS is a disruptive technology.

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UASs found their way into the force by means of rapid acquisition procedures that were designed to deliver new technologies to the warfighter much faster than traditional procedures could, but often at the cost of not having in place the support these new systems required to become a sustained part of the force structure. Because of the rapid acquisition of these systems, the services have had to rely upon contractor support in ways that are inconsistent with the full and sustaining integration of these systems into service inventories. Such integration starts with the development of an appropriate concept for training.

Training Concepts and Frameworks

We will begin by discussing the general ideas that should guide UAS training—the training *concept*. Then, we will consider how the parts identified in the concept fit together into a conceptual structure for that training—a training *framework* designed to enhance combat power and other operational capabilities.

Joint Operations; Multiservice Tactics, Techniques, and Procedures; and UAS Training

Military operations today are usually referred to as *joint operations*, emphasizing the interdependence of the services. That might lead one to think that joint doctrine; joint concepts of operation; and joint tactics, techniques, and procedures would provide focus for training. Clearly, training does not take place for its own sake; it should be driven by doctrine. In his cover letter to Joint Publication 3-0, 2011, ADM Mike Mullen stated that it established "the framework for our forces' ability to fight as a joint team," but nowhere does it discuss the management of UASs. Moreover, nowhere in any other joint publication is there a grand doctrine for the employment or management of UASs on the battlefield. While the services have agreed to a set of multiservice tactics, techniques, and procedures (MTTPs) to be incorporated into their respective training programs, note the use of *multiservice* rather than *joint*.

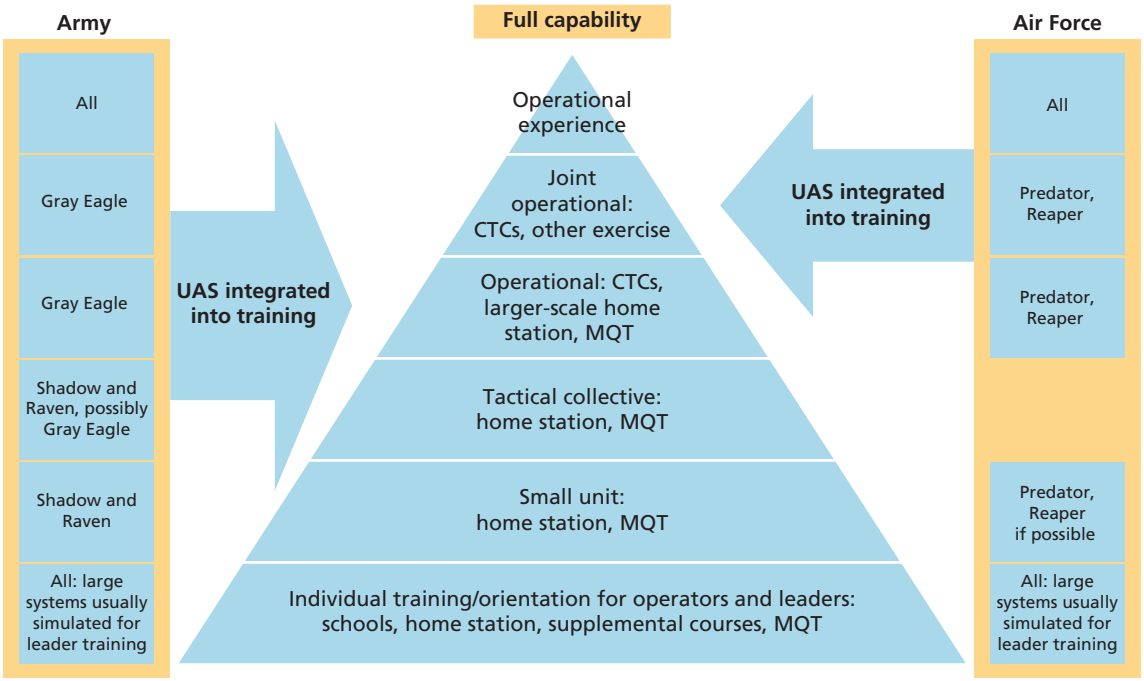
At least for the foreseeable future, each service will continue to field UASs and must bring to the fight forces fully capable of operating them and integrating their capabilities into operations. While grand doctrinal issues remain unresolved, common procedures agreed to and trained by the services will remain the foundation on which American military operations must be built. In this way, rather than being the foundation for UAS training, joint operations are the goal of such training, which must be firmly grounded on the UAS training each service gives both its supported and supporting units.

The general concept we advance for UAS training here rests on the notion that the greatest beneficial effect—that is, an increase in the force's operational effectiveness—occurs with a synergy among the UAS platforms, those who operate them, and those who integrate them into combat operations. While the report considers training concepts for ground, air, and sea forces, they share a common framework. Figure S.1 depicts our framework for ground and air forces; the one for naval forces is similar.

The concept underpinning the framework calls for increasing integration of its several parts as the level of training moves up the pyramid. Army systems appear on the left, Air Force on the right. At the bottom, training begins with individual training for operators and leaders, grounding each group in the basics of the system. Training then progresses to the small unit level, which, as with individual training, is largely done at home station. Moving up the pyramid, training occurs at increasingly higher echelons, battalion and brigade. Moving to joint

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Figure S.1
UAS Training Framework



RAND *RR440-S.1*

operations involves Air Force units, which have gone through a similar process of progressive training. They join together in exercises, many of which are conducted at the large combat training centers (CTCs), to integrate close air support and Air Force UASs into the ground maneuver plan.

Assessment of the State of UAS Training in 2012: Service and Interoperability Training and the Role of Simulators

Service Training

Speaking generally, the services have been relatively effective at training the individual skills required to operate and maintain the UASs, although the services differ in their approaches. The Army, which tends to use enlisted personnel to staff its UAS units, has developed courses that award Military Occupational Specialties for the operators and maintainers for its Shadow and Gray Eagle systems. Training for the Raven UAS, which is about the size of a large model airplane and is used to support lower-echelon units, is a unit responsibility carried out through a "train-the-trainer" concept. The Marines use officers who are qualified aviators or aviation command and control officers as pilots, and enlisted personnel operate the payloads. The Air Force pilots are officers and are either rated pilots who graduated from pilot training or UAS-only pilots who graduated from a program designed specifically for flying UASs. Sensor operators for Reaper and Predator are either trained into a new career field or cross-trained from another Air Force Specialty Code. Those for Global Hawk come from the imagery analyst

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career field. Maintenance personnel come through the Air Force's maintenance education and training programs.

The more challenging part of the training comes at the integration level, where UAS personnel must meld their efforts with those of ground combat units. This occurs within and between services. Integration requires substantial practice under realistic conditions that do not occur frequently. Rotations at a CTC are often the only occasions, short of actual operations in theater, in which commanders face the challenge of integrating all battlefield operating systems at once, and the addition of the UASs necessarily complicates synchronization and integration tasks. Thus, it is not surprising that initial assessments of UASs during integrated training are, at best, mixed.

The key concerns of UAS units tend to be similar across services. For ground and Air Force units, the concerns are beddown and support facilities, airspace limitations, and simulators. Many of the beddown and support issues can be resolved with relatively minor construction. Some airspace issues, however, are not likely to improve. The Navy has airspace issues at specific installations but generally faces fewer restrictions because it can operate outside the 12-mile coastal limit with relative freedom.

Interoperability Training

To date, interoperability training at the National Training Center (NTC) and the Joint Readiness Training Center has been limited. The Government Accountability Office (GAO) has cited two significant challenges for improved interoperability training: (1) "establishing effective partnerships with program stakeholders through comprehensive communication and coordination and (2) developing joint training requirements that meet combatant commanders' needs," with particular emphasis on tactical-level training (GAO, 2005, p. 2).[1] To meet this challenge, the Department of Defense (DoD) established an implementation plan that gives the Office of the Under Secretary of Defense for Personnel and Readiness overall responsibility and the Deputy Under Secretary of Defense for Readiness executive agent responsibility for training transformation planning, programming, budgeting, and execution progress.[2]

While RAND did not assess interoperability training in detail, our discussions with the training community, including trainers at the NTC, suggest that such training opportunities have been limited because Air Force assets, particularly the Predator, have generally been unavailable due to pressing operational requirements in Iraq and Afghanistan. This same general observation was also reported by the GAO (2010b, p. 26). The problem of transiting Air Force UASs from Creech Air Force Base, Nevada, to the NTC at Fort Irwin, California, through Federal Aviation Administration–controlled airspace is often cited. Permanently stationing Air Force UAVs at the NTC, much as the Marine Corps has done by stationing Shadow UAS squadrons at the Marine Corps Air Ground Combat Center at Twentynine Palms, California, to support training there, would of course negate that problem. However, the experience of the Marine Corps suggests that the mere presence of UASs will not ensure

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[1] GAO, 2005, p. 18, noted that,

> [i]n the past, joint training tasks were primarily focused at the command level and were identified through DOD's authoritative processes that built requirements by translating combatant commander inputs into training requirements. Training transformation has expanded joint training requirements to include those at the tactical level in addition to joint command-level training.

[2] See Director, Readiness and Training Policy and Programs, 2006.

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that the forces are properly trained. The forces must be prepared for such training at their home stations. In addition, given the common MTTP, forces trained to operate with their own service UASs should find working with UASs from the other services less challenging.

Simulators

Congress has pressed for information on the role simulators might play in a UAS training strategy, seeking an "informed balance between live training and simulated training."[3] But the conditions that make a compelling case for using simulators in the training of fighter pilots are largely absent when it comes to UAS training:

1. UAS flying hours are much less expensive than flying hours for manned aircraft.
2. The kinds of operational activities that need more training emphasis, in particular air-ground coordination, are generally not activities for which simulators per se can substitute for live flying.
3. While simulators are an inherent part of the systems used for initial training of pilots and sensor operators,[4] they are not well suited (and not designed) for training operating forces on the full spectrum of UAS capabilities.
4. At best, simulators complement rather than substitute for live training. Given the current state of the fielding of UAS, first priority must be given to building the live flying infrastructure. Then, and only then, might funds be used to undertake the research and development that must precede any consideration of fielding the kind of interactive UAS air-ground simulators that could train both UAS crews and ground troops.

We concluded that, given current budget limitations and the importance of fully developing the opportunities for live training and the relatively low cost of such training, diverting funds to develop higher fidelity UAS-ground simulators would be unwise at this time. However, the Army's air-ground integration ranges provide a good example of judicious use of simulators to do what simulators do best—in this case, scoring target hits without using expensive live munitions and without blowing up fairly expensive targets. In the future, the services should reevaluate the need for virtual training based on a cost and effectiveness analysis (COEA) that includes developmental costs for simulators, savings based on the costs of flying UASs, and the critical availability of air space for training.

Implications and Recommendations

The Guiding Principle: "Train As We Fight"

DoD has been under some pressure from the Congress and such organizations as the General Accountability Office for the lack of central control and the lack of the development of joint DoD strategy for training. In reality, the services continue to develop UAS training initiatives primarily to meet their own unique requirements, and the opportunity for joint training is limited. Progress has, however, been made with the development of the MTTP and the recognition that interoperability training is a service responsibility. For now, DoD should encourage

[3] See, for example, Chairman, House Armed Services Committee, undated.

[4] See Shawn Johnson, UAS cost per flying hours, personal communication, April 10, 2013.

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each service to solve its own UAS training problems, not constrain any one service under the guise of joint training. Given strong service programs, there will be ample opportunity to focus on joint training in the future, when the opportunity presents itself. Today, however, the services are still struggling with how to incorporate these new systems. The appropriate strategy for UAS training is to insist that the services train as they will fight. Accordingly, to *train as we fight* in the future, DoD training strategy must

- engender better appreciation of UAS capabilities throughout the chain of command
- address organizational, structural, and infrastructure and support issues
- enable "train as we fight" in collective unit training
- enable "train as we fight" in exercises.

Initiatives with Near-Term Payoff

To accomplish these goals, a number of initiatives should pay off in the near term, including

1. increasing exposure to the capabilities and limitations of UASs
2. harnessing the lessons-learned process to guide the development of service and joint doctrine and tactics, techniques, and procedures
3. addressing well-known but underresourced training infrastructure shortfalls.

Institutionalize Training for UAS Capabilities Over the Longer Term

Institutionalization will require more-general efforts, including

1. acculturation (Many end users do not yet have a well-developed appreciation of UAS capabilities.)
2. development of a cadre of UAS professionals with hands-on experience in all echelons of UAS operation
3. integration of UASs into service force structures
4. adaptation, including
   a. accounting for the evolution of the roles of UASs in the full range of military operations
   b. continuous resolution of UAS doctrinal issues.

Summary of Findings and Recommendations

The findings and recommendations are summarized below:

1. The proper strategy for DoD at this time is to encourage each service to solve its own UAS training problems, rather than to constrain any one of them under the guise of joint operations.
2. DoD should support current and future programs to develop ranges and beddown and support facilities similar to those in the Army's current programs.
3. In spite of the demands of deploying units and sustaining combat operations in Afghanistan, Army trainers indicate that Army units are better at maintaining qualification for Shadows than for Ravens. Nevertheless, not all units have been able to maintain high

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Shadow qualification rates—some units arrive at the NTC with one-half or fewer of their operators qualified.

4. If joint training becomes a priority, the Air Force's current basing and beddown posture will become a problem. The Air Force could consider the location of Army hubs when choosing where to base its UAS fleet. A location that is near Army maneuver elements might make airspace access less of a restriction or at least make certificates of authorization more practical. Proximity might provide more opportunities for training UAS integration throughout the entire mission planning process.
5. Given current budget limitations and the importance of fully developing the opportunities for live training and the relatively low cost of such training, diverting funds to a research and development program to develop higher-fidelity simulators would seem to be unwise at this time.

Path to the Future

This report presents and discusses a multitude of means for setting up UAS training strategies for success, including supporting ongoing facilities and basing initiatives; expanding such facilities, where possible, to enable wider availability of UASs to support collective training; and increasing the use of UASs—the complete UAS package, including joint tactical air controllers and other coordinating elements—in collective training, both local and in larger exercises. We have noted the need to support continuing efforts to resolve airspace access issues, observing as we did so that there are ways to keep such restrictions from imposing serious limitations on much of the UAS training envisioned here. Similarly, we have discussed the potential for simulators to add value in training, now and perhaps more in the future. But we have also cautioned that simulators in their current state are not a good substitute for live use of UASs in collective training.

The path to the future for UAS strategies starts now, with support for ongoing initiatives that will continue the trends toward better training integration, thus improving the ability of end users to employ the multiple capabilities of UASs in their operations. The path continues, using that foundation, with longer-term efforts to add to acculturation of end users, professionalization of the UAS community, and integration of the two to harmonize the capabilities of UASs as key elements of overall force effectiveness.

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Acknowledgments

The research presented here is the result of numerous field visits and discussions with members of service and department staffs in the Pentagon, commanders and operations staffs in operational arms of all the services, planners and training developers in service training commands, trainers and staffs at the various combat training centers, students in UAS operator schools, and UAS operators. So many shared information and data and providing thoughtful comments, advice, and insights that it is impossible to single out anyone without possibly slighting someone else. Moreover, the views expressed in this report are our own and should not be attributed to any individual or organization.

We would be remiss, however, if we did not recognize the support we received from Frank DiGiovanni, Director of Training Readiness and Strategy in the Office of the Under Secretary of Defense (Personnel and Readiness), and Joan Vandervort, our project coordinator in Mr. DiGiovanni's Office. Their commitment to developing an appropriate training strategy for UASs was the driving force behind this study.

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Abbreviations

ABSAA	airborne sense-and-avoid
ACA	airspace control authority
ACO	airspace control order
ACTD	advanced concept technology demonstration
AECV	All-Environment Capable Variant
AFB	Air Force base
AFSC	Air Force specialty code
ALO	air liaison officer
AMB	air mission brief
AMPS	Aviation Mission Planning System
ARB	Air Reserve base
ATO	air tasking order
AVO	air vehicle operator
BAM	broad area maritime
BAMS-D	Broad Area Maritime Surveillance–Demonstrator
C2	command and control
CAOC	combined air operations center
CAP	combat air patrol
CAS	close air support
CCDR	combatant commander
COA	certificate of authorization
COCOM	combatant commander

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CONUS	continental United States
CSG	carrier strike group
CTC	combat training center
DAS	Defense Acquisition System
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director of Defense Research and Engineering
DoD	Department of Defense
DSB	Defense Science Board
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FRS	fleet replacement squadron
FTU	formal training unit
FY	fiscal year
GAO	Government Accountability Office
GBSAA	ground-based sense-and-avoid
IQT	initial qualification training
ISR	intelligence, surveillance, and reconnaissance
JBLM	Joint Base Lewis-McChord
JFACC	joint force air component commander
JFC	joint force commander
JFCOM	Joint Forces Command
JIEDDO	Joint Improvised Explosive Device Defeat Organization
JRAC	Joint Rapid Acquisition Cell
JTAC	joint tactical air controller
LAA	limited acquisition authority
LCS	littoral combat ship
LRE	launch and recovery element
MCAGCC	Marine Corps Air Ground Combat Center
MCS	mission control system

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MOS	military occupation specialties
MPO	mission payload operators
MTTP	mulltiservice tactics, techniques, and procedures
MQ-8B	Fire Scout
MQT	mission qualification training
NAS	National Airspace System
NCTE	Naval Continuous Training Environment
NDRI	RAND National Defense Research Institute
NTC	National Training Center
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
PACOM	U.S. Pacific Command
PPBE	Planning, Programming, Budgeting, and Execution
REF	Rapid Equipping Force
RSTA	reconnaissance, surveillance, and target acquisition
RPA	remotely piloted aircraft
SOCOM	Special Operations Command
SOF	special operations forces
SOUTHCOM	U.S. Southern Command
SPINS	special instructions
SUAS	small unmanned aircraft system
TACP	tactical air control party
TEMF	tactical equipment maintenance facility
TF	task force
TRADOC	Training and Doctrine Command
UAS	unmanned aircraft system
UAV	unmanned aerial vehicle
UGS	Unmanned Ground School (Ft. Huachuca)
USD (AT&L)	Under Secretary of Defense (Acquisition, Technology, and Logistics)

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USMC	U.S. Marine Corps
WSMR	White Sands Missile Range
YTC	Yakima Training Center

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CHAPTER ONE

Introduction

UASs Play an Increasing Role on the Battlefield

During the last decade, in large part because of the dynamic nature of operations during Operation Enduring Freedom and Operation Iraqi Freedom, recognition of the importance of developing new capabilities to meet the ever-changing threats our military forces face has grown. As a result, the Department of Defense (DoD) has undertaken operational and technology demonstration projects to test new technologies and systems outside the traditional acquisition process. Many of these systems involve unmanned vehicles and some unmanned aircraft systems (UASs). In 2000, the DoD had fewer than 50 unmanned aircraft in its inventory; by 2012, it had more than 7,100, as shown in Table 1.1 (Gertler, 2012).[1] The size of the Department's investment in these systems today similarly dwarfs prewar levels. In 2000, the DoD spent $284 million on UASs, while the 2010 budget for UASs has grown to over $6.1 billion (GAO, 2010a, p. 1). Figure 1.1 shows the growth of UASs from 1988 to 2013. Figure 1.2 shows projected growth in UAS programs as of 2012.

UASs have two main advantages over manned aircraft: They eliminate the risk to a pilot's life, and they provide capabilities not subject to human limitations. They are also cheaper to procure and operate than manned aircraft. While they minimize risk to operational crews, they introduce new complications and hazards not associated with manned aircraft. While some think of UASs simply as a substitute for manned aircraft, UASs increasingly complement manned aircraft, providing new capabilities for the force to utilize. Combined UAS and helicopter operations are but one example (McLeary, 2012).

Originally, UASs were used to gather intelligence. During the Vietnam War, drones flew strategic reconnaissance missions over denied areas. The Israeli Air Force successfully used UASs during operations in Lebanon in 1982 and for many years led the world in developing UASs and tactics for employment. Subsequently, longer-endurance systems introduced the ability to maintain surveillance on distant and moving targets. More recently, UASs originally designed for reconnaissance have been modified to carry precision-guided weapons to attack ground targets, greatly expanding the role such systems play on the modern battlefield. This also has expanded and complicated the training of UAS crews as full participants in the joint and combined arms battle.

Successful operational tests and demonstrations of the expanded range of UAS capabilities have led to rapid fielding of new systems, often placing unanticipated demands on logistics

[1] See Appendix A for descriptions of the major systems.

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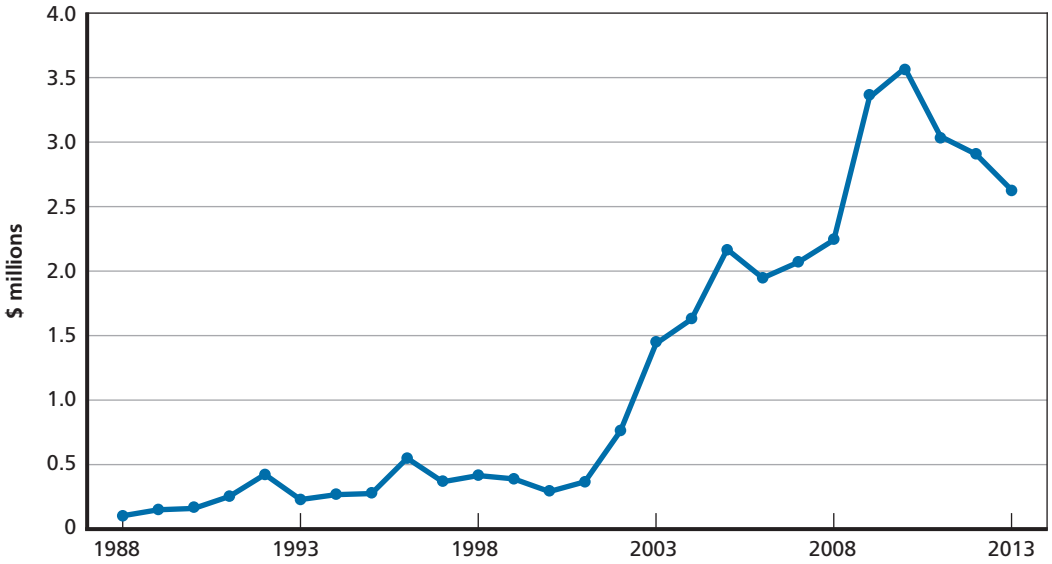
Table 1.1
DoD UAS Platforms as of 2011

Name	Vehicles	Ground Control Stations	Employing Service(s)	Capability/Mission
RQ-4A Global Hawk/ BAMS-D Block 10	9	3	USAF Navy	ISR Maritime domain awareness (Navy)
RQ-4B Global Hawk Block 20/30	15	3	USAF	ISR
RQ-4B Global Hawk Block 40	1	1	USAF	ISR Battle management command and control
MQ-9 Reaper	54	61	USAF	ISR RSTA EW Precision strike Force protection
MQ-1A/B Predator	161	61	USAF	ISR RSTA Precision strike Force protection (MQ-1C Only-C3/LG)
MQ-1 Warrior/MQ-1C Gray Eagle	26	24	Army	ISR RSTA Precision strike /force protection (MQ-1C Only-C3/LG)
UCAS-D	2	0	Navy	Demonstration Only
MQ-8B Fire Scout vertical takeoff and landing tactical UAV	9	7	Navy	ISR RSTA Antisubmarine warfare Antisurface warfare Mine warfare Organic mine countermeasures
MQ-5 Hunter	25	16	Army	ISR RSTA Battle damage assessment
RQ-7 Shadow	364	262	Army USMC SOCOM	ISR RSTA Battle damage assessment
A160T Hummingbird	8	3	SOCOM DARPA Army	Demonstration
Small tactical UASs	0	0	Navy USMC	ISR Explosive ordnance disposal Force protection
ScanEagle	122	39	Navy SOCOM	ISR RSTA Force protection
RQ-11 Raven	5,346	3,291	Army Navy SOCOM	ISR RSTA
Wasp	916	323	USMC SOCOM	ISR RSTA
SUAS AECV Puma	39	26	SOCOM	ISR RSTA
Gasoline-powered micro air vehicle (gMAV) T-Hawk	377	194	Army (gMAV) Navy (T-Hawk)	ISR RSTA Explosive ordnance disposal

SOURCE: Gertler, 2012, p. 8.

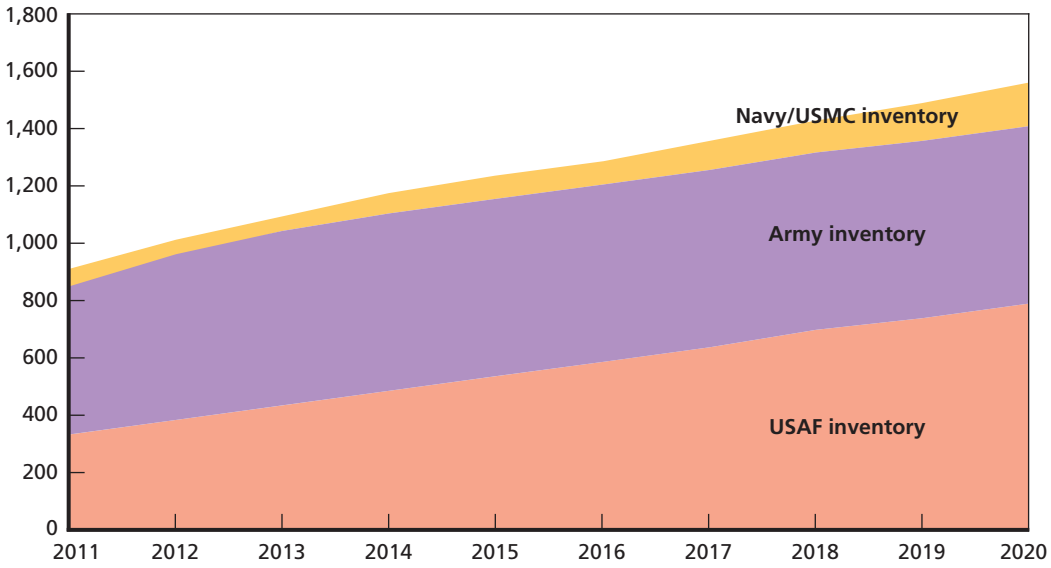
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Figure 1.1
UAS Budgets from 1988 to 2013



SOURCE: Gertler, 2012, p. 14.
RAND *RR440-1.1*

Figure 1.2
DoD Inventories for Medium and Large Unmanned Aircraft



SOURCE: Kempinski, B. (2011, Tables 1-2,1-3,1-4). Policy Options for Unmanned Aircraft Systems, Congressional Budget Office.
RAND *RR440-1.2*

and training systems and on field commanders to employ the new systems effectively. UASs must now be integrated into the training programs of the services.

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Building a responsive, effective, and efficient UAS training program is a challenge in a time of reduced budgets. Any new program must be based on a review of existing training capabilities and new investments across the services.

Integrating UASs into the core operations of the DoD presents the kinds of special problems that are common when new technologies appear and clash with existing ways of doing business. Such clashes happen frequently enough that there is a term for such innovations: disruptive technologies. The rapid introduction of UASs into operations in operations Enduring Freedom and Iraqi Freedom and the attendant force structure growth have presented just such challenges (as discussed in Chapter Two). The resulting disruption has contributed to lags in the ability of joint doctrine, tactics, techniques, and procedures (TTP) to keep pace and in the ability of joint training[2] and service-specific managers to develop and execute training programs.[3]

Focus and Approach of this Research

The Deputy Director, Readiness and Training Policy and Programs in the Office of the Under Secretary of Defense for Personnel and Readiness asked RAND to assess the adequacy of UAS training to support current and future requirements. Proposals to resolve service and joint UAS training issues must be informed by a clear understanding of current problems, opportunities for correction, and associated costs and benefits of the corrections. In addition, the current extraordinary pressures on the overall federal budget, including the defense "top line," and the ongoing review of U.S. strategy will likely have implications for force structure and basing, resulting in a number of yet-unknown factors that could profoundly affect the future of UAS programs. These uncertainties notwithstanding, a number of issues must be addressed: (1) a general concept for UAS training; (2) an appropriate framework for addressing UAS training requirements, including the use of simulators; and (3) the airspace requirements necessary for UAS training.

The research reported on here covers UASs in the Army, Navy, Air Force, and Marine Corps as fielded and plans as they existed in 2012. Because of the increasing use of these unmanned systems to support to ground operations, the RAND effort has more closely examined the interface between UASs and operating elements of ground forces. To this end, a team from RAND carried out extensive field visits to understand the current ability of the services to conduct (1) service-specific training and (2) joint training at both home station and joint train-

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[2] Department of Defense Directive 1322.18, January 13, 2009, defines joint training as "Training, including mission rehearsals, of individuals, units, and staffs using joint doctrine or tactics, techniques, and procedures to prepare joint forces or joint staffs to respond to strategic, operational, or tactical requirements that the Combatant Commanders (CCDRs) consider necessary to execute their assigned or anticipated missions."

[3] Chairman of the Joint Chiefs of Staff Instruction 3500.01G, March 15, 2012, p. C-2, defines service training as follows:

> Service Training: Service Active Component (AC) and RC training (including USSOCOM) is based on joint and Service policy and doctrine. Service training includes basic, technical, operational, and interoperability training to both individuals and units in response to operational requirements identified by the CCDRs to execute their assigned missions.
>
> Joint Training. Training, including mission rehearsals, of individuals, staffs, and units, using joint doctrine and tactics, techniques, and procedures, to prepare joint forces or joint staffs to respond to strategic, operational, or tactical requirements considered necessary by the CCDRs to execute their assigned or anticipated missions.

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ing facilities. Members of the team interviewed officials involved with UAS training operations at the following Army, Navy, Air Force, and Marine installations and units:

- Beale Air Force Base (AFB), California
  - Global Hawk operations and Distributed Common Ground Station 2
- March Air Reserve Base (ARB), California
  - Air Force National Guard Ground Control Station school
- Holloman AFB, New Mexico
  - (Air Force Predator and Reaper training)
- Fort Irwin, California
  - (Air Force training support unit and selected individuals from the operations group)
- Creech AFB, Nevada
  - (the Joint Unmanned Aircraft Systems Center of Excellence and the operational UAS wing)
- Fort Rucker, Alabama
  - Training and Doctrine Command (TRADOC) capability manager for UASs
- Fort Huachuca, Arizona
  - TRADOC Capability Manager for Intelligence Sensors and the UAS Training Battalion
- Fort Benning, Georgia
  - Maneuver Center of Excellence
- Fort Campbell, Kentucky
  - 101st Airborne Division (Air Assault)
- Marine Corps Base Twentynine Palms, California
  - Marine Corps Air Ground Combat Center (MCAGCC) and two of three active U.S. Marine Corps (USMC) UAS squadrons
- Naval Air Station Patuxent River, Maryland
  - Naval Air Systems Command (Navy and Marine Corps)
- Fort Eustis, Virginia
  - TRADOC Capability Manager for Live Fire Training, Army Capabilities Integration Center, and TRADOC G-3
- North Island Naval Base, San Diego, California
  - Commander, Naval Air Forces.

In addition, the RAND team had extensive discussions with the strategy and planning staffs at U.S. Pacific Command (PACOM) and U.S. Navy Pacific Command concerning rapid acquisition of new technologies, such as the UASs reported on here. In that process, the RAND team gained important insights into the challenges the services face, first in identifying new or disruptive technologies and then in using operational demonstrations or experiments to understand and develop the changes to operational concepts that these technologies would drive.

During these visits, the RAND team talked with operators and support personnel; those who train operators and associated members of the team; those who train and observe the forces that employ UASs in their operations; staff elements concerned with the planning and resourcing of training, both for UAS operators and for the force more generally; and those concerned with the ongoing development of doctrine and concepts of operations for UASs, including their integration into operations.

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Plan for the Report

Chapter Two starts the report with a discussion of disruptive technologies, rapid acquisition processes, and the challenges the DoD faces in integrating UASs into the operations of the military departments. Chapter Three presents a general concept and a framework for training focused on the integration of UASs into military operations. Using the framework, the assessment in Chapter Four considers the current ability of the services to conduct service-specific training at both home station and joint training facilities. This includes a compilation of observations and insights largely gained during our visits to the bases listed above, with our interpretation of their implications for the specification and resourcing of training strategies. Finally, Chapter Five summarizes our research and looks toward the evolving training strategy for DoD in the future. The appendixes present additional material, including a description of ongoing systems, a further discussion of the Defense Acquisition System (DAS), UAS descriptions, and infrastructure considerations and the results of a RAND assessment of training infrastructure.

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CHAPTER TWO

The Case for and Implications of Unmanned Aircraft Systems Being a "Disruptive Technology"

Over decades, DoD has developed a structured and deliberate approach for the way it acquires new systems, which is formalized in the DAS and the 5000 series of DoD instructions. However, the exigencies of recent military operations have led DoD to develop new technology and acquire and field new systems without going through the steps the defense acquisition process generally requires. While near-term requirements drove such acquisition decisions, these decisions have long-term consequences. Rapid acquisition without a fully developed plan for how the new systems will be sustained over time may well diminish operational effectiveness. A potent example of such an effect is the extent to which the rapid and large-scale introduction of UASs has outpaced investments in the training infrastructure necessary to support the associated operation and maintenance. In the future, personnel will not be able to use or maintain the new systems properly. The Defense Science Board (DSB) made this point forcefully in 2003: "(1) military proficiency is as dependent on the warriors who operate weapon systems as it is on the weapon system technology, and (2) a superb way to waste personnel or system acquisition money is to ignore training" (DSB, 2003, p. 2). Despite the inefficiency of poorly coordinated investments, the DSB found that "systems continue to be created and then fielded with little consideration for the costs that must be incurred during the life cycle to train the weapon's users" (DSB, 2003, p. 44). As it turns out, the difficulty of incorporating new technologies into existing operations and processes is not unusual. It happens frequently enough that there is a term for such innovations: *disruptive technologies*.

The Disruptive Technology Experience in the Business Community

Clayton Christensen introduced the term *disruptive technology* in 1995. He distinguished disruptive technology from what he termed *sustaining technology*. In his nomenclature, a sustaining technology improves the performance of an existing system and does not require significant structural adjustments to processes, organizations, or operational paradigms. Disruptive technologies, however, change the way a business operates (Govindarajan, Kapalle, and Daneels, 2011).

Since the concept was first introduced, a number of studies have focused on ways that enable an organization to incorporate disruptive technologies. Christensen found that many organizations fail to meet the challenges disruptive technologies pose because they focus only on costs and not on how the new technologies change business processes and create new values for customers (Christensen and Overdorf, 2000). As Christensen used the term, *pro-*

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cesses include the coordination, communication, decisionmaking, and interaction patterns that transform resources into a product. Under normal conditions, processes are stable. They are designed not to be easy to change, and this inertia can impede the adoption and exploitation of emerging disruptive technology (Looy, Martens, and Debackere, 2005). Tellis makes the point that, given limited resources, investments in unfamiliar technologies with unproven returns are opposed because they are seen as "cannibalizing" both resources and customers from established products (Tellis, 2006). Because it is often difficult to introduce such new technologies into existing business units, much of the literature discusses how "spinout" organizations were created to nurture these new technologies (e.g., Henderson and Clark, 1990). For example, in a study of several game-changing technological developments, te Kulve and Smit, 2010, found that successful new product lines usually had a "champion" with "dedicated change strategies" to further the introduction of disruptive technologies.

Unmanned Aircraft Systems: A Case of Disruptive Technology for the Department of Defense

Although DoD operates in a different environment with different incentive structures from those of the business community, it is not immune to the difficulties disruptive technologies have introduced in the private sector.[1] From DoD's perspective, a technology is disruptive when it has the potential to alter the scope and effectiveness of military operations dramatically and is applied in sufficiently large numbers that it can no longer be supported in the same manner as during its initial development (i.e., the military must incorporate its support into its standard logistics and training systems). The UAS qualifies as a disruptive technology on multiple counts. First, as Christensen notes, the advent of the UAS changed the way the U.S. military operated, that is, its "business processes" changed. Second, UASs have broadened the scope of military operations substantially and greatly enhanced the effectiveness of both intelligence processes and strike operations. Finally, they have arrived in sufficient numbers that they now need to be integrated into the standard processes.

As the U.S. went to war in Afghanistan and Iraq, concern grew about the lack of speed and responsiveness in the traditional process for getting new systems into the hands of warfighters.[2] Critics complained about bureaucratic processes that make the traditional system too slow and too risk averse to acquire and field effective solutions rapidly.[3] As late in the conflicts as 2008, Secretary of Defense Robert Gates expressed frustration with the defense bureaucracy, arguing "we must not be so preoccupied with preparing for future conventional and

[1] There are numerous examples of disruptive technologies and how they displaced formerly dominant technologies in both the private sector and the military: Just a few examples are commercial airlines displacing passenger trains, internal-combustion-engine vehicles replacing horse-drawn vehicles, aircraft carriers replacing battleships as the Navy's capital ship, and tanks replacing cavalry.

[2] Appendix B describes DoD's traditional acquisition system.

[3] For example, Lt. General Robert P. Lennox, the Army's Deputy Chief of Staff for Programs and Resources, explained, "This is one of our most common topics of conversation: How do we rapidly field capabilities when technology advances so quickly?" (quoted in Erwin, 2010).

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strategic conflicts that we neglect to provide both short-term and long-term all the capabilities necessary to fight and win conflicts such as we are in today."[4]

A Challenge to the Traditional Acquisition System

The virtues of the deliberate and structured traditional acquisition system must be weighed against the fact that the system can take years to field new capabilities. From requirements generation through the DAS and the Planning, Programming, Budgeting, and Execution (PPBE) process, the traditional acquisition system generally takes several years to meet materiel warfighter needs; some systems can take decades (GAO, 2010b). While this long time frame makes some sense for large and complex programs of record, it poses a significant challenge when required capabilities are needed more quickly or are focused more narrowly. This lack of responsiveness has led some observers to argue that the traditional system is not optimized for delivering the full spectrum of desired capabilities. While the system should, in theory, be adaptable for both small and large acquisition programs, it works best in practice for major defense acquisition programs. However, much recent acquisition activity has not been in the form of large programs of record that entail the institutional backing necessary for proper sustainment strategies. The fast rate and large volume demanded for unfamiliar technologies, in particular, have strained the system and pressured traditional acquisition relationships to change.

Rapid Acquisition Programs Met the Challenge

To meet an urgent demand to incorporate new technologies, a series of acquisition processes was created outside the traditional acquisition process and was unencumbered by the prior restrictions designed to mitigate cost, capability, and schedule risk. Unfortunately, while these "workarounds" fostered the fielding of numerous systems, they generally neglected to provide for the institutional sustainment—training and logistical support—needed to facilitate introducing these systems into the force on any basis other than as technology demonstrations. Figure 2.1 captures the proliferation of a selection of these rapid acquisition processes. Below, we discuss several of the more important ones.

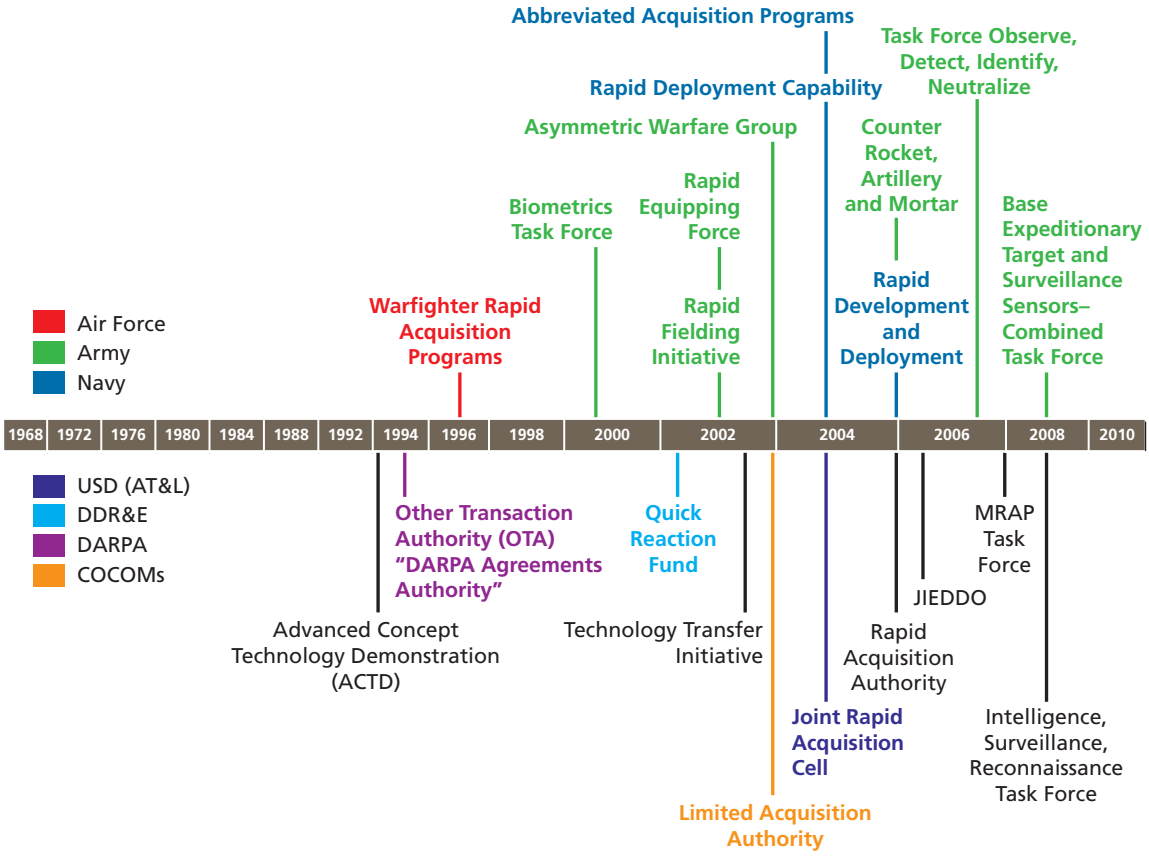
Advanced Concept Technology Demonstration

In 1994, in response to recommendations from the Packard Commission and the DSB, DoD introduced the advanced concept technology demonstration (ACTD) (Drezner, Sommer, and Leonard, 1999, p. 23). The Global Hawk UAS, which has found broad applicability in the wars in Iraq and Afghanistan, began as an ACTD. This approach to technological development was intended to improve speed and promote innovation by limiting acquisition hurdles. A system designated as an ACTD could use streamlined management and had reduced oversight requirements (Drezner, Sommer, and Leonard, 1999, p. xiv). ACTDs were intended to bridge the innovation-adoption gap by existing somewhere beyond demonstration of technical feasibility without quite yet becoming major defense acquisition programs. Toward the same end of nudging innovation and eliminating procedural hurdles, in 1994 the National Defense

[4] Gates' distinction reflects what is often a difficult balance between short- and long-term requirements and planning horizons. This creates an institutional tension that has, for example, made the military departments resistant to prioritizing the acquisition of unmanned technology that had near-term applicability but that was not intended to be part of a longer-term vision. See Gates, 2008.

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Figure 2.1
Select Rapid Acquisition Processes, Approaches, Authorities, and Funding Mechanisms



SOURCE: Derived from Anderson (1992), AUSA (2003), DSB (2009b), GAO (1998), GAO (2010b), Sullivan (2009a), Thirtle (1997).

RAND *RR440-2.1*

Authorization Act introduced an authority that allowed the Defense Advanced Research Projects Agency (DARPA), long seen as a mechanism for moving innovative ideas toward materiel solutions, more flexibility in contracting; facilitated use of commercial practices; and waived certain Federal Acquisition Regulations (FARs) and other laws (Drezner, Sommer, and Leonard, 1999, p. 27).

Limited Acquisition Authority

In time of war, new requirements arise that the long and deliberate acquisition system is ill suited to meet. As a result, both Congress and DoD's civilian leadership put in place ad hoc arrangements to seed the development and fielding of new systems. In fiscal year (FY) 2004, Congress granted the Secretary of Defense the authority to delegate a limited acquisition authority (LAA) to Joint Forces Command (JFCOM) to speed the research and development and limited fielding of new systems (GAO, 2007a). However, LAA is an authority, rather than a program, and does not translate into budgeted funds.[5] In the first three years of the authority,

[5] JFCOM had to reallocate funding from its own budget or gain funds from another DoD organization. Over one-half the programs JFCOM supported came from its own budget. In addition, after the systems were acquired, funds were not

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JFCOM used the LAA to support six projects. After that, LAA activities slowed significantly, a trend GAO suggests may be linked to lack of access to funding (GAO, 2007a, p. 3).

Joint Rapid Acquisition Cell

The Joint Rapid Acquisition Cell (JRAC), also established in 2004 by the Deputy Secretary of Defense and organized in the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, constituted another rapid acquisition program. The intent of this cell was to meet new requirements that the combatant commanders (COCOMs) identified as operationally critical; the COCOMs' prominent role in JRAC has led some to tag it the "COCOM's acquisition process" (Middleton, 2006, p. 19; see GAO, 2010b, p. 1). During its initial three years, JRAC supported 24 programs, at a cost of $335.5 million.[6] These funds came primarily from war supplemental appropriations and were not part of the military departments' programs or budgets. A 2009 DSB report found that this meant that "these programs continue to lack serious institutional commitments; very little is being built into the service or other DOD budgets for these programs" (DSB, 2009, p. 6). While JRAC required a life-cycle plan as part of the acquisition process, the DSB found this planning inadequate. Training relied more "on learning on the job with little emphasis on support, training, and sustainment." (DSB, 2009, p. 6). The typical institutional support in the services that is needed to fund, for example, investments in the training infrastructure does not exist for every rapidly acquired system.

Rapid Equipping Force

In 2002, the Army established the Rapid Equipping Force (REF), whose mission was to equip operational commanders with technological solutions to urgent war needs in no more than six months (DSB, 2009, p. 12). In 2005, the REF was made permanent (Kennedy, 2006, pp. 43–45). The organization began with a staff of 14 personnel, which expanded to 150 by 2007 (Dietrich, 2007, p. 5). In 2005 alone, it purchased more than 20,000 items, including robots, surveillance systems, digital translators, and weapon accessories (Dietrich, 2007, p. 6). The REF supported the rapid acquisition and fielding of a widely adopted technology called PackBot, which became a vital tool in the identification and defusing of deadly improvised explosive devices. The REF also supported other unmanned and robotic technology, including the development of the battery-powered, hand-launched, and camera-equipped Tactical Mini Unmanned Aerial Vehicle (UAV) in 2005. The REF project leader described that UAV as a technology that allowed soldiers to "go into situations knowing what's in front of them" (Ainsworth, 2005). REF purchased the mini-UAV commercially and, after some software modifications, quickly had it ready for theater operations (Miles, 2005). Yet, insufficient consideration for back-end support reportedly plagued early REF efforts, and steps have been taken to ameliorate the difficulties. COL Gregory Tubbs, REF director, conceded that the early ad hoc "wild west" days of REF logistical support were a challenge (Kennedy, 2004).

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readily available for long-term sustainment. A 2005 report from the Center for Strategic and International Studies called for providing rapid acquisition approaches with more-secure funding: "Urgent requirements will be met much faster if they can be resourced without taking funds from existing programs" (Murdock and Flournoy, 2005, p. 98).

[6] The process begins when a COCOM identifies and validates an urgent operational needs statement (or a joint urgent operational needs statement for joint requirements), defined as "urgent, combatant commander-prioritized operational needs that, if left unfilled, could result in loss of life and/or prevent the successful completion of a near term military mission." *Immediate warfighter needs* were the urgent operational needs statements certified as requiring a solution in 120 days or less. For a given system, JRAC is authorized to expend $365 million in research, testing, development, and evaluation funds and up to $2.19 billion in procurement. See GAO, 2007a, p. 12.

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Intelligence, Surveillance, and Reconnaissance Task Force

The high value placed on UASs, specifically in new intelligence, surveillance, and reconnaissance roles, can be seen in the robustly funded Intelligence, Surveillance, and Reconnaissance (ISR) Task Force, which supported the fielding of numerous unmanned systems. In spring 2008, Secretary Gates established this task force to expedite the fielding of ISR assets to combat areas (Sherman, 2008). The task force originally had a 120-day charter; two years after the task force's founding, the secretary announced that it would become a permanent part of the Office of the Under Secretary of Defense for Intelligence (Bennett, 2010). Its mission was to address unmet ISR requirements and to rapidly acquire and field capabilities by coordinating activities and pursuing innovative solutions (Loxterkamp, 2010). The ISR Task Force was to recommend ways to maximize the availability of systems in the inventory and to boost acquisition of additional systems (Best, 2010, p. 17). In FY 2008 alone, Congress approved the reprogramming of $1.3 billion based on ISR-TF recommendations (GAO, 2008b). Among the systems the task force supported were the Navy's unmanned MQ-8 Fire Scout and the fielding and sustainment of 50 unmanned Predators.

Informal Approaches to Rapid Acquisition

The formal approaches highlighted above support rapid acquisition in a variety of ways. Some consist of an acquisition authority but no money (LAA); some consist of funding (REF); some facilitate stronger requirements inputs (JRAC); and some, like Special Operations Command (SOCOM), have everything. Yet importantly, some rapid acquisition has taken place outside even these ad hoc institutional arrangements. For example, in one case, the personal relationships enabled rapid acquisition of command and control (C2) systems. In another, ADM James Stavridis instituted a "culture of innovative thought" into U.S. Southern Command (SOUTHCOM) by developing his own in-house technical capabilities through a process he called Linking Plans to Resources, an approach aiming to associate capabilities with specific solutions (Hicks, 2008, p. 33). He chartered the Joint Innovation and Experimentation Directorate, tasking it with improving how the command trains, fights, and does business (Stavridis, 2010, p. 177). This small innovation staff was to "research, explore, and test emerging technologies available commercially or through Federal research centers" (Stavridis, 2010, p. 89). The directorate was to take the lead in identifying new and creative ways of meeting the command missions, and was given the primary responsibility for "developing validated solutions into an initial operational capability," materiel or nonmateriel (Stavridis, 2010, pp. 178–179). These innovations, looking for better ways to link requirements to resources and developing in-house capabilities for acquiring solutions, reflected new acquisition roles.

PACOM's version was the Plans to Resources to Outcomes Process, which helped in the development of the command's integrated priority list. PACOM also developed its own in-house means of meeting requirements (Murdock and Flournoy, 2005, p. 40). PACOM's Joint Innovation and Experimentation Division uses the integrated priority list to develop rapid, innovative solutions for filling the gap and injecting them into PACOM exercises. Similarly, in 2009, U.S. European Command appointed a special assistant for innovation and technology to field equipment for the war in Afghanistan. Navy Captain Jay Chestnut, special assistant in charge of the project, explained that European Command "knows that 'big acquisition' [the traditional system] is trying to do the right thing but sometimes you need someone working on the side, looking innovatively" (Francis, 2009).

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In addition to the development of in-house approaches, informal rapid acquisition has also involved forging relationships between the COCOMs and technical expertise outside the military departments. As described by Stavridis, SOUTHCOM worked to both build in-house staff and forge relationships with a "technological base" external to the organization. He highlights, in particular, the partnership with DARPA, in which DARPA pursues "exploration and technology where risk and payoff are both very high, and where success may provide dramatic advances" to the SOUTHCOM mission (Stavridis, 2010, p. 89). Included in Admiral Stavridis' list of outcomes of this productive symbiotic relationship with DARPA are unmanned aerial craft and unmanned surface vessels.

The Use of Fast Track Authorities Can Cause Problems

For acquisitions to be "rapid," certain aspects of the traditional acquisition process have been left out. In many cases, it is the training and support planning that have been omitted. In 2008, the GAO reported that the

> rapid fielding of new systems and the considerable expansion of existing Air Force and Army programs has [sic] posed challenges for military planners to fully account for UAS support elements, such as developing comprehensive plans that account for personnel and facilities needed to operate and sustain programs." (GAO, 2010a, p. 37)

Because many of these programs do not pass through the system development and demonstration phase or a logistics supportability analysis, the data needed to generate training and support planning and ultimately guide investment decisions are unavailable. In 2010, the GAO found that the Air Force had not developed a servicewide plan that identified the number of personnel to be trained, the specific training required, and the resources necessary to establish a dedicated UAS training pipeline (GAO, 2010a). The Air Force has reportedly been struggling to staff significant increases in unmanned systems (Baldor, 2010). Going from a handful of drones in 2007 to 45 by 2010, with plans to operate 50 by 2011 and 65 by 2013, had created significant resource challenges for the department. These resource challenges became heavily pronounced with the "surge" in UAS requirements for operations in Libya and Afghanistan beginning in March and extending into summer 2011. The Air Force, to fulfill combat air patrol (CAP) requirements, stood down a portion of its formal training structure to form three CAPs (U.S. Air Force, 2011). As the Air Force's Deputy Chief of Staff for Operations, Plans, and Requirements explained in 2010, the "number one manning problem in our Air Force is manning our unmanned platforms" (Baldor, 2010).

The GAO similarly found that the Army's personnel authorizations were insufficient to support UAS operations. The Army has determined on at least three separate occasions since 2006 that Shadow UAS platoons did not have adequate personnel to support the near-term and projected pace of operations (GAO, 2010a). Officials from seven Army Shadow platoons in the United States and Iraq told the GAO that approved personnel levels for these platoons did not provide an adequate number of vehicle operators and maintenance soldiers to support operations (GAO, 2010a). Army officials told the GAO that currently approved personnel levels for the Shadow platoons were based on planning factors that assumed that the Shadow would operate for 12 hours per day with the ability to extend operations to up to 16 hours for a limited time (GAO, 2010a). However, personnel with these platoons told the GAO that UASs in Iraq routinely operated 24 hours per day for extended periods (GAO, 2010a). Army officials

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also reported that combat brigades and divisions require additional personnel to provide UAS expertise to assist commanders in making effective use of new technological systems (GAO, 2010a).

UASs exemplify the challenges of integrating training and sustainment considerations outside the strictures of the formal acquisition process. Ad hoc rapid acquisition processes were able to field UASs rapidly, but because of the nature of these processes, the fielded UASs lacked sustainable institutional support and funding needed for future investments in the training infrastructure. Frequently, the services try to sustain and support these programs by relying on contractors, just as they did during system development.[7] Of course, employing contractors to provide training is not in itself a problem. But it does reflect the extent to which training has been more about expediency than about effective institutionalization, particularly with regard to the imperative to train as we fight and the need to fully appreciate the need to integrate UAS training across the full spectrum of combat units.

[7] For example, the Air Force continues to rely on contractors to perform a considerable portion of UAS maintenance. For example, contractors perform approximately 75 percent of organization-level maintenance requirements for the Air Combat Command's Predator and Reaper UASs. See GAO, 2010a.

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CHAPTER THREE

Training Concept and Framework for Unmanned Aircraft Systems

We will begin by discussing the general ideas that should guide UAS training—the training *concept*. Then, we will consider how the parts identified in the concept fit together into a conceptual structure for that training—a training *framework* designed to enhance combat power and other operational capabilities. Note that the term *UAS* can be misleading. In fact, there is not a single UAS but rather a family of aircraft that share the common feature that they fly without a pilot on board.[1] These aircraft have very different personnel and training requirements. The vast majority of UASs support ground operations, and that will be our primary focus. As noted in Table 1.1, ground forces—the Army and Marine Corps—own many of these systems themselves, but the Air Force owns some of them and often flies them in support of ground operations. UASs are sometimes flown in support of conventional ground operations and sometimes in support of special operations. Our main focus is on support of conventional forces. UASs are now also being developed that will support maritime forces, and we also consider them.

Training Transformation, Joint Doctrine, Joint Operations, and UASs

Large military operations today are usually joint operations requiring and emphasizing the interdependence of the services. It follows naturally that joint doctrine, joint concepts of operation, and joint TTP would provide focus for training. Accordingly, the DoD's Training Transformation Implementation Plan requires that in order to "improve joint force readiness" there be a "unity of effort in training across Services, agencies and organizations."[2] That said, joint training guidance and publications generally provide guidance direction on the coordination and collaboration among elements of different services to optimize the joint employment of their various capabilities, and not on the employment of any one, specific system or even family of systems, such as UASs.

Clearly, training does not take place for the sake of training; it should be driven by doctrine. Thus, in line with the general focus described above, JP 3-0 (2001) "establishes the framework for our forces' ability to fight as a joint team," but nowhere does the document discuss the management of UASs or any other specific system. Moreover, nowhere in any other joint publication is there a grand doctrine for the employment or management of UASs on

[1] In 2014, the Air Force republished its vision for its system, replacing the term *unmanned aircraft systems* with the term *remotely piloted aircraft* (RPA) (U.S. Air Force, 2014, p. iii).

[2] See Director, Readiness and Training Policy and Programs, 2006, p. 5.

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the battlefield. However, the services have agreed to a set of TTP to be incorporated into their respective training programs. They describe these as a "multiservice" rather than a joint TTP, thereby avoiding doctrinal issues on how to deploy and manage UAS even as the services support joint operations.

Air Force Maj David Buchanan explored the difficulty of developing a joint doctrine for UASs in a 2010 Naval War College paper, summing up the difference this way: The Air Force believes in centralized control, and the Army believes in decentralized operations. He noted that the

> Air Force's proposal to assume executive agency for all medium- and high-altitude UASs in March 2007 was an attempt to establish unity of command and increase UAS efficiencies. … The Army's position … was that a single-service approach to UAS employment would infringe on the effectiveness of UASs in combat.
>
> The Air Force's centralized approach may result in a more efficient allocation of limited UAS assets, but that efficiency comes at the cost of combat effectiveness. The Army's answer to regain effectiveness has been to decentralize command and control for its unmanned aircraft systems. Ground commanders rely on UASs to provide timely, relevant, and useful intelligence without the lengthy processing and dissemination associated with the Air Force's centrally controlled, theater-wide assets. The Army's Training and Doctrine Command noted that the joint (CAOC [combined air operations center]) solution to meeting the high demand for these low-density assets has been ineffective, arguing against relying on the JFACC [Joint Force Air Component Commander] for UAS coverage. (Buchanan, 2010, p. 7).

JP 3-55.1 reflects a more service-centric notion of jointness.[3] When it was written in 1993, UASs were primarily thought of as reconnaissance, surveillance, and target acquisition (RSTA) assets. As envisioned then, mission planning was to be "based on the requirements of the supported unit," with due consideration for "airspace management conflicts" (JP 3-55.1, 1993, p. II-9).

Over time and with practical experience in Iraq and Afghanistan, the utility of UASs has expanded from consisting primarily of ISR to include armed surveillance and armed overwatch (e.g., for movement support and area security), targeting, communications support, attack, strike, and engagement; in the future, it will further expand to encompass logistical support and casualty evacuation missions. This expanded range of missions presents a challenge that was addressed in 2011 with the publication of a common set of multiservice TTP (MTTP).[4] Each of the four services has agreed to incorporate the MTTP into its respective training. The agreed-to MTTP document requires that

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[3] JP 3-55.1, 1993, p. II-1, states that the

> [p]rimary mission of UAS units is to support their respective Service component commands as a tactical RSTA system providing the commander a capability to gather near-real-time data on opposing force position, composition, and state of readiness. However, as is the case with all assets and groupings within the joint force, the joint force commander (JFC) has full authority to assign missions to and task component UAS to conduct operations in support of the overall joint force.

[4] Reflecting the multiservice, rather than joint, nature of the document, each service has assigned its own number to it: Army Tactics, Techniques and Procedures 3-04.15, Marine Corps Reference Publication 3-42.1A, Navy Tactics, Techniques and Procedures 3-55.14, and Air Force Tactics, Techniques and Procedures 3-2.64. From here onward in this report, we will refer to the document simply as "the MTTP."

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> group 3-5 UAS operations will be coordinated with the ACA (airspace control authority) and included in the ACO (airspace control order), SPINS (special instructions) and the ATO (air tasking order) in order to separate UASs from manned aircraft and to prevent engagement by friendly air defense systems. (MTTP, 2011, p. 12)

Table 3.1 describes the five UAS groups. The TTP for UASs that the services agreed to recognize that UASs may either be controlled by a centralized or joined C2 node (MTTP, 2011, p. 15) or be operated independently and that the service component commander may retain operational control of UASs (MTTP, 2011, p. 16), thereby avoiding the doctrinal issue that divided the Army and Air Force. In general, UAS control during the execution of an operation should be at the lowest tactical level to streamline the decision time lines and thus optimize responsiveness. The MTTP provides vignettes to help supporting and supported units understand how to incorporate and use available UAS assets more effectively. It should also be noted that no distinction is made between organic and nonorganic UAS support (MTTP, 2011, p. 40).

At least for the foreseeable future, each service will continue to field UASs and must bring to the fight forces fully capable of operating these aircraft and integrating their capabilities into joint operations. While some overarching doctrinal issues remain unresolved, the common procedures the services have agreed to and train for will remain the foundation on which UAS operations must be built, just as they are for military operations more generally. In this way, rather than being the foundation for UAS training, joint training is the apex of such training, which must be firmly grounded on the UAS training each service gives both its supported units and the supporting UASs.[5] This is the main focus of this report.

The UAS Training Concept: A General Notion for UAS Training

The contribution that UASs make to the modern battlefield results from a synergy among the platforms themselves, those who operate the platforms, and those who incorporate the UASs into the battle. Combat power cannot expand unless all three work together. A platform flown

Table 3.1
UAS Tiers by Service

Group	Capability	Examples
I	Hand-launched, self-contained, portable systems employed for a small unit or base security.	RQ-11A/B Raven
II	Small to medium in size and usually support brigade and intelligence, surveillance, reconnaissance, and target acquisition requirements.	ScanEagle
III	Operate at medium altitudes with medium to long range and endurance.	RQ-7 Shadow
IV	Relatively large UASs that operate at medium to high altitudes and have extended range and endurance.	MQ-1 Predator
V	Large, high-altitude, long-endurance UAV platforms	RQ-4 Global Hawk

SOURCE: DoD, 2011, pp. D-2 and D-3

[5] The terms *supported unit* and the *supporting UAS* are basic constructs of MTTP, 2011, p. 9.

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by a skilled pilot does not add anything to the battle unless those on the ground who are engaged know how to exploit the information and other support the UAS provides. Similarly, if the pilot and payload operator cannot respond to the ground commander, the support they provide will not be what the commander needs. Only when all three work together will UASs be effective as a force multiplier. This can be achieved through training and practice that brings the platform, the operator, and the users together, starting at home station and progressing through ever-more-complicated exercises at the major training centers, such as the National Training Center (NTC) at Fort Irwin, California; the MCAGCC at Twentynine Palms, California; and the Joint Readiness Training Center at Fort Polk, Louisiana. Accordingly, how to achieve this synergy is the fundamental organizing concept for UAS training.

Let us be clear. The organizing concept developed here is not built around the training of a UAS pilot or payload operator per se. Their proficiency is certainly a necessary condition for UAS operations but is not, by itself, sufficient to enhance combat power. Enhanced combat power is achieved through the synergistic process that brings the platforms, the operators, and the users together. It starts at home station with small UASs and builds through the echelons of the ground forces as larger UASs are integrated into the combat operations of higher-echelon formations. Properly done, the maintenance or refinement of proficiency levels for UAS pilots and payload operators will be achieved incidental to the training that should take place with ground forces. But even before training can start, the services must decide how these systems will be used and how they will be incorporated into the force.

A Concept of Operations for UASs Is a Prerequisite for Training

As noted in the previous chapter, UASs are a classic disruptive technology. Integrating them into existing military operations is still a work in progress. This creates a problem for those charged with building training programs because, before training can start, the services must decide how these systems will be used and how they will be incorporated into the force. The services are still learning how best to use these new systems and the capabilities they provide. Each service is doing it differently.

Army

Initially, the UAS was thought of as just another platform for RSTA sensors, and the intelligence community was the proponent in the Army. In 2003, proponency for UASs transferred from Army Military Intelligence to the Army Aviation Branch. Since then, the UAS role in the Army has been changing from the relatively passive intelligence-gathering mission to the more active scout-reconnaissance and attack missions. One consequence of this transition is that UAS operators frequently team with manned aircrews to perform the scout-reconnaissance role. However, UAS operators and manned aircraft crews are currently separate communities and undergo separate programs of training.

At another level, the Army is experimenting with how to support the Raven, a small, hand-launched UAV. There is no dedicated military occupational specialty (MOS) for Raven operators. Being a Raven operator is an additional duty that requires additional training. Master Raven Training, a three-week train-the-trainer course, takes place both in the classroom and in the field. Students are taught how to maintain and operate the equipment and how to judge when and when not to fly. The plan calls for the trainer to return to home station and train squad-level personnel to operate the Raven.

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Navy

The Navy has a different scheme for integrating the Fire Scout UAS and Broad Area Maritime Surveillance (BAMS) into the fleet. Typically, maintainers and pilots for Fire Scout have already gained technical training on manned helicopters. The Fire Scout–specific training is six weeks long and takes place at the Fire Scout Training Center at Naval Air Station Jacksonville, Florida (U.S. Army Maneuver Center of Excellence, undated).

The Navy's version of the Air Force's Global Hawk is the MQ-4C Triton, developed under the BAMS program. While the Navy continues to fly it to refine TTP for use in a maritime environment, the concept is for it to be integrated into active Navy maritime patrol units to complement the P-8 Poseidon, Boeing's 737–based multimission maritime aircraft, a traditional manned aircraft.

Air Force

The Air Force has yet another concept of operations that emphasizes remote split operations and reaches back to the Global Operations Center at Creech AFB, Nevada. Today, six operations centers in the continental United States (CONUS) support five launch-and-recover units in theater. Integration with tactical units is through tactical air control parties (TACPs) at the division, brigade, and battalion levels, and often at lower levels when supporting special operations forces (SOF). The TACPs coordinate directly with the Predator operations center via ultrahigh frequency radios on the aircraft or via satellite communications. As with other Air Force assets (and many air assets of other services), UAS assets are assigned to support ground commanders through the ATO. In the Air Force, the UAS pilots and payload operators are commissioned officers.

Marine Corps

The Marine Corps has dedicated UAV squadrons located at the MCAGCC at Twentynine Palms, California, and recently at Camp Pendleton, California. In the Marine Corps, enlisted Marines are responsible for almost every facet of the mission, from flying the aircraft and operating the payload camera to takeoffs and landings.

Summary

Even as the services are experimenting with the best way to use UASs and to integrate them into their forces, the overall purpose for UAS training should be clear. It is to increase combat power through the synergistic process that brings the platforms, the operators, *and the users* together. Putting these pieces together is the primary theme of the training framework we present.

Training Framework for Tactical UASs

The focus of the UAS training framework we offer is the enhancement of combat power, which starts with well-trained individuals who learn to work as a unit and ultimately leads to units that coordinate their efforts to produce military force. As we have seen, however, each service uses UASs differently.

Moreover, the great variety of UASs adds to this complexity. UASs are classified into tiers. Military planners designate the various individual aircraft elements in an overall usage plan using a tier system. The tiers do not refer to specific models of aircraft but rather to roles the

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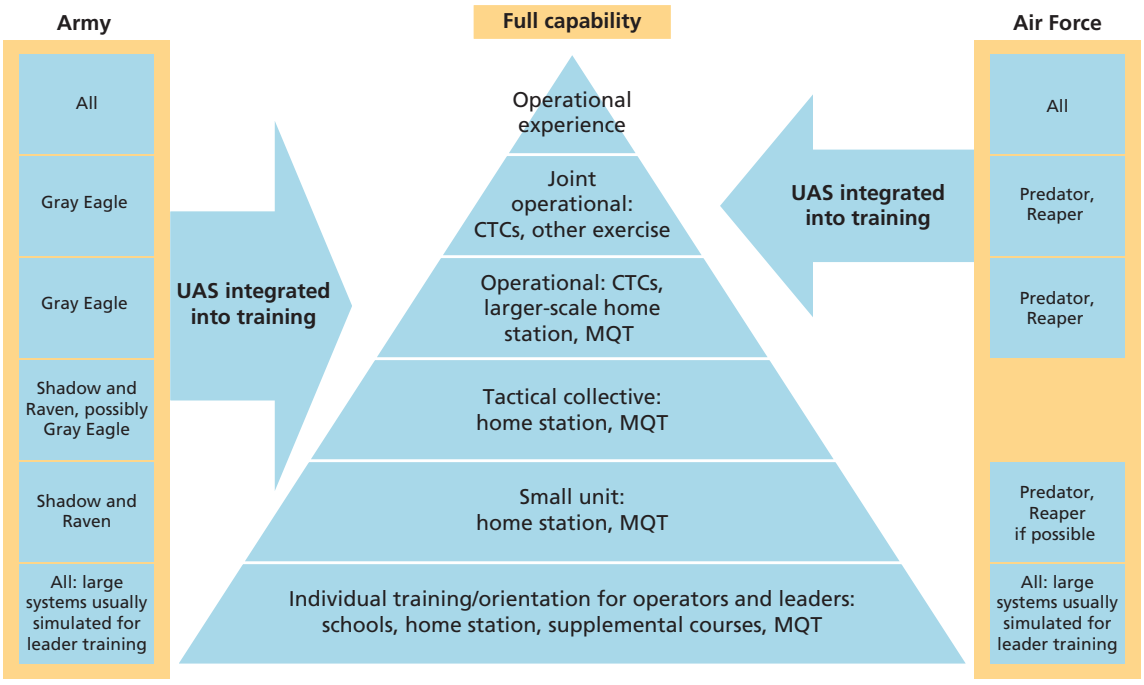
aircraft typically fill. Table 3.1 shows the UAS groups and their roles and offers the examples of systems assigned to them.

The following discussion of training frameworks refers primarily to tactical UASs and not such Tier V systems as Global Hawk and its naval variant, the BAMS-D Triton.

The Training Framework for Ground Combat: Army, Marine Corps, and Air Force

The pyramid shown in Figure 3.1 represents our idea of the training framework to enhance combat power for the Army and Marine Corps, integrating organic UASs and Air Force UASs, when available, in support of ground forces. It is a graphic representation of the synergy achieved through training and practice that brings the platform, the operator, and the users together, starting at home station and progressing to higher echelons and ever-more-complicated battle exercises. The services have committed to align their training with the agreed-to MTTP. As with any good framework, the UAS framework must have a strong base. The base of this framework, represented by the lowest level of the pyramid, includes the initial and individual skills training of those who operate, maintain, and use the systems. The higher levels of the pyramid roughly align with the echelons of ground forces from the platoon or squad level through the company level and moving up to battalions, then to brigades. Each level incorporates the C2 of subordinate units to create combat power that is more than the sum of its parts. A battalion is more than just a collection of companies, each of which is more than just a collection of platoons and squads. In creating this combat power, the battalion utilizes UASs that are not normally available to its subordinate companies. In this way, the battalion and its UASs are "combat multipliers." This increase of combat power is repeated as we move up the pyramid to higher echelons each supported by the UASs that are organic to that

Figure 3.1
UAS Training Framework for Army, Marine Corps/Air Force Joint Combat Operations



RAND *RR440-3.1*

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tier. The two different-sized arrows, coming in from the left for the Army and from the right for the Air Force, show the specific UASs and the echelons they support.

In our concept of the training framework for UASs, the ground force systems—those of the Army and Marine Corps—and Air Force systems are "stacked" along the sides and paired with the level of the pyramid they support. The entries at each level of the pyramid identify the type of training that needs to be accomplished and where that training takes place. For example, small-unit training, at the lowest level of the squad and platoon, incorporates the Raven UAV and is accomplished at home station. Company training, which generally entails C2 of four platoons, is also accomplished at home station. The individual platoons may each be using their own Ravens, and the company commander may have access to the information from a Shadow UAS.

This process is repeated at home station with companies being brought together under the C2 of the battalion commander and his staff. During a battalion exercise, the battalion commander will generally be able to task the Shadow UASs either individually or as part of the combat support from assigned Army aviation. In some cases, this may include information provided by the Gray Eagle UAS. In some instances—these have historically been very rare—available Air Force UASs, such as Reaper or Predator, may support home station battalion exercises.

Brigade-level training can be carried out at some home stations, but the maneuver combat training centers (CTCs) generally provide a better venue. All available Army UASs will support these training exercises, from the small Ravens to the larger and higher-flying Gray Eagle, when available. In addition, it is at this level and during these exercises that joint Army–Air Force support is usually integrated to include close air support (CAS) and support from Air Force UASs.

Not shown on the pyramid is the training needed to meet the certification requirements of UAS operators. Such requirements will normally be met incidental to their training with ground forces. For example, Shadow operators need to operate their equipment 4.5 hours per month to maintain their certification. It is expected that they will be spending more than that supporting ground units during home station training. Operators not actively engaged with the training of ground units can achieve the needed proficiency training using the same training equipment as during their initial skill training.

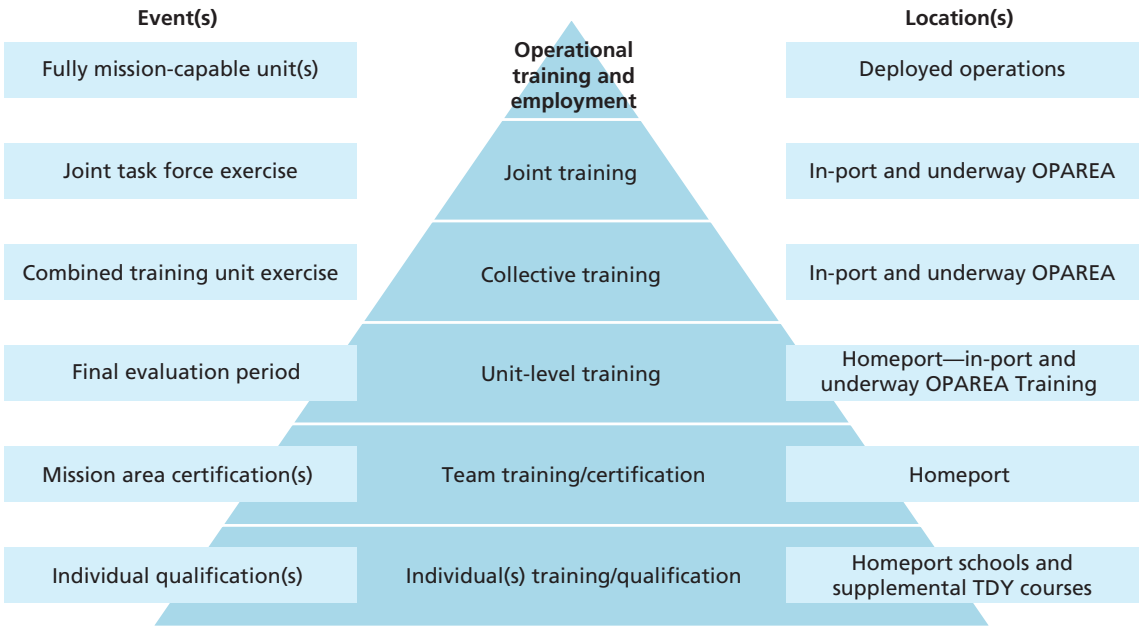
The Training Framework for Fleet Operations

A similar pyramid also represents our framework for Navy UAS training (Figure 3.2). It differs from the previous pyramid in that the Navy does not have a hierarchy of systems introduced at higher echelons of command. At the tactical level, the only UAS the Navy has is Fire Scout, which will be introduced into fleet operations following a similar path as discussed above. As with land forces and the systems that support them, combat proficiency is generated through the synergy of the platform, operators, and staffs that incorporate the UASs into the battle planning. Initial operator training is the base of the pyramid and takes place in the schoolhouse in the vicinity of the homeport. Operational training occurs under way in fleet operating areas. The Navy trains continuously, and the training continues through the operational use of UASs when the units are deployed.

UAS operators and maintainers require initial training to obtain the skills needed for operational effectiveness. As individuals become qualified as UAS operators and maintainers, they undergo team training to achieve mission area certification. For example, UAS operators

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Figure 3.2
UAS Training Framework for Navy Tactical UAS



RAND *RR440-3.2*

may be linked to and integrated with an antisurface warfare mission team to support certification for the surface warfare mission area. For ships, unit-level training occurs both in port and under way and culminates in a final evaluation period. During that evaluation, the immediate superior in command evaluates the ship in all mission areas to determine that it is ready for advanced phase training. The final evaluation period comprises in-port and underway training events geared to assess the unit's ability to operate independently.

Collective training occurs after the final evaluation period, when the ship begins to operate with other units and staffs. During this time, the ship conducts operations with and becomes an integral part of a carrier strike group (CSG).[6] Collective training is a combination of in-port and underway training events and culminates in a combined training unit exercise evaluated at the fleet commander level. The Navy is in the process of developing its UAS tactics and procedures and plans to integrate UAS training into predeployment preparations.

Deployed naval ships and units must also operate in a joint environment. After completing a combined training unit exercise, a deploying CSG conducts a final exercise with elements of other services (e.g., Air Force aircraft) to demonstrate its ability to communicate and operate effectively in joint warfare. Joint training is conducted both in port and under way. An underway joint task force exercise is the culminating event, with Navy units operating with forces of the other services; on satisfactory completion, units are deemed ready to deploy. Units then continue the operational training and employment of their systems en route to their deployed operational areas.

[6] While we address surface units as being part of a CSG, surface units can also deploy independently, with other ships, or with an expeditionary strike group.

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Navy units deployed to 5th Fleet do have experience with BAMS–Demonstrator (BAMS-D), the predecessor to the Triton, and a variant of the Air Force's Global Hawk. Despite being a demonstrator, BAMS-D was deployed to meet surveillance needs in the 5th Fleet. Navy strike groups operating in 5th Fleet were provided with imagery and data feeds from BAMS-D and used these data to build a common operational picture, which increased situational awareness. The BAMS-D was integrated into actual fleet operations and provided near-real-time updates for surface surveillance. Units learned to use BAMS-D "on the fly," by processing, exploiting, and disseminating imagery and sensor data; building the surface picture; and increasing the positive identification of surface contacts in the area of operations.

As UAS assets are fielded, they will be incorporated to a greater degree into predeployment training and increase opportunities to train and hone the tasking, collection, processing, exploitation, and dissemination of UAS sensor data.

Applying the Training Framework

The training framework presented here focuses on the synergy among three key elements: the platform itself, those who operate the platform, and those who incorporate UASs into the battle. The framework emphasizes using UASs to enhance warfighting proficiency. It provides a useful tool for organizing and evaluating training options and assessing the current state of training and plans for improvement. As discussed in the next chapter, we used the framework to assess the state of UAS training, as it existed in 2012.

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CHAPTER FOUR

Assessment of the State of UAS Training in 2012: Service and Interoperability Training and the Role for Simulators

For more than a decade, UAS training has concentrated on preparing UAS pilots and payload operators to support ongoing operations in Afghanistan and Iraq. This remained true in 2012 and 2013, and the services continue to evolve how best to use these systems and integrate them into ongoing operations. With the operations in Afghanistan winding down, the services must now integrate all facets of UAS training, including the infrastructure for training addressed in Appendix C, into a largely CONUS-based inventory of UASs that continues to grow, even as real-time operations continue for some systems.[1] Moreover, operational demands and technical innovations will continue to evolve and affect training and organizational requirements. As a result, UAS training and training support programs must be viewed as works in progress.

In assessing the current state of UAS training, using the UAS training framework discussed in the previous chapter, we view proficiency in flying UASs not as an end in itself but as only a means to an operational end: accomplishment of a military mission. As noted, this is achieved through the synergistic use of UASs with the forces they support, in ways similar to those in which the timely integration of intelligence or the delivery of fire support is accomplished in combat operations. This convergence requires full integration of UASs into the collective training of operational forces, attendant training and education for leaders and staffs, and the integration of lessons learned from previous and ongoing operations into education and training programs.

The preceding should by no means be construed to understate the need for training those directly involved in the operation of UAS—among them pilots, crews, support personnel, and those who maintain the aircraft and communications systems. Such training, both to develop and to maintain proficiency in the operation of UAS, is critical for the overall success of a UAS training strategy. But proficiency in these areas is not in itself sufficient. Full understanding of UAS integration, from the smallest to the largest systems at every echelon, as outlined in the previous chapter, is also necessary.

To be clear, members of the UAS community not only must understand how to operate their systems—a challenge largely being met successfully—but must also be familiar with the fundamentals of the operations they support and how their capabilities contribute to the successful accomplishment of the mission. Similarly, battle staffs must fully understand the many capabilities of UASs, how these capabilities supplement or complement other capabilities available to the joint force, and how best to integrate the capabilities into their operations.

[1] The Air Force UAS community believes high demand for its systems—Predator and Reaper—will persist, with requirements to support other kinds of demands increasing as demands for support of ground maneuver operations decrease.

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This chapter assesses the state of training for UASs across the ground, air, and sea forces. It discusses information, observations, and insights gained from a wide variety of sources but mainly through visits to a select number of service bases in 2012. During these visits, the RAND team talked with operators and support personnel; those who train operators and associated members of the team; those who train and observe the forces who employ UASs; staff elements concerned with the planning and resourcing of training, both for UAS operators and for the force more generally; and those concerned with the ongoing development of doctrine and concepts of operations for UASs, including their integration into operations. What follows is a compilation of the observations and insights from these individuals and our interpretation of the implications for the specification and resourcing of training strategies.

Ground Forces

Ground force operations of the Army and Marine Corps, even at low echelons, can be highly complex, and the complexity increases significantly at higher echelons. Commanders at higher echelons not only have to coordinate and use the information and capabilities subordinate units provide but also have to manage and integrate information and capabilities from a widening variety of other sources available to them. Adding the integration of UAS capabilities into the operational command further increases its complexity and thus the complexity of associated training management processes. Evidence from both training exercises and actual operations in combat theaters shows that, when properly managed, UASs provide significant new capabilities that commanders at every echelon can effectively employ. UASs truly have the potential to be force multipliers—but more so when employed by users fully competent in integrating their capabilities with those of the rest of the force and its supporting elements.

As shown in the training framework presented in Chapter Three, the proper integration of UASs to create combat capability starts with the training of UAS operators and support personnel and progresses through the integration of UAS operations with supported forces.

Training for Operators and Support Personnel

In general, the RAND team found that qualification training in the Army and Marine Corps for designated UAS-specific MOS is well established. In the Army, positions are filled by enlisted soldiers. The ranks of operators typically range from private first class to master sergeant (E-3 to E-8). The Marine Corps is organized much like the Air Force, with a UA commander who is a company grade, qualified aviator or aviation C2 officer on his or her second or third tour (O-3/O-4) and a mission payload operator (MPO) who is typically a corporal through master sergeant (E-3 to E-8).

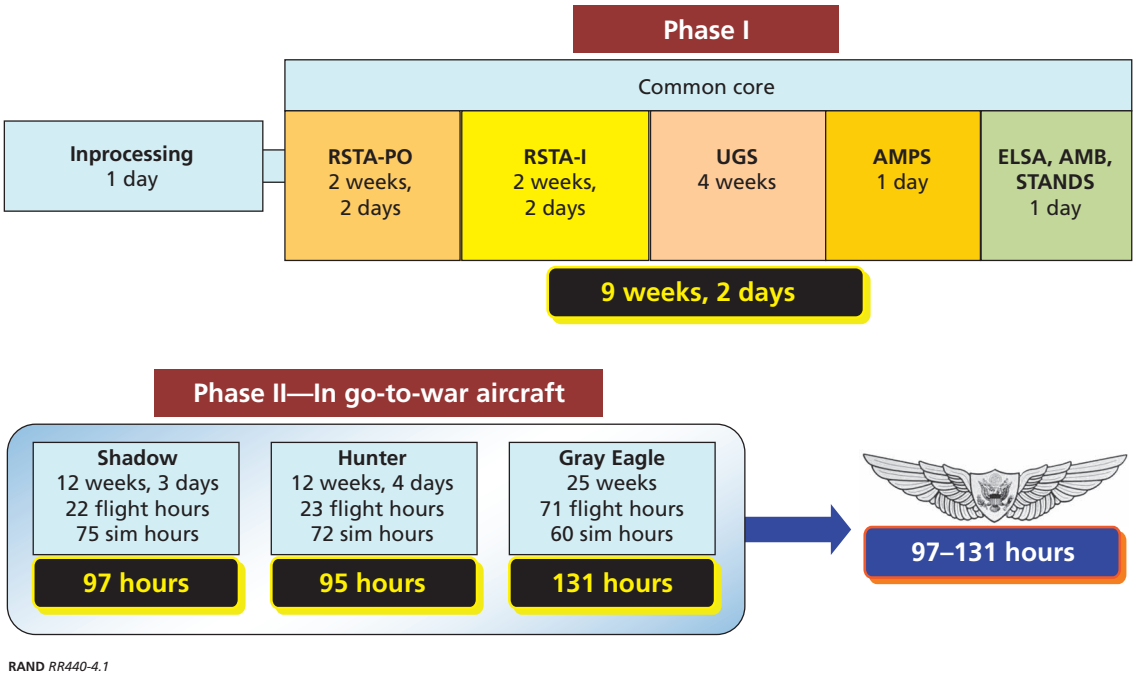
Army Air Vehicle and Sensor Operators for Hunter, Gray Eagle, and Shadow UASs

Training for Army UAS operators—pilots and payload operators—is carried out in two phases: The first, at Fort Huachuca, consists of a common core course for all operators of UASs not launched by hand.[2] This phase lasts nine weeks and two days and has five sections. (See Figures 4.1 and 4.2.)

[2] The 2nd Battalion, 13th Aviation Regiment, which was previously called the Unmanned Aircraft Systems Training Battalion, conducts the training. See Appendix D for RAND's "military value analysis of training bases" assessment of training at Fort Huachuca, Arizona.

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Figure 4.1
Army UAS Air Vehicle Operator and APO Training Pipeline



RAND *RR440-4.1*

After completing Phase I, the operators continue to Phase II. This section is unique for each airframe and consists of both simulation and flight hours. It typically takes 12.5 weeks for Shadow and Hunter classes to finish and 25 weeks for Gray Eagle classes. After completing Phase II, the UAS operators earn their wings.

Maintenance for Hunter, Gray Eagle, and Shadow UASs

The Army UAS maintainers take the MOS 15E Repairer course from the 2nd Battalion, 13th Aviation Regiment (see Figure 4.3). As shown in Figure 4.4, the course lasts 17 weeks, and a new class of up to 16 students starts every two weeks. After completion, 15E personnel are qualified to maintain the Shadow. Maintainers must take additional training to earn additional skill identifiers and thus qualify to maintain the Hunter and Gray Eagle. The additional training takes ten weeks for Hunter and 18 weeks for Gray Eagle.

Army Raven Operators

Without a dedicated MOS, the development and maintenance of Raven operators is a unit personnel and training management issue. Assignment as a Raven operator is an additional duty. In the past, this has meant that many units did not have the required Raven-qualified personnel to employ the systems properly. The Army is well aware of this problem and, short of creating a dedicated MOS, has recently initiated a program to deal with the Raven training problem. The Army Maneuver Center of Excellence at Fort Benning manages a certification course designed to qualify selected soldiers as small UAS (SUAS) master trainers capable of conducting initial qualification training (IQT) and certification of new operators at home stations throughout the Army. This train-the-trainer course focuses on how to teach and manage an aircrew training program at home base and how to assist small-unit commanders in evaluat-

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Figure 4.2
Shadow (top) and Gray Eagle UAVs



SOURCE: DoD.



SOURCE: U.S. Army via social media outreach.
RAND *RR440-4.2*

ing academic and flight instruction and managing SUAS accident prevention.[3] It is envisioned that new master trainers returning to their home stations will be able to develop and maintain

[3] The 15-day course includes classroom and hands-on training, with instruction on reporting procedures, fundamentals of instruction, semiannual evaluations, and familiarization with Raven A and B and digital downlink systems. At the conclusion of the training program, graduates should have the ability to evaluate and certify operators. See U.S. Army Maneuver Center of Excellence, undated.

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Figure 4.3
Raven UAS



SOURCE: U.S. Army via social media outreach.
RAND *RR440-4.3*

a sufficient number of operators within their units and manage a tracking program to ensure that their units have the required number of certified Raven operators.

Marine Corps Unmanned Aircraft Commanders—Pilots

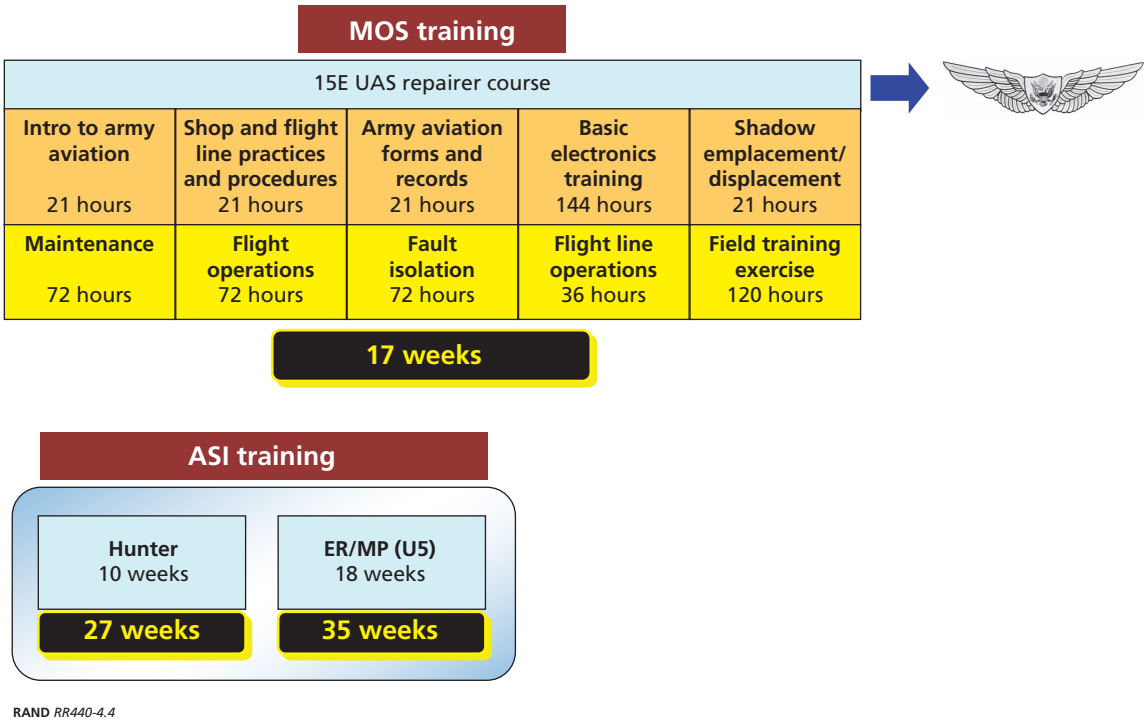
Training begins with the Unmanned Aircraft Commander course, which last two weeks and is taught by the U.S. Army at Fort Huachuca. Career-level training takes place at the squadron level. Marine Aviation Weapons and Tactics Squadron 1, at Marine Corps Air Station Yuma, Arizona, provides advanced training (the Weapons and Tactics Instructor course).

Air Vehicle Operators and Mission Payload Operators

Training for air vehicle operators (AVOs) and MPOs is accomplished jointly with the U.S. Army at Fort Huachuca. USMC operators take the nine-week common course and the 12-week Shadow course. Career-level training takes place at the squadron level. Marine Aviation Weapons and Tactics Squadron 1 provides advanced training.

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Figure 4.4
Army UAS Maintainer Pipeline



RAND *RR440-4.4*

Operational Training[4]

Larger UASs have dedicated MOS training, so operators and maintenance personnel arrive at home station having completed their IQT. To maintain their proficiency and certification, crews must log a minimum number of flying hours. The Army's Gray Eagle UAS has its own simulator capability built into the operating hardware. Currently, the Army's requirement is for 4.5 live flying hours per crew per month for the Shadow UAS. The Army has had difficulty maintaining sufficient numbers of Raven-qualified SUAS operators, in part because units do not always do well in tracking their qualified operators, maintaining their proficiency through hands-on work, and providing for their timely replacement when they move on. Discussions with Army trainers indicate that, despite the demands of deploying units and sustaining combat operations in Afghanistan, Army units are doing better at maintaining Shadow qualification. Nevertheless, not all units have been able to maintain high Shadow qualification rates: Some units arrive at the NTC with one-half or fewer of their operators qualified.

For these systems, the critical issue for the future will be securing enough flying time for UAS crews to train with ground forces. Marine Corps experience offers a good illustration of this issue. The Marine Corps has based Shadow squadrons at the MCAGCC, where there is adequate restricted airspace both to maintain crew proficiency and to fly in support of ground forces. However, both the ground trainers and squadron personnel the RAND team interviewed reported having to start what was essentially remedial training because the ground

[4] Joint Publication 1-02 defines *operational training* as "training that develops, maintains, or improves the operational readiness of individuals or units" (JP 1-02, 2013).

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forces were not adequately trained at home station to integrate UAS capabilities into their operations. These students generally could not progress to the level of proficiency desired.

The foregoing suggests the biggest challenge in developing and implementing a training strategy for UASs is gaining and maintaining proficiency on the part of end users—the leaders and staff members who will integrate UAS capabilities into their operations.[5] Ground units that undertake joint training at CTCs are often unprepared to use organic and nonorganic UASs effectively, and thus tend to develop battle plans that underutilize them.[6] Further, their intelligence and operations staffs sometimes find themselves at cross purposes over employment of UASs, an issue that could be better dealt with during home-station training.

Despite all this, discussions with operators, users, trainers, and training managers suggest that properly employed UASs consistently prove to be valuable combat multipliers. One example was an Army unit training at the NTC, which had successfully employed its UASs as part of a manned-unmanned team. In this instance, the UAS had acted as a scout and observer as manned attack helicopters delivered fires on selected targets, all in support of a ground maneuver unit. Another battalion well versed in the myriad tasks associated with employing Shadows—communication of commander's intent and concept, priority and time sensitivity of information requirements, targeting priorities, use of the communications relay package, to list just a few—was far more successful in employing the Shadows supporting it than another unit was. In the latter unit, the UAS platoon was simply given "areas to look at," without specific guidance on what to look for, e.g., named areas of interest and targeted areas of interest. Interviewees told the RAND team that many UAS operators do not get enough opportunity to interact with either crews of manned aircraft or the elements of ground units—commanders and operations and intelligence sections—that they will support.

The latter problem, ground units' lack of experience in employing UASs, is all too common. It is also true for the USMC, whose units face considerable limitations on using UASs at their home stations or local training events.[7] Marine ground force units are thus typically not well versed in employment of UASs when they arrive at Twentynine Palms. Although they learn while there, many are still not fully capable when they deploy.[8]

Improvements in Facilities and Basing for UASs Will Improve Training Integration

To date, the Army has had reasonable opportunity to train at home station, and current programs to increase UAS facilities will appreciably add to this. Table 4.1 summarizes responses the U.S. Army Training and Doctrine Command (TRADOC) received from active, National Guard, and reserve bases in November 2012 concerning the availability of restricted airspace and resulting limitations on UAS operations stemming from lack of availability. The responses

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[5] We refer to anyone who could benefit from the information a UAS provides as an *end user*. The MTTP calls end users *supported units*.

[6] *Organic* assets are ones owned by a unit, and *nonorganic* assets are ones that the commander of a unit does not own and thus does not have full control over.

[7] Recall that the Marines' Shadow squadrons are based at Twentynine Palms when not deployed.

[8] This brings up the question of whether we should expect units to continue learning sound tactics and procedures while they are deployed. They should, of course. The issue is how much; officials we have consulted have given us the sense that many units are still on the steep part of the learning curve when they leave the MCGACC. These units would be more operationally effective sooner in their deployments if they could be better trained to integrate UAS capabilities before they deploy.

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indicate that, in many cases, relatively minor military construction projects are all that is necessary to expand training opportunities at home stations. In most locations, additional beddown facilities will allow better use of existing restricted airspace to facilitate live training. In a few cases, however, the proximity of training areas to the Federal Aviation Administration (FAA)–controlled National Airspace System (NAS) remains a problem. The summary in Table 4.1 provides a snapshot of the kinds of issues that have already been raised and will have to be revisited at some point because of the ongoing pressure to reduce defense budgets.

Table 4.1
Select Summary of Army UAS Installation Survey as of November 21, 2012

Base/Commands	Answer To Question E: Does Available Restricted Airspace Affect/Limit UAS Operations at Your Installation?	Answer To Question J: What Solutions Would You Recommend for Unsolved Issues?	Shadow Strips Planned for FY 2013
Alaska (Forts Wainwright and Richardson)	No.	We have been able to accommodate all down range requests. However, the hangars are nonstandard and need to be evaluated for suitability as the Shadow and Gray Eagle platforms evolve.	
Fort A. P. Hill	During landings the tactical approach landing system orbit is outside the restricted airspace.		Yes
Fort Bliss	Our special use airspace is bisected by a major highway which requires a COA.	Yes, a Shadow Strip in the SUA.	Yes
Fort Bragg	Yes.	Yes. Primarily commercial power and hardened maintenance facilities. Temporary solutions are power generation equipment and tentage.	Yes
Fort Carson	Yes, limited by the volume of manned/unmanned platforms operating within the airspace.	Yes, requests for designated UAS facilities and airstrip for launches and recovery. Funding established to build a multiple platoon facility for UAS units.	Yes
Fort Drum	No.	No. We have no unresolved UAS issues.	Yes
Fort Hood	Not currently.		
Fort Knox	No.	Yes; the construction of a tactical UAS field support structure (build it).	
Hawaii	Yes, we have requested to use the Kahuku and East Ranges for flights but due to FAA restrictions, we cannot fly UAS/SUAS platforms in these airspaces.	No. We need more airspace to train in. Our current location is becoming less and less amicable to flight conditions due to public demands on land. In 2010, plans were drawn up to provide for a permanent UAS facility at Wheeler Airfield, but they were cancelled due to program funding.	

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Table 4.1—Continued

Base/Commands	Answer To Question E: Does Available Restricted Airspace Affect/Limit UAS Operations at Your Installation?	Answer To Question J: What Solutions Would You Recommend for Unsolved Issues?	Shadow Strips Planned for FY 2013
Fort Lewis (Joint Base Lewis-McChord [JBLM])	1. Yakima Training Center (YTC): No not an issue. 2. JBLM: Yes, both the limited restricted airspace and the large number of installation units requiring restricted airspace, challenge UAS/SUAS operations.	1. YTC: Shadow Training Facility 2. JBLM: Construction of a second Shadow landing strip. 3. JBLM: Construction of any type of permanent, securable facility alongside the existing Shadow landing strip (location is outside JBLM's guarded area). 4. JBLM: Shadow Training Facility or TEMF.	
Fort Riley	Not currently. (See response to Q h & i.)	Nothing to comment on.	Yes
Fort Stewart	Not significantly. However, reductions in air traffic control manning are a concern. There are currently no significant restricted airspace challenges negatively affecting UAS operations.	Funding, we have a plan and the requisite site approvals, we just need funding support. We need the funding ($701,000) now for our third Shadow platoon hangar; we have the design ready to go and at contracting.	
USAREUR	Yes. 173rd Shadow out of Italy is currently based in Bamberg due to no restricted airspace to fly in Italy. Currently fly in restricted airspace in Grafenwoehr/Vilseck Training Areas.		
Camp Atterbury	No, both UAS facilities are within restricted airspace.		
Fort Chaffee	No restricted airspace limitations to TUAS flight operations.		Yes
Orchard Range	Yes, UAS operations are limited to using R-3203.	Fixed support facilities UAS operations. Facilities will be in Range Complex Management Plan.	
Fort Pickett	No, we have one of the largest SUAs in the Midatlantic.		
Camp Ripley	No, the restricted airspace at Camp Ripley (R-4301) provides enough area to conduct training for the current systems.	Yes. The current tactical strip will be removed for the construction of a MPTR. UAS commanders have requested a tactical strip for replacement that includes hard-stand buildings and electrical power. The Combat Readiness Training Center currently has a location selected that has power in close proximity to the existing tactical strip. Camp Ripley is one of the sites to receive $730,000 for construction of a UAS strip in the down-range area in FY 2013.	Yes
Camp Roberts	No.	Funding.	Yes

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Table 4.1—Continued

Base/Commands	Answer To Question E: Does Available Restricted Airspace Affect/Limit UAS Operations at Your Installation?	Answer To Question J: What Solutions Would You Recommend for Unsolved Issues?	Shadow Strips Planned for FY 2013
Fort Dix	Yes.	We have accommodated all downrange requests. However, the size restriction of the UAS in R-5001 limits operation of large UAS operations.	
Fort Hunter-Liggett	No, we use R-2513 airspace.	None.	
Fort McCoy	Yes, Current coutilization of Young Air Assault Ship, a 6,250-ft. C-17/C-130 landing strip in R-6901 B. The UAS operations at this landing strip affect Sparta/ Fort McCoy airport operations.	Yes. Hangers for Shadows and permanent facilities with commercial power, and asphalt. Standard design and funding required.	
Fort Campbell	Fort Campbell currently has two approved sites for Shadow Flight operation; both are located among numerous field artillery firing points, which requires de-confliction during launches and landings because the firing points have to check fire. As a result, UAS flight training is significantly reduced. However, an additional UAS strip is being constructed to alleviate this problem.	Yes. Permanent facilities with commercial power and utilities.	

SOURCE: Installation UAS survey responses from TRADOC Capability Manager—Live, as of November 21, 2012.

Key Areas of Concern

As the war in Afghanistan draws to a close, the services must pay close attention not only to the training of UAS crews and support personnel but also to the routine exercise of these systems as part of combined arms training at home station and at the CTCs. This will require attention to a number of issues.

Beddown and Related Support Facilities

To facilitate the efforts described above, DoD should support current and future programs to develop ranges and beddown and support facilities similar to those in the Army's current programs. The Army has been implementing a robust program to establish Shadow beddown facilities—runways, shelters, and attendant support structures—on many of its installations, both active and National Guard. This will enable more opportunities both for UAS operators and for end users.

Airspace Considerations

As the responses reported in Table 4.1 suggest, the unique limitations of UASs pertaining to operations in the NAS can make integration into home station training difficult. Currently, UASs can operate only in restricted military airspace or, in the NAS, with certificates of authorization (COAs) from the FAA. In some cases, it should be possible to increase UAS training with ground forces (and with collocated manned aircraft units) without impinging in any significant way on the NAS. Although this will certainly require better coordination of restricted airspace at individual installations, better availability of restricted airspace will make better

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access to the NAS less of a key element in supporting training strategies, at least as they pertain to home-station or local training of ground forces. However, less-cumbersome procedures for NAS access will, among other things, facilitate opportunities for units to employ larger UASs, such as Gray Eagle, Predator, and Reaper, in home-station training events.[9]

Air Force

The Army and the Air Force have significantly different concepts for employment of UASs. The Air Force uses a remote split operations concept to employ its UASs. Under this approach, the Air Force flies UASs from home station using satellite or other relay links. It maintains only small deployed footprints at consolidated operating locations to launch, recover, and maintain the aircraft.[10] This approach enables the deployment of the vast majority of its systems, yet the majority of the personnel who operate Air Force UASs do so from home station and require no reconstitution following deployments. By using remote split operations, 85 percent of the Air Force's UASs would be forward deployed for combat operations. The remaining 15 percent would support training at each operational base. The Air Force employment concept, however, does not facilitate integrated operations with Army tactical-level units during training at Army home stations. Once deployed, Army brigades, battalions, and SOF must learn to work with Air Force TACPs to coordinate UAS operations.

Training for Pilots, Operators, and Support Personnel

The Air Force uses a crew of one pilot and one sensor operator to man each UAS mission.[11] The pilots are officers and are either rated pilots who graduated from undergraduate pilot training or UAS-only pilots who graduated from a new program called undergraduate remotely piloted aircraft training.[12] UAS-only pilots have the 18X Air Force Specialty Code (AFSC) and will be discussed in more detail later. Following the structure of the training pipelines for other platforms, the training is broken into three phases: IQT, mission qualification training (MQT), and crew mission ready training. Air Education and Training Command conducts IQT and MQT, with the latter taking place in a formal training unit (FTU).

[9] In some cases, basing for the larger systems, especially Gray Eagle, will be contiguous with the training areas in which they are needed; Fort Hood, Texas, is an example. But this will not always be possible. The larger systems require longer and better runways and larger and more-sophisticated beddown and support facilities. It may be more cost-effective to move these UASs to support training where they are needed, rather than establishing beddown facilities in a large number of additional locations.

[10] The 432nd Wing at Creech AFB operates MQ-1 Predators and MQ-9 Reapers from seven forward bases overseas. Maintainers at forward bases serve four-month rotations in theater.

[11] Many more people are involved in RPA operations, including the mission intelligence commander. Also, there is a weapon school course for advanced training of RPA operations. For this research, we were primarily interested in the initial training of pilots and sensor operators.

[12] Some Air Force navigators who had commercial instrument qualifications have been allowed to train as pilots for the RQ-4. This avenue for sourcing RQ-4 pilots closed in spring 2011.

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Pilots

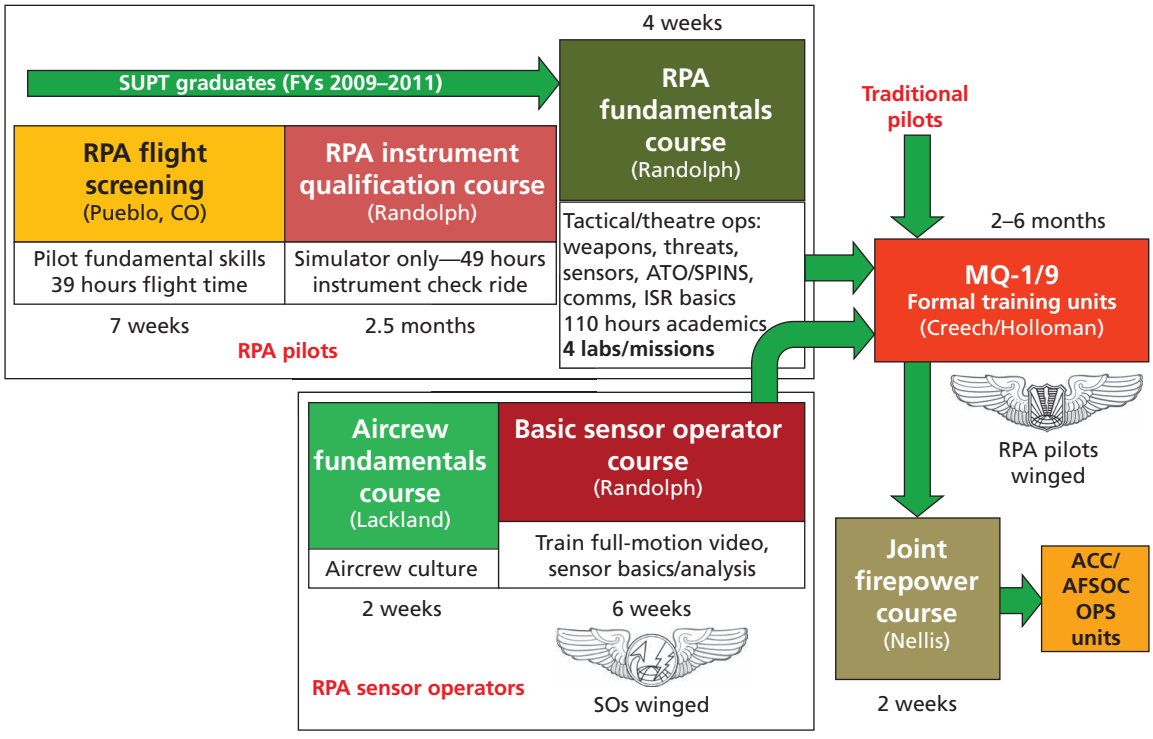
Reaper and Predator

In response to the need to reach and sustain the manpower to fulfill Reaper and Predator requirements, the Air Force initiated a new program to produce RPA pilots.[13] Currently, Reaper training takes place at Hancock Field Air National Guard Base in Syracuse, and Predator training takes place at Holloman AFB. New RPA pilots have attained the foundational skills to conduct RPA missions and are qualified to operate in the NAS or International Civilian Aviation Organization airspace. Figure 4.5 outlines the training pipeline. Figure 4.6 shows the UASs.

Global Hawk

Currently, most Global Hawk pilots are traditional Air Force pilots who volunteered for a tour in the Global Hawk (see Figure 4.7), a majority of whom are qualified to fly multiengine transport aircraft. Prior to 2011, navigators who also had commercial pilot licenses and had completed commercial instrument qualifications were allowed to become Global Hawk pilots; however, the Air Force has not decided whether to retain navigators who are currently Global Hawk pilots in the community or return them to navigator duties. The third source of Global Hawk pilots is the 18X career field, UAS-only pilots who have graduated from undergraduate remotely piloted aircraft training. After finishing the three preparatory courses, candidate Global Hawk pilots head to the RQ-4 FTU, the 1st Reconnaissance Squadron at Beale AFB.

Figure 4.5
Air Force UAS Pilot and Sensor Operator Pipeline



RAND *RR440-4.5*

[13] The Air Force uses the term *RPA* to refer to unmanned aircraft systems. The accepted joint terminology is *UAS*.

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Figure 4.6
Reaper (top) and Predator UASs



SOURCE: U.S. Air Force.



SOURCE: DoD.
RAND *RR440-4.6*

Once at the FTU, pilots are trained first on simulators designed for pilots with an instructor pilot. Then, they participate in on-the-job training, flying live missions with an instructor pilot in the mission control element.

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Figure 4.7
Global Hawk UAS



SOURCE: DoD.
RAND *RR440-4.7*

Sensor Operators

Reaper and Predator

Enlisted sensor operators for Reaper and Predator are either trained into a new career field or cross-trained from another AFSC (1U00X). After graduating from the Air Force's basic training or being reclassified, they attend a two-week course at Lackland AFB, Texas, with other aircrew AFSCs. Then they go to Randolph AFB, Texas, for a six-week basic sensor operator course. After completion, they go to the appropriate FTU for the system they will be flying.

Global Hawk

Sensor operators for the Global Hawk are trained differently from those for other UASs. Sensor operators for the Global Hawk come from the intelligence imagery analyst career field (1N1XXs). They receive MQT at Beale AFB, where they learn to use the Global Hawk system. After one tour as sensor operators (approximately three years), they move on to other imagery analyst assignments; therefore, it is difficult to maintain expert sensor operators for the Global Hawk.

Maintenance

Training for those who maintain Air Force UASs takes place at three locations.[14] The fundamentals are taught at the maintenance schoolhouse at Sheppard AFB, Texas. Initial skills training and advanced skills training take place at the unit.

[14] Contractors provide certain UAS maintenance, for example, depot-level maintenance.

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Operational Training

Given the emphasis on current operations and the Air Force's remote split operations concept for employing UASs, few opportunities exist to support ground troops either during home-station or CTC training. In general, with a few limited exceptions, Air Force UAS crews do not train in exercises or other training events in CONUS and do not support training in CONUS of Army or Marine Corps units at either their home stations or at the CTCs. Air Force UAS crews do conduct operational missions in theater, and these missions frequently are the chief or even the only way deployed Army and Marine Corps units get an opportunity to work directly with Air Force UAS crews. Thus, most elements of the UAS force in theater often have no experience working together before they have to do so in combat operations.

The result of not working with ground troops either at home station or the CTC is that ground units generally do not integrate Air Force UAS capabilities into their planning. RAND's conversations with the training community, including trainers at the NTC, as well as what officials told the GAO, confirmed that the

> effective integration of UAS in training exercises, like the integration of other types of joint air assets, depends on the priority that ground units place on developing training objectives that require the participation of joint air assets and their ability to plan for the use of these assets in the exercise. … [As a result], Army combat brigades often focus UAS training objectives during exercises on integrating their Shadow UAS and do not emphasize planning for and employing Air Force UAS.[15]

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[15] Independent RAND team visits also confirmed what the Air Force told the GAO, that

> unmanned aircraft are deployed to support overseas operations except for those that are supporting the initial training of UAS personnel or the testing of aircraft." These officials [from the 432 Wing] stated that in the event that additional aircraft were made available, the wing's personnel levels are insufficient to support additional training events because the unit does not have adequate personnel to support projected operational commitments and greater numbers of training exercises. Second, Army and Air Force officials told us that when Air Force UASs are at the training center, these aircraft are not always available to support ground unit training because a considerable portion of the UAS flight time is dedicated to accomplishing Air Force crewmember training tasks. Officials told us that the Army and Air Force have reached an informal agreement to allot about half of the time that an Air Force UAS is flying at the training center to support Army ground unit training objectives and the other half to accomplish Air Force training tasks. Air Force officials pointed out that although they try to align their crewmember training syllabi with ground unit training objectives at the National Training Center, training new personnel to operate these aircraft is their priority. Third, UASs may not be available during certain hours to support ground unit training, which during exercises goes on 24 hours a day. For example, Predator UASs from the California Air National Guard are available to support ground units only during daylight hours. To travel to the training center, these aircraft must pass through segments of national airspace that are not restricted for DOD's use and therefore must rely on a ground-based observer or on chase aircraft to follow them to and from the training center. Because of this reliance on ground or airborne observers, flights to and from the training center must be accomplished during daylight hours and are necessarily more expensive as well.
>
> As a result of the limited number of unmanned Air Force assets that are available to support ground unit training at the National Training Center and the Joint Readiness Training Center, Army ground units conducting training exercises have frequently relied on manned aircraft to replicate the capabilities of the Air Force's Predator and Reaper UAS. Officials told us that the use of manned aircraft in this role permits ground units to practice the process to request and integrate the capabilities provided by Air Force UASs in joint operations. However, this practice is not optimal, as the manned aircraft do not replicate all of the capabilities of the Predator and Reaper aircraft, such as longer dwell times.

GAO, 2010a, p. 26.

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Key Areas of Concern

We note above that, as the war in Afghanistan draws to a close, the services must pay close attention not only to the training of UAS crews and support personnel but also to routinely including these systems in combined arms training at home station and at the CTCs. This will require attention to a number of issues.

Beddown and Related Support Facilities

Discussions with officers of the 432d Wing suggest an Air Force future much like the past: flying in support of COCOM requirements worldwide. If this comes about, there will continue to be limited opportunities for the Air Force to support Army or Marine Corps training at the home station or CTCs. Alternatively, if providing such training becomes a priority, the Air Force's current basing and beddown posture will become a problem.

Airspace Considerations

The unique limitations of UASs pertaining to operations in the NAS make integration into home-station training difficult. Currently, UASs can operate only in restricted military airspace or, in the NAS, with COAs from the FAA. These COAs can often be prohibitive to participating in joint training. For example, the MQ-1 FTU from March ARB tried to participate in training with the Marines at Twentynine Palms. Unfortunately, the COA requires a manned chase plane and, given the geography, the contracted chase plane cannot fly the shortest route. The only option is to fly through the restricted airspace between Fort Irwin and Twentynine Palms, which is prohibitively long because the COA permits operations only during daylight hours. These limitations restrict where UASs can be used because an installation must have access to a significant amount of restricted airspace. Other limitations include the basing expense of sprinkling UASs across the country to embed with Army or Marine units at home station.

Several different possibilities could be considered to help increase joint training opportunities. The Air Force could consider the location of Army hubs when choosing where to base its UAS fleet. A location that is near Army maneuver elements might make airspace access less of a restriction or at least make COAs more practical. Proximity might provide more opportunities for training UAS integration throughout the entire mission planning process.

Alternatively, the Air Force could permanently leave a small number of UASs at a training location and remotely operate these from Holloman AFB, Creech AFB, or other locations. These systems are designed to employ remote split operations, in which the crew operating the platform need not be colocated with the platform. The various Air Force units could get flying time by cycling through these dedicated aircraft. This option would provide Air Force crews—including launch and recovery crews—practice integrating with ground forces and would simultaneously support the ground forces' need for integrated training. This plan would also reduce the issue of airspace access because the aircraft would be located within the restricted airspace in which they would be used or at an auxiliary airfield close enough that a COA would be practical.

A promising development that enhances UAS training is the advancement of ground-based sense-and-avoid (GBSAA) and airborne sense-and-avoid (ABSAA) technologies. These may open up regions of civil airspace for properly equipped UASs to operate safely in accordance with the FAA's mandate to "do no harm" without requiring FAA issuance of COAs. In particular, GBSAA has recently completed a series of successful demonstrations, and the

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Army is planning to GBSAA equip a number of its UAS training bases to extend their current military airspace with adjoining civil airspace to increase UAS training capacity by 2015. The Army is the lead for the development of GBSAA, but GBSAA has been designed for the use of all the services. Each service, like the Army, would use one of its existing ground based radars in implementing GBSAA. ABSAA's implementation uses UAS-borne sensors and electronics, including those not currently on UASs. Current development of all-weather ABSAA that could operate without FAA COAs is restricted to Global Hawk, with plans to scale down to Reaper. ABSAA availability is not known at this time but will be some years after GBSAA becomes available.

Navy

Relative to the Air Force and Army, the Navy has had limited experience with UASs. To date, Navy ships have employed the Scan Eagle, a non–program of record UAS, fielded through a rapid-acquisition program (see Chapter Two). Scan Eagles are flown from frigates. The Navy has also operated BAMS-D,[16] which is scheduled to be replaced by the MQ-4C, Triton.[17] The Navy is acquiring the Fire Scout (MQ-8B). While we limited most of our study effort to the period through FY 2012, the Navy's most recent experience is the best example of the evolution of UASs and their implications for operational capabilities. In early May 2013, the Navy launched an X-47B experimental drone from the nuclear powered aircraft carrier USS *George H.W. Bush* as it operated off the coast of Virginia (Vergakis, 2013). This launch represented the latest step in introducing a disruptive technology into the operating forces and helped mark a paradigm shift in warfare because this particular UAS is capable of autonomous flight.

The Navy's approaches to integrating UASs and to training and developing UAS operators differ significantly from those of the Army and Air Force. Generally, Navy UASs are being incorporated into existing fleet aviation units and organizations, and the personnel who will operate them are, to a large extent, the same personnel who will operate traditional aircraft assigned to these organizations. In this way, the Navy is addressing several problems often seen when disruptive technologies are introduced. The Navy approach has emphasized the complementarity of the systems, rather than pitting the new technology and its proponents against the old technology and its proponents. In addition, the Navy will reduce cost by capitalizing

[16] While the Air Force has conducted Global Hawk UAS operations since 2001, the Navy has just recently pursued using the system. The Navy purchased Global Hawk airframes from the Air Force and is using them to test operational concepts and technologies. The aim for the Global Hawk maritime demonstration program, BAMS-D, is to better understand maritime surveillance with UASs that fly at high altitude. The goal is to improve the fleet's operational understanding of the battlespace, and the Navy deployed BAMS-D in 2009.

[17] The Navy's BAMS UAS (MQ-4C), now called Triton, is a persistent maritime intelligence, surveillance, and reconnaissance system. As a persistent airborne asset, Triton's sensors will support increased situational awareness for naval forces. The imagery and data provided by the airframe's sensors will be directly available within federated networks, allowing Navy, joint, allied, and coalition exploitation centers to use MQ-4C UAS data.

While the Navy is currently operating only BAMS-D (in FY 2012), it plans to purchase a total of 68 Triton MQ-4C UAS airframes from FY 2014 through FY 2026. This acquisition plan will increase deployment of BAMS to operational commanders throughout the world. The current concept of operations includes plans for the Navy to operate Triton UASs in five separate geographic locations. These operations would provide continuous maritime surveillance, with persistent ISR support 24 hours a day, seven days a week, out to ranges of 2,000 nautical miles from the deployed location. (Derived from Department of the Navy, 2010.)

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on investments already made in personnel aviation training. For example, the Fire Scout UAS will be embedded in Navy H-60 squadrons.[18] This enables taking advantage of H-60 pilots' training and experience, because they will also pilot the Fire Scout. The flying skills of the H-60 pilot are utilized for both airframes and minimize the potentially disruptive effects of this new technology. Similarly, Triton, the follow-on to BAMS-D, is intended to complement Navy P-3/8 aircraft with its long loitering capability and sensors. The Navy plans to have P-3/8 officers both be in tactical command of the UAS and pilot the Triton UAS. These officers will first serve and qualify in the P-3/8 aircraft, rotate to a UAS training unit, then assume duties in a UAS squadron. The Triton UAS capabilities complement the capabilities of the P-8 aircraft. The training construct the Navy is pursuing will capitalize, complement, and exploit the capabilities of both aircraft and the personnel assigned to them.

Training for Operators and Support Personnel

Scan Eagle

Qualification training for personnel directly associated with UAS operations is not yet well established for the Navy. Currently, contractors operate the Scan Eagle UAS. (See Figure 4.8.)

Fire Scout

The Navy will have two approaches for Fire Scout operator training—one for littoral combat ship (LCS) employment and another for SOF support. The majority of Fire Scouts will be flown from the LCS. (See Figure 4.8.)

Littoral Combat Ship Employment

The aviation detachment that will deploy with the LCS will consist of one H-60R helicopter and two Fire Scouts and will have 23 assigned personnel. The training these personnel will need is similar to that for deploying with H-60 detachments on guided missile destroyers today (normally, two H-60 helicopters deploy with a guided missile destroyer). In the future, ships will deploy with a mix of H-60s, and Fire Scout and aviation detachment personnel will fly both aircraft depending on mission requirements.

The skills needed to operate and maintain the Fire Scout are complementary to those needed for the H-60. The operators and maintainers of Fire Scout will be the same as for the H-60, with some additional training on the Fire Scout. An H-60 fleet replacement squadron's (FRS's) Fire Scout fleet introduction team will provide this training to the AVOs and MPOs en route. The AVO course for H-60 pilots lasts five weeks. This initial and all sustainment training for the Fire Scout will be conducted via simulator.

Fire Scout Support for Special Operations Forces

The Navy is establishing dedicated units to support SOF, rather than integrating Fire Scout into existing units. The first of these units, Unmanned Helicopter Reconnaissance Squadron One, will be both a training and an operational squadron. The Navy's plan is to organize each such squadron to have nine detachments, each consisting of three Fire Scout airframes, seven to eight AVOs, eight MPOs, and 16 maintenance and support personnel. The Fire Scouts that will be flown off LCSs will be piloted by commissioned officers. The Fire Scouts supporting

[18] The Fire Scout will greatly contribute to increased mission readiness and response by conducting persistent ISR operations immediately around seaborne task forces, as well as over the horizon. The persistence, range, sensors, and data sharing of UASs extend the ISR reach of Navy ships and increase situational awareness.

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Figure 4.8
Scan Eagle (top) and Fire Scout UASs



SOURCE: DoD.



SOURCE: DoD.

RAND *RR440-4.8*

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SOF units will be piloted by enlisted AVOs. Initially, these AVOs will be air warfare operators who have completed tours as MPOs with an LCS Fire Scout.

Fire Scout Maintainers

The Fire Scout maintainers consist of four Navy specialties. Enlisted aviation machinist mates and aviation structural mechanics will take the mechanical course for LCS Fire Scout. Enlisted aviation electronics technicians and aviation electrician's mates will take an electronic technical course for LCS Fire Scout. The maintenance and support skills needed for the Fire Scout are complementary skills for Navy enlisted technicians.

Triton

Operator Training

The MQ-4C Triton UAS is composed of several systems: the airframe; a suite of mission payloads; communications systems; a mission control system (MCS) used for mission planning, control, and execution; and a support system. The Triton UAS will be deployed as an adjunct system to P-3/8 squadrons. The MCS will be based at a main operating base in CONUS, and BAMS maintenance and launch and recovery operations will take place at a forward location.

The Triton watch organization will consist of a mission commander (P-8 naval flight officer),[19] one AVO (officer, P-8 pilot), and two mission payload (enlisted) air warfare operators. Training plans for the Triton watch organization are being developed, and the initial operating capability of Triton will be in FY 2016. The Navy plans to use P-3/8 pilots as tactical coordinators and AVOs on the Triton. Future aviators will first go through flight school, earn wings on the P-3/8 aircraft, then perform an initial operational tour on the P-3/8.[20] After that, aviators will rotate to the FRS for training on Triton before reporting to their squadrons. Designated FRS for BAMS is Patrol Squadron 30 (VP-30), located at Naval Air Station Jacksonville, Florida. FRS training provides initial and refresher qualification training for personnel who will be assigned to Triton units.

Maintenance personnel and the pilot who launches and recovers the airframe are located at the forward operating base. The Navy plans to rotate personnel through the forward base every several months.

A simulation training capability will be built into the MCS. Initial Navy manning plans indicate that there will be eight to ten crews per squadron. The crews will be flying real missions that will sustain their proficiency. Triton UASs are flown via point and click; there is no stick and rudder. VP-30 is developing the tailored Naval Air Training and Operating Procedures Standardization requirements for the Triton; the final training and readiness manual for Triton is due in 2013.

Maintenance Training

The Triton airframe, engines, and associated equipment are different from the P-3/8; one is a UAS and the other a manned aircraft. Separate training will thus be necessary. When the

[19] The mission control officer is a naval flight officer who is responsible for the mission planning and the overall tactical employment of the airframe. The AVO is a naval aviator, responsible for flight planning and safety of flight, and is the pilot in command of the airframe. The MPOs are enlisted air warfare operators, responsible for the operation and employment of the sensors and the detection and analysis of targets.

[20] The notional pilot training track for P-3/8 pilots is (1) attend and graduate from flight school, (2) attend FRS for P-8 training, and (3) conduct an operational P-8 squadron tour.

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Triton UAS is introduced into the fleet, the Chief of Naval Air Technical Training will stand up a technical school to train enlisted personnel to perform Triton maintenance.

Operational Training

BAMS/Triton

The P-8A's missions overlap with those of Triton. The missions the two have in common include maintaining the maritime common operational picture and the classification, identification, detection, and tracking of surface units. The P-8A, however, has missions that the Triton does not perform (e.g., antisubmarine warfare) and vice versa. However, the increased utilization and cross training of P-8A and Triton crews over time can and is expected to increase understanding and employment of these systems in support of the warfighter.

While the Navy was operating only BAMS-D in FY 2012,[21] the Navy has plans to purchase a total of 68 Triton MQ-4Cs UAS airframes from FY 2014 through FY 2026. This acquisition plan will increase deployment of Triton UAS to operational commanders throughout the world. The current concept of operations includes plans for the Navy to operate Triton UAS in five geographic locations. These operations would provide continuous maritime surveillance, with persistent ISR support 24 hours a day, seven days a week, out to ranges of 2,000 nautical miles from the deployed location (Department of the Navy, 2010). The LCS does not have the Navy Continuous Training Environment (NCTE) synthetic training capability, and Fire Scouts assigned to the LCS will have no capability to train in the NCTE. Integrated training plans for Fire Scout are being developed.

Integrated Training

Triton's MCS will be configured so that it can participate in fleet training exercises synthetically via NCTE. Fleet synthetic training events for BAMS-D and Triton are being developed.

Key Areas of Concern

Airspace Considerations

Airspace planning is a critical requirement when conducting UAS operations but is less of a constraint for UASs in naval operations. The FAA controls the airspace up to the 12-mile limit from land. Navy surface ships with Scan Eagle and Fire Scout can embark the UASs, travel 12 nautical miles out to sea to a naval operating area, then conduct UAS training.

BAMS-D and Triton use special use airspace and fly at altitudes higher than commercial airlines do. They file instrument flight rules flight plans. However, BAMS-D and Triton do not incorporate sense-and-avoid technology, and conflicts can exist with visual flight rules aircraft in the airspace. Airspace issues exist at some Navy training installations as well. For example, along the North Carolina coast, the expeditionary readiness group must work with the FAA to route commercial aircraft around the established restricted operating zone units.

[21] BAMS-D has participated in CSG training events in the Virginia Capes operating area, including combined training unit exercises and joint task force exercises. Navy officials emphasized that Triton is a tactical asset and will respond to the requirements of the task force.

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The Need for Interoperability

So far, this report has emphasized that home-station training is not as effective as it should be, thus reducing the effectiveness of multiservice, or interoperability, training at CTCs and during joint exercises. The importance of interoperability training is stressed in Chairman of the Joint Chiefs of Staff Guide 3501 (2012, pp. B-2 and B-3), which notes that the

> ability of systems, units, or forces to operate in synergy in the execution of assigned tasks is critical to successful operations. This ability to operate effectively together describes interoperability. From a joint training perspective, interoperability is a Service component responsibility. Interoperability training is based on joint doctrine, or where no joint doctrine exists, on Service or [SOF] doctrine to prepare forces or staffs from more than one Service component to respond to operational and tactical requirements deemed necessary by CCDRs [combatant commanders] to execute their assigned missions. Interoperability training involves forces of two or more Service components (including SOF) with no interaction with a CCDR or subordinate JFC [joint force commander] or joint staff.

The publication in 2011 of the MTTP for UASs was designed to address the problem of interoperability. As designed, it is

> a single source, descriptive reference guide to ensure effective planning, integration, and utilization of multi-service UAS capability. It provides commanders, operational staffs, requestors, and UAS operators with a comprehensive resource for planning and employing unmanned aircraft . . . . US Air Force (USAF) uses the term [RPA] for the air vehicle component of a UAS. (MTTP, 2011, p. i)

To date, interoperability training at the NTC and the Joint Readiness Training Center has been limited.[22] GAO (2005, p. 2) cited two significant challenges for improving interoperability training: (1) "establishing effective partnerships with program stakeholders through comprehensive communication and coordination and (2) developing joint training requirements that meet combatant commanders' needs," with particular emphasis on tactical level training (GAO, 2005, p. 2).[23] To meet this challenge, DoD established the Training Transformation Implementation Plan (Director, Readiness and Training Policy and Programs, 2006), giving the Office of the Under Secretary of Defense for Personnel and Readiness overall responsibility and giving the Deputy Under Secretary of Defense for Readiness executive agent responsibility for training transformation planning, programming, budgeting, and execution progress.

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[22] GAO, 2005, p. 1, found that

> U.S. forces are conducting significantly more complex operations, requiring increased interoperability between and among the military services, combatant commands, and other DOD and non-DOD organizations. In the past, military services experienced some joint operations training during joint exercises, but most service training focused on individual service competencies with limited joint context.

[23] GAO, 2005, p. 18, noted that,

> in the past, joint training tasks were primarily focused at the command level and were identified through DOD authoritative processes that built requirements by translating command combat commanders inputs into training requirements. Training transformation has expanded joint training requirements to include those at the tactical level in addition to joint command level training.

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While RAND did not assess interoperability training in detail, discussions with the Army's training community, as noted above and as reported in GAO, 2010a, p. 26, suggest that such opportunities have been limited by the lack of Air Force assets, particularly the Predator, due to pressing operational requirements in Iraq and Afghanistan. The problem of transiting Air Force UAVs from Creech AFB to the NTC at Fort Irwin through FAA controlled airspace is often cited. Permanently stationing Air Force UAVs at the NTC would, of course, negate that problem, much as the Marine Corps has done by basing UASs at the MCAGCC at Twentynine Palms, California, to support training there. However, the experience of the Marine Corps suggests that the mere presence of UASs will not ensure that the forces are properly trained. The forces must prepare at their home stations for such training. In addition, given the common MTTP, forces trained to operate with their own services' UASs should find working with UASs from the other services less challenging.

Simulators

Congress has pressed for information on the role that simulators might play in a UAS training strategy, seeking an informed balance between live training and simulated training. In addition, the GAO reported that the

> military services lacked simulators that were capable of supporting training that is intended to build proficiency in skills required of UAS vehicle and sensor operators and prepare these personnel to conduct UAS combat missions. … [And] the Air Force and the Army have not fully developed comprehensive plans that address long-term UAS simulator requirements and associated funding needs. (GAO, 2010a, pp. 27–28)

Implicit in the GAO's comments is an assumption that simulators should play an important role in the future of UAS training. Our review questions that conclusion.

DoD has historically viewed simulator training and joint use of training facilities as an exercise in cost reduction. It is first necessary to understand how simulation better enables the introduction of the technology and, similarly, how joint use of the disruptive technology enables more effective military operations. For the purposes of this report, we have clearly focused on these aspects of simulation and jointness, which must be understood before the more-traditional perspectives of resource allocation can be applied. Currently, the usual significant savings that the department has garnered from simulators in the past do not appear to obtain in this instance. The danger is that, if the department starts with a savings orientation, it will not fully capitalize on the capabilities UASs represent.

For traditional aircraft systems, one major appeal of using simulators, rather than live flying, is the cost differential. For example, a RAND study of the trade-off between live and simulated training for manned aircraft noted that "the Marines and British are starting to give greater recognition to use of simulators as they seek either to reduce the high costs of live training or conserve the limited life of operational aircraft" (Schank et al., 2002, p. 49). In this case, the cost of flying the strike fighter aircraft they were discussing was many times greater than the cost of using a simulator, and the procurement cost of the aircraft itself was also significantly greater than that of the simulator. That said, they also noted that,

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> [t]o increase that use, several improvements must happen to integrate simulators more fully into their unit training. The fidelity and availability of simulators must increase to the point that fighter pilots see their benefit in training. This requires additional funding for simulators. (Schank et al., 2002, p. 49)

The report further argues that, even given the cost advantage of simulators for strike fighter aircraft training, simulators are a complement to live training, not a substitute for it.

The same point was made to us concerning UAS simulators. Officials of the 432d Wing also noted that simulators were not very good for training on landings. Moreover, a substantial investment in new simulator technology would be necessary to improve the realism of UAS simulators to the point it could prove useful for training UAS crews and ground forces. For example, GAO, 2010a, p. 28, found that currently Air Force and Army simulators did not have the ability

> to replicate all UAS procedures and to enable the integration of UAS training with other types of aircraft, [e.g.,] … the Army's Shadow Institutional Mission Simulator is not currently capable of replicating system upgrades that are being fielded directly to ongoing combat operations, such as a laser target designator and communications relay equipment. … Air Force and Army simulators are also … incapable of providing virtual, integrated training opportunities between manned and unmanned aircraft because of interoperability and information security concerns.

The conditions that make a compelling case for simulators for the training of fighter pilots are largely absent when it comes to UAS training:

- First, UAS flying hours are much less expensive than flying hours for manned aircraft. By one account, the flying hour cost of Shadow was $705; a comparable figure for Gray Eagle was $4,275.[24] By comparison, the Air Force told the GAO that "the live training cost of one F-15E flight hour is approximately $17,449" (Pickup, 2012, pp. 15–16). Other sources peg the flying hour costs of manned aircraft much higher.[25]
- Second, the kinds of operational activities that need more training emphasis, in particular, air-ground coordination, are generally not activities in which simulators *per se* can substitute for live flying. A good example of both the limitations and the value of simulators can be found at the digital air-ground integration ranges the Army operates today. On these ranges, only the weapon system engagement is simulated. Everything else—planning, coordination, UAS operation, ground unit and/or manned aircraft activity, target acquisition—is live.
- Third, while simulators are inherent in the systems used for initial training of pilots and sensor operators,[26] they are not well suited (and not designed) for training operating

[24] Ron Moring, UAS cost per flying hours, personal communication, April 5, 2013. The cost for the Gray Eagle is similar to the costs the Air Force reported for Predator at $3,679 and Reaper at $4,762, as reported by Mark Thompson, "Costly Flight Hours," *Time*, April 2, 2013.

[25] Recently, the Air Force comptroller's office told *Time* that the flying hour cost for the F-15C was $41,921. Other aircraft had considerably higher flying hour costs; e.g., the cost of flying an F-22 for one hour was reported to be $68,362. See Thompson, 2013.

[26] See Shawn Johnson, DAMO-TRC Army Flying Hour Program, "UAS cost per flying hours," personal communication, with Joan Vandervort, Office of the Office USDP&R, April 10, 2013.

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forces on the full spectrum of UAS capabilities. Simulators may be useful as a supplement to live training of pilots and crews but do not replicate the myriad activities and stimuli that a live training environment provides well for maneuver forces.
- Fourth, as noted previously, simulators at best complement rather than substitute for live training. Given the current state of UAS fielding, first priority must be given to building the live-flying infrastructure. Then, and only then, might funds be used to undertake the research and development that must precede any consideration of fielding the kind of interactive UAS air-ground simulators that could train both UAS crews and ground troops.

In the future, the services should reevaluate the need for virtual training using a cost and effectiveness analysis (COEA) including developmental costs for simulators, the savings based on the costs of flying UASs, and the critical availability of air space for training. Given current budget limitations and the importance of fully developing the opportunities for live training and the relatively low cost of such training, diversion of funds to a research and development program to develop higher-fidelity UAS-ground simulators is not appropriate at this time.

Summary

This chapter presented an overview of UAS training in 2012. Our focus was on service-specific and interoperability training. The training framework presented in Chapter Three was our starting point, with an emphasis on preparing forces for joint training and deployment. We looked at ground, air, and sea forces. Insights came from a wide variety of sources but mainly through visits to selected service bases, where we talked with operators and support personnel, those who train operators and associated team members, and those who train and observe the forces who employ UASs. In general, the RAND team found that qualification training in all the services for designated UAS-specific MOSs is well established. The critical issue is being able to train with ground forces at home station. The experience of the Marine Corps illustrates the importance of such opportunities. The Marine Corps has Shadow squadrons based at the MCAGCC at Twentynine Palms, California, where the restricted airspace is adequate both for maintaining crew proficiency and for supporting ground forces. However, both the ground trainers and squadron personnel the RAND team interviewed reported that the ground forces are not adequately trained at home station to integrate UAS capabilities into their operations. This required starting with what amounted to "remedial" training at Twentynine Palms, and trainees thus did not achieve the level of proficiency desired. This suggests that the biggest challenge in developing and implementing a training strategy for UASs is gaining and maintaining proficiency on the part of end users or "supported units"—the leaders and staffs who will integrate UAS capabilities into their operations.

Thus, as the war in Afghanistan draws to a close, the services must pay close attention not only to training UAS crews and support personnel but also to routinely exercising these systems during combined arms training at home station and at the CTCs. We addressed a number of issues for this, including beddown and support facilities and airspace considerations.

We found that home station training is generally not as effective as it should be, thus reducing the potential effectiveness of multiservice or "interoperability" training at CTCs and during joint exercises. We noted that, to date, interoperability training at the CTCs has been

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limited by the lack of Air Force assets, particularly the Predator, due to pressing operational requirements in Iraq and Afghanistan. However, given the common MTTP, forces trained to operate with their own service UASs should find working with UASs from the other services less challenging.

Finally, we considered the case for UAS simulators. Currently, such simulators do not appear to offer the significant savings that the Department has usually garnered from simulation in the past. We concluded that, given current budget limitations and the importance of fully developing the opportunities for live training and the relatively low cost of such training, diversion of funds to a research and development program to develop higher fidelity UAS-ground simulators would be unwise at this time.

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CHAPTER FIVE

Implications and Recommendations

The Guiding Principle: "Train As We Fight"

DoD has been under some pressure from Congress and such organizations as GAO for the lack of central control and the lack of the development of a joint DoD strategy for training. For example, "DOD Lacks a Comprehensive, Results-Oriented Strategy to Resolve UAS Training Challenges," was the summary title of a section of a recent GAO report (GAO, 2010a, p. 29). The Joint Unmanned Aircraft System Center of Excellence was established to support the joint operator and the services by facilitating the development and integration of common unmanned aircraft system operating standards, capabilities, concepts, technologies, doctrine, tactics, techniques, procedures, and training. The center, however, was disestablished in May 2011, and its UAS oversight function was reassigned to the Joint Staff Force Structure, Resources, and Assessment Directorate (J8), with some responsibilities assigned to the UAS Task Force. However, the 2011 publication of the MTTP for UASs addressed the problem of interoperability, and the services have agreed to incorporate the MTTP in their training.
While the services have agreed to a common set of TTP, each service continues to develop its own UASs to meet its own requirements. Moreover, the GAO (2010a, p. 25) has well documented that the opportunity for joint training is limited. While the GAO identified a number of organizations and initiatives addressing UAS training challenges, only one of the eight organizations and initiatives it listed were led by the services. Given the current maturation of UAS platforms, this emphasis is misplaced; the military services employs their UASs in very different ways. Today, the services are still struggling with how to incorporate these new systems. The appropriate strategy for UAS training is to encourage each service to solve its own UAS training problems, then to coordinate the resulting TTPs by updating the MTTP to achieve a high level of interoperability.

Commanders and operators from the bottom up are discovering and adapting to the revolutionary operational changes that UASs have brought about. The most apparent changes are in the persistence and responsiveness of UASs relative to other platforms in the permissive threat environments in which they are currently operating. These characteristics help develop valuable shared situational awareness between UASs and the supported forces and also make ISR capabilities more responsive and immediately available. Processing, exploitation, and dissemination concepts for UAS-generated information, however, are still evolving. In addition, armed UASs provide strike capabilities similar in some ways to those of CAS; the evolution of UASs from pure ISR platforms to small, lightly armed ISR platforms, to bigger, more heavily armed, faster, and even stealthier reconnaissance-strike platforms has crossed operational and cultural seams. This has lead to the need for continual resolution of disputes between intelli-

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gence and operations staffs over priorities for UASs and their implications for mission planning and execution.

To date, the services have, in a variety of important ways, been "training *while* they fight." Iraq and Afghanistan have served as de facto training ranges, as well as an active theater of war. For example, Air Force Predator and Reaper pilots and sensor operators have frequently gone straight from flight instruction and certification to flying real-world missions, learning and adapting as they support operations. Army and Marine Corps units have also learned in theater how to capitalize on the robust set of capabilities UASs provide.

The demonstrated ability of the services to learn on the fly should be cause for optimism about continued success in UAS training as operations wind down. But that continued success will depend on preserving training opportunities in an environment in which training is not an incidental by-product of operational requirements. Operational experiences, for example, typically do not suffer from the inherent limitations of CONUS training venues, such as limited area, limited time, and limited fidelity. Because of such limitations, it has been harder to train as we fight in CONUS. Infrastructure and other limitations currently make it difficult or impossible to train at night or in bad weather, to train with live or dummy munitions, or to train in a communications environment that represents the environment and demands of actual operations in theater. Preservation of the current levels of proficiency, improvement where needed, and adaptation to changing circumstances will not come without effort; they will require overcoming or at least alleviating the limitations mentioned here.

Elements of a Strategic Training Plan

To *train as we fight*, the DoD training strategy must

- engender better appreciation of UAS capabilities throughout the chain of command
- address organizational, structural, and infrastructure and support issues
- enable training as we fight in collective unit training
- enable training as we fight in larger exercises.

Engender Better Appreciation of UAS Capabilities

Many ground force commanders and their battle staffs today do not fully recognize the potential benefits UASs bring to the fight and, as a result, are not in a position to benefit from them in circumstances that would improve units' warfighting capabilities. This is traceable in part to limited use of UASs in home-station and CTC training but also to other inherent limitations, such as a shortage of experienced personnel and UAS assets and airspace and infrastructure limitations. Overcoming these limitations will enable more opportunities to foster better understanding and improve integration. Training guidance should emphasize the value of UASs, using examples of how units have benefited by preparing themselves to use such systems through training and attending familiarization courses. Such vignettes can be inserted into professional education and training materials to share positive experiences working with UASs.

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Address Organizational, Structural, and Training Infrastructure and Support Issues

Organization and Structure

UASs are a disruptive technology, and their introduction can create tensions between operations and intelligence staffs on the right balance between using UASs to collect intelligence or launch strikes. In the Army, for example, one could ask, is Gray Eagle an ISR asset or an armed reconnaissance system? Doctrine development efforts should produce a doctrine flexible enough to allow changes in allocation and organizational balances and address the attendant training issues accordingly.

Also, in the Army, the organizational placement of UASs remains a challenge, as illustrated by the fact that the assignment of responsibilities for the Raven is still being worked out. A more-systematic approach to monitoring and maintaining Raven operator qualifications will better enable integration of the system into maneuver forces and thus improve overall training and help develop better appreciation of the system's capabilities and limitations. In addition, the Army is currently examining alternatives for placing Shadow platoons in the headquarters company of a brigade combat team or consolidating them in the developing full-spectrum combat aviation brigade. Resolution of these organizational issues will likewise aid in training integration.

Training Infrastructure, Training Support Issues, and Related Factors

Some of the most important ways in which shortfalls can detract from UAS training are

- incompatible or different communications capabilities
- airspace restrictions
- inability to train at night or in bad weather
- inability to use live or dummy munitions
- UAS unavailability
- insufficient time.

These shortfalls cannot always be fully corrected. Some, such as differences in communications capabilities, are inherent but can be alleviated to some extent. The full correction of others may be unaffordable, but partial correction should still be possible. Inability to train at night or in bad weather, for example, is to some extent a result of FAA restrictions on when Air Force UASs can fly from their bases to the NTC. Basing Air Force UASs at the NTC would significantly reduce the effect of these restrictions and might also make it possible for the UASs to use live or dummy munitions, further improving realism for both customers and operators.

Research suggests that airspace restrictions, while sometimes nettlesome, need not pose a serious obstacle to most UAS training at a unit's home station, either for operators or end users. Nevertheless, efforts to gain more access to airspace should continue with the research and development of the joint program for GBSAA systems, led by the Army's program manager for UAS. This system uses ground-based radars to provide an extra layer of airspace safety, which could enable the FAA to make the use of civil airspace adjacent to UAS training airspace less restrictive and thus expand the airspace available for UAS training. A promising initial demonstration with Gray Eagle took place in summer 2011, but GBSAA is not expected to be certified for use until 2015.

The insufficient number of UASs for training should be alleviated to some extent as some systems redeploy from overseas theaters and also by the recent decision to increase the number

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of Predator/Reaper CAPs from 61 available today to 85 in the future. Similarly, the Operation Enduring Freedom drawdown will likely free up more RPA trainers, alleviating the shortfall.

Enable Training as We Fight in Unit Collective Training

To facilitate home station training, the following steps need to be taken:

- Training must make full use of units' UASs and must use simulation or surrogates, despite their limitations, when live use is not possible.
- Training should include the systems of other services and their associated joint tactical air controllers (JTACs) and air liaison officers (ALOs) to the extent possible.
- Air Force preparation training of JTACs and ALOs should be available for support of unit-level training, as well as for larger exercises.
- After-action reviews and reports should be expanded to reinforce lessons learned; they can also provide a sound basis for continued measurable improvements. Over time, the reports growing out of these documents should become more detailed and should incorporate measures of performance and effectiveness, so that these metrics can drive future improvements.

Enable Training as We Fight in Larger Exercises

By design, larger exercises like those at maneuver CTCs provide considerable opportunities for more-realistic training. They are thus already better postured to provide training on the use and integration of UAS. However, more can be done to enhance the use of training opportunities in such large exercises to further the goal of better UAS integration in the force. Specifically, we recommend

- continued stress on training realism
- including live UASs and their associated JTACs and ALOs as much as possible
- including the CAS-like and ISR missions that UASs, especially Air Force UASs, will be performing in theater
- providing a small paved air strip to base RPAs, launch and recovery elements (LREs), and support crews at the maneuver CTCs to avoid the NAS constraints associated with remote operation
- continued efforts to integrate additional Creech AFB–based UASs into CTC training, when needed.

Initiatives with Likely Near-Term Payoffs

Other things can be done that should provide near-term payoffs:

- **Increase exposure to the capabilities and limitations of UAS—**Continue to expose appropriate commanders to UAS operations through short (one- to two-day) familiarization courses, such as those the Air Force offers at various UAS squadrons' locations (e.g., Creech AFB, Beale AFB, and March ARB). These also need to be introduced as part of the joint training curriculum in a more formal and standardized fashion across the force. The proliferation of Air Force UAS squadrons geographically within CONUS should provide ready access for ground units whatever their home station.

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- **Harness the lessons-learned process to guide the development of service and joint doctrine and TTP—**Formalize and standardize these processes as appropriate, and share best practices more extensively across services and regions. Right now, most extended learning is done "on the job," with lessons learned shared informally among operators and trainers. Different UAS elements tend to focus support on different ground units, each with geographical and other mission differences. Best practices across these geographic and mission boundaries need to be understood to inform joint doctrine and, hence, responsive training requirements.
- **Address well-known but underresourced training infrastructure shortfalls—**Consider this issue in light of our previous discussions of basing. UASs can be based at maneuver CTCs to minimize the impact of FAA restrictions. If this is done as a part of the drawdown and redeployment of RPA units to CONUS, this should not be too disruptive or expensive; many details remain to be worked out, but military construction and other costs appear to be manageable. Communications infrastructure and C2 organizations and processes at the ranges can be enhanced to better mirror operational capabilities.

Institutionalizing Training for UAS Capabilities over the Longer Term

Institutionalizing UAS training over the longer term will naturally depend on continued support for the specific programs and initiatives and others like them that we outlined earlier. Institutionalization will also require more-general efforts, falling into three broad categories: acculturation, professional development of the UAS force (operators, maintainers, and a UAS chain of command), and integration of the UAS community (a subprofession, if you will) into the aviation profession. These three are somewhat interwoven, and the third depends on the first two. Finally, institutionalization over the longer term will require adaptation: The strategies must be designed to be adaptive, and those who develop and implement them must be willing to adapt them.

Acculturation

The RAND team heard from many sources that many end users do not yet have a well-developed appreciation of the capabilities UASs can bring to an operation. In some cases, this lack of appreciation has derived from negative experiences. Some of these experiences resulted from inexperienced operators, some from mechanical failures, some from sheer bad luck (e.g., weather). The need to deconflict airspace and the need to do so, even when using restricted airspace reserved for military use, often led to utilization problems and contributed to negative impressions about the value of UAS. First impressions do count, and avoiding bad ones is much easier than overcoming them later.

Professional Development

All the services need to maintain professional development strategy for the UAS force. The services are developing a professional force of operators for UASs, both systems and payloads, consisting of enlisted soldiers, noncommissioned officers, and warrant and commissioned officers, although the Army currently has no UAS officer specialty. It is important to develop a cadre of UAS professionals with hands-on experience in all echelons of UAS operation; the Army may

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wish to consider a career pipeline for such officers, perhaps with an additional skill identifier. Such a professional cadre is a key element in full integration of UAS capabilities.

Integration

The services are making significant efforts to integrate UASs into their force structures. Army efforts would be aided by more access during training to the operational and even strategic capabilities of Air Force UASs. These efforts will be aided by better acculturation and an institutionalized UAS career field that, over time, develops professionals with a more-complete understanding of UAS capabilities and limitations and sufficient rank, technical expertise, and operational experience to enable better integration of the capabilities into the overall operations of the end users. Related issues include integration of UAS capabilities with other ISR systems and with the intelligence warfighting function more generally, the tension between those who value the strike capabilities of UASs and those who value the intelligence collection capabilities, and the further tensions likely to emerge as UAS capabilities widen further. As UAS capabilities grow and broaden, integrating them into other warfighting functions will also present challenges.

Adaptation

The training strategy must adapt to future technical innovations and changes in operational demands. To enable this adaptability, those concerned with overall training strategy development will need to remain cognizant of and to guide the following, where possible:

- evolution of the roles of UASs in the full range of military operations, and the speed and breadth of the expansion of those roles
- surfacing and resolving UAS doctrinal issues (In particular, how will the requirements of intelligence and operations be integrated and deconflicted? How will both organic and nonorganic systems be better integrated to support ground forces, and which warfighting functions will they support? How will technological advances and changes in expected operational conditions influence decisions regarding these roles and missions?)
- service adjustments of force structures and personnel management processes to accommodate the disruptive technology effects of UASs
- influence of the above and related issues on the development, promulgation, and adaptation of joint and service doctrines so these doctrines can continue to form a solid basis for UAS training.

Summary of Findings and Recommendations

Our findings and recommendations are summarized as follows:

1. The proper strategy for DoD at this time is to encourage each service to solve its own UAS training problems, rather than to constrain any one service under the guise of joint operations.
2. DoD should support current and future programs to develop ranges and beddown and support facilities similar to those in the Army's current programs.

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3. In spite of the demands of deploying units and sustaining combat operations in Afghanistan, Army trainers indicate that Army units are better at maintaining qualification for Shadow qualification than for Raven. Nevertheless, not all units have been able to maintain high Shadow qualification rates—some units arrive at the NTC with one-half or fewer of their operators qualified. Better tracking of operators and their sustainment training is needed, particularly but not exclusively for Ravens.
4. If joint training becomes a priority, the Air Force's current basing and beddown posture will become more of a problem. The Air Force could consider the location of Army hubs when choosing where to base its UAS fleet. A location that is near Army maneuver elements might make airspace access less of a restriction or at least make COAs more practical. Proximity might provide more opportunities for training UAS integration throughout the entire mission planning process.
5. Given current budget limitations and the importance of fully developing the opportunities for live training and the relatively low cost of such training, diversion of funds to a research and development program to develop higher fidelity simulators would seem unwise at this time.

Path to the Future

We have presented and discussed a multitude of means for setting up UAS training strategies for success. These means include support for ongoing facilities and basing initiatives; expansion of such facilities, where possible, to enable wider availability of UASs to support collective training; and efforts to increase the use of UASs—the complete UAS package, including JTACs and other coordinating elements—in collective training, both local and in larger exercises. We have noted the need to support continuing efforts to resolve airspace access issues, observing as we did so that there are ways to keep such restrictions from imposing serious limitations on much of the UAS training envisioned here. Similarly, we have discussed the potential for simulators to add value in training, now and perhaps more in the future. But we have also cautioned that simulators, in their current state, are not a good substitute for live use of UASs in collective training.

The path to the future for UAS strategies starts now, with support for ongoing initiatives that will continue the trends towards better training integration and thus better ability on the part of end users to employ the multiple capabilities of UASs in their operations. The path continues, using that foundation, with longer-term efforts to add to acculturation of end users, professionalization of the UAS community, and integration of the two to harmonize the capabilities of UASs as key elements of overall force effectiveness.

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APPENDIX A

Current Major DoD UAS Programs in FY 2012

The following pages come directly from a Congressional Research Service report on U.S. UASs (Gertler, 2012, pp. 31–46).

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Current Major DOD UAS Programs

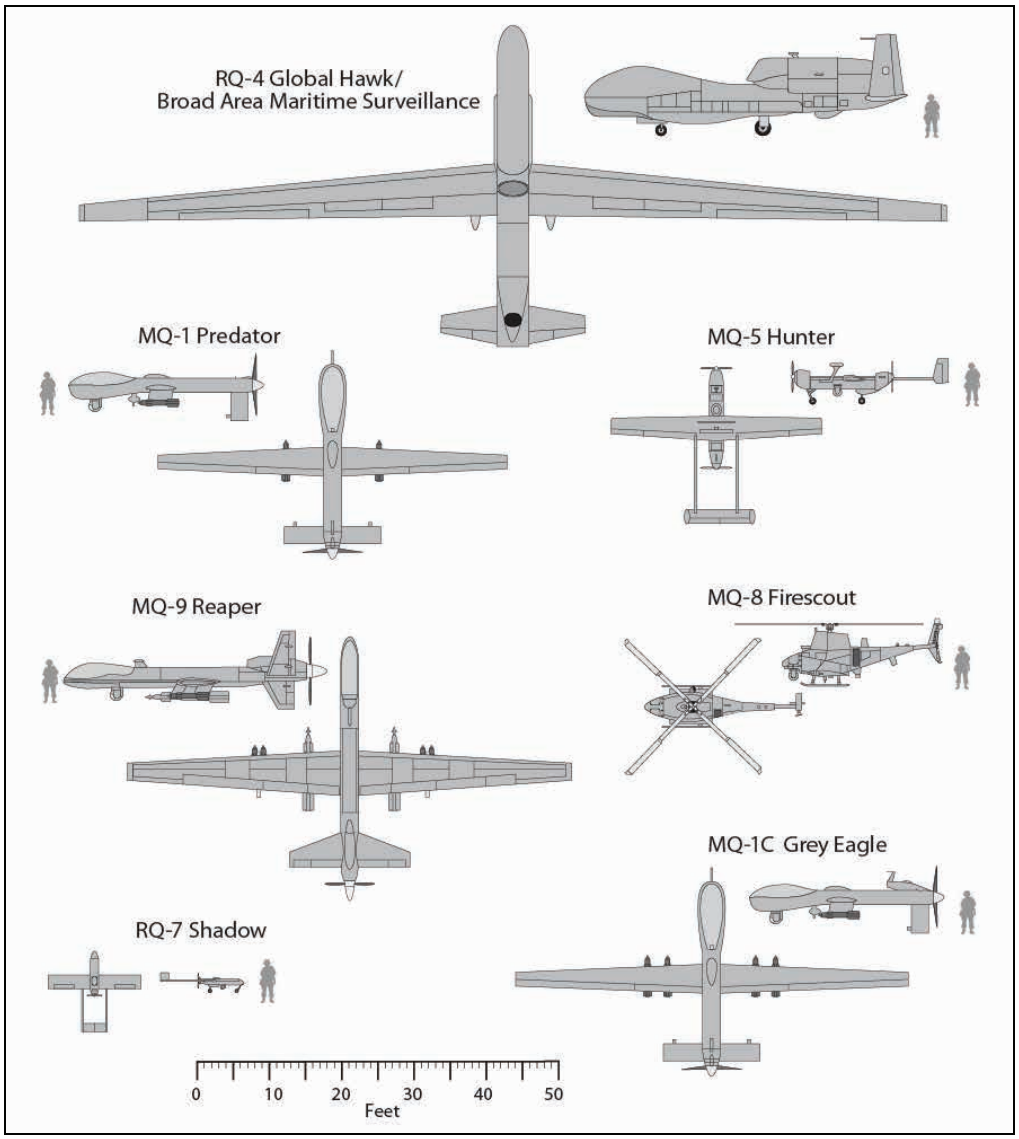
This section addresses the program status and funding of some of the most prominent UAS programs being pursued by DOD, and most likely to compete for congressional attention. This section does not attempt to provide a comprehensive survey of all UAS programs, nor to develop a classification system for different types of UAS (e.g., operational vs. developmental, single mission vs. multi mission, long range vs. short range). One exception is a short subsection below titled "Small UAVs." The UAVs described in this section are distinguished from the proceeding UAVs by being man-portable and of short range and loiter time. These smaller UAVs are not currently, and are unlikely to be, weaponized. The services do not provide as detailed cost and budget documentation for these UAVs as they do for major UAS programs. Individually, these UAVs appear very popular with ground forces, yet do not necessarily demand as much congressional attention as larger UAS programs like Predator or Global Hawk. As a whole, however, these small, man-portable UAVs appear likely to increasingly compete with major UAS programs for congressional attention and funding.

Table 6. Characteristics of Selected Tactical and Theater-Level Unmanned Aircraft

System	Length (ft)	Wingspan (ft)	Gross weight (lbs)	Payload capacity (lbs)	Endurance (hours)	Maximum altitude (ft)
Predator	27	55	2,250	450	24+	25,000
Grey Eagle	28	56	3,200	800	40	25,000
Reaper	36	66	10,500	3,750	24	50,000
Shadow	11	14	375	60	6	15,000
Fire Scout	23	28	3,150	600	6+	20,000
Global Hawk	48	131	32,250	3,000	28	60,000
BAMS	48	131	32,250	3,200	34+	60,000

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Figure 5. U.S. Medium-Sized and Large Unmanned Aircraft Systems



Source: Congressional Budget Office, *Policy Options for Unmanned Aircraft Systems*, Publication 4083, Washington, DC, June 2011.

Notes: All aircraft are drawn to the same scale. The silhouette figure is a 6-foot-tall soldier, also drawn to scale.

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Table 7. Acquisition Cost of Medium-Sized and Large Unmanned Aircraft Systems Under the Department of Defense's 2012 Plan

(Millions of 2011 dollars)

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total, 2011-2020
Air Force											
RQ-4 Global Hawk	1,200	1,060	890	790	810	710	1,160	530	80	60	7,290
MQ-1 Predator	30	10	10	10	[a]	[a]	[a]	[a]	[a]	[a]	60
MQ-9 Reaper	1,700	1,550	1,740	1,440	1,350	1,150	1,060[b]	1,040[b]	1,030[b]	1,010[b]	13,070
Army											
MQ-1C Grey Eagle	870	1,060	1,040	740	220	90	[a]	[a]	[a]	[a]	4,020
RQ-7 Shadow	610	250	270	200	300	280	[a]	[a]	[a]	[a]	1,910
Navy and Marine Corps											
RQ-4 Broad Area Maritime Surveillance	530	560	760	880	900	1,010	1,230	1,260	1,130	1,130	9,390
MQ-8 Fire Scout	60	70	60	80	80	90	130	160	150	150	1,030
RQ-7 Shadow	90	10	10	10	[a]	[a]	[a]	[a]	[a]	[a]	120
All services											
	5,090	4,570	4,780	4,150	3,660	3,330	3,580	2,990	2,390	2,350	36,890

Source: Congressional Budget Office based on data from the Department of Defense's budget request for 2012, Selected Acquisition Reports for December 2010, and Aircraft Procurement Plan: Fiscal Years 2012-2041 (submitted with the 2012 budget, March 2011).

Notes: Acquisition cost includes the cost of procuring air vehicles, sensors, and grounds stations, plus the cost for research. development, test, and evaluation. The services' cost data have been adjusted using CBO's projection of inflation and rounded to the nearest $10 million.

a. The Department of Defense has no plans to acquire or modify the specified system in these years.

b. The cost is for the follow-on aircraft the Air Force plans to acquire instead of the Reaper.

MQ-1 Predator

Through its high-profile use in Iraq and Afghanistan and its multi-mission capabilities, the MQ-1 Predator has become the Department of Defense's most recognizable UAS. Developed by General Atomics Aeronautical Systems in San Diego, CA, the Predator has helped to define the modern role of UAS with its integrated surveillance payload and armament capabilities. Consequently, Predator has enjoyed accelerated development schedules as well as increased

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procurement funding. The wide employment of the MQ-1 has also facilitated the development of other closely related UAS (described below) designed for a variety of missions.

System Characteristics. Predator is a medium-altitude, long-endurance UAS. At 27 feet long, 7 feet high and with a 48-foot wingspan, it has long, thin wings and a tail like an inverted "V." The Predator typically operates at 10,000 to 15,000 feet to get the best imagery from its video cameras, although it has the ability to reach a maximum altitude of 25,000 feet. Each vehicle can remain on station, over 500 nautical miles away from its base, for 24 hours before returning home. The Air Force's Predator fleet is operated by the 15th and 17th Reconnaissance Squadrons out of Creech Air Force Base, NV; the 11th Reconnaissance Squadron provides training. A second control station has been established at Whiteman AFB, MO.[104] Further, "[t]here are plans to set up Predator operations at bases in Arizona, California, New York, North Dakota, and Texas."[105] The Air Force has about 175 Predators;[106] the CIA reportedly owns and operates several Predators as well.

Mission and Payload. The Predator's primary function is reconnaissance and target acquisition of potential ground targets. To accomplish this mission, the Predator is outfitted with a 450-lb surveillance payload, which includes two electro-optical (E-O) cameras and one infrared (IR) camera for use at night. These cameras are housed in a ball-shaped turret that can be easily seen underneath the vehicle's nose. The Predator is also equipped with a Multi-Spectral Targeting System (MTS) sensor ball which adds a laser designator to the E-O/IR payload that allows the Predator to track moving targets. Additionally, the Predator's payload includes a synthetic aperture radar (SAR), which enables the UAS to "see" through inclement weather. The Predator's satellite communications provide for beyond line-of-sight operations. In 2001, as a secondary function, the Predator was outfitted with the ability to carry two Hellfire missiles. Previously, the Predator identified a target and relayed the coordinates to a manned aircraft, which then engaged the target. The addition of this anti-tank ordnance enables the UAS to launch a precision attack on a time sensitive target with a minimized "sensor-to-shoot" time cycle. Consequently, the Air Force changed the Predator's military designation from RQ-1B (reconnaissance unmanned) to the MQ-1 (multi-mission unmanned).[107] The air vehicle launches and lands like a regular aircraft, but is controlled by a pilot on the ground using a joystick.

MQ-1C Grey Eagle

A slightly larger, longer-endurance version of the Predator, the Army's MQ-1C Grey Eagle entered low-rate initial production on March 29, 2010.[108] The Grey Eagle can remain aloft for 36 hours, 12 hours longer than its Air Force sibling.

An Army platoon operates four aircraft with electro-optical/infrared and/or laser rangefinder/designator payloads, communications relay equipment, and up to four Hellfire

[104] Phillip O'Connor, "Drones seeking terrorists guided from Missouri air base," *St. Louis Post-Dispatch*, May 10, 2011.

[105] P.W. Singer, *Wired for War* (New York: The Penguin Press, 2009), p. 33.

[106] Congressional Budget Office, *Policy Options for Unmanned Aircraft Systems*, Pub. No. 4083, June 2011, p. 5.

[107] Glenn W. Goodman, Jr., "UAVs Come of Age," *The ISR Journal*, July 2002, p. 24.

[108] Department of Defense, *Selected Acquisition Report (SAR), MQ-1C UAS Gray (sic) Eagle*, DD-A&T(Q&A)823-420, Washington, DC, December 31, 2010.

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missiles. Each platoon includes two ground control stations, two ground data terminals, one satellite communication ground data terminal, one portable ground control station, one portable ground data terminal, an automated takeoff and landing system, two tactical automatic landing systems, and ground support equipment. In total, the program will be 124 aircraft, plus 21 attrition aircraft and 7 schoolhouse aircraft, for a total of 152 aircraft. The average procurement unit cost of a Grey Eagle system is $114.1 million.[109]

MQ-9 Reaper

The MQ-9 Reaper, formerly the "Predator B," is General Atomics' follow-on to the MQ-1. The Reaper is a medium- to high-altitude, long-endurance Predator optimized for surveillance, target acquisition, and armed engagement. While the Reaper borrows from the overall design of the Predator, the Reaper is 13 feet longer and carries a 16-foot-longer wingspan. It also features a 900 hp turboprop engine, which is significantly more powerful than the Predator's 115 hp engine. These upgrades allow the Reaper to reach a maximum altitude of 50,000 feet, a maximum speed of 225 knots, a maximum endurance of 32 hours, and a maximum range of 2,000 nautical miles.[110] However, the feature that most differentiates Reaper from its predecessor is its ordnance capacity. While the Predator is outfitted to carry 2 100-pound Hellfire missiles, the Reaper now can carry as many as 16 Hellfires, equivalent to the Army's Apache helicopter, or a mix of 500-pound weapons and Small Diameter Bombs.

As of February 4, 2011, General Atomics Aeronautical Systems had delivered 65 of 399 planned Reapers, 43 of which are operationally active.[111]

The MQ-9 is operated by the 17th Reconnaissance Squadron and the 42nd Attack Squadron, both at Creech Air Force Base, NV, and the 29th Attack Squadron at Holloman AFB, NM.[112]

Program Status. Predator–family UAS are operated as part of a system, which consists of four air vehicles, a ground control station, and a primary satellite link. The unit cost in FY2009 for one Predator system was approximately $20 million,[113] while the average procurement unit cost for a Reaper system was $26.8 million.[114]

[109] Ibid.

[110] OSD, *UAS Roadmap 2005-2030*, August 2005, p. 10.

[111] Department of Defense, *Selected Acquisition Report (SAR), MQ-9 UAS Reaper*, DD-A&T(Q&A)823-424, Washington, DC, December 31, 2010.

[112] U.S. Air Force, *Fact Sheet: MQ-9 Reaper*, August 18, 2010.

[113] U.S. Air Force, *Fact Sheet: MQ-1 Predator*, July 20, 2010.

[114] Department of Defense, *Selected Acquisition Report (SAR), MQ-9 UAS Reaper*, DD-A&T(Q&A)823-424, Washington, DC, December 31, 2010.

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Table 8. Predator and Reaper Combined Funding

($ in Millions)

		Procurement	RDT&E
FY11			
Request	62 air vehicles	1600.0	
	Mods	31.8	
Appropriations Conference	12 air vehicles	176.6	83.2
	Mods	31.8	
FY12			
Request	9 air vehicles	125.5	61
	Mods	30.2	

RQ-4 Global Hawk

Northrop Grumman's RQ-4 Global Hawk has gained distinction as the largest and most expensive UAS currently in operation for the Department of Defense. Global Hawk incorporates a diverse surveillance payload with performance capabilities that rival or exceed most manned spy planes. However, Pentagon officials and Members of Congress have become increasingly concerned with the program's burgeoning cost, which resulted in Nunn-McCurdy breaches in April 2005 and April 2011.[115] Also, the RQ-4B Block 30 was deemed "not operationally suitable" due to "low air vehicle reliability" by the office of Operational Test and Evaluation in May 2011.[116]

System Characteristics. At 44 feet long and weighing 26,750 lbs, Global Hawk is about as large as a medium sized corporate jet. Global Hawk flies at nearly twice the altitude of commercial airliners and can stay aloft at 65,000 feet for as long as 35 hours. It can fly to a target area 5,400 nautical miles away, loiter at 60,000 feet while monitoring an area the size of the state of Illinois for 24 hours, and then return. Global Hawk was originally designed to be an autonomous drone capable of taking off, flying, and landing on pre-programmed inputs to the UAV's flight computer. Air Force operators have found, however, that the UAS requires frequent intervention by remote operators.[117] The RQ-4B resembles the RQ-4A, yet features a significantly larger airframe. In designing the B-model, Northrop Grumman increased the Global Hawk's length from 44 feet to 48 feet and its wingspan from 116 feet to 132 feet. The expanded size enables the RQ-4B to carry an extra 1000 pounds of surveillance payload.

[115] Amy Butler, "USAF Declares Second Major Global Hawk Cost Breach," Aerospace Daily, April 13, 2011. The 2005 breach stemmed from costs in transitioning from the Block 10 Global Hawk to the larger Block 30; the 2011 breach was attributed primarily to reduced procurement quantities rather than issues with the program.

[116] J. Michael Gilmore, *RQ-4B Global Hawk Block 30* , OSD Director, Operational Test and Evaluation, Operational Test and Evaluation Report, May 2011. John T. Bennett, "Pentagon testers slam aerial spy drone as unfit for operations," *The Hill*, June 7, 2011.

[117] Jeff Morrison, "USAF No Longer Viewing Global Hawk As An Autonomous System, Official Says," *Aerospace Daily*, December 3rd, 2005.

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Mission and Payload. The Global Hawk UAS has been called "the theater commander's around-the-clock, low-hanging (surveillance) satellite."[118] The UAS provides a long-dwell presence over the battlespace, giving military commanders a persistent source of high-quality imagery that has proven valuable in surveillance and interdiction operations. The RQ-4A's current imagery payload consists of a 2,000-lb integrated suite of sensors much larger than those found on the Predator. These sensors include an all-weather SAR with Moving Target Indicator (MTI) capability, an E-O digital camera and an IR sensor. As the result of a January 2002 Air Force requirements summit, Northrop Grumman expanded its payload to make it a multi-intelligence air vehicle. The subsequent incarnation, the RQ-4B, is outfitted with an open-system architecture that enables the vehicle to carry multiple payloads, such as signals intelligence (SIGINT) and electronic intelligence (ELINT) sensors. Furthermore, the classified Multi-Platform Radar Technology Insertion Program (MP-RTIP) payload will be added in order to increase radar capabilities. These new sensor packages will enable operators to eavesdrop on radio transmissions or to identify enemy radar from extremely high altitudes. Future plans include adding hyper-spectral sensors for increased imagery precision and incorporating laser communications to expand information transfer capabilities.[119] The end goal is to field a UAS that will work with space-based sensors to create a "staring net" that will prevent enemies from establishing a tactical surprise.[120] In August 2003, the Federal Aviation Administration granted the Global Hawk authorization to fly in U.S. civilian airspace, which further expanded the system's mission potential.[121] This distinction, in combination with the diverse surveillance capabilities, has led many officials outside the Pentagon to consider the Global Hawk an attractive candidate for anti-drug smuggling and Coast Guard operations.[122]

Program Status. Developed by Northrop Grumman Corporation of Palmdale, CA, Global Hawk entered low-rate initial production in February 2002. The Air Force has stated that it intends to acquire 51 Global Hawks, at an expected cost of $6.6 billion for development and procurement costs. As of November 2009, the Air Force possessed 7 RQ-4As and 3 RQ-4Bs.[123] Another 32 Global Hawks had been authorized and appropriated through FY2011.[124] According to the most recent Selected Acquisition Report, the current average procurement unit cost for the Global Hawk has reached $140.9 million in current dollars.[125]

In April 2005, the Air Force reported to Congress that the program had overrun by 18% as a result of an "increasing aircraft capacity to accommodate requirements for a more sophisticated, integrated imagery and signals intelligence senor suite."[126] A Government Accountability Office report in December 2004 noted that the program had increased by nearly $900 million since 2001 and recommended delaying the purchase of future Global Hawks until an appropriate

[118] Glenn W. Goodman, Jr., "UAVs Come Of Age," *The ISR Journal*, July 2002.

[119] David A. Fulghum, "Global Hawk Shows Off Updated Package of Sensors," *Aviation Week & Space Technology,* September 08, 2003.

[120] Ibid.

[121] Sue Baker, "FAA Authorizes Global Hawk Flights," Aeronautical Systems Center Public Affairs, August 21, 2003.

[122] Ron Laurenzo, "Global Hawk Scouts Ahead for Other UAVs," *Defense Week*, September 2, 2003.

[123] U.S. Air Force, *Fact Sheet: RQ-4 Global Hawk*, November 19, 2009.

[124] Department of Defense, *Department of Defense Fiscal Year 2012 Budget Estimates, Aircraft Procurement, Air Force*, February 2011.

[125] OSD, *Selected Acquisition Report,* December 31, 2010, p. 29.

[126] James R. Asker, "Global Hawk 18% Over Budget," *Aviation Week & Space Technology*, April 25, 2005.

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development strategy could be implemented.[127] The rising costs of the UAV and accusations of Air Force mismanagement have caused concern among many in Congress and in the Pentagon as well as facilitating an overall debate on the Air Force's development strategy.[128]

Following a 2010 Defense Acquisition Board review of the Global Hawk program,

> Air Force acquisition executive David Van Buren told reporters that he is "not happy" with the pace of the program, both on the government and the contractor side. Chief Pentagon arms buyer Ashton Carter also criticized the program, saying that it was "on a path to being unaffordable."[129]

In April 2011, a reduction in the number of Global Hawk Block 40 aircraft requested in the FY2012 budget from 22 to 11 caused overall Global Hawk unit prices to increase by 11%, again triggering Nunn-McCurdy.[130]

In its markup of the FY2011 defense authorization bill, the House Armed Services Committee expressed concern "that differing, evolving service unique requirements, coupled with Global Hawk UAS vanishing vendor issues, are resulting in a divergence in each service's basic goal of maximum system commonality and interoperability, particularly with regard to the communications systems." The bill report directs the Under Secretary of Defense for Acquisition, Technology, and Logistics to certify and provide written notification to the congressional defense committees by March 31, 2011, that he has reviewed the communications requirements and acquisition strategies for both Global Hawk and BAMS. The subcommittee wants assurance that the requirements for each service's communications systems have been validated and that the acquisition strategy for each system "achieves the greatest possible commonality and represents the most cost effective option" for each program.[131]

A May 20, 2011, report from the Air Force Operational Test and Evaluation Center found the Global Hawk Block 20/30 to be "effective with significant limitations ... not suitable and partially mission capable." The report cited "lackluster performance of the EISS imagery collector and ASIP sigint collectors at range" rather than issues with the Global Hawk airframe itself.[132]

[127] United States Government Accountability Office, GAO-05-6 *Unmanned Aerial Vehicles[:] Changes in Global Hawk's Acquisition Strategy Are Needed to Reduce Program Risks,* November 2004, p. 3-4.

[128] See H.Rept. 109-89. House Armed Service Committee "National Defense Authorization Act for the Fiscal Year 2006." May 20, 2005, p. 91.

[129] Marina Malenic, "Air Force, Navy Pledge Greater Global Hawk-BAMS Cooperation," *Defense Daily*, July 2, 2010.

[130] The Nunn-McCurdy provision requires DOD to notify Congress when cost growth on a major acquisition program reaches 15%. If the cost growth hits 25%, Nunn-McCurdy requires DOD to justify continuing the program based on three main criteria: its importance to U.S. national security; the lack of a viable alternative; and evidence that the problems that led to the cost growth are under control. For more information, see CRS Report R41293, *The Nunn-McCurdy Act: Background, Analysis, and Issues for Congress* , by Moshe Schwartz.

[131] U.S. Congress, House Committee on Armed Services, *National Defense Authorization Act for Fiscal Year 2011*, Report to accompany H.R. 5136, 111th Cong., May 21, 2010, H.Rept. 111-491, p. 178.

[132] Amy Butler, "Poor Testing Results Latest Hurdle for Global Hawk," *Aviation Week/Ares blog*, June 3, 2011.

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Table 9. Global Hawk Funding

($ in Millions)

	Quantity	Procurement	RDT&E	Advance Procurement
FY11				
Request	4	649.6	251.3	90.2
Authorization Conference[a]	N/A	N/A	N/A	N/A
Appropriations Conference	4	503.0	220.3	72.3
FY12				
Request	3	323.9		71.5

a. As passed, H.R. 6523, the Ike Skelton National Defense Authorization Act For Fiscal Year 2011, did not include program-level detail, so no amounts were specified for these program elements.

BAMS

The Navy's Broad Area Maritime Surveillance system is based on the Global Hawk Block 20 airframe but with significantly different sensors from its Air Force kin. This, coupled with a smaller fleet size, results in a higher unit cost. "The air service's drone costs $27.6 million per copy, compared to an expected $55 million per BAMS UAV, including its sensors and communications suite…. At 68 aircraft, the BAMS fleet will be the world's largest purchase of long-endurance marinized UAVs."[133]

System Characteristics and Mission. "BAMS ... provides persistent maritime intelligence, surveillance, and reconnaissance data collection and dissemination capability to the Maritime Patrol and Reconnaissance Force. The MQ-4C BAMS UAS is a multi-mission system to support strike, signals intelligence, and communications relay as an adjunct to the MMA/P-3 community to enhance manpower, training and maintenance efficiencies worldwide."[134]

"The RQ-4 ... features sensors designed to provide near worldwide coverage through a network of five orbits inside and outside continental United States, with sufficient air vehicles to remain airborne for 24 hours a day, 7 days a week, out to ranges of 2000 nautical miles. Onboard sensors will provide detection, classification, tracking and identification of maritime targets and include maritime radar, electro-optical/infra-red and Electronic Support Measures systems. Additionally, the RQ-4 will have a communications relay capability designed to link dispersed forces in the theater of operations and serve as a node in the Navy's FORCEnet strategy."[135]

[133] Gayle S. Putrich, "Northrop selected to build BAMS drone," *Navy Times*, April 22, 2008.

[134] Northrop Grumman, "MQ-4C BAMS UAS," press release, http://www.as.northropgrumman.com/products/bams/index.html.

[135] Department of Defense, *Department of Defense Fiscal Year 2012 Budget Estimates, Research, Development, Test & Evaluation, Navy*, Budget Activity 7, February 2011.

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"The drones ... will collect information on enemies, do battle-damage assessments, conduct port surveillance and provide support to Navy forces at sea. Each aircraft is expected to serve for 20 years."[136]

Program Status. The Administration's FY2012 budget request documents place Milestone C for BAMS in the third quarter of FY2013, with initial operational capability in the first quarter of 2016. "Since Milestone B for the Navy BAMS UAS program, identifying opportunities for the RQ-4-based BAMS and Global-Hawk programs has been a significant interest item for the UAS TF and has been well documented within the Department."[137] In one effort to integrate development, on June 12, 2010, the Navy and Air Force concluded a Memorandum of Agreement (MOA) regarding their Global Hawk and BAMS programs, which use a common airframe. "Shared basing, maintenance, command and control, training, logistics and data exploitation are areas that could be ripe for efficiencies, says Lt. Gen David Deptula, Air Force deputy chief of staff for intelligence, surveillance and reconnaissance…. Also, a single pilot and maintenance training program is being established at Beale AFB, Calif., for both fleets."[138] However, issues still exist over common control stations and whether one service's pilots should be able to operate the other service's aircraft.

MQ-8B Fire Scout

Now in deployment, the Fire Scout was initially designed as the Navy's choice for an unmanned helicopter capable of reconnaissance, situational awareness, and precise targeting.[139] Although the Navy canceled production of the Fire Scout in 2001, Northrop Grumman's vertical take-off UAV was rejuvenated by the Army in 2003, when the Army designated the Fire Scout as the interim Class IV UAV for the future combat system. The Army's interest spurred renewed Navy funding for the MQ-8, making the Fire Scout DOD's first joint UAS helicopter.

System Characteristics and Mission. Northrop Grumman based the design of the Fire Scout on a commercial helicopter. The RQ-8B model added a four-blade rotor to reduce the aircraft's acoustic signature.[140] With a basic 127-pound payload, the Fire Scout can stay aloft for up to 9.5 hours; with the full-capacity sensor payload, endurance diminishes to roughly 6 hours. Fire Scout possesses autonomous flight capabilities. The surveillance payload consists of a laser designator and range finder, an IR camera and a multi-color EO camera, which when adjusted with specific filters could provide mine-detection capabilities.[141] Fire Scout also currently possesses line-of-sight communication data links. Initial tests of an armed Fire Scout were conducted in 2005, and the Navy expects to add "either Raytheon's Griffin or BAE's Advanced Precision Kill Weapon System" small missiles to currently deployed Fire Scouts soon.[142] Discussions of future missions

[136] Gayle S. Putrich, "Northrop selected to build BAMS drone," *Navy Times*, April 22, 2008.

[137] Under Secretary of Defense (Acquisition, Technology and Logistics), *Department of Defense Report to Congress on Addressing Challenges for Unmanned Aircraft Systems*, September 2010.

[138] Amy Butler, "U.S. Navy/Air Force UAV Agreement Raises Questions," *Aerospace Daily*, July 6, 2010.

[139] "RQ-8A Fire Scout, Vertical Take Off and Landing Tactical Unmanned Aerial Vehicle (VTUAV)," GlobalSecurity.org, http://www.globalsecurity.org/intell/systems/vtuav.htm, April 26th, 2004.

[140] David A. Fulghum, "Army Adopts Northrop Grumman's Helicopter UAV," *Aviation Week & Space Technology*, October 20th, 2003.

[141] Northrop Grumman Corp. Press Release, "Northrop Grumman's Next-Generation Fire Scout UAV on Track," June 23rd, 2005.

[142] Joshua Stewart, "Navy plans to arm Fire Scout UAV with missiles," *Navy Times*, August 18, 2011.

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have also covered border patrol, search and rescue operations, medical resupply, and submarine spotting operations.

Program Status. Six production MQ-8 air vehicles have been delivered to date.[143] The Pentagon's 2009 UAS Roadmap estimates a future inventory of 131 RQ-8Bs for the Navy to support the Littoral Combat Ship class of surface vessels.[144] The Army had intended to use the Fire Scout as the interim brigade-level UAV for its Future Combat System program,[145] but canceled its participation in January, 2010.[146]

A Fire Scout attracted media attention in August 2010, when it flew through Washington, DC, airspace after losing its control link. "A half-hour later, Navy spokesmen said, operators re-established control and the drone landed safely."[147]

FIRE-X/MQ-8C

The FIRE-X project, recently designated MQ-8C but continuing the Fire Scout name, is a developmental effort to adapt the Fire Scout software and navigation systems to a full-size standard helicopter. The Navy "is to award Northrop Grumman a contract to supply 28 MQ-8C Fire Scout ... to be fielded by the first quarter of 2014 to meet an urgent operational requirement."[148]

> Fire Scout can fly for 8 hours with a maximum range of 618 nautical miles? Well, Fire-X will fly for 15, with a max range of 1227. Fire Scout tops out at 100 knots? Fire-X can speed by at 140. Fire-X will carry a load of 3200 lbs. to Fire Scout's 1242. All this talk from a drone helicopter that just took its first flight in December.... Fire-X isn't going to be a big departure from Fire Scout, though. The BRITE STAR II and other radars will remain on board, as will its software for relaying information to a ship.[149]

RQ-170 Sentinel

Although publicly acknowledged to exist, most information about the Lockheed Martin RQ-170 Sentinel is classified. First photographed in the skies over Afghanistan, but also reportedly in operation from South Korea,[150] the RQ-170 is a tailless "flying wing" stealthier than other current

[143] Department of the Navy, *Fiscal Year (FY) 2012 Budget Estimates, MQ-8 UAV*, February 2011.

[144] Northrop Grumman Corp. Press Release, "Northrop Grumman's Next-Generation Fire Scout UAV on Track," June 23rd, 2005. *FY2009–2034 Unmanned Systems Integrated Roadmap*, p. 66.

[145] The Army intended to field four different classes of UAVs as part of its Future Combat System (FCS): Class I for platoons, Class II for companies, Class III for battalions, and Class IV for brigades. See CRS Report RL32888, *Army Future Combat System (FCS) "Spin-Outs" and Ground Combat Vehicle (GCV): Background and Issues for Congress*, by Andrew Feickert and Nathan J. Lucas, for more information.

[146] April M. Havens, "U.S. Army wants to cancel Fire Scouts (sic) program," *The Mississippi Press*, January 15, 2010, As presented on http://www.gulflive.com.

[147] Elisabeth Bumiller, "Navy Drone Violated Washington Airspace," *The New York Times*, August 26, 2010.

[148] Graham Warwick, "U.S. Navy Goes Ahead With Bell 407-Based Fire Scout UAV," *Aerospace Daily*, September 8, 2011.

[149] Spencer Ackerman, "Navy Upgrades Its Spying, Drug-Sniffing Robot Copter," *Wired.com/Danger Room blog*, April 11, 2011.

[150] Bill Sweetman, "Beast Sighted In Korea," *Aviation Week/Ares blog*, February 16, 2010.

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U.S. UAS. An RQ-170 was reported to have performed surveillance and data relay related to the operation against Osama bin Laden's compound on May 1, 2011. The government of Iran claimed on December 2, 2011, to be in possession of an intact RQ-170 following its incursion into Iranian airspace.

System Characteristics. Built by Lockheed Martin, the RQ-170 has a wingspan of about 65 feet and is powered by a single jet engine. It appears to have two sensor bays (or satellite dish enclosures) on the upper wing surface. Although an inherently low-observable blended wing/fuselage design like the B-2, the RQ-170's conventional inlet, exhaust, and landing gear doors suggest a design not fully optimized for stealth.[151]

Potential Mission and Payload. "The RQ-170 will directly support combatant commander needs for intelligence, surveillance and reconnaissance to locate targets."[152]

Program Status. "The RQ-170 is a low observable unmanned aircraft system (UAS) being developed, tested and fielded by the Air Force."[153] No further official status is available.

Other Current UAS Programs

RQ-5A Hunter/MQ-5B Hunter II

Originally co-developed by Israel Aircraft Industries and TRW (now owned by Northrop Grumman) for a joint U.S. Army/Navy/Marine Corps short-range UAS, the Hunter system found a home as one of the Army's principal unmanned platforms. The service has deployed the RQ-5A for tactical ISR in support of numerous ground operations around the world. At one time, the Army planned to acquire 52 Hunter integrated systems of eight air vehicles apiece, but the Hunter program experienced some turbulence. The Army canceled full-rate production of the RQ-5A in 1996, but continued to use the seven systems already produced. It acquired 18 MQ-5B Hunter IIs through low-rate initial production in FY2004 and FY2005. The MQ-5B's design includes longer endurance and the capability to be outfitted with anti-tank munitions. Both variants are currently operated by the 224th Military Intelligence Battalion out of Fort Stewart, GA; by the 15th Military Intelligence Battalion out of Ft. Hood, TX; and by 1st Military Intelligence Battalion out of Hohenfels, Germany.

System Characteristics. The RQ-5A can fly at altitudes up to 15,000 feet, reach speeds of 106 knots, and spend up to 12 hours in the air. Weighing 1,600 pounds, it has an operating radius of 144 nautical miles. The MQ-5B includes an elongated wingspan of 34.3 feet up from 29.2 feet of the RQ-5A and a more powerful engine, which allows the Hunter II to stay airborne for three extra hours and to reach altitudes of 18,000 feet.[154] The Hunter system consists of eight aircraft, ground control systems and support devices, and launch/recovery equipment. In FY2004, the final year of Hunter procurement, a Hunter system cost $26.5 million.

[151] U.S. Air Force, *Fact Sheet: RQ-170 Sentinel*, December 2, 2010. and CRS analysis of available RQ-170 photography.

[152] U.S. Air Force, *Fact Sheet: RQ-170 Sentinel*, December 2, 2010.

[153] Ibid.

[154] OSD, *UAS Roadmap 2005-2030*, August 2005, p. 7

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Mission and Payload. The Army has mostly used the Hunter system for short- and medium-range surveillance and reconnaissance. More recently, however, the Army expanded the Hunter's missions, including weaponization for tactical reconnaissance/strike operations with the GBU-44/B Viper Strike precision guided munition, which can designate targets either from the munition's laser, from another aerial platform, or from a ground system. This weapon makes the Hunter the Army's first armed UAS. "Also, in 2004, the Department of Homeland Security, Customs and Border Protection Bureau, and Office of Air and Marine utilized Hunter under a trial program for border patrol duties. During this program, the Hunter flew 329 flight hours, resulting in 556 detections."[155]

Program Status. The Army halted Hunter production in 2005. As of May 2011, 45 Hunter UAVs were still in operation and periodically receiving upgrades and modifications. In August 2005, the Army awarded General Atomics' Warrior UAS (which later became Grey Eagle) the contract for the Extended Range-Multi Purpose UAS program over the Hunter II.[156]

RQ-7 Shadow

The RQ-7 Shadow found a home when the Army, after a two-decade search for a suitable system, selected AAI's close range surveillance platform for its tactical unmanned aerial vehicle (TUAV) program. Originally, the Army, in conjunction with the Navy explored several different UAVs for the TUAV program, including the now-cancelled RQ-6 Outrider system. However, in 1997, after the Navy pursued other alternatives, the Army opted for the low-cost, simple design of the RQ-7 Shadow 200. Having reached full production capacity and an IOC in 2002, the Shadow has become the primary airborne ISR tool of numerous Army units around the world and is expected to remain in service through the decade.

The Administration's FY2011 budget request did not include funding for Shadow aircraft, although it did include continued RDT&E funding for Shadow.[157]

System Characteristics. Built by AAI Corporation (now owned by Textron), the Shadow is 11 feet long with a wingspan of 13 feet. It has a range of 68 nautical miles, a distance picked to match typical Army brigade operations, and average flight duration of five hours. Although the Shadow can reach a maximum altitude of 14,000 feet, its optimum level is 8,000 feet. The Shadow is catapulted from a rail-launcher, and recovered with the aid of arresting gear. The UAS also possesses automatic takeoff and landing capabilities. The upgraded version, the RQ-7B Shadow, features a 16-inch greater wingspan and larger fuel capacity, allowing for an extra two hours of flight endurance.

Mission and Payload. The Shadow provides real-time reconnaissance, surveillance, and target acquisition information to the Army at the brigade level. A potential mission for the Shadow is the perilous job of medical resupply. The Army is considering expanding the UAS's traditional missions to include a medical role, where several crucial items such as blood, vaccines, and fluid

[155] Kari Hawkins, "Pioneer platform soars to battlefield success," *www.army.mil*, May 19, 2011.

[156] Jefferson Morris, "Army More Than Doubles Expected Order for ERMP with General Atomics Win," *Aerospace Daily & Defense Report,* August 10th, 2005.

[157] Todd Harrison, *Analysis of the FY 2011 Defense Budget* (Washington, DC: Center for Strategic & Budgetary Assessments, 2010), p. 38.

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infusion systems could be delivered to troops via parachute.[158] For surveillance purposes, the Shadow's 60-pound payload consists of an E-O/IR sensor turret, which produces day or night video and can relay data to a ground station in real-time via a line-of-sight data link. As part of the Army's Future Combat System plans, the Shadow will be outfitted with the Tactical Common Data Link currently in development to network the UAS with battalion commanders, ground units, and other air vehicles.[159] The Marine Corps is considering how to arm Shadow.[160]

Program Status. The Army and Marine Corps currently maintain an inventory of 364 Shadow UAVs.[161] The program cost for a Shadow UAV system—which includes four vehicles, ground control equipment, launch and recovery devices, remote video terminals, and High Mobility Multipurpose Wheeled Vehicles for transportation—reached $11.1 million in current year dollars for FY2008.[162] The Army procured 102 systems through 2009.[163] In FY2012, the Army requested $25 million for 20 Shadow aircraft to replace combat losses, and approximately $200 million for payload upgrades.

"Small UAVs"

RQ-14 Dragon Eye

AeroVironment's Dragon Eye is a backpack-carried, battery-operated UAV employed by the Marines at the company level and below for reconnaissance, surveillance, and target acquisition. Dragon Eye features a 3.8-foot rectangular wing, twin propellers, and two camera ports each capable of supporting day-light electro-optical cameras, low-light TV cameras, and infrared cameras. The compact and lightweight design of the UAV allows an operational endurance of 45 minutes and can travel as far as 2.5 nautical miles from the operator. Low-rate-initial-production of 40 aircraft began in 2001. After a 2003 operational assessment, the Marine Corps awarded AeroVironment a contract to deliver approximately 300 systems of full-rate-production Dragon Eyes.[164] However, that contract was later revised to acquire Raven UAS instead. One Dragon Eye system consists of three air vehicles and one ground station. The final Marine Corps procurement budget request in FY2006 anticipated the current unit cost per Dragon Eye system as $154,000.[165]

FQM-151 Pointer

Although procurement of this early UAS began in 1990, the electric-powered Pointer has seen service in Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF). Pointer is a

[158] Erin Q. Winograd, "Army Eyes Shadow UAVs Potential For Medical Resupply Missions," *InsideDefense.com*, December 20, 2002, p.14.

[159] "Upgraded Shadow UAV Rolls Off Production Line," *Defense Today*, August 5, 2004.

[160] Paul McCleary, "Marines Want a Big Bang From a Small Package," *Aviation Week/Ares blog*, October 26, 2010.

[161] OSD, *UAS Roadmap 2005-2030*, August 2005, p. 8.

[162] Department of the Army, Army Procurement OPA 02: Communications and Electronics FY2009, February 2008, TUAS (B00301), Item No. 61, p. 18 of 23.

[163] Department of the Army, *Committee Staff Procurement Backup Book, Fiscal Year 2012 Budget Estimate, Aircraft Procurement, Army, RQ-7 UAV MODS*, Washington, DC, February 2011, p. 1 of 10.

[164] Peter La Franchi, "Directory: Unmanned Air Vehicles," *Flight International*, June 21st, 2005, p. 56.

[165] Department of the Navy, FY2006-FY2007 Budget Estimate - Marine Corps Procurement, February 2005, BLI No. 474700, Item 44, p. 20 of 22.

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short-range reconnaissance and battlefield surveillance UAV developed by AeroVironment. Its flight endurance (two hours) is greater than most similar small UAVs, in part due to its relatively large, 9-foot wingspan. That wingspan decreases portability of the 8.5-pound Pointer, and as a result, transportation of a Pointer system (two air vehicles and a ground control unit) requires two personnel. Although superseded by the Raven (below), Pointer remains a valued short-range ISR asset for the Air Force and Special Operations Command.

RQ-11 Raven

Engineered from the basic design of the Pointer, the Raven is two-thirds the size and weight of its predecessor, with a much smaller control station, making the system man-portable.[166] "The RQ-11A is essentially a down-sized FQM-151 *Pointer*, but thanks to improved technology can carry the same navigation system, control equipment, and payload."[167] The Raven provides Army and SOCOM personnel with "over-the-hill" reconnaissance, sniper spotting, and surveillance scouting of intended convoy routes. The electric motor initiates flight once hand-launched by a running start from the ground operator. The vehicle is powered by an electric battery that needs to be recharged after 90 minutes, but deployed soldiers are equipped with four auxiliary batteries that can be easily charged using the 28 volt DC outlet in a Humvee. The vehicle lands via a controlled crash in which the camera separates from the body, which is composed of Kevlar plating for extra protection. Like the Pointer, the Raven can carry either an IR or an E-O camera and transmits real-time images to its ground operators. The relatively simple system allows soldiers to be trained in-theater in a matter of days. Raven systems can either be deployed in three-aircraft or two-aircraft configurations. "Raven was adopted as the US Army's standardised short range UAV system in 2004 with a total of 2469 air vehicles (including older RQ-11A series models) in operational service by mid 2007."[168] "The US Army has an ongoing acquisition objective for about 2,200 Raven systems and has taken delivery of more than 1,300 to date."[169] A three-aircraft system costs approximately $167,000.[170]

ScanEagle

Developed by the Insitu Group (owned by Boeing) as a "launch-and-forget" UAV, the ScanEagle autonomously flies to points of interest selected by a ground operator.[171] The ScanEagle has gained notice for its long endurance capabilities and relative low cost. The gasoline-powered UAV features narrow 10 foot wings that allow the 40-pound vehicle to reach altitudes as high as 19,000 feet, distances of more than 60 nautical miles, and a flight endurance of almost 20 hours. Using an inertially stabilized camera turret carrying both electro-optical and infrared sensors, ScanEagle currently provides Marine Corps units in Iraq with force-protection ISR and is also used by Special Operations Command. ScanEagle operations began in 2004,[172] and continue

[166] Peter La Franchi, "Directory: Unmanned Air Vehicles," *Flight International*, June 21st, 2005, p. 57.

[167] Andreas Parsch, "AeroVironment RQ-11 Raven," *Directory of U.S. Military Rockets and Missiles*, September 12, 2006.

[168] "UAV Directory - Aircraft Specification AeroVironment - RQ-11A Raven," *FlightGlobal.com*, (2011).

[169] "UAV Directory - Aircraft Specification AeroVironment - RQ-11B Raven," *FlightGlobal.com*, (2011).

[170] The FY2012 budget request includes $70.8 million for 424 systems and supporting equipment. Department of Defense, *Department of Defense Fiscal Year 2012 Budget Estimates, Aircraft Procurement, Army*, February 2011.

[171] Jim Garamone, "ScanEagle Proves Worth in Fallujah Fight," *American Forces Press Service*, January 11th, 2005.

[172] Insitu, "Backgrounder: ScanEagle® Unmanned Aircraft System," press release, September 22, 2011, (continued...)

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today. Although ScanEagle was expected to cost about $100,000 per copy, the Navy and SOCOM have contracted for operations instead of procurement, with Boeing providing ISR services utilizing ScanEagle under a fee-for-service arrangement.[173]

ScanEagle is also in use by non-military organizations for surveillance purposes, including tracking whale migrations.[174]

Small Tactical Unmanned Aerial System (STUAS)

In July 2010, the Department of the Navy awarded Insitu a two-year, $43.7 million contract for the design, development, integration, and test of the Small Tactical Unmanned Aircraft System (STUAS) for use by the Navy and Marine Corps to provide persistent maritime and land-based tactical reconnaissance, surveillance, and target acquisition (RSTA) data collection and dissemination. "For the USMC, STUAS will provide the Marine Expeditionary Force and subordinate commands (divisions and regiments) a dedicated ISR system capable of delivering intelligence products directly to the tactical commander in real time. For the Navy, STUAS will provide persistent RSTA support for tactical maneuver decisions and unit-level force defense/force protection for Navy ships, Marine Corps land forces, and Navy Special Warfare Units."[175]

Payloads include day/night video cameras, an infrared marker, and a laser range finder, among others. STUAS can be launched and recovered from an unimproved expeditionary/urban environment, as well as from the deck of Navy ships.[176]

STUAS uses Insitu's Integrator airframe, which uses common launch, control, and recovery equipment with ScanEagle. STUAS has a takeoff weight of up to 125 pounds with a range of 50 nautical miles. However, STUAS will be procured and operated by the services rather than operated on a fee-for-service basis because "the Scan Eagle's current fee-for-service contract limits the way the UAS is deployed ... with Boeing/Insitu employees usually operating the aircraft in the field due to liability issues." Procuring the system will allow the services to train their own operators. Initial operating capability is expected in the fourth quarter of FY2013.[177]

(...continued)

http://www.boeing.com/bds/mediakit/2011/ausa/pdf/bkgd_scaneagle.pdf.

[173] See, inter alia, Boeing, "Boeing Awarded Navy Contract for ScanEagle Services," press release, June 6, 2008, http://www.boeing.com/news/releases/2008/q2/080606a_nr.html and Insitu, "Boeing Wins $250M Special Ops Contract for ScanEagle ISR Services," press release, May 22, 2009, http://www.insitu.com/print.cfm?cid=3774.

[174] Boeing, " From saving soldiers to saving whales," undated press release, http://www.boeing.com.au/ViewContent.do?id=61784&aContent=ScanEagle.

[175] Naval Air Systems Command, *Aircraft and Weapons: Small Tactical Unmanned Aircraft System*, http://www.navair.navy.mil/index.cfm?fuseaction=home.display&key=4043B5FA-7056-4A3A-B038-C60B21641288.

[176] Ibid.

[177] Gayle Putrich, "Insitu wins long-awaited US Navy STUAS deal," *FlightGlobal.com*, July 30, 2010.

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APPENDIX B

The Department of Defense's Traditional Acquisition System

Overview

The DAS is a structured and deliberate process for establishing requirements and planning and resourcing the procurement of new capabilities. The need for accountability and oversight in the allocation of national resources has led to the buildup over decades of a large bureaucratic apparatus around the DAS. The complexity of the process can be seen in Figure B.1.

This bureaucracy has many virtues. It provides for a structured process governed by regulations and accountable authorities and includes provisions for relatively stable funding over system life cycles. Such provisions are far from perfect. For example, observers have long noted that the process can be slow and unresponsive to the immediate needs of warfighters. Such concerns have led, as will be discussed below, to evolving roles for the combatant commanders in resource allocation processes. Another concern is that provision of training and sustainment considerations, while formally required, is an afterthought to the acquisition and fielding of new equipment. Both concerns will be discussed below.

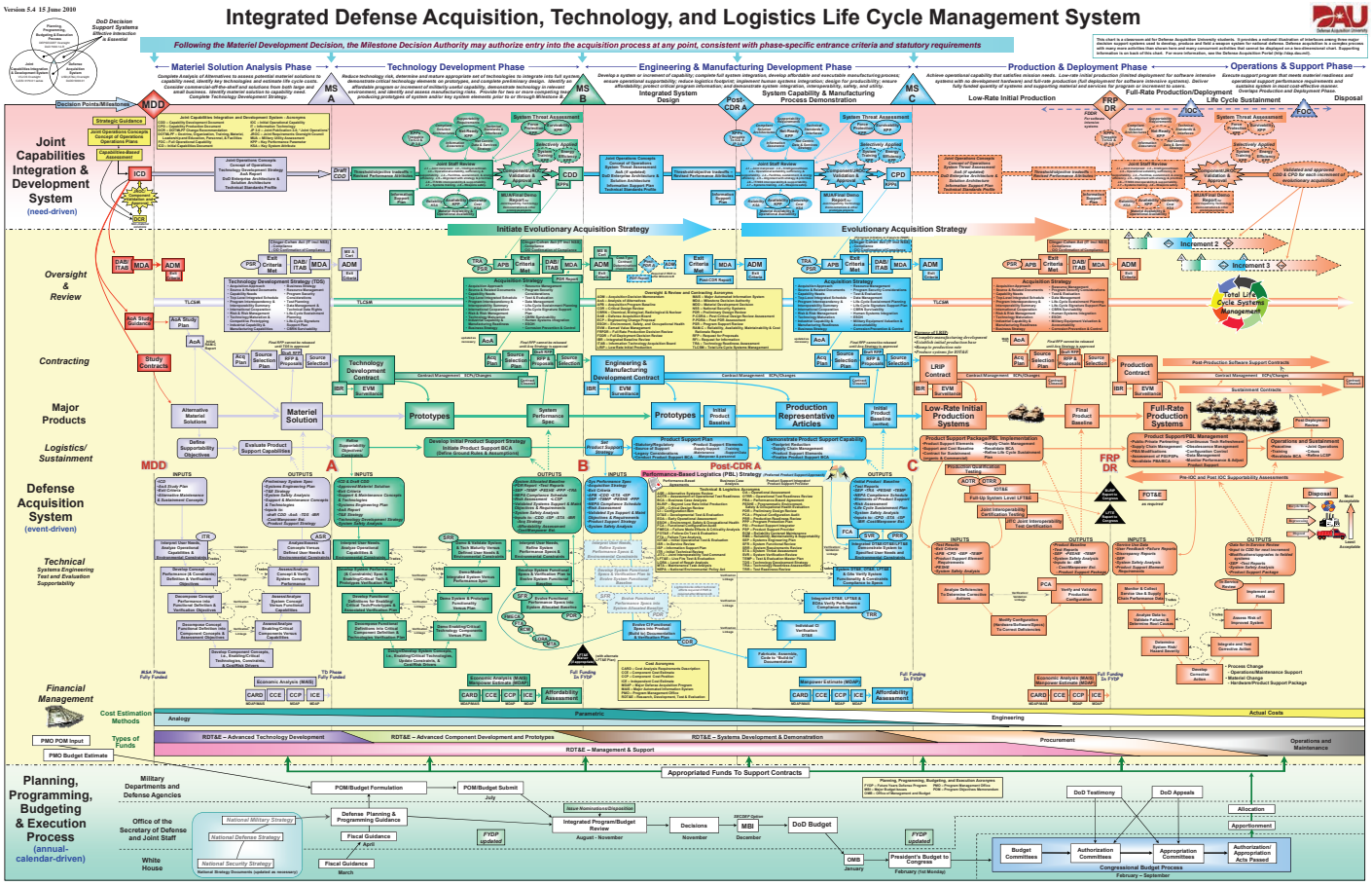
Role of Combatant Commanders in Traditional Acquisition

To meet current warfighter needs, the DoD has in recent years advanced changes to some existing acquisition processes and relationships. As a result, the roles of the COCOMs in the traditional system have evolved. For example, the Secretary of Defense approved a "streamlined and refocused" integrated priority list process to better support the development of service program objective memorandums (Hicks et al., 2008, p. 59). In November 2005, the Vice Chairman of the Joint Chiefs of Staff launched a process by which the Joint Requirements Oversight Council, in consultation with the COCOMs, identified a list of "most pressing" military issues to support resourcing and planning decisions (Hicks et al., 2008, p. 59). In 2006 the Senior Warfighters Forum, consisting of COCOM deputies, began meeting every four to six weeks to discuss coordination issues, and the Vice Chairman of the Joint Chiefs of Staff began coordinating regular trips to the COCOMs with critical PPBE decision points to better represent the COCOM position in resourcing decisions (Hicks et al., 2008, p. 60). Furthermore, SOCOM's traditional acquisition activities have increased, and its budget has grown significantly (GAO, 2007b, p. 1).

The COCOMS do not lead the process, but their ability to participate in acquisition, particularly in identifying requirements, has expanded. An emphasis on warfighting in recent years has given new weight to the capabilities and solutions that the COCOMs identify as

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Figure B.1
Defense Acquisition System



SOURCE: Defense Acquisition University, June 2010.

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required. Beyond the current fight, however, observers argue that the nature of future challenges and the technology necessary to meet them are so dynamic that fundamental acquisition relationships need to be rethought. As the commander of SOUTHCOM recently wrote:

> We are living in an age of rapid change facilitated by advancing technologies and increasingly networked systems, societies, and economies. In order for security agencies to be successful in this complex environment, those organizations must be flexible, open and forward-thinking. (Stavridis, 2010, p. xxii)

Leadership of traditional acquisition processes is vested in the military departments (the force providers) rather than the combatant commanders (the force users). The DAS consists of the interrelationship between the establishment of requirements (Joint Capabilities Integration and Development), the process of providing solutions, and the allocation of resources (PPBE). All processes are primarily driven by the military departments, with some inputs from the COCOMs. The logic behind the vesting of acquisition authority in the military departments reflects both Title 10 responsibilities and unique competencies for acquisition. The division of labor has traditionally been that the COCOMs provide inputs to the determination of requirements, and the services lead on providing solutions. A recent RAND assessment concluded that it "is the job of those in Washington, D.C., to reach out to the COCOMs and demonstrate that their needs are being addressed, rather than turn the process over to them" (Blickstein and Nemfakos, 2009, p. 7). Traditionally, the COCOMs are viewed as best suited to fighting wars, while the military departments are best suited to balancing other priorities and managing resource decisionmaking.

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APPENDIX C

Military Value Analysis of Unmanned Aircraft System Training Bases

Training Locations

The information on specific training locations included in this appendix is drawn from RAND interviews, service presentations to congressional oversight committees, and Army surveys and consolidated snapshots of selected Army bases compiled in November 2012.

Initial training for UAS operators and sensor operators is concentrated at a few locations. The Air Force uses Beale AFB for training its Global Hawk crews and primarily Holloman AFB for its Predator crews.[1] The Navy plans to leverage the similarities between the Global Hawk and BAMS by having some joint training at Beale AFB. The Army conducts all its initial UAS training at Fort Huachuca, Arizona. The Marine Corps trains its Shadow crews with the Army.[2] Current and continuing pressures on the defense budget are likely to result in further changes. We limited our efforts to analyze military value in depth to activities that any training base would more certainly include, regardless of budget reductions. After we gain a fuller understanding of the results of Secretary of Defense decisions on the content of the FY 2014 and FY 2015 programs, we will renew our efforts to complete this military value analysis.

The approach to the *military value analysis of training bases* presented here is based on the Department of the Navy's 1995 Base Realignment and Closure documents. These categories and a brief description are listed below:

- flight training areas and airspace—covers access to special use airspace, availability of training areas, etc.
- airfield and maintenance facilities—includes facilities available for housing and maintaining the aircraft
- expansion potential—any comments on future plans for expansion or capacity for expansion
- training and training facilities—includes classrooms or other similar infrastructure and equipment required for training
- military and general support mission—any impacts of the other military missions housed at the same installation

[1] The training for the LRE is separate from the FTU and takes place at Creech AFB, Nevada.

[2] The Marines will also operate the RQ-20A Puma. We do not discuss the training for that SUAS.

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- weather—any impacts of weather on training capacity
- location—description of the where the installation is located
- base loading—comments on consolidation of training.

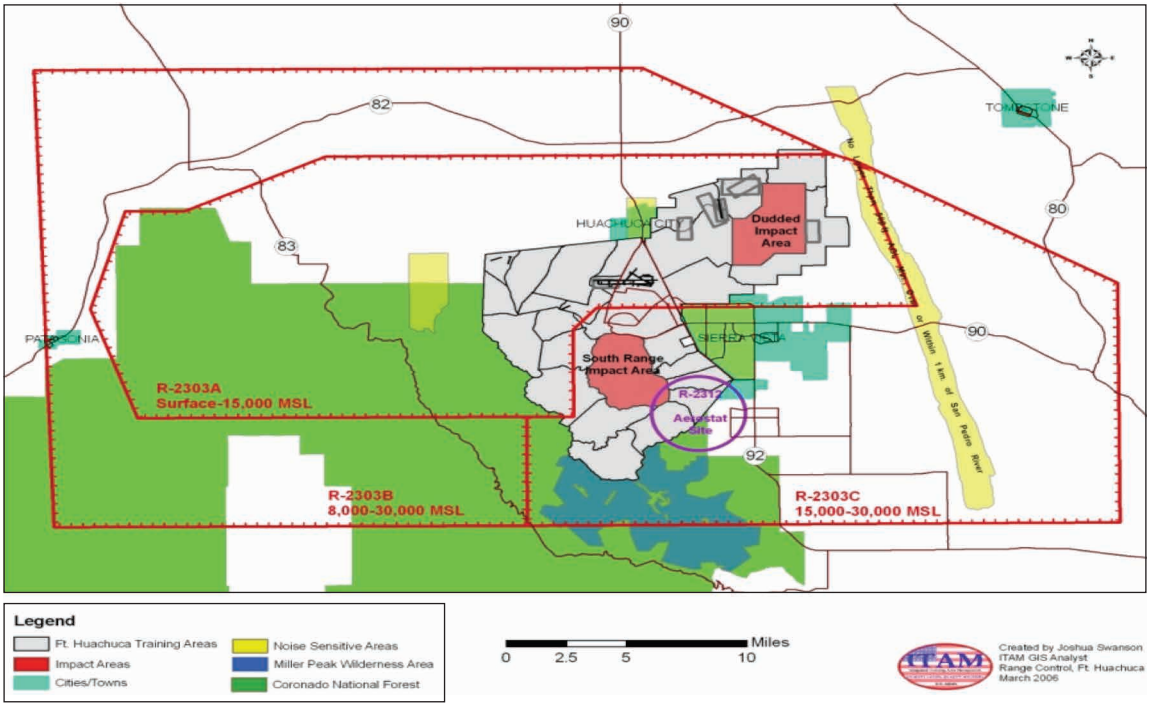
Army RQ-7 and MQ-1C Training IQT Fort Huachuca, Arizona

Fort Huachuca, Arizona, is home to the 2-13th Aviation Regiment (formally the Unmanned Aircraft Systems Training Battalion). The 2-13th trains operators and maintainers for the RQ-7 Shadow, the Warrior Alpha, and the MQ-1C Gray Eagle. The training pipeline for each of these was described in the body of this report.

Flight Training Areas and Airspace

See Figure C.1. R-2303 is a major operational area used for airspace manned and unmanned operations, Army and joint service training along with Department of Homeland Security border security operations. Fort Huachuca is the controlling authority and so can activate this restricted use airspace on demand, at any time. It covers 850 mi^2 of land outside Fort Huachuca and encompasses 4,600 mi^3 of airspace from the surface to 30,000 feet, much of it over private land. The FAA has issued several waivers to ensure the safe operations of manned and unmanned traffic. The area also has unencumbered radio frequency spectrum for the foreseeable future.

Figure C.1
Airspace Surrounding Fort Huachuca



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Airfield and Maintenance Facilities

See Figure C.2. UAS operations split between the Libby Army Airfield and Black Tower. Shadow and Hunter training takes place at Black Tower. There are dedicated maintenance facilities as well as hangers and airstrips. Gray Eagle training takes place at Libby Army Airfield.

Expansion Potential

The IQT common core and the course for Shadow are currently running 24-hour operations. It would be difficult to expand the student capacity without committing more resources. The Gray Eagle course is just beginning, and the Hunter course is winding down. There is enough infrastructure for the planned capacity. Any expansion would require more resources.

Training and Training Facilities

Most UAS training operations take place at the Black Tower complex. Gray Eagle and Warrior Alpha vehicles are flown out of Libby Army Airfield.

Military and General Support Mission

Fort Huachuca is home to the military intelligence schoolhouse. This proximity could provide a unique opportunity for collective training between the two schoolhouses. Huachuca is also home to the Buffalo Soldier Electronic Testing Range.

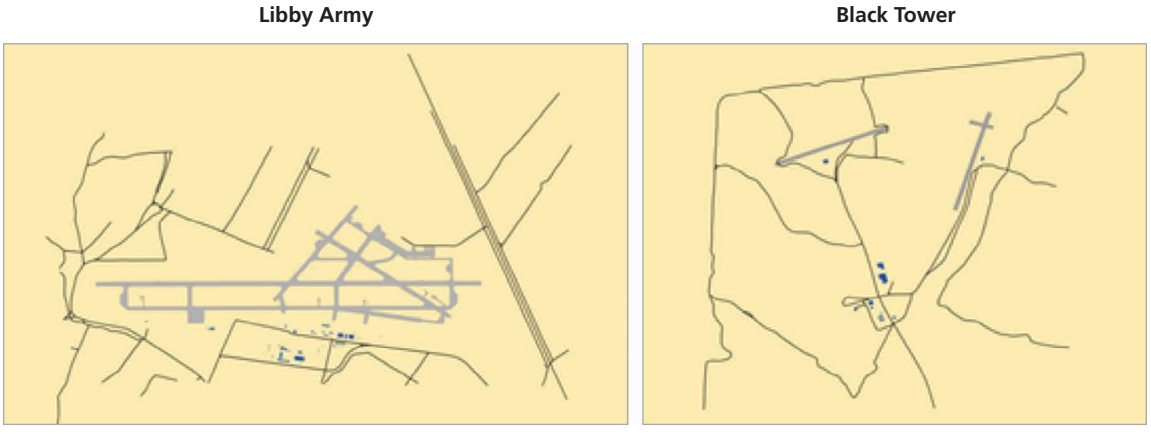
Weather

Fort Huachuca has excellent weather for UAS operations. It has approximately 270 training days a year.

Location

See Figure C.3. Fort Huachuca is situated in southeastern Arizona, near the town of Sierra Vista. There are approximately 60,000 people at Fort Huachuca.

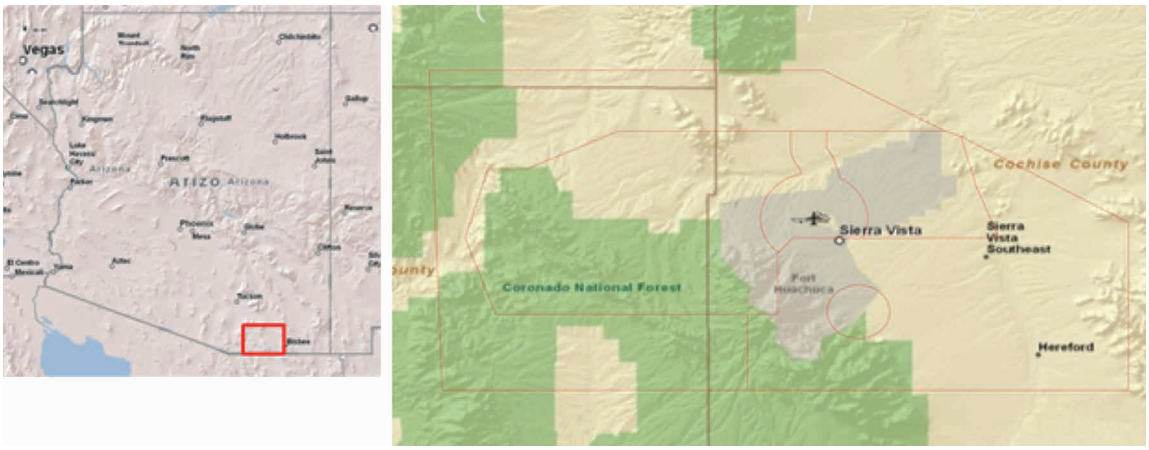
Figure C.2
Airfield and Maintenance Facilities at Fort Huachuca



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Figure C.3
Location of Fort Huachuca



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Base Loading

Fort Huachuca is the hub for Army UAS training. This consolidation could be both good and bad. The lack of redundancy elsewhere limits the ability to expand operations when needed. For example, if one of the runways were damaged, the entire Army UAS training capability could be severely affected.

Air Force Active Duty MQ-1/9 Formal Training Unit—Holloman AFB, New Mexico

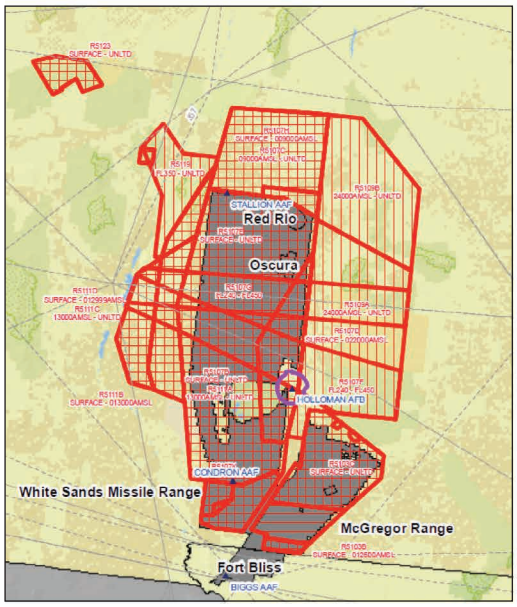
Flight Training Areas and Airspace

See Figure C.4. Holloman AFB has access to the restricted airspace areas within the White Sands Missile Range (WSMR) and McGregor airspace. It is possible to reach both ranges without leaving restricted airspace. While competition for airspace is fierce, WSMR supports flying RPA operations out of Holloman AFB. The current plan is for MQ1/MQ9 to depart Holloman AFB northbound for WSMR airspace and to remain totally within R-5107 B/C/D/H. An alternative is to depart Holloman AFB southbound and climb to FL-180 in R-5107D. There is a three-way memorandum of understanding in place, but the testing mission at WSMR occasionally conflicts with RPA training. A few other areas near Holloman AFB have potential for RPA operations, although they require COAs from the FAA.

The MQ-1/9 FTU completed the transition from Creech AFB to Holloman AFB. Plans call for an additional FTU, bringing a total of five MQ-1/9 training squadrons, including one maintenance squadron, to Holloman AFB. These squadrons will fall under the 49th Wing and bring in an additional 200 officers, 250 enlisted, and 150 contractors. Two hundred students are expected to cycle through in three-month training periods. Holloman AFB would have 28 MQ-1s and 10 MQ-9s. To operate the aircraft, they would have 12 common ground stations, four Predator Primary Satellite Links, two LREs, and five mission control elements. They expect to fly approximately 2,800 sorties a year, 540 at night.

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Figure C.4
Restricted and Non–Joint Use Class D Airspace near Holloman AFB



	Altitudes		Hours of Use	
	Minimum	Maximum	From	To
Airspace				
Beak A MOA	12,500 feet MSL	UTBNI FL180	0600	Sunset
Beak B MOA	12,500 feet MSL	UTBNI FL180	0600	Sunset
Beak C MOA	12,500 feet MSL	UTBNI FL180	0600	Sunset
Beak A/B/C ATCAAs	FL180	UTBNI FL230	As scheduled and coordinated	
Ancho A/B/C ATCAAs	FL180	UTBNI FL230	As scheduled and coordinated	
Cowboy A/B/C ATCAAs	FL230	FL600	As scheduled and coordinated	
Talon High East MOA	12,500 feet MSL	FL180	Sunrise	Sunset
Talon High West MOA	12,500 feet MSL	FL180	Sunrise	Sunset
Talow Low MOA	300 FEET AGL	UTBNI 12,500 feet MSL	Sunrise	Sunset
Talon High East and West ATCAAs	FL180	FL600	As scheduled and coordinated	
Valmont ATCAA	FL180	FL600	As scheduled and coordinated	
Restricted Area				
R-5103B (McGregor)	Surface	Unlimited	0700†	2000†
R-5103C (McGregor)	Surface	Unlimited	0700†	2000†
R-5107A (Ft Bliss)	Surface	Unlimited	Continuous	
R-5107B (WSMR)	Surface	Unlimited	Continuous	
R-5107C (WSMR)	9,000 feet MSL	Unlimited	Continuous Monday - Friday 12 hours in advance††	
R-5107D (WSMR)	Surface	FL220	Continuous	
R-5107E (WSMR)	Surface	Unlimited	By NoTAM 12 hours in advance	
R-5107F (WSMR)	FL240	FL450	Continuous M-F; 12 hours in advance pm weekends	
R-5107G (WSMR)	FL240	FL450	Continuous M-F; 12 hours in advance pm weekends	
R-5107H (WSMR)	Surface	UTBNI 9,000 feet MSL	By NoTAM 12 hours in advance	
R-5107J (WSMR)	Surface	UTBNI 9,000 feet MSL	Continuous Mon-Fri 12 hours in advance ††	
R-5109A	24,000 feet MSL	Unlimited	Intermittent by NoTAM	
R-5109B	24,000 feet MSL	Unlimited	Intermittent by NoTAM	
R-5111A (WSMR)	13,000 feel MSL	Unlimited	By NoTAM 12 hours in advance	
R-5111B (WSMR)	Surface	UTBNI 13,000 feet MSL	By NoTAM 12 hours in advance	
R-5111C (WSMR)	13,000 feel MSL	Unlimited	By NoTAM 12 hours in advance	
R-5111D (WSMR)	Surface	13,000 feet MSL	By NoTAM 12 hours in advance	

Notes: † – other times by NOTAM, †† – other times by NOTAM, 12 hours in advance
UTBNI = Up to, but not including; AGL = above ground level; FL = Flight level. FL 180 is approximately 18,000
Feet MSL; MSL= mean sea level; NOTAM = Notice to Airmen
Source: U.S. Air Force 2006

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Airfield and Maintenance Facilities

These are included with the training facilities.

Expansion Potential

The second MQ-9 FTU is scheduled to open in FY 2013, making Holloman home to three MQ-1/MQ-9 FTUs. There is currently a year lag in infrastructure to be able to support a third FTU. The new facilities were supposed to have been finished prior to the standup of the new FTU; however, construction is running approximately a year behind schedule. It is difficult to comment on the ability to meet the required capacity as the capacity requirement is in flux.

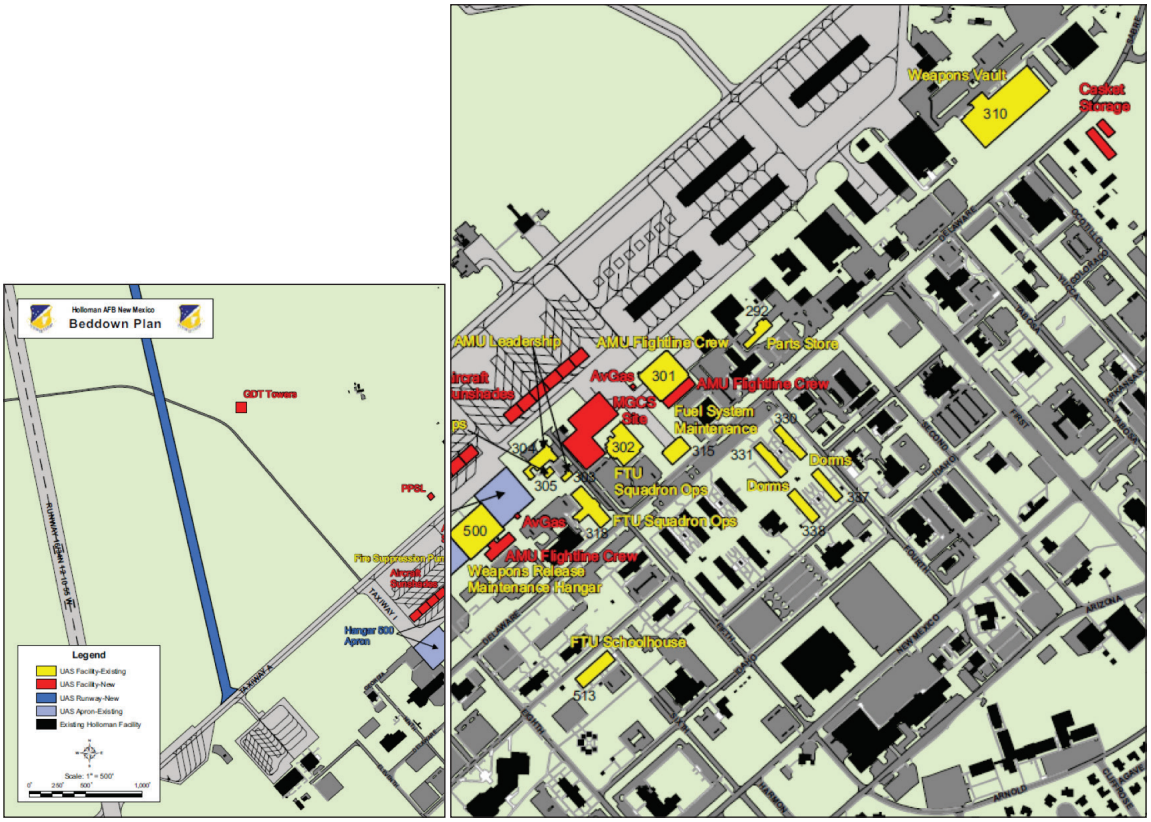
Training and Training Facilities

See Figure C.5. Holloman AFB has 200,000 ft^2 of existing and open facilities, including office space and hangars that could accommodate the FTUs with minor renovations. The map in Figure C.5 shows where new facilities would be located and identifies existing facilities.

Table C.1 shows the space required to start up the unit, as well as the required final bed-down space, as defined by military construction. Table C.2 shows the facility plan for each functional requirement.

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Figure C.5
MQ-1/MQ-9 Beddown Plan



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Military and General Support Mission

Other aircraft flown at Holloman currently include the T-38, MQ-1, MQ-9, the QF-4, and the German Tornado.[3] There are plans to move at least a portion of the F-16 FTUs from Luke AFB, Arizona, to Holloman AFB. This could affect the availability of airspace access.

Location

Holloman AFB is located in southern New Mexico, near the town of Alamogordo. The base encompasses about 59,600 acres and has a population of about 21,000 military, civilian, and families.

Base Loading

Moving the FTUs from Creech AFB to Holloman AFB freed up some capacity at the former and allowed the latter to focus purely on training.[4] There is some redundancy with the Air National Guard FTU at March ARB; however, that FTU is much smaller and primarily trains

[3] A German training unit is stationed at Holloman AFB. The F-22s will be transitioning from the base. Air Combat Command and the Air Staff are deciding what to put in place of the F-22 squadron.

[4] The LRE training is a separate course from the FTU and still taught at Creech.

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Table C.1
Beddown Plans

Function/Activity	Space Required for	
	Initial Startup	Final Beddown
Parking apron (000 ft^2)	30	60
Squadron operations facility (000 ft^2)	16	48
FTU schoolhouse	20	50
(classrooms and simulators) (000 ft^2)	11	11
MCE facility (000 ft^2)	12	24
Aircraft maintenance unit (000 ft^2)	30	70
Munitions PGM shop (000 ft^2)	2	Unknown
Munitions storage (000 ft^2)	3	Unknown
Aircraft parts store (000 ft^2)	10	10
Weapon load trainer (bays)	1 bay	1 bay[a]
Casket storage (000 ft^2)	8	16
Bulk fuel storage (gal)	32	32
Lodging (rooms)	60	200
All backshops (000 ft^2)	24	24

[a] Use maintenance bay.

Air National Guard operators. March ARB currently has adequate infrastructure and capacity for its training mission.

Air Force RQ-4 Formal Training Unit—Beale AFB, California

Flight Training Areas and Airspace

Because of the altitude at which RQ-4s conduct their primary mission, airspace access is manageable at Beale AFB. A cylinder is used to access Class A airspace. The FAA provides a standing window for flights into this cylinder of 10 hours a day, every weekday. Requests outside this window are handled individually and have not been a limitation.

Airfield and Maintenance Facilities

Beale AFB has dedicated airfield and maintenance facilities.

Expansion Potential

There is enough capacity for expanding the training mission of RQ-4s at Beale AFB. There are plans to include some portion of the operator or maintenance training for the Navy's MQ-4 BAMS at Beale, but this would be several years from now.

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Table C.2
Facility Requirements

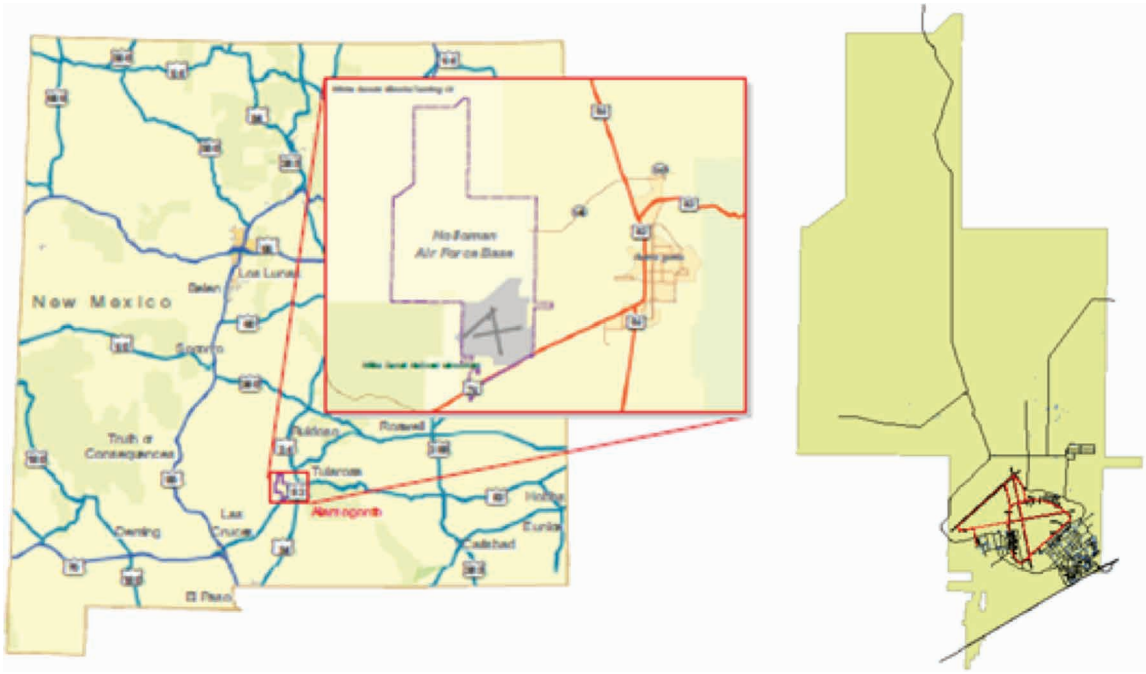
Function Description	Remarks
Flightline pavement	Use main ramp.
Live ordnance load area	Construct new LOLA on taxiway Echo.
Maintenance hangar (new FTU)	Use building 500.
Maintenance hangar (3 FTU squadrons)	Use building 301.
FTU squadron operations (new FTU)	For initial capability, use building 513 and a portion of building 302; when project is complete, transition from building 513 into building 318.
FTU squadron operations (Creech UAS)	If there are two FTU squadrons, use building 318; a third FTY squadron can occupy all of building 302 after F-22A transition is complete.
Aircraft maintenance unit (new FTU)	Initially locate leadership team in building 303 and operate flightline crews out of building 301 until completion of building 500 new construction (10,000 ft^2).
Aircraft maintenance unit (3 FTU squadrons)	If two units, locate both leadership teams in building 303 and flightline crews of the second unit in building 301. If three units, locate third leadership team in building 302 and locate flightline crew in building 302. New construction for building 301 can also be considered for the third crew.
Fuel system maintenance	Use building 315.
Precision guided munitions facility	Construct two maintenance bays and administration.
Munitions storage	Construct 26-by-120-ft Hayman igloo (possibly two 60-ft sections).
Aircraft parts store (new FTU)	Use existing contract support or shared building 292 (T-38 parts store).
Aircraft parts store (3 FTU squadrons)	If T-38 mission relocates, use building 292. If no relocation, add space to building 292.
Weapon release shop	Use each respective maintenance bay (building 500 for one and building 302 for two).
Casket storage	Construct 50-by-800-ft covered storage pad in logistics readiness squadron yard. Requirement may grow, depending on quantity of MQ-9 caskets on hand.
Bulk fuel storage	Construct two 8,000-gallon tanks adjacent to hangars 301 and 500 (for aviation gas) for MQ-1 and use existing JP-8 capacity for MQ-9.
Various backshops	Construct 5,000-ft^2 addition on building 500. Building 301 may require new additional space.

Training and Training Facilities

Beale AFB has adequate training space. There are several different aspects of training: classroom, simulation, and live flights. There is enough classroom space available for both the sensor operator training and the pilot training. The pilots use a pilot simulator to cover emergency procedures and aircraft operation. This simulator is very limited in its ability to mimic real-life contingencies. The sensor operators train on Data Analysis Workstations. These two simulators are not compatible, so there is no true crew simulator. Such a simulator has been

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Figure C.6
Location of Holloman AFB



RAND *RR440-C.6*

programmed but is still eight to ten years away.[5] Crew training takes place on live missions, with instructors flying the mission with students.

Military and General Support Mission

Beale AFB is home to several other aircraft, including the MC-12, the U-2, and the T-38. The RQ-4 fits well with the mission of other aircraft at Beale since it was designed to eventually replace the U-2. RQ-4 pilots are also doing tours in the MC-12. There was some talk of maintaining dual currency in the two platforms, but the status of that plan is unknown.

Location

Beale AFB is located in northern California, approximately one hour outside Sacramento. The nearest town is Marysville, California.

Base Loading

Beale AFB is the hub for high-altitude surveillance. The installation is extremely large, with plenty of room for growth.

[5] We understand this decision to be based on resources since on-the-job training on live missions is available.

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Unmanned aircraft systems (UASs) have become increasingly prevalent in and important to U.S. military operations. Initially serving only as reconnaissance or intelligence platforms, they now carry out such other missions as attacking enemy forces. The swift expansion in their numbers and in the demand for their employment has, however, significantly increased demands on logistics and training systems. The challenge is not simply training system operators but also training operational forces and their commanders to integrate the systems into combat operations. Much of that aspect of training has thus far happened as units employ the systems in actual operations—essentially, on-the-job training. UAS training, particularly for the employment of UASs, now needs to be integrated more formally and cost-effectively into service and joint training programs. This report develops a general concept for training military forces in employment of UASs and a framework for addressing the training requirements and discusses the limits of existing infrastructure in supporting UAS training. Interoperability among services is another issue, because services have thus far mainly developed training suitable for their own needs. But the services have established a set of multiservice tactics, techniques, and procedures for UASs, which should facilitate interoperability training. At present, units are not always ready for joint training, so the focus should be on improving training at the unit level in the employment of UAS capabilities, with the overall guiding principle being to "train as we fight."



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Bernard D. Rostker, Charles Nemfakos, Henry A. Leonard, Elliot Axelband, Abby Doll, Kimberly N. Hale, Brian McInnis, Richard Mesic, Daniel Tremblay, Roland J. Yardley, Stephanie Young

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Preface

During the most recent rounds of Base Closure and Realignment Commission activities in 2005, a significant number of training bases were closed. In light of the introduction of new technologies and the great expansion of unmanned aircraft systems (UASs) in the force, Department of Defense planners and some in Congress have become concerned that the existing training infrastructure—bases and their training support facilities—may not be adequate to train UAS air and ground components and the ground forces that use such equipment to capitalize fully on their capabilities. Accordingly, the Deputy Director, Readiness and Training Policy and Programs in the Office of the Under Secretary of Defense for Personnel and Readiness (OUSD [P&R]) asked the RAND Corporation to assess the adequacy of UAS training to support current and future requirements. In addition, the House Armed Services Committee report accompanying the Fiscal Year 2013 National Defense Appropriations Act raised a number of questions concerning training strategies with particular reference to the use of simulators to facilitate training.[1]

This report considers three issues: (1) the development of a general concept for UAS training in the context of current and anticipated future UAS inventories, (2) the development of an appropriate framework based on the general concept to address UAS training requirements, including the appropriate use of simulators, and (3) the airspace requirements necessary for UAS training. The research reported on here covers UASs in the Army, Navy, Air Force, and Marine Corps as fielded and plans as they existed during 2012. A RAND team carried out extensive field visits to understand the current ability of the services to conduct (1) service-specific training and (2) joint training at both home station and joint training facilities. The research will be of interest to those concerned with UAS programs and operations; joint training; or more generally, the incorporation of disruptive technologies into Department of Defense programs and operations.

This research was sponsored by the OUSD (P&R) Directorate for Training and Readiness Policy and Programs, in coordination with the Joint Forces Command's Joint Warfighting Center and the Joint Unmanned Aircraft Systems Center of Excellence. The research was conducted within the Forces and Resources Policy Center of the RAND National Defense Research Institute (NDRI), a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the Defense Intelligence Community. For

[1] House Armed Services Committee, *Conference Report Accompanying the Fiscal Year 2013 National Defense Appropriations Act*, 112th Cong., 2nd Sess., December 17, 2012, p. 136.

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Summary

Unmanned aircraft systems (UASs) have become increasingly prevalent in and important to U.S. military operations. The number of systems has surged, as has the slice of the defense budget allocated to them. Roles have also changed. Initially employed only as reconnaissance or intelligence platforms, they now carry out other missions, including attacking enemy forces. Successful operational tests and demonstrations of the expanded range of UAS capabilities have led to rapid fielding of new systems, often placing unanticipated demands on logistics and training systems and on field commanders to employ new systems effectively. UASs must now be integrated into the training programs of the services. Building a responsive, effective, and efficient UAS training program is a challenge during times of reduced budgets. Any new program must be based on a review of existing training capabilities and new investments across the services.

Focus of this Research

The Deputy Director, Readiness and Training Policy and Programs, in the Office of the Under Secretary of Defense for Personnel and Readiness (OUSD [P&R]) asked the RAND National Defense Research Institute (NDRI) to assess the adequacy of UAS training to support current and future requirements. Proposals to resolve service and joint UAS training issues must be informed by a clear understanding of current problems, opportunities for correction, and associated costs and benefits of the corrections. In this report, we address a number of issues, including (1) a general concept for UAS training; (2) an appropriate framework to address UAS training requirements, including the use of simulators; and (3) the limitations of the infrastructure to accommodate UAS training, including those due to national airspace restrictions. The research considers UASs in the Army, Navy, Air Force, and Marine Corps, both those that are currently fielded and those that were planned to be fielded as of 2012.

Disruptive Technologies and Acquisition Processes

In 1995, Clayton Christensen introduced the term *disruptive technology*, distinguishing it from what he termed *sustaining technology*. In his nomenclature, a sustaining technology improves the performance of an existing system and does not require significant structural adjustments to processes, organizations, or operational paradigms. Disruptive technologies, however, change the way a business operates. The UAS is a disruptive technology.

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UASs found their way into the force by means of rapid acquisition procedures that were designed to deliver new technologies to the warfighter much faster than traditional procedures could, but often at the cost of not having in place the support these new systems required to become a sustained part of the force structure. Because of the rapid acquisition of these systems, the services have had to rely upon contractor support in ways that are inconsistent with the full and sustaining integration of these systems into service inventories. Such integration starts with the development of an appropriate concept for training.

Training Concepts and Frameworks

We will begin by discussing the general ideas that should guide UAS training—the training *concept*. Then, we will consider how the parts identified in the concept fit together into a conceptual structure for that training—a training *framework* designed to enhance combat power and other operational capabilities.

Joint Operations; Multiservice Tactics, Techniques, and Procedures; and UAS Training

Military operations today are usually referred to as *joint operations*, emphasizing the interdependence of the services. That might lead one to think that joint doctrine; joint concepts of operation; and joint tactics, techniques, and procedures would provide focus for training. Clearly, training does not take place for its own sake; it should be driven by doctrine. In his cover letter to Joint Publication 3-0, 2011, ADM Mike Mullen stated that it established "the framework for our forces' ability to fight as a joint team," but nowhere does it discuss the management of UASs. Moreover, nowhere in any other joint publication is there a grand doctrine for the employment or management of UASs on the battlefield. While the services have agreed to a set of multiservice tactics, techniques, and procedures (MTTPs) to be incorporated into their respective training programs, note the use of *multiservice* rather than *joint*.

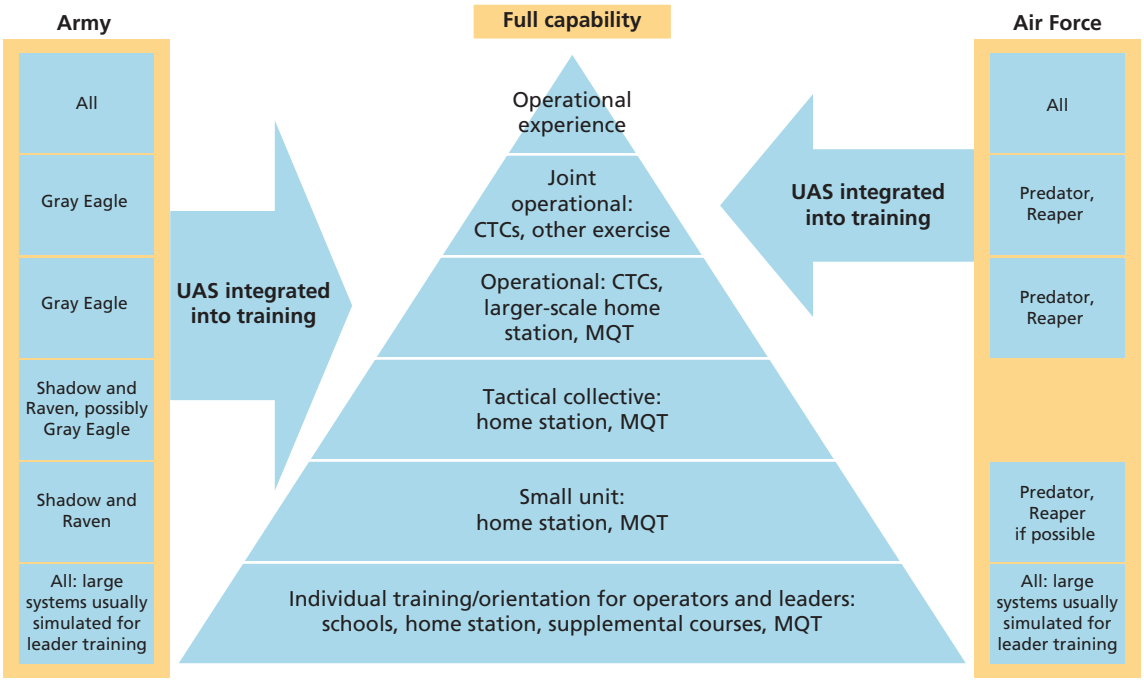
At least for the foreseeable future, each service will continue to field UASs and must bring to the fight forces fully capable of operating them and integrating their capabilities into operations. While grand doctrinal issues remain unresolved, common procedures agreed to and trained by the services will remain the foundation on which American military operations must be built. In this way, rather than being the foundation for UAS training, joint operations are the goal of such training, which must be firmly grounded on the UAS training each service gives both its supported and supporting units.

The general concept we advance for UAS training here rests on the notion that the greatest beneficial effect—that is, an increase in the force's operational effectiveness—occurs with a synergy among the UAS platforms, those who operate them, and those who integrate them into combat operations. While the report considers training concepts for ground, air, and sea forces, they share a common framework. Figure S.1 depicts our framework for ground and air forces; the one for naval forces is similar.

The concept underpinning the framework calls for increasing integration of its several parts as the level of training moves up the pyramid. Army systems appear on the left, Air Force on the right. At the bottom, training begins with individual training for operators and leaders, grounding each group in the basics of the system. Training then progresses to the small unit level, which, as with individual training, is largely done at home station. Moving up the pyramid, training occurs at increasingly higher echelons, battalion and brigade. Moving to joint

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Figure S.1
UAS Training Framework



RAND *RR440-S.1*

operations involves Air Force units, which have gone through a similar process of progressive training. They join together in exercises, many of which are conducted at the large combat training centers (CTCs), to integrate close air support and Air Force UASs into the ground maneuver plan.

Assessment of the State of UAS Training in 2012: Service and Interoperability Training and the Role of Simulators

Service Training

Speaking generally, the services have been relatively effective at training the individual skills required to operate and maintain the UASs, although the services differ in their approaches. The Army, which tends to use enlisted personnel to staff its UAS units, has developed courses that award Military Occupational Specialties for the operators and maintainers for its Shadow and Gray Eagle systems. Training for the Raven UAS, which is about the size of a large model airplane and is used to support lower-echelon units, is a unit responsibility carried out through a "train-the-trainer" concept. The Marines use officers who are qualified aviators or aviation command and control officers as pilots, and enlisted personnel operate the payloads. The Air Force pilots are officers and are either rated pilots who graduated from pilot training or UAS-only pilots who graduated from a program designed specifically for flying UASs. Sensor operators for Reaper and Predator are either trained into a new career field or cross-trained from another Air Force Specialty Code. Those for Global Hawk come from the imagery analyst

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career field. Maintenance personnel come through the Air Force's maintenance education and training programs.

The more challenging part of the training comes at the integration level, where UAS personnel must meld their efforts with those of ground combat units. This occurs within and between services. Integration requires substantial practice under realistic conditions that do not occur frequently. Rotations at a CTC are often the only occasions, short of actual operations in theater, in which commanders face the challenge of integrating all battlefield operating systems at once, and the addition of the UASs necessarily complicates synchronization and integration tasks. Thus, it is not surprising that initial assessments of UASs during integrated training are, at best, mixed.

The key concerns of UAS units tend to be similar across services. For ground and Air Force units, the concerns are beddown and support facilities, airspace limitations, and simulators. Many of the beddown and support issues can be resolved with relatively minor construction. Some airspace issues, however, are not likely to improve. The Navy has airspace issues at specific installations but generally faces fewer restrictions because it can operate outside the 12-mile coastal limit with relative freedom.

Interoperability Training

To date, interoperability training at the National Training Center (NTC) and the Joint Readiness Training Center has been limited. The Government Accountability Office (GAO) has cited two significant challenges for improved interoperability training: (1) "establishing effective partnerships with program stakeholders through comprehensive communication and coordination and (2) developing joint training requirements that meet combatant commanders' needs," with particular emphasis on tactical-level training (GAO, 2005, p. 2).[1] To meet this challenge, the Department of Defense (DoD) established an implementation plan that gives the Office of the Under Secretary of Defense for Personnel and Readiness overall responsibility and the Deputy Under Secretary of Defense for Readiness executive agent responsibility for training transformation planning, programming, budgeting, and execution progress.[2]

While RAND did not assess interoperability training in detail, our discussions with the training community, including trainers at the NTC, suggest that such training opportunities have been limited because Air Force assets, particularly the Predator, have generally been unavailable due to pressing operational requirements in Iraq and Afghanistan. This same general observation was also reported by the GAO (2010b, p. 26). The problem of transiting Air Force UASs from Creech Air Force Base, Nevada, to the NTC at Fort Irwin, California, through Federal Aviation Administration–controlled airspace is often cited. Permanently stationing Air Force UAVs at the NTC, much as the Marine Corps has done by stationing Shadow UAS squadrons at the Marine Corps Air Ground Combat Center at Twentynine Palms, California, to support training there, would of course negate that problem. However, the experience of the Marine Corps suggests that the mere presence of UASs will not ensure

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[1] GAO, 2005, p. 18, noted that,

> [i]n the past, joint training tasks were primarily focused at the command level and were identified through DOD's authoritative processes that built requirements by translating combatant commander inputs into training requirements. Training transformation has expanded joint training requirements to include those at the tactical level in addition to joint command-level training.

[2] See Director, Readiness and Training Policy and Programs, 2006.

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that the forces are properly trained. The forces must be prepared for such training at their home stations. In addition, given the common MTTP, forces trained to operate with their own service UASs should find working with UASs from the other services less challenging.

Simulators

Congress has pressed for information on the role simulators might play in a UAS training strategy, seeking an "informed balance between live training and simulated training."[3] But the conditions that make a compelling case for using simulators in the training of fighter pilots are largely absent when it comes to UAS training:

1. UAS flying hours are much less expensive than flying hours for manned aircraft.
2. The kinds of operational activities that need more training emphasis, in particular air-ground coordination, are generally not activities for which simulators per se can substitute for live flying.
3. While simulators are an inherent part of the systems used for initial training of pilots and sensor operators,[4] they are not well suited (and not designed) for training operating forces on the full spectrum of UAS capabilities.
4. At best, simulators complement rather than substitute for live training. Given the current state of the fielding of UAS, first priority must be given to building the live flying infrastructure. Then, and only then, might funds be used to undertake the research and development that must precede any consideration of fielding the kind of interactive UAS air-ground simulators that could train both UAS crews and ground troops.

We concluded that, given current budget limitations and the importance of fully developing the opportunities for live training and the relatively low cost of such training, diverting funds to develop higher fidelity UAS-ground simulators would be unwise at this time. However, the Army's air-ground integration ranges provide a good example of judicious use of simulators to do what simulators do best—in this case, scoring target hits without using expensive live munitions and without blowing up fairly expensive targets. In the future, the services should reevaluate the need for virtual training based on a cost and effectiveness analysis (COEA) that includes developmental costs for simulators, savings based on the costs of flying UASs, and the critical availability of air space for training.

Implications and Recommendations

The Guiding Principle: "Train As We Fight"

DoD has been under some pressure from the Congress and such organizations as the General Accountability Office for the lack of central control and the lack of the development of joint DoD strategy for training. In reality, the services continue to develop UAS training initiatives primarily to meet their own unique requirements, and the opportunity for joint training is limited. Progress has, however, been made with the development of the MTTP and the recognition that interoperability training is a service responsibility. For now, DoD should encourage

[3] See, for example, Chairman, House Armed Services Committee, undated.

[4] See Shawn Johnson, UAS cost per flying hours, personal communication, April 10, 2013.

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each service to solve its own UAS training problems, not constrain any one service under the guise of joint training. Given strong service programs, there will be ample opportunity to focus on joint training in the future, when the opportunity presents itself. Today, however, the services are still struggling with how to incorporate these new systems. The appropriate strategy for UAS training is to insist that the services train as they will fight. Accordingly, to *train as we fight* in the future, DoD training strategy must

- engender better appreciation of UAS capabilities throughout the chain of command
- address organizational, structural, and infrastructure and support issues
- enable "train as we fight" in collective unit training
- enable "train as we fight" in exercises.

Initiatives with Near-Term Payoff

To accomplish these goals, a number of initiatives should pay off in the near term, including

1. increasing exposure to the capabilities and limitations of UASs
2. harnessing the lessons-learned process to guide the development of service and joint doctrine and tactics, techniques, and procedures
3. addressing well-known but underresourced training infrastructure shortfalls.

Institutionalize Training for UAS Capabilities Over the Longer Term

Institutionalization will require more-general efforts, including

1. acculturation (Many end users do not yet have a well-developed appreciation of UAS capabilities.)
2. development of a cadre of UAS professionals with hands-on experience in all echelons of UAS operation
3. integration of UASs into service force structures
4. adaptation, including
   a. accounting for the evolution of the roles of UASs in the full range of military operations
   b. continuous resolution of UAS doctrinal issues.

Summary of Findings and Recommendations

The findings and recommendations are summarized below:

1. The proper strategy for DoD at this time is to encourage each service to solve its own UAS training problems, rather than to constrain any one of them under the guise of joint operations.
2. DoD should support current and future programs to develop ranges and beddown and support facilities similar to those in the Army's current programs.
3. In spite of the demands of deploying units and sustaining combat operations in Afghanistan, Army trainers indicate that Army units are better at maintaining qualification for Shadows than for Ravens. Nevertheless, not all units have been able to maintain high

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Shadow qualification rates—some units arrive at the NTC with one-half or fewer of their operators qualified.

4. If joint training becomes a priority, the Air Force's current basing and beddown posture will become a problem. The Air Force could consider the location of Army hubs when choosing where to base its UAS fleet. A location that is near Army maneuver elements might make airspace access less of a restriction or at least make certificates of authorization more practical. Proximity might provide more opportunities for training UAS integration throughout the entire mission planning process.
5. Given current budget limitations and the importance of fully developing the opportunities for live training and the relatively low cost of such training, diverting funds to a research and development program to develop higher-fidelity simulators would seem to be unwise at this time.

Path to the Future

This report presents and discusses a multitude of means for setting up UAS training strategies for success, including supporting ongoing facilities and basing initiatives; expanding such facilities, where possible, to enable wider availability of UASs to support collective training; and increasing the use of UASs—the complete UAS package, including joint tactical air controllers and other coordinating elements—in collective training, both local and in larger exercises. We have noted the need to support continuing efforts to resolve airspace access issues, observing as we did so that there are ways to keep such restrictions from imposing serious limitations on much of the UAS training envisioned here. Similarly, we have discussed the potential for simulators to add value in training, now and perhaps more in the future. But we have also cautioned that simulators in their current state are not a good substitute for live use of UASs in collective training.

The path to the future for UAS strategies starts now, with support for ongoing initiatives that will continue the trends toward better training integration, thus improving the ability of end users to employ the multiple capabilities of UASs in their operations. The path continues, using that foundation, with longer-term efforts to add to acculturation of end users, professionalization of the UAS community, and integration of the two to harmonize the capabilities of UASs as key elements of overall force effectiveness.

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Acknowledgments

The research presented here is the result of numerous field visits and discussions with members of service and department staffs in the Pentagon, commanders and operations staffs in operational arms of all the services, planners and training developers in service training commands, trainers and staffs at the various combat training centers, students in UAS operator schools, and UAS operators. So many shared information and data and providing thoughtful comments, advice, and insights that it is impossible to single out anyone without possibly slighting someone else. Moreover, the views expressed in this report are our own and should not be attributed to any individual or organization.

We would be remiss, however, if we did not recognize the support we received from Frank DiGiovanni, Director of Training Readiness and Strategy in the Office of the Under Secretary of Defense (Personnel and Readiness), and Joan Vandervort, our project coordinator in Mr. DiGiovanni's Office. Their commitment to developing an appropriate training strategy for UASs was the driving force behind this study.

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Abbreviations

ABSAA	airborne sense-and-avoid
ACA	airspace control authority
ACO	airspace control order
ACTD	advanced concept technology demonstration
AECV	All-Environment Capable Variant
AFB	Air Force base
AFSC	Air Force specialty code
ALO	air liaison officer
AMB	air mission brief
AMPS	Aviation Mission Planning System
ARB	Air Reserve base
ATO	air tasking order
AVO	air vehicle operator
BAM	broad area maritime
BAMS-D	Broad Area Maritime Surveillance–Demonstrator
C2	command and control
CAOC	combined air operations center
CAP	combat air patrol
CAS	close air support
CCDR	combatant commander
COA	certificate of authorization
COCOM	combatant commander

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CONUS	continental United States
CSG	carrier strike group
CTC	combat training center
DAS	Defense Acquisition System
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director of Defense Research and Engineering
DoD	Department of Defense
DSB	Defense Science Board
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FRS	fleet replacement squadron
FTU	formal training unit
FY	fiscal year
GAO	Government Accountability Office
GBSAA	ground-based sense-and-avoid
IQT	initial qualification training
ISR	intelligence, surveillance, and reconnaissance
JBLM	Joint Base Lewis-McChord
JFACC	joint force air component commander
JFC	joint force commander
JFCOM	Joint Forces Command
JIEDDO	Joint Improvised Explosive Device Defeat Organization
JRAC	Joint Rapid Acquisition Cell
JTAC	joint tactical air controller
LAA	limited acquisition authority
LCS	littoral combat ship
LRE	launch and recovery element
MCAGCC	Marine Corps Air Ground Combat Center
MCS	mission control system

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MOS	military occupation specialties
MPO	mission payload operators
MTTP	mulltiservice tactics, techniques, and procedures
MQ-8B	Fire Scout
MQT	mission qualification training
NAS	National Airspace System
NCTE	Naval Continuous Training Environment
NDRI	RAND National Defense Research Institute
NTC	National Training Center
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
PACOM	U.S. Pacific Command
PPBE	Planning, Programming, Budgeting, and Execution
REF	Rapid Equipping Force
RSTA	reconnaissance, surveillance, and target acquisition
RPA	remotely piloted aircraft
SOCOM	Special Operations Command
SOF	special operations forces
SOUTHCOM	U.S. Southern Command
SPINS	special instructions
SUAS	small unmanned aircraft system
TACP	tactical air control party
TEMF	tactical equipment maintenance facility
TF	task force
TRADOC	Training and Doctrine Command
UAS	unmanned aircraft system
UAV	unmanned aerial vehicle
UGS	Unmanned Ground School (Ft. Huachuca)
USD (AT&L)	Under Secretary of Defense (Acquisition, Technology, and Logistics)

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USMC	U.S. Marine Corps
WSMR	White Sands Missile Range
YTC	Yakima Training Center

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CHAPTER ONE

Introduction

UASs Play an Increasing Role on the Battlefield

During the last decade, in large part because of the dynamic nature of operations during Operation Enduring Freedom and Operation Iraqi Freedom, recognition of the importance of developing new capabilities to meet the ever-changing threats our military forces face has grown. As a result, the Department of Defense (DoD) has undertaken operational and technology demonstration projects to test new technologies and systems outside the traditional acquisition process. Many of these systems involve unmanned vehicles and some unmanned aircraft systems (UASs). In 2000, the DoD had fewer than 50 unmanned aircraft in its inventory; by 2012, it had more than 7,100, as shown in Table 1.1 (Gertler, 2012).[1] The size of the Department's investment in these systems today similarly dwarfs prewar levels. In 2000, the DoD spent $284 million on UASs, while the 2010 budget for UASs has grown to over $6.1 billion (GAO, 2010a, p. 1). Figure 1.1 shows the growth of UASs from 1988 to 2013. Figure 1.2 shows projected growth in UAS programs as of 2012.

UASs have two main advantages over manned aircraft: They eliminate the risk to a pilot's life, and they provide capabilities not subject to human limitations. They are also cheaper to procure and operate than manned aircraft. While they minimize risk to operational crews, they introduce new complications and hazards not associated with manned aircraft. While some think of UASs simply as a substitute for manned aircraft, UASs increasingly complement manned aircraft, providing new capabilities for the force to utilize. Combined UAS and helicopter operations are but one example (McLeary, 2012).

Originally, UASs were used to gather intelligence. During the Vietnam War, drones flew strategic reconnaissance missions over denied areas. The Israeli Air Force successfully used UASs during operations in Lebanon in 1982 and for many years led the world in developing UASs and tactics for employment. Subsequently, longer-endurance systems introduced the ability to maintain surveillance on distant and moving targets. More recently, UASs originally designed for reconnaissance have been modified to carry precision-guided weapons to attack ground targets, greatly expanding the role such systems play on the modern battlefield. This also has expanded and complicated the training of UAS crews as full participants in the joint and combined arms battle.

Successful operational tests and demonstrations of the expanded range of UAS capabilities have led to rapid fielding of new systems, often placing unanticipated demands on logistics

[1] See Appendix A for descriptions of the major systems.

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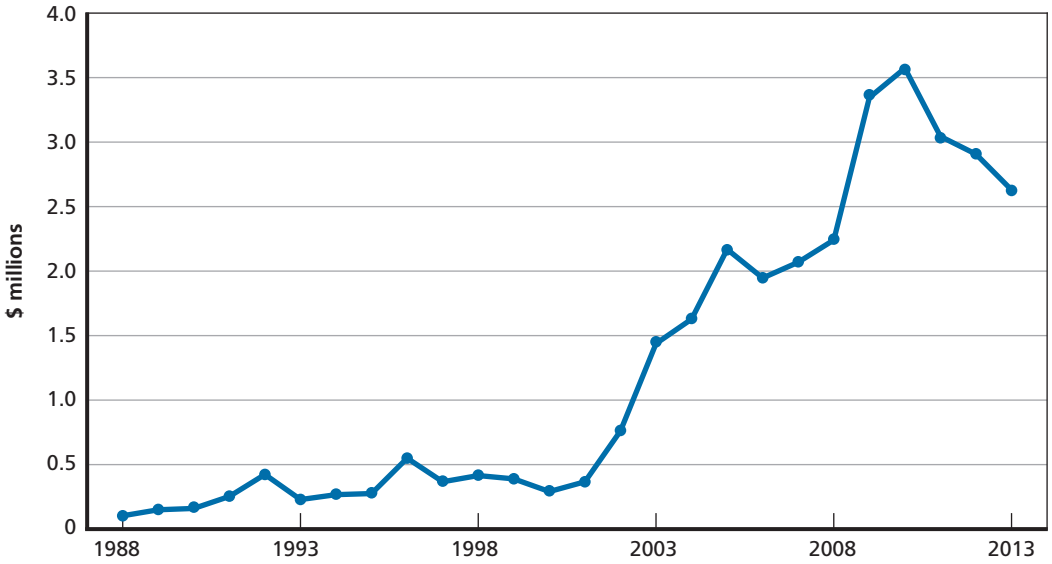
Table 1.1
DoD UAS Platforms as of 2011

Name	Vehicles	Ground Control Stations	Employing Service(s)	Capability/Mission
RQ-4A Global Hawk/ BAMS-D Block 10	9	3	USAF Navy	ISR Maritime domain awareness (Navy)
RQ-4B Global Hawk Block 20/30	15	3	USAF	ISR
RQ-4B Global Hawk Block 40	1	1	USAF	ISR Battle management command and control
MQ-9 Reaper	54	61	USAF	ISR RSTA EW Precision strike Force protection
MQ-1A/B Predator	161	61	USAF	ISR RSTA Precision strike Force protection (MQ-1C Only-C3/LG)
MQ-1 Warrior/MQ-1C Gray Eagle	26	24	Army	ISR RSTA Precision strike /force protection (MQ-1C Only-C3/LG)
UCAS-D	2	0	Navy	Demonstration Only
MQ-8B Fire Scout vertical takeoff and landing tactical UAV	9	7	Navy	ISR RSTA Antisubmarine warfare Antisurface warfare Mine warfare Organic mine countermeasures
MQ-5 Hunter	25	16	Army	ISR RSTA Battle damage assessment
RQ-7 Shadow	364	262	Army USMC SOCOM	ISR RSTA Battle damage assessment
A160T Hummingbird	8	3	SOCOM DARPA Army	Demonstration
Small tactical UASs	0	0	Navy USMC	ISR Explosive ordnance disposal Force protection
ScanEagle	122	39	Navy SOCOM	ISR RSTA Force protection
RQ-11 Raven	5,346	3,291	Army Navy SOCOM	ISR RSTA
Wasp	916	323	USMC SOCOM	ISR RSTA
SUAS AECV Puma	39	26	SOCOM	ISR RSTA
Gasoline-powered micro air vehicle (gMAV) T-Hawk	377	194	Army (gMAV) Navy (T-Hawk)	ISR RSTA Explosive ordnance disposal

SOURCE: Gertler, 2012, p. 8.

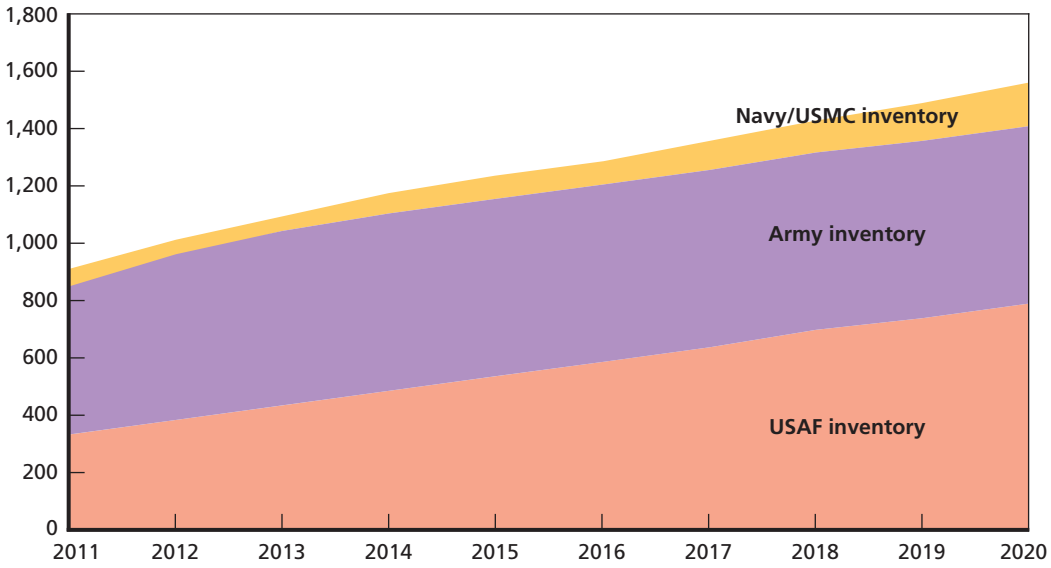
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Figure 1.1
UAS Budgets from 1988 to 2013



SOURCE: Gertler, 2012, p. 14.
RAND *RR440-1.1*

Figure 1.2
DoD Inventories for Medium and Large Unmanned Aircraft



SOURCE: Kempinski, B. (2011, Tables 1-2,1-3,1-4). Policy Options for Unmanned Aircraft Systems, Congressional Budget Office.
RAND *RR440-1.2*

and training systems and on field commanders to employ the new systems effectively. UASs must now be integrated into the training programs of the services.

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Building a responsive, effective, and efficient UAS training program is a challenge in a time of reduced budgets. Any new program must be based on a review of existing training capabilities and new investments across the services.

Integrating UASs into the core operations of the DoD presents the kinds of special problems that are common when new technologies appear and clash with existing ways of doing business. Such clashes happen frequently enough that there is a term for such innovations: disruptive technologies. The rapid introduction of UASs into operations in operations Enduring Freedom and Iraqi Freedom and the attendant force structure growth have presented just such challenges (as discussed in Chapter Two). The resulting disruption has contributed to lags in the ability of joint doctrine, tactics, techniques, and procedures (TTP) to keep pace and in the ability of joint training[2] and service-specific managers to develop and execute training programs.[3]

Focus and Approach of this Research

The Deputy Director, Readiness and Training Policy and Programs in the Office of the Under Secretary of Defense for Personnel and Readiness asked RAND to assess the adequacy of UAS training to support current and future requirements. Proposals to resolve service and joint UAS training issues must be informed by a clear understanding of current problems, opportunities for correction, and associated costs and benefits of the corrections. In addition, the current extraordinary pressures on the overall federal budget, including the defense "top line," and the ongoing review of U.S. strategy will likely have implications for force structure and basing, resulting in a number of yet-unknown factors that could profoundly affect the future of UAS programs. These uncertainties notwithstanding, a number of issues must be addressed: (1) a general concept for UAS training; (2) an appropriate framework for addressing UAS training requirements, including the use of simulators; and (3) the airspace requirements necessary for UAS training.

The research reported on here covers UASs in the Army, Navy, Air Force, and Marine Corps as fielded and plans as they existed in 2012. Because of the increasing use of these unmanned systems to support to ground operations, the RAND effort has more closely examined the interface between UASs and operating elements of ground forces. To this end, a team from RAND carried out extensive field visits to understand the current ability of the services to conduct (1) service-specific training and (2) joint training at both home station and joint train-

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[2] Department of Defense Directive 1322.18, January 13, 2009, defines joint training as "Training, including mission rehearsals, of individuals, units, and staffs using joint doctrine or tactics, techniques, and procedures to prepare joint forces or joint staffs to respond to strategic, operational, or tactical requirements that the Combatant Commanders (CCDRs) consider necessary to execute their assigned or anticipated missions."

[3] Chairman of the Joint Chiefs of Staff Instruction 3500.01G, March 15, 2012, p. C-2, defines service training as follows:

> Service Training: Service Active Component (AC) and RC training (including USSOCOM) is based on joint and Service policy and doctrine. Service training includes basic, technical, operational, and interoperability training to both individuals and units in response to operational requirements identified by the CCDRs to execute their assigned missions.
>
> Joint Training. Training, including mission rehearsals, of individuals, staffs, and units, using joint doctrine and tactics, techniques, and procedures, to prepare joint forces or joint staffs to respond to strategic, operational, or tactical requirements considered necessary by the CCDRs to execute their assigned or anticipated missions.

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ing facilities. Members of the team interviewed officials involved with UAS training operations at the following Army, Navy, Air Force, and Marine installations and units:

- Beale Air Force Base (AFB), California
  - Global Hawk operations and Distributed Common Ground Station 2
- March Air Reserve Base (ARB), California
  - Air Force National Guard Ground Control Station school
- Holloman AFB, New Mexico
  - (Air Force Predator and Reaper training)
- Fort Irwin, California
  - (Air Force training support unit and selected individuals from the operations group)
- Creech AFB, Nevada
  - (the Joint Unmanned Aircraft Systems Center of Excellence and the operational UAS wing)
- Fort Rucker, Alabama
  - Training and Doctrine Command (TRADOC) capability manager for UASs
- Fort Huachuca, Arizona
  - TRADOC Capability Manager for Intelligence Sensors and the UAS Training Battalion
- Fort Benning, Georgia
  - Maneuver Center of Excellence
- Fort Campbell, Kentucky
  - 101st Airborne Division (Air Assault)
- Marine Corps Base Twentynine Palms, California
  - Marine Corps Air Ground Combat Center (MCAGCC) and two of three active U.S. Marine Corps (USMC) UAS squadrons
- Naval Air Station Patuxent River, Maryland
  - Naval Air Systems Command (Navy and Marine Corps)
- Fort Eustis, Virginia
  - TRADOC Capability Manager for Live Fire Training, Army Capabilities Integration Center, and TRADOC G-3
- North Island Naval Base, San Diego, California
  - Commander, Naval Air Forces.

In addition, the RAND team had extensive discussions with the strategy and planning staffs at U.S. Pacific Command (PACOM) and U.S. Navy Pacific Command concerning rapid acquisition of new technologies, such as the UASs reported on here. In that process, the RAND team gained important insights into the challenges the services face, first in identifying new or disruptive technologies and then in using operational demonstrations or experiments to understand and develop the changes to operational concepts that these technologies would drive.

During these visits, the RAND team talked with operators and support personnel; those who train operators and associated members of the team; those who train and observe the forces that employ UASs in their operations; staff elements concerned with the planning and resourcing of training, both for UAS operators and for the force more generally; and those concerned with the ongoing development of doctrine and concepts of operations for UASs, including their integration into operations.

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Plan for the Report

Chapter Two starts the report with a discussion of disruptive technologies, rapid acquisition processes, and the challenges the DoD faces in integrating UASs into the operations of the military departments. Chapter Three presents a general concept and a framework for training focused on the integration of UASs into military operations. Using the framework, the assessment in Chapter Four considers the current ability of the services to conduct service-specific training at both home station and joint training facilities. This includes a compilation of observations and insights largely gained during our visits to the bases listed above, with our interpretation of their implications for the specification and resourcing of training strategies. Finally, Chapter Five summarizes our research and looks toward the evolving training strategy for DoD in the future. The appendixes present additional material, including a description of ongoing systems, a further discussion of the Defense Acquisition System (DAS), UAS descriptions, and infrastructure considerations and the results of a RAND assessment of training infrastructure.

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CHAPTER TWO

The Case for and Implications of Unmanned Aircraft Systems Being a "Disruptive Technology"

Over decades, DoD has developed a structured and deliberate approach for the way it acquires new systems, which is formalized in the DAS and the 5000 series of DoD instructions. However, the exigencies of recent military operations have led DoD to develop new technology and acquire and field new systems without going through the steps the defense acquisition process generally requires. While near-term requirements drove such acquisition decisions, these decisions have long-term consequences. Rapid acquisition without a fully developed plan for how the new systems will be sustained over time may well diminish operational effectiveness. A potent example of such an effect is the extent to which the rapid and large-scale introduction of UASs has outpaced investments in the training infrastructure necessary to support the associated operation and maintenance. In the future, personnel will not be able to use or maintain the new systems properly. The Defense Science Board (DSB) made this point forcefully in 2003: "(1) military proficiency is as dependent on the warriors who operate weapon systems as it is on the weapon system technology, and (2) a superb way to waste personnel or system acquisition money is to ignore training" (DSB, 2003, p. 2). Despite the inefficiency of poorly coordinated investments, the DSB found that "systems continue to be created and then fielded with little consideration for the costs that must be incurred during the life cycle to train the weapon's users" (DSB, 2003, p. 44). As it turns out, the difficulty of incorporating new technologies into existing operations and processes is not unusual. It happens frequently enough that there is a term for such innovations: *disruptive technologies*.

The Disruptive Technology Experience in the Business Community

Clayton Christensen introduced the term *disruptive technology* in 1995. He distinguished disruptive technology from what he termed *sustaining technology*. In his nomenclature, a sustaining technology improves the performance of an existing system and does not require significant structural adjustments to processes, organizations, or operational paradigms. Disruptive technologies, however, change the way a business operates (Govindarajan, Kapalle, and Daneels, 2011).

Since the concept was first introduced, a number of studies have focused on ways that enable an organization to incorporate disruptive technologies. Christensen found that many organizations fail to meet the challenges disruptive technologies pose because they focus only on costs and not on how the new technologies change business processes and create new values for customers (Christensen and Overdorf, 2000). As Christensen used the term, *pro-*

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cesses include the coordination, communication, decisionmaking, and interaction patterns that transform resources into a product. Under normal conditions, processes are stable. They are designed not to be easy to change, and this inertia can impede the adoption and exploitation of emerging disruptive technology (Looy, Martens, and Debackere, 2005). Tellis makes the point that, given limited resources, investments in unfamiliar technologies with unproven returns are opposed because they are seen as "cannibalizing" both resources and customers from established products (Tellis, 2006). Because it is often difficult to introduce such new technologies into existing business units, much of the literature discusses how "spinout" organizations were created to nurture these new technologies (e.g., Henderson and Clark, 1990). For example, in a study of several game-changing technological developments, te Kulve and Smit, 2010, found that successful new product lines usually had a "champion" with "dedicated change strategies" to further the introduction of disruptive technologies.

Unmanned Aircraft Systems: A Case of Disruptive Technology for the Department of Defense

Although DoD operates in a different environment with different incentive structures from those of the business community, it is not immune to the difficulties disruptive technologies have introduced in the private sector.[1] From DoD's perspective, a technology is disruptive when it has the potential to alter the scope and effectiveness of military operations dramatically and is applied in sufficiently large numbers that it can no longer be supported in the same manner as during its initial development (i.e., the military must incorporate its support into its standard logistics and training systems). The UAS qualifies as a disruptive technology on multiple counts. First, as Christensen notes, the advent of the UAS changed the way the U.S. military operated, that is, its "business processes" changed. Second, UASs have broadened the scope of military operations substantially and greatly enhanced the effectiveness of both intelligence processes and strike operations. Finally, they have arrived in sufficient numbers that they now need to be integrated into the standard processes.

As the U.S. went to war in Afghanistan and Iraq, concern grew about the lack of speed and responsiveness in the traditional process for getting new systems into the hands of warfighters.[2] Critics complained about bureaucratic processes that make the traditional system too slow and too risk averse to acquire and field effective solutions rapidly.[3] As late in the conflicts as 2008, Secretary of Defense Robert Gates expressed frustration with the defense bureaucracy, arguing "we must not be so preoccupied with preparing for future conventional and

[1] There are numerous examples of disruptive technologies and how they displaced formerly dominant technologies in both the private sector and the military: Just a few examples are commercial airlines displacing passenger trains, internal-combustion-engine vehicles replacing horse-drawn vehicles, aircraft carriers replacing battleships as the Navy's capital ship, and tanks replacing cavalry.

[2] Appendix B describes DoD's traditional acquisition system.

[3] For example, Lt. General Robert P. Lennox, the Army's Deputy Chief of Staff for Programs and Resources, explained, "This is one of our most common topics of conversation: How do we rapidly field capabilities when technology advances so quickly?" (quoted in Erwin, 2010).

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strategic conflicts that we neglect to provide both short-term and long-term all the capabilities necessary to fight and win conflicts such as we are in today."[4]

A Challenge to the Traditional Acquisition System

The virtues of the deliberate and structured traditional acquisition system must be weighed against the fact that the system can take years to field new capabilities. From requirements generation through the DAS and the Planning, Programming, Budgeting, and Execution (PPBE) process, the traditional acquisition system generally takes several years to meet materiel warfighter needs; some systems can take decades (GAO, 2010b). While this long time frame makes some sense for large and complex programs of record, it poses a significant challenge when required capabilities are needed more quickly or are focused more narrowly. This lack of responsiveness has led some observers to argue that the traditional system is not optimized for delivering the full spectrum of desired capabilities. While the system should, in theory, be adaptable for both small and large acquisition programs, it works best in practice for major defense acquisition programs. However, much recent acquisition activity has not been in the form of large programs of record that entail the institutional backing necessary for proper sustainment strategies. The fast rate and large volume demanded for unfamiliar technologies, in particular, have strained the system and pressured traditional acquisition relationships to change.

Rapid Acquisition Programs Met the Challenge

To meet an urgent demand to incorporate new technologies, a series of acquisition processes was created outside the traditional acquisition process and was unencumbered by the prior restrictions designed to mitigate cost, capability, and schedule risk. Unfortunately, while these "workarounds" fostered the fielding of numerous systems, they generally neglected to provide for the institutional sustainment—training and logistical support—needed to facilitate introducing these systems into the force on any basis other than as technology demonstrations. Figure 2.1 captures the proliferation of a selection of these rapid acquisition processes. Below, we discuss several of the more important ones.

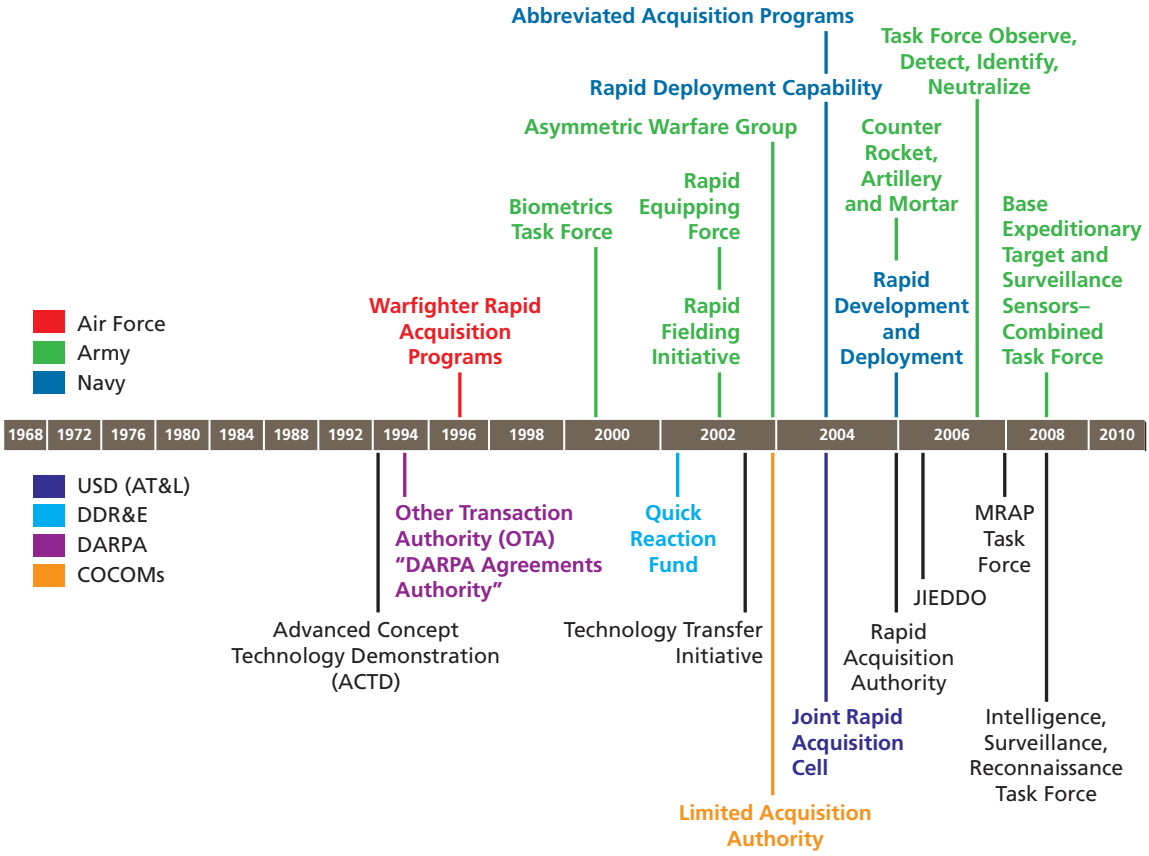
Advanced Concept Technology Demonstration

In 1994, in response to recommendations from the Packard Commission and the DSB, DoD introduced the advanced concept technology demonstration (ACTD) (Drezner, Sommer, and Leonard, 1999, p. 23). The Global Hawk UAS, which has found broad applicability in the wars in Iraq and Afghanistan, began as an ACTD. This approach to technological development was intended to improve speed and promote innovation by limiting acquisition hurdles. A system designated as an ACTD could use streamlined management and had reduced oversight requirements (Drezner, Sommer, and Leonard, 1999, p. xiv). ACTDs were intended to bridge the innovation-adoption gap by existing somewhere beyond demonstration of technical feasibility without quite yet becoming major defense acquisition programs. Toward the same end of nudging innovation and eliminating procedural hurdles, in 1994 the National Defense

[4] Gates' distinction reflects what is often a difficult balance between short- and long-term requirements and planning horizons. This creates an institutional tension that has, for example, made the military departments resistant to prioritizing the acquisition of unmanned technology that had near-term applicability but that was not intended to be part of a longer-term vision. See Gates, 2008.

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Figure 2.1
Select Rapid Acquisition Processes, Approaches, Authorities, and Funding Mechanisms



SOURCE: Derived from Anderson (1992), AUSA (2003), DSB (2009b), GAO (1998), GAO (2010b), Sullivan (2009a), Thirtle (1997).

RAND *RR440-2.1*

Authorization Act introduced an authority that allowed the Defense Advanced Research Projects Agency (DARPA), long seen as a mechanism for moving innovative ideas toward materiel solutions, more flexibility in contracting; facilitated use of commercial practices; and waived certain Federal Acquisition Regulations (FARs) and other laws (Drezner, Sommer, and Leonard, 1999, p. 27).

Limited Acquisition Authority

In time of war, new requirements arise that the long and deliberate acquisition system is ill suited to meet. As a result, both Congress and DoD's civilian leadership put in place ad hoc arrangements to seed the development and fielding of new systems. In fiscal year (FY) 2004, Congress granted the Secretary of Defense the authority to delegate a limited acquisition authority (LAA) to Joint Forces Command (JFCOM) to speed the research and development and limited fielding of new systems (GAO, 2007a). However, LAA is an authority, rather than a program, and does not translate into budgeted funds.[5] In the first three years of the authority,

[5] JFCOM had to reallocate funding from its own budget or gain funds from another DoD organization. Over one-half the programs JFCOM supported came from its own budget. In addition, after the systems were acquired, funds were not

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JFCOM used the LAA to support six projects. After that, LAA activities slowed significantly, a trend GAO suggests may be linked to lack of access to funding (GAO, 2007a, p. 3).

Joint Rapid Acquisition Cell

The Joint Rapid Acquisition Cell (JRAC), also established in 2004 by the Deputy Secretary of Defense and organized in the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, constituted another rapid acquisition program. The intent of this cell was to meet new requirements that the combatant commanders (COCOMs) identified as operationally critical; the COCOMs' prominent role in JRAC has led some to tag it the "COCOM's acquisition process" (Middleton, 2006, p. 19; see GAO, 2010b, p. 1). During its initial three years, JRAC supported 24 programs, at a cost of $335.5 million.[6] These funds came primarily from war supplemental appropriations and were not part of the military departments' programs or budgets. A 2009 DSB report found that this meant that "these programs continue to lack serious institutional commitments; very little is being built into the service or other DOD budgets for these programs" (DSB, 2009, p. 6). While JRAC required a life-cycle plan as part of the acquisition process, the DSB found this planning inadequate. Training relied more "on learning on the job with little emphasis on support, training, and sustainment." (DSB, 2009, p. 6). The typical institutional support in the services that is needed to fund, for example, investments in the training infrastructure does not exist for every rapidly acquired system.

Rapid Equipping Force

In 2002, the Army established the Rapid Equipping Force (REF), whose mission was to equip operational commanders with technological solutions to urgent war needs in no more than six months (DSB, 2009, p. 12). In 2005, the REF was made permanent (Kennedy, 2006, pp. 43–45). The organization began with a staff of 14 personnel, which expanded to 150 by 2007 (Dietrich, 2007, p. 5). In 2005 alone, it purchased more than 20,000 items, including robots, surveillance systems, digital translators, and weapon accessories (Dietrich, 2007, p. 6). The REF supported the rapid acquisition and fielding of a widely adopted technology called PackBot, which became a vital tool in the identification and defusing of deadly improvised explosive devices. The REF also supported other unmanned and robotic technology, including the development of the battery-powered, hand-launched, and camera-equipped Tactical Mini Unmanned Aerial Vehicle (UAV) in 2005. The REF project leader described that UAV as a technology that allowed soldiers to "go into situations knowing what's in front of them" (Ainsworth, 2005). REF purchased the mini-UAV commercially and, after some software modifications, quickly had it ready for theater operations (Miles, 2005). Yet, insufficient consideration for back-end support reportedly plagued early REF efforts, and steps have been taken to ameliorate the difficulties. COL Gregory Tubbs, REF director, conceded that the early ad hoc "wild west" days of REF logistical support were a challenge (Kennedy, 2004).

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readily available for long-term sustainment. A 2005 report from the Center for Strategic and International Studies called for providing rapid acquisition approaches with more-secure funding: "Urgent requirements will be met much faster if they can be resourced without taking funds from existing programs" (Murdock and Flournoy, 2005, p. 98).

[6] The process begins when a COCOM identifies and validates an urgent operational needs statement (or a joint urgent operational needs statement for joint requirements), defined as "urgent, combatant commander-prioritized operational needs that, if left unfilled, could result in loss of life and/or prevent the successful completion of a near term military mission." *Immediate warfighter needs* were the urgent operational needs statements certified as requiring a solution in 120 days or less. For a given system, JRAC is authorized to expend $365 million in research, testing, development, and evaluation funds and up to $2.19 billion in procurement. See GAO, 2007a, p. 12.

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Intelligence, Surveillance, and Reconnaissance Task Force

The high value placed on UASs, specifically in new intelligence, surveillance, and reconnaissance roles, can be seen in the robustly funded Intelligence, Surveillance, and Reconnaissance (ISR) Task Force, which supported the fielding of numerous unmanned systems. In spring 2008, Secretary Gates established this task force to expedite the fielding of ISR assets to combat areas (Sherman, 2008). The task force originally had a 120-day charter; two years after the task force's founding, the secretary announced that it would become a permanent part of the Office of the Under Secretary of Defense for Intelligence (Bennett, 2010). Its mission was to address unmet ISR requirements and to rapidly acquire and field capabilities by coordinating activities and pursuing innovative solutions (Loxterkamp, 2010). The ISR Task Force was to recommend ways to maximize the availability of systems in the inventory and to boost acquisition of additional systems (Best, 2010, p. 17). In FY 2008 alone, Congress approved the reprogramming of $1.3 billion based on ISR-TF recommendations (GAO, 2008b). Among the systems the task force supported were the Navy's unmanned MQ-8 Fire Scout and the fielding and sustainment of 50 unmanned Predators.

Informal Approaches to Rapid Acquisition

The formal approaches highlighted above support rapid acquisition in a variety of ways. Some consist of an acquisition authority but no money (LAA); some consist of funding (REF); some facilitate stronger requirements inputs (JRAC); and some, like Special Operations Command (SOCOM), have everything. Yet importantly, some rapid acquisition has taken place outside even these ad hoc institutional arrangements. For example, in one case, the personal relationships enabled rapid acquisition of command and control (C2) systems. In another, ADM James Stavridis instituted a "culture of innovative thought" into U.S. Southern Command (SOUTHCOM) by developing his own in-house technical capabilities through a process he called Linking Plans to Resources, an approach aiming to associate capabilities with specific solutions (Hicks, 2008, p. 33). He chartered the Joint Innovation and Experimentation Directorate, tasking it with improving how the command trains, fights, and does business (Stavridis, 2010, p. 177). This small innovation staff was to "research, explore, and test emerging technologies available commercially or through Federal research centers" (Stavridis, 2010, p. 89). The directorate was to take the lead in identifying new and creative ways of meeting the command missions, and was given the primary responsibility for "developing validated solutions into an initial operational capability," materiel or nonmateriel (Stavridis, 2010, pp. 178–179). These innovations, looking for better ways to link requirements to resources and developing in-house capabilities for acquiring solutions, reflected new acquisition roles.

PACOM's version was the Plans to Resources to Outcomes Process, which helped in the development of the command's integrated priority list. PACOM also developed its own in-house means of meeting requirements (Murdock and Flournoy, 2005, p. 40). PACOM's Joint Innovation and Experimentation Division uses the integrated priority list to develop rapid, innovative solutions for filling the gap and injecting them into PACOM exercises. Similarly, in 2009, U.S. European Command appointed a special assistant for innovation and technology to field equipment for the war in Afghanistan. Navy Captain Jay Chestnut, special assistant in charge of the project, explained that European Command "knows that 'big acquisition' [the traditional system] is trying to do the right thing but sometimes you need someone working on the side, looking innovatively" (Francis, 2009).

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In addition to the development of in-house approaches, informal rapid acquisition has also involved forging relationships between the COCOMs and technical expertise outside the military departments. As described by Stavridis, SOUTHCOM worked to both build in-house staff and forge relationships with a "technological base" external to the organization. He highlights, in particular, the partnership with DARPA, in which DARPA pursues "exploration and technology where risk and payoff are both very high, and where success may provide dramatic advances" to the SOUTHCOM mission (Stavridis, 2010, p. 89). Included in Admiral Stavridis' list of outcomes of this productive symbiotic relationship with DARPA are unmanned aerial craft and unmanned surface vessels.

The Use of Fast Track Authorities Can Cause Problems

For acquisitions to be "rapid," certain aspects of the traditional acquisition process have been left out. In many cases, it is the training and support planning that have been omitted. In 2008, the GAO reported that the

> rapid fielding of new systems and the considerable expansion of existing Air Force and Army programs has [sic] posed challenges for military planners to fully account for UAS support elements, such as developing comprehensive plans that account for personnel and facilities needed to operate and sustain programs." (GAO, 2010a, p. 37)

Because many of these programs do not pass through the system development and demonstration phase or a logistics supportability analysis, the data needed to generate training and support planning and ultimately guide investment decisions are unavailable. In 2010, the GAO found that the Air Force had not developed a servicewide plan that identified the number of personnel to be trained, the specific training required, and the resources necessary to establish a dedicated UAS training pipeline (GAO, 2010a). The Air Force has reportedly been struggling to staff significant increases in unmanned systems (Baldor, 2010). Going from a handful of drones in 2007 to 45 by 2010, with plans to operate 50 by 2011 and 65 by 2013, had created significant resource challenges for the department. These resource challenges became heavily pronounced with the "surge" in UAS requirements for operations in Libya and Afghanistan beginning in March and extending into summer 2011. The Air Force, to fulfill combat air patrol (CAP) requirements, stood down a portion of its formal training structure to form three CAPs (U.S. Air Force, 2011). As the Air Force's Deputy Chief of Staff for Operations, Plans, and Requirements explained in 2010, the "number one manning problem in our Air Force is manning our unmanned platforms" (Baldor, 2010).

The GAO similarly found that the Army's personnel authorizations were insufficient to support UAS operations. The Army has determined on at least three separate occasions since 2006 that Shadow UAS platoons did not have adequate personnel to support the near-term and projected pace of operations (GAO, 2010a). Officials from seven Army Shadow platoons in the United States and Iraq told the GAO that approved personnel levels for these platoons did not provide an adequate number of vehicle operators and maintenance soldiers to support operations (GAO, 2010a). Army officials told the GAO that currently approved personnel levels for the Shadow platoons were based on planning factors that assumed that the Shadow would operate for 12 hours per day with the ability to extend operations to up to 16 hours for a limited time (GAO, 2010a). However, personnel with these platoons told the GAO that UASs in Iraq routinely operated 24 hours per day for extended periods (GAO, 2010a). Army officials

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also reported that combat brigades and divisions require additional personnel to provide UAS expertise to assist commanders in making effective use of new technological systems (GAO, 2010a).

UASs exemplify the challenges of integrating training and sustainment considerations outside the strictures of the formal acquisition process. Ad hoc rapid acquisition processes were able to field UASs rapidly, but because of the nature of these processes, the fielded UASs lacked sustainable institutional support and funding needed for future investments in the training infrastructure. Frequently, the services try to sustain and support these programs by relying on contractors, just as they did during system development.[7] Of course, employing contractors to provide training is not in itself a problem. But it does reflect the extent to which training has been more about expediency than about effective institutionalization, particularly with regard to the imperative to train as we fight and the need to fully appreciate the need to integrate UAS training across the full spectrum of combat units.

[7] For example, the Air Force continues to rely on contractors to perform a considerable portion of UAS maintenance. For example, contractors perform approximately 75 percent of organization-level maintenance requirements for the Air Combat Command's Predator and Reaper UASs. See GAO, 2010a.

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CHAPTER THREE

Training Concept and Framework for Unmanned Aircraft Systems

We will begin by discussing the general ideas that should guide UAS training—the training *concept*. Then, we will consider how the parts identified in the concept fit together into a conceptual structure for that training—a training *framework* designed to enhance combat power and other operational capabilities. Note that the term *UAS* can be misleading. In fact, there is not a single UAS but rather a family of aircraft that share the common feature that they fly without a pilot on board.[1] These aircraft have very different personnel and training requirements. The vast majority of UASs support ground operations, and that will be our primary focus. As noted in Table 1.1, ground forces—the Army and Marine Corps—own many of these systems themselves, but the Air Force owns some of them and often flies them in support of ground operations. UASs are sometimes flown in support of conventional ground operations and sometimes in support of special operations. Our main focus is on support of conventional forces. UASs are now also being developed that will support maritime forces, and we also consider them.

Training Transformation, Joint Doctrine, Joint Operations, and UASs

Large military operations today are usually joint operations requiring and emphasizing the interdependence of the services. It follows naturally that joint doctrine, joint concepts of operation, and joint TTP would provide focus for training. Accordingly, the DoD's Training Transformation Implementation Plan requires that in order to "improve joint force readiness" there be a "unity of effort in training across Services, agencies and organizations."[2] That said, joint training guidance and publications generally provide guidance direction on the coordination and collaboration among elements of different services to optimize the joint employment of their various capabilities, and not on the employment of any one, specific system or even family of systems, such as UASs.

Clearly, training does not take place for the sake of training; it should be driven by doctrine. Thus, in line with the general focus described above, JP 3-0 (2001) "establishes the framework for our forces' ability to fight as a joint team," but nowhere does the document discuss the management of UASs or any other specific system. Moreover, nowhere in any other joint publication is there a grand doctrine for the employment or management of UASs on

[1] In 2014, the Air Force republished its vision for its system, replacing the term *unmanned aircraft systems* with the term *remotely piloted aircraft* (RPA) (U.S. Air Force, 2014, p. iii).

[2] See Director, Readiness and Training Policy and Programs, 2006, p. 5.

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the battlefield. However, the services have agreed to a set of TTP to be incorporated into their respective training programs. They describe these as a "multiservice" rather than a joint TTP, thereby avoiding doctrinal issues on how to deploy and manage UAS even as the services support joint operations.

Air Force Maj David Buchanan explored the difficulty of developing a joint doctrine for UASs in a 2010 Naval War College paper, summing up the difference this way: The Air Force believes in centralized control, and the Army believes in decentralized operations. He noted that the

> Air Force's proposal to assume executive agency for all medium- and high-altitude UASs in March 2007 was an attempt to establish unity of command and increase UAS efficiencies. … The Army's position … was that a single-service approach to UAS employment would infringe on the effectiveness of UASs in combat.
>
> The Air Force's centralized approach may result in a more efficient allocation of limited UAS assets, but that efficiency comes at the cost of combat effectiveness. The Army's answer to regain effectiveness has been to decentralize command and control for its unmanned aircraft systems. Ground commanders rely on UASs to provide timely, relevant, and useful intelligence without the lengthy processing and dissemination associated with the Air Force's centrally controlled, theater-wide assets. The Army's Training and Doctrine Command noted that the joint (CAOC [combined air operations center]) solution to meeting the high demand for these low-density assets has been ineffective, arguing against relying on the JFACC [Joint Force Air Component Commander] for UAS coverage. (Buchanan, 2010, p. 7).

JP 3-55.1 reflects a more service-centric notion of jointness.[3] When it was written in 1993, UASs were primarily thought of as reconnaissance, surveillance, and target acquisition (RSTA) assets. As envisioned then, mission planning was to be "based on the requirements of the supported unit," with due consideration for "airspace management conflicts" (JP 3-55.1, 1993, p. II-9).

Over time and with practical experience in Iraq and Afghanistan, the utility of UASs has expanded from consisting primarily of ISR to include armed surveillance and armed overwatch (e.g., for movement support and area security), targeting, communications support, attack, strike, and engagement; in the future, it will further expand to encompass logistical support and casualty evacuation missions. This expanded range of missions presents a challenge that was addressed in 2011 with the publication of a common set of multiservice TTP (MTTP).[4] Each of the four services has agreed to incorporate the MTTP into its respective training. The agreed-to MTTP document requires that

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[3] JP 3-55.1, 1993, p. II-1, states that the

> [p]rimary mission of UAS units is to support their respective Service component commands as a tactical RSTA system providing the commander a capability to gather near-real-time data on opposing force position, composition, and state of readiness. However, as is the case with all assets and groupings within the joint force, the joint force commander (JFC) has full authority to assign missions to and task component UAS to conduct operations in support of the overall joint force.

[4] Reflecting the multiservice, rather than joint, nature of the document, each service has assigned its own number to it: Army Tactics, Techniques and Procedures 3-04.15, Marine Corps Reference Publication 3-42.1A, Navy Tactics, Techniques and Procedures 3-55.14, and Air Force Tactics, Techniques and Procedures 3-2.64. From here onward in this report, we will refer to the document simply as "the MTTP."

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> group 3-5 UAS operations will be coordinated with the ACA (airspace control authority) and included in the ACO (airspace control order), SPINS (special instructions) and the ATO (air tasking order) in order to separate UASs from manned aircraft and to prevent engagement by friendly air defense systems. (MTTP, 2011, p. 12)

Table 3.1 describes the five UAS groups. The TTP for UASs that the services agreed to recognize that UASs may either be controlled by a centralized or joined C2 node (MTTP, 2011, p. 15) or be operated independently and that the service component commander may retain operational control of UASs (MTTP, 2011, p. 16), thereby avoiding the doctrinal issue that divided the Army and Air Force. In general, UAS control during the execution of an operation should be at the lowest tactical level to streamline the decision time lines and thus optimize responsiveness. The MTTP provides vignettes to help supporting and supported units understand how to incorporate and use available UAS assets more effectively. It should also be noted that no distinction is made between organic and nonorganic UAS support (MTTP, 2011, p. 40).

At least for the foreseeable future, each service will continue to field UASs and must bring to the fight forces fully capable of operating these aircraft and integrating their capabilities into joint operations. While some overarching doctrinal issues remain unresolved, the common procedures the services have agreed to and train for will remain the foundation on which UAS operations must be built, just as they are for military operations more generally. In this way, rather than being the foundation for UAS training, joint training is the apex of such training, which must be firmly grounded on the UAS training each service gives both its supported units and the supporting UASs.[5] This is the main focus of this report.

The UAS Training Concept: A General Notion for UAS Training

The contribution that UASs make to the modern battlefield results from a synergy among the platforms themselves, those who operate the platforms, and those who incorporate the UASs into the battle. Combat power cannot expand unless all three work together. A platform flown

Table 3.1
UAS Tiers by Service

Group	Capability	Examples
I	Hand-launched, self-contained, portable systems employed for a small unit or base security.	RQ-11A/B Raven
II	Small to medium in size and usually support brigade and intelligence, surveillance, reconnaissance, and target acquisition requirements.	ScanEagle
III	Operate at medium altitudes with medium to long range and endurance.	RQ-7 Shadow
IV	Relatively large UASs that operate at medium to high altitudes and have extended range and endurance.	MQ-1 Predator
V	Large, high-altitude, long-endurance UAV platforms	RQ-4 Global Hawk

SOURCE: DoD, 2011, pp. D-2 and D-3

[5] The terms *supported unit* and the *supporting UAS* are basic constructs of MTTP, 2011, p. 9.

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by a skilled pilot does not add anything to the battle unless those on the ground who are engaged know how to exploit the information and other support the UAS provides. Similarly, if the pilot and payload operator cannot respond to the ground commander, the support they provide will not be what the commander needs. Only when all three work together will UASs be effective as a force multiplier. This can be achieved through training and practice that brings the platform, the operator, and the users together, starting at home station and progressing through ever-more-complicated exercises at the major training centers, such as the National Training Center (NTC) at Fort Irwin, California; the MCAGCC at Twentynine Palms, California; and the Joint Readiness Training Center at Fort Polk, Louisiana. Accordingly, how to achieve this synergy is the fundamental organizing concept for UAS training.

Let us be clear. The organizing concept developed here is not built around the training of a UAS pilot or payload operator per se. Their proficiency is certainly a necessary condition for UAS operations but is not, by itself, sufficient to enhance combat power. Enhanced combat power is achieved through the synergistic process that brings the platforms, the operators, and the users together. It starts at home station with small UASs and builds through the echelons of the ground forces as larger UASs are integrated into the combat operations of higher-echelon formations. Properly done, the maintenance or refinement of proficiency levels for UAS pilots and payload operators will be achieved incidental to the training that should take place with ground forces. But even before training can start, the services must decide how these systems will be used and how they will be incorporated into the force.

A Concept of Operations for UASs Is a Prerequisite for Training

As noted in the previous chapter, UASs are a classic disruptive technology. Integrating them into existing military operations is still a work in progress. This creates a problem for those charged with building training programs because, before training can start, the services must decide how these systems will be used and how they will be incorporated into the force. The services are still learning how best to use these new systems and the capabilities they provide. Each service is doing it differently.

Army

Initially, the UAS was thought of as just another platform for RSTA sensors, and the intelligence community was the proponent in the Army. In 2003, proponency for UASs transferred from Army Military Intelligence to the Army Aviation Branch. Since then, the UAS role in the Army has been changing from the relatively passive intelligence-gathering mission to the more active scout-reconnaissance and attack missions. One consequence of this transition is that UAS operators frequently team with manned aircrews to perform the scout-reconnaissance role. However, UAS operators and manned aircraft crews are currently separate communities and undergo separate programs of training.

At another level, the Army is experimenting with how to support the Raven, a small, hand-launched UAV. There is no dedicated military occupational specialty (MOS) for Raven operators. Being a Raven operator is an additional duty that requires additional training. Master Raven Training, a three-week train-the-trainer course, takes place both in the classroom and in the field. Students are taught how to maintain and operate the equipment and how to judge when and when not to fly. The plan calls for the trainer to return to home station and train squad-level personnel to operate the Raven.

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Navy

The Navy has a different scheme for integrating the Fire Scout UAS and Broad Area Maritime Surveillance (BAMS) into the fleet. Typically, maintainers and pilots for Fire Scout have already gained technical training on manned helicopters. The Fire Scout–specific training is six weeks long and takes place at the Fire Scout Training Center at Naval Air Station Jacksonville, Florida (U.S. Army Maneuver Center of Excellence, undated).

The Navy's version of the Air Force's Global Hawk is the MQ-4C Triton, developed under the BAMS program. While the Navy continues to fly it to refine TTP for use in a maritime environment, the concept is for it to be integrated into active Navy maritime patrol units to complement the P-8 Poseidon, Boeing's 737–based multimission maritime aircraft, a traditional manned aircraft.

Air Force

The Air Force has yet another concept of operations that emphasizes remote split operations and reaches back to the Global Operations Center at Creech AFB, Nevada. Today, six operations centers in the continental United States (CONUS) support five launch-and-recover units in theater. Integration with tactical units is through tactical air control parties (TACPs) at the division, brigade, and battalion levels, and often at lower levels when supporting special operations forces (SOF). The TACPs coordinate directly with the Predator operations center via ultrahigh frequency radios on the aircraft or via satellite communications. As with other Air Force assets (and many air assets of other services), UAS assets are assigned to support ground commanders through the ATO. In the Air Force, the UAS pilots and payload operators are commissioned officers.

Marine Corps

The Marine Corps has dedicated UAV squadrons located at the MCAGCC at Twentynine Palms, California, and recently at Camp Pendleton, California. In the Marine Corps, enlisted Marines are responsible for almost every facet of the mission, from flying the aircraft and operating the payload camera to takeoffs and landings.

Summary

Even as the services are experimenting with the best way to use UASs and to integrate them into their forces, the overall purpose for UAS training should be clear. It is to increase combat power through the synergistic process that brings the platforms, the operators, *and the users* together. Putting these pieces together is the primary theme of the training framework we present.

Training Framework for Tactical UASs

The focus of the UAS training framework we offer is the enhancement of combat power, which starts with well-trained individuals who learn to work as a unit and ultimately leads to units that coordinate their efforts to produce military force. As we have seen, however, each service uses UASs differently.

Moreover, the great variety of UASs adds to this complexity. UASs are classified into tiers. Military planners designate the various individual aircraft elements in an overall usage plan using a tier system. The tiers do not refer to specific models of aircraft but rather to roles the

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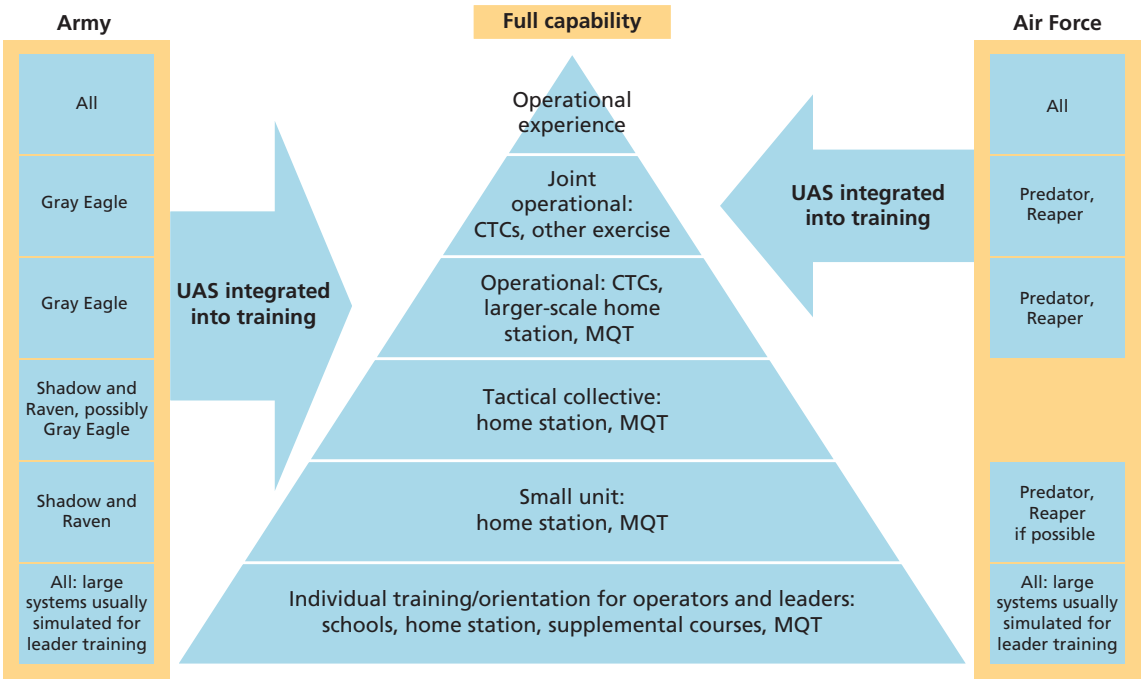
aircraft typically fill. Table 3.1 shows the UAS groups and their roles and offers the examples of systems assigned to them.

The following discussion of training frameworks refers primarily to tactical UASs and not such Tier V systems as Global Hawk and its naval variant, the BAMS-D Triton.

The Training Framework for Ground Combat: Army, Marine Corps, and Air Force

The pyramid shown in Figure 3.1 represents our idea of the training framework to enhance combat power for the Army and Marine Corps, integrating organic UASs and Air Force UASs, when available, in support of ground forces. It is a graphic representation of the synergy achieved through training and practice that brings the platform, the operator, and the users together, starting at home station and progressing to higher echelons and ever-more-complicated battle exercises. The services have committed to align their training with the agreed-to MTTP. As with any good framework, the UAS framework must have a strong base. The base of this framework, represented by the lowest level of the pyramid, includes the initial and individual skills training of those who operate, maintain, and use the systems. The higher levels of the pyramid roughly align with the echelons of ground forces from the platoon or squad level through the company level and moving up to battalions, then to brigades. Each level incorporates the C2 of subordinate units to create combat power that is more than the sum of its parts. A battalion is more than just a collection of companies, each of which is more than just a collection of platoons and squads. In creating this combat power, the battalion utilizes UASs that are not normally available to its subordinate companies. In this way, the battalion and its UASs are "combat multipliers." This increase of combat power is repeated as we move up the pyramid to higher echelons each supported by the UASs that are organic to that

Figure 3.1
UAS Training Framework for Army, Marine Corps/Air Force Joint Combat Operations



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tier. The two different-sized arrows, coming in from the left for the Army and from the right for the Air Force, show the specific UASs and the echelons they support.

In our concept of the training framework for UASs, the ground force systems—those of the Army and Marine Corps—and Air Force systems are "stacked" along the sides and paired with the level of the pyramid they support. The entries at each level of the pyramid identify the type of training that needs to be accomplished and where that training takes place. For example, small-unit training, at the lowest level of the squad and platoon, incorporates the Raven UAV and is accomplished at home station. Company training, which generally entails C2 of four platoons, is also accomplished at home station. The individual platoons may each be using their own Ravens, and the company commander may have access to the information from a Shadow UAS.

This process is repeated at home station with companies being brought together under the C2 of the battalion commander and his staff. During a battalion exercise, the battalion commander will generally be able to task the Shadow UASs either individually or as part of the combat support from assigned Army aviation. In some cases, this may include information provided by the Gray Eagle UAS. In some instances—these have historically been very rare—available Air Force UASs, such as Reaper or Predator, may support home station battalion exercises.

Brigade-level training can be carried out at some home stations, but the maneuver combat training centers (CTCs) generally provide a better venue. All available Army UASs will support these training exercises, from the small Ravens to the larger and higher-flying Gray Eagle, when available. In addition, it is at this level and during these exercises that joint Army–Air Force support is usually integrated to include close air support (CAS) and support from Air Force UASs.

Not shown on the pyramid is the training needed to meet the certification requirements of UAS operators. Such requirements will normally be met incidental to their training with ground forces. For example, Shadow operators need to operate their equipment 4.5 hours per month to maintain their certification. It is expected that they will be spending more than that supporting ground units during home station training. Operators not actively engaged with the training of ground units can achieve the needed proficiency training using the same training equipment as during their initial skill training.

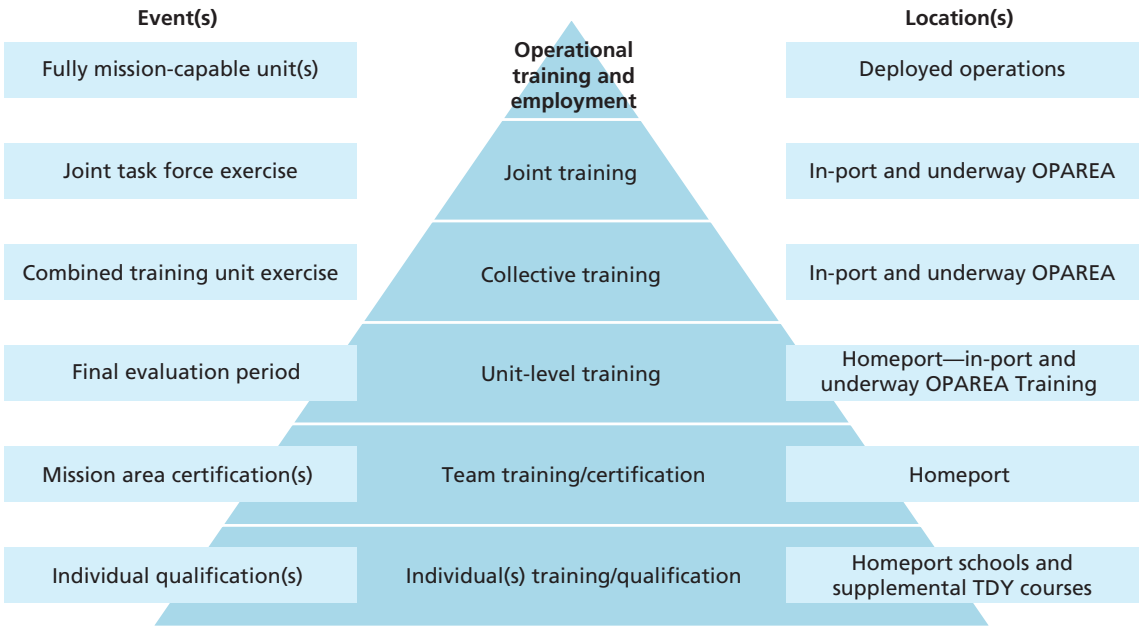
The Training Framework for Fleet Operations

A similar pyramid also represents our framework for Navy UAS training (Figure 3.2). It differs from the previous pyramid in that the Navy does not have a hierarchy of systems introduced at higher echelons of command. At the tactical level, the only UAS the Navy has is Fire Scout, which will be introduced into fleet operations following a similar path as discussed above. As with land forces and the systems that support them, combat proficiency is generated through the synergy of the platform, operators, and staffs that incorporate the UASs into the battle planning. Initial operator training is the base of the pyramid and takes place in the schoolhouse in the vicinity of the homeport. Operational training occurs under way in fleet operating areas. The Navy trains continuously, and the training continues through the operational use of UASs when the units are deployed.

UAS operators and maintainers require initial training to obtain the skills needed for operational effectiveness. As individuals become qualified as UAS operators and maintainers, they undergo team training to achieve mission area certification. For example, UAS operators

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Figure 3.2
UAS Training Framework for Navy Tactical UAS



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may be linked to and integrated with an antisurface warfare mission team to support certification for the surface warfare mission area. For ships, unit-level training occurs both in port and under way and culminates in a final evaluation period. During that evaluation, the immediate superior in command evaluates the ship in all mission areas to determine that it is ready for advanced phase training. The final evaluation period comprises in-port and underway training events geared to assess the unit's ability to operate independently.

Collective training occurs after the final evaluation period, when the ship begins to operate with other units and staffs. During this time, the ship conducts operations with and becomes an integral part of a carrier strike group (CSG).[6] Collective training is a combination of in-port and underway training events and culminates in a combined training unit exercise evaluated at the fleet commander level. The Navy is in the process of developing its UAS tactics and procedures and plans to integrate UAS training into predeployment preparations.

Deployed naval ships and units must also operate in a joint environment. After completing a combined training unit exercise, a deploying CSG conducts a final exercise with elements of other services (e.g., Air Force aircraft) to demonstrate its ability to communicate and operate effectively in joint warfare. Joint training is conducted both in port and under way. An underway joint task force exercise is the culminating event, with Navy units operating with forces of the other services; on satisfactory completion, units are deemed ready to deploy. Units then continue the operational training and employment of their systems en route to their deployed operational areas.

[6] While we address surface units as being part of a CSG, surface units can also deploy independently, with other ships, or with an expeditionary strike group.

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Navy units deployed to 5th Fleet do have experience with BAMS–Demonstrator (BAMS-D), the predecessor to the Triton, and a variant of the Air Force's Global Hawk. Despite being a demonstrator, BAMS-D was deployed to meet surveillance needs in the 5th Fleet. Navy strike groups operating in 5th Fleet were provided with imagery and data feeds from BAMS-D and used these data to build a common operational picture, which increased situational awareness. The BAMS-D was integrated into actual fleet operations and provided near-real-time updates for surface surveillance. Units learned to use BAMS-D "on the fly," by processing, exploiting, and disseminating imagery and sensor data; building the surface picture; and increasing the positive identification of surface contacts in the area of operations.

As UAS assets are fielded, they will be incorporated to a greater degree into predeployment training and increase opportunities to train and hone the tasking, collection, processing, exploitation, and dissemination of UAS sensor data.

Applying the Training Framework

The training framework presented here focuses on the synergy among three key elements: the platform itself, those who operate the platform, and those who incorporate UASs into the battle. The framework emphasizes using UASs to enhance warfighting proficiency. It provides a useful tool for organizing and evaluating training options and assessing the current state of training and plans for improvement. As discussed in the next chapter, we used the framework to assess the state of UAS training, as it existed in 2012.

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CHAPTER FOUR

Assessment of the State of UAS Training in 2012: Service and Interoperability Training and the Role for Simulators

For more than a decade, UAS training has concentrated on preparing UAS pilots and payload operators to support ongoing operations in Afghanistan and Iraq. This remained true in 2012 and 2013, and the services continue to evolve how best to use these systems and integrate them into ongoing operations. With the operations in Afghanistan winding down, the services must now integrate all facets of UAS training, including the infrastructure for training addressed in Appendix C, into a largely CONUS-based inventory of UASs that continues to grow, even as real-time operations continue for some systems.[1] Moreover, operational demands and technical innovations will continue to evolve and affect training and organizational requirements. As a result, UAS training and training support programs must be viewed as works in progress.

In assessing the current state of UAS training, using the UAS training framework discussed in the previous chapter, we view proficiency in flying UASs not as an end in itself but as only a means to an operational end: accomplishment of a military mission. As noted, this is achieved through the synergistic use of UASs with the forces they support, in ways similar to those in which the timely integration of intelligence or the delivery of fire support is accomplished in combat operations. This convergence requires full integration of UASs into the collective training of operational forces, attendant training and education for leaders and staffs, and the integration of lessons learned from previous and ongoing operations into education and training programs.

The preceding should by no means be construed to understate the need for training those directly involved in the operation of UAS—among them pilots, crews, support personnel, and those who maintain the aircraft and communications systems. Such training, both to develop and to maintain proficiency in the operation of UAS, is critical for the overall success of a UAS training strategy. But proficiency in these areas is not in itself sufficient. Full understanding of UAS integration, from the smallest to the largest systems at every echelon, as outlined in the previous chapter, is also necessary.

To be clear, members of the UAS community not only must understand how to operate their systems—a challenge largely being met successfully—but must also be familiar with the fundamentals of the operations they support and how their capabilities contribute to the successful accomplishment of the mission. Similarly, battle staffs must fully understand the many capabilities of UASs, how these capabilities supplement or complement other capabilities available to the joint force, and how best to integrate the capabilities into their operations.

[1] The Air Force UAS community believes high demand for its systems—Predator and Reaper—will persist, with requirements to support other kinds of demands increasing as demands for support of ground maneuver operations decrease.

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This chapter assesses the state of training for UASs across the ground, air, and sea forces. It discusses information, observations, and insights gained from a wide variety of sources but mainly through visits to a select number of service bases in 2012. During these visits, the RAND team talked with operators and support personnel; those who train operators and associated members of the team; those who train and observe the forces who employ UASs; staff elements concerned with the planning and resourcing of training, both for UAS operators and for the force more generally; and those concerned with the ongoing development of doctrine and concepts of operations for UASs, including their integration into operations. What follows is a compilation of the observations and insights from these individuals and our interpretation of the implications for the specification and resourcing of training strategies.

Ground Forces

Ground force operations of the Army and Marine Corps, even at low echelons, can be highly complex, and the complexity increases significantly at higher echelons. Commanders at higher echelons not only have to coordinate and use the information and capabilities subordinate units provide but also have to manage and integrate information and capabilities from a widening variety of other sources available to them. Adding the integration of UAS capabilities into the operational command further increases its complexity and thus the complexity of associated training management processes. Evidence from both training exercises and actual operations in combat theaters shows that, when properly managed, UASs provide significant new capabilities that commanders at every echelon can effectively employ. UASs truly have the potential to be force multipliers—but more so when employed by users fully competent in integrating their capabilities with those of the rest of the force and its supporting elements.

As shown in the training framework presented in Chapter Three, the proper integration of UASs to create combat capability starts with the training of UAS operators and support personnel and progresses through the integration of UAS operations with supported forces.

Training for Operators and Support Personnel

In general, the RAND team found that qualification training in the Army and Marine Corps for designated UAS-specific MOS is well established. In the Army, positions are filled by enlisted soldiers. The ranks of operators typically range from private first class to master sergeant (E-3 to E-8). The Marine Corps is organized much like the Air Force, with a UA commander who is a company grade, qualified aviator or aviation C2 officer on his or her second or third tour (O-3/O-4) and a mission payload operator (MPO) who is typically a corporal through master sergeant (E-3 to E-8).

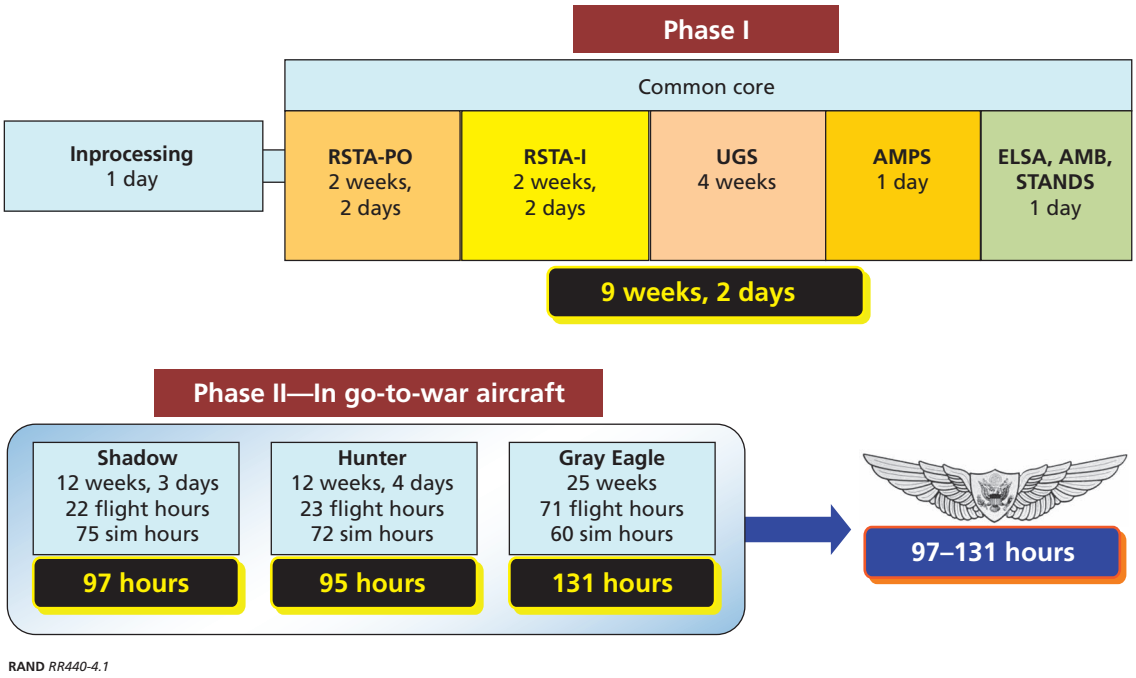
Army Air Vehicle and Sensor Operators for Hunter, Gray Eagle, and Shadow UASs

Training for Army UAS operators—pilots and payload operators—is carried out in two phases: The first, at Fort Huachuca, consists of a common core course for all operators of UASs not launched by hand.[2] This phase lasts nine weeks and two days and has five sections. (See Figures 4.1 and 4.2.)

[2] The 2nd Battalion, 13th Aviation Regiment, which was previously called the Unmanned Aircraft Systems Training Battalion, conducts the training. See Appendix D for RAND's "military value analysis of training bases" assessment of training at Fort Huachuca, Arizona.

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Figure 4.1
Army UAS Air Vehicle Operator and APO Training Pipeline



After completing Phase I, the operators continue to Phase II. This section is unique for each airframe and consists of both simulation and flight hours. It typically takes 12.5 weeks for Shadow and Hunter classes to finish and 25 weeks for Gray Eagle classes. After completing Phase II, the UAS operators earn their wings.

Maintenance for Hunter, Gray Eagle, and Shadow UASs

The Army UAS maintainers take the MOS 15E Repairer course from the 2nd Battalion, 13th Aviation Regiment (see Figure 4.3). As shown in Figure 4.4, the course lasts 17 weeks, and a new class of up to 16 students starts every two weeks. After completion, 15E personnel are qualified to maintain the Shadow. Maintainers must take additional training to earn additional skill identifiers and thus qualify to maintain the Hunter and Gray Eagle. The additional training takes ten weeks for Hunter and 18 weeks for Gray Eagle.

Army Raven Operators

Without a dedicated MOS, the development and maintenance of Raven operators is a unit personnel and training management issue. Assignment as a Raven operator is an additional duty. In the past, this has meant that many units did not have the required Raven-qualified personnel to employ the systems properly. The Army is well aware of this problem and, short of creating a dedicated MOS, has recently initiated a program to deal with the Raven training problem. The Army Maneuver Center of Excellence at Fort Benning manages a certification course designed to qualify selected soldiers as small UAS (SUAS) master trainers capable of conducting initial qualification training (IQT) and certification of new operators at home stations throughout the Army. This train-the-trainer course focuses on how to teach and manage an aircrew training program at home base and how to assist small-unit commanders in evaluat-

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Figure 4.2
Shadow (top) and Gray Eagle UAVs



SOURCE: DoD.



SOURCE: U.S. Army via social media outreach.
RAND *RR440-4.2*

ing academic and flight instruction and managing SUAS accident prevention.[3] It is envisioned that new master trainers returning to their home stations will be able to develop and maintain

[3] The 15-day course includes classroom and hands-on training, with instruction on reporting procedures, fundamentals of instruction, semiannual evaluations, and familiarization with Raven A and B and digital downlink systems. At the conclusion of the training program, graduates should have the ability to evaluate and certify operators. See U.S. Army Maneuver Center of Excellence, undated.

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Figure 4.3
Raven UAS



SOURCE: U.S. Army via social media outreach.
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a sufficient number of operators within their units and manage a tracking program to ensure that their units have the required number of certified Raven operators.

Marine Corps Unmanned Aircraft Commanders—Pilots

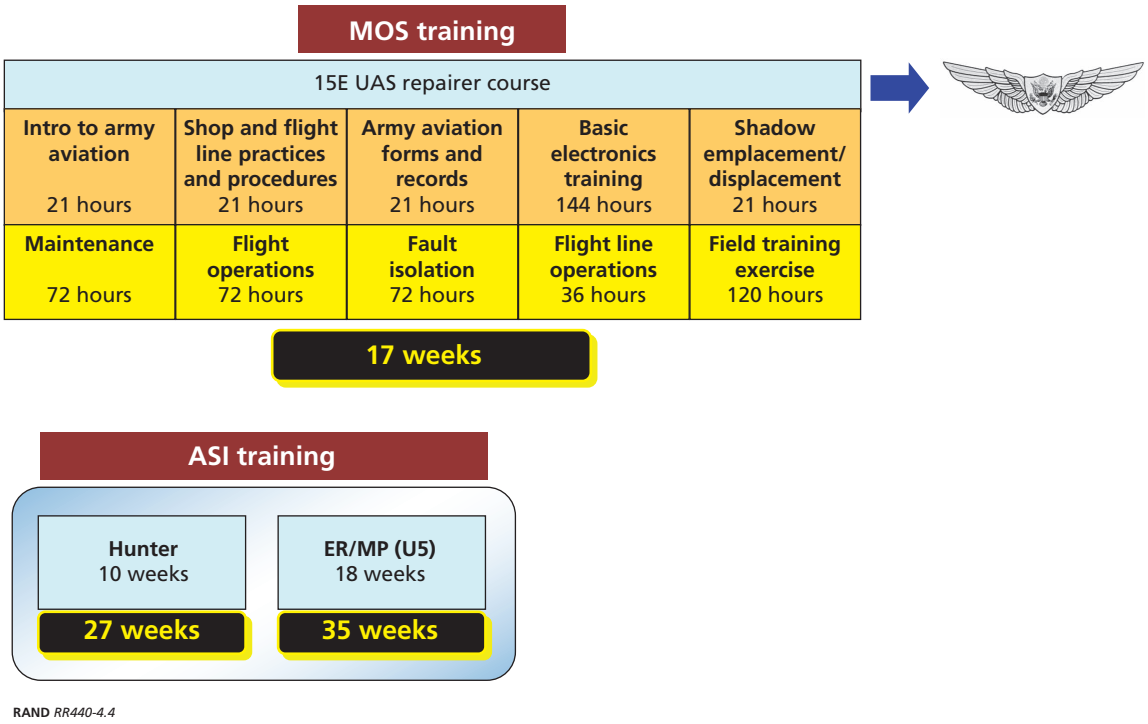
Training begins with the Unmanned Aircraft Commander course, which last two weeks and is taught by the U.S. Army at Fort Huachuca. Career-level training takes place at the squadron level. Marine Aviation Weapons and Tactics Squadron 1, at Marine Corps Air Station Yuma, Arizona, provides advanced training (the Weapons and Tactics Instructor course).

Air Vehicle Operators and Mission Payload Operators

Training for air vehicle operators (AVOs) and MPOs is accomplished jointly with the U.S. Army at Fort Huachuca. USMC operators take the nine-week common course and the 12-week Shadow course. Career-level training takes place at the squadron level. Marine Aviation Weapons and Tactics Squadron 1 provides advanced training.

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Figure 4.4
Army UAS Maintainer Pipeline



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Operational Training[4]

Larger UASs have dedicated MOS training, so operators and maintenance personnel arrive at home station having completed their IQT. To maintain their proficiency and certification, crews must log a minimum number of flying hours. The Army's Gray Eagle UAS has its own simulator capability built into the operating hardware. Currently, the Army's requirement is for 4.5 live flying hours per crew per month for the Shadow UAS. The Army has had difficulty maintaining sufficient numbers of Raven-qualified SUAS operators, in part because units do not always do well in tracking their qualified operators, maintaining their proficiency through hands-on work, and providing for their timely replacement when they move on. Discussions with Army trainers indicate that, despite the demands of deploying units and sustaining combat operations in Afghanistan, Army units are doing better at maintaining Shadow qualification. Nevertheless, not all units have been able to maintain high Shadow qualification rates: Some units arrive at the NTC with one-half or fewer of their operators qualified.

For these systems, the critical issue for the future will be securing enough flying time for UAS crews to train with ground forces. Marine Corps experience offers a good illustration of this issue. The Marine Corps has based Shadow squadrons at the MCAGCC, where there is adequate restricted airspace both to maintain crew proficiency and to fly in support of ground forces. However, both the ground trainers and squadron personnel the RAND team interviewed reported having to start what was essentially remedial training because the ground

[4] Joint Publication 1-02 defines *operational training* as "training that develops, maintains, or improves the operational readiness of individuals or units" (JP 1-02, 2013).

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forces were not adequately trained at home station to integrate UAS capabilities into their operations. These students generally could not progress to the level of proficiency desired.

The foregoing suggests the biggest challenge in developing and implementing a training strategy for UASs is gaining and maintaining proficiency on the part of end users—the leaders and staff members who will integrate UAS capabilities into their operations.[5] Ground units that undertake joint training at CTCs are often unprepared to use organic and nonorganic UASs effectively, and thus tend to develop battle plans that underutilize them.[6] Further, their intelligence and operations staffs sometimes find themselves at cross purposes over employment of UASs, an issue that could be better dealt with during home-station training.

Despite all this, discussions with operators, users, trainers, and training managers suggest that properly employed UASs consistently prove to be valuable combat multipliers. One example was an Army unit training at the NTC, which had successfully employed its UASs as part of a manned-unmanned team. In this instance, the UAS had acted as a scout and observer as manned attack helicopters delivered fires on selected targets, all in support of a ground maneuver unit. Another battalion well versed in the myriad tasks associated with employing Shadows—communication of commander's intent and concept, priority and time sensitivity of information requirements, targeting priorities, use of the communications relay package, to list just a few—was far more successful in employing the Shadows supporting it than another unit was. In the latter unit, the UAS platoon was simply given "areas to look at," without specific guidance on what to look for, e.g., named areas of interest and targeted areas of interest. Interviewees told the RAND team that many UAS operators do not get enough opportunity to interact with either crews of manned aircraft or the elements of ground units—commanders and operations and intelligence sections—that they will support.

The latter problem, ground units' lack of experience in employing UASs, is all too common. It is also true for the USMC, whose units face considerable limitations on using UASs at their home stations or local training events.[7] Marine ground force units are thus typically not well versed in employment of UASs when they arrive at Twentynine Palms. Although they learn while there, many are still not fully capable when they deploy.[8]

Improvements in Facilities and Basing for UASs Will Improve Training Integration

To date, the Army has had reasonable opportunity to train at home station, and current programs to increase UAS facilities will appreciably add to this. Table 4.1 summarizes responses the U.S. Army Training and Doctrine Command (TRADOC) received from active, National Guard, and reserve bases in November 2012 concerning the availability of restricted airspace and resulting limitations on UAS operations stemming from lack of availability. The responses

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[5] We refer to anyone who could benefit from the information a UAS provides as an *end user*. The MTTP calls end users *supported units*.

[6] *Organic* assets are ones owned by a unit, and *nonorganic* assets are ones that the commander of a unit does not own and thus does not have full control over.

[7] Recall that the Marines' Shadow squadrons are based at Twentynine Palms when not deployed.

[8] This brings up the question of whether we should expect units to continue learning sound tactics and procedures while they are deployed. They should, of course. The issue is how much; officials we have consulted have given us the sense that many units are still on the steep part of the learning curve when they leave the MCGACC. These units would be more operationally effective sooner in their deployments if they could be better trained to integrate UAS capabilities before they deploy.

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indicate that, in many cases, relatively minor military construction projects are all that is necessary to expand training opportunities at home stations. In most locations, additional beddown facilities will allow better use of existing restricted airspace to facilitate live training. In a few cases, however, the proximity of training areas to the Federal Aviation Administration (FAA)–controlled National Airspace System (NAS) remains a problem. The summary in Table 4.1 provides a snapshot of the kinds of issues that have already been raised and will have to be revisited at some point because of the ongoing pressure to reduce defense budgets.

Table 4.1
Select Summary of Army UAS Installation Survey as of November 21, 2012

Base/Commands	Answer To Question E: Does Available Restricted Airspace Affect/Limit UAS Operations at Your Installation?	Answer To Question J: What Solutions Would You Recommend for Unsolved Issues?	Shadow Strips Planned for FY 2013
Alaska (Forts Wainwright and Richardson)	No.	We have been able to accommodate all down range requests. However, the hangars are nonstandard and need to be evaluated for suitability as the Shadow and Gray Eagle platforms evolve.	
Fort A. P. Hill	During landings the tactical approach landing system orbit is outside the restricted airspace.		Yes
Fort Bliss	Our special use airspace is bisected by a major highway which requires a COA.	Yes, a Shadow Strip in the SUA.	Yes
Fort Bragg	Yes.	Yes. Primarily commercial power and hardened maintenance facilities. Temporary solutions are power generation equipment and tentage.	Yes
Fort Carson	Yes, limited by the volume of manned/unmanned platforms operating within the airspace.	Yes, requests for designated UAS facilities and airstrip for launches and recovery. Funding established to build a multiple platoon facility for UAS units.	Yes
Fort Drum	No.	No. We have no unresolved UAS issues.	Yes
Fort Hood	Not currently.		
Fort Knox	No.	Yes; the construction of a tactical UAS field support structure (build it).	
Hawaii	Yes, we have requested to use the Kahuku and East Ranges for flights but due to FAA restrictions, we cannot fly UAS/SUAS platforms in these airspaces.	No. We need more airspace to train in. Our current location is becoming less and less amicable to flight conditions due to public demands on land. In 2010, plans were drawn up to provide for a permanent UAS facility at Wheeler Airfield, but they were cancelled due to program funding.	

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Table 4.1—Continued

Base/Commands	Answer To Question E: Does Available Restricted Airspace Affect/Limit UAS Operations at Your Installation?	Answer To Question J: What Solutions Would You Recommend for Unsolved Issues?	Shadow Strips Planned for FY 2013
Fort Lewis (Joint Base Lewis-McChord [JBLM])	1. Yakima Training Center (YTC): No not an issue. 2. JBLM: Yes, both the limited restricted airspace and the large number of installation units requiring restricted airspace, challenge UAS/SUAS operations.	1. YTC: Shadow Training Facility 2. JBLM: Construction of a second Shadow landing strip. 3. JBLM: Construction of any type of permanent, securable facility alongside the existing Shadow landing strip (location is outside JBLM's guarded area). 4. JBLM: Shadow Training Facility or TEMF.	
Fort Riley	Not currently. (See response to Q h & i.)	Nothing to comment on.	Yes
Fort Stewart	Not significantly. However, reductions in air traffic control manning are a concern. There are currently no significant restricted airspace challenges negatively affecting UAS operations.	Funding, we have a plan and the requisite site approvals, we just need funding support. We need the funding ($701,000) now for our third Shadow platoon hangar; we have the design ready to go and at contracting.	
USAREUR	Yes. 173rd Shadow out of Italy is currently based in Bamberg due to no restricted airspace to fly in Italy. Currently fly in restricted airspace in Grafenwoehr/Vilseck Training Areas.		
Camp Atterbury	No, both UAS facilities are within restricted airspace.		
Fort Chaffee	No restricted airspace limitations to TUAS flight operations.		Yes
Orchard Range	Yes, UAS operations are limited to using R-3203.	Fixed support facilities UAS operations. Facilities will be in Range Complex Management Plan.	
Fort Pickett	No, we have one of the largest SUAs in the Midatlantic.		
Camp Ripley	No, the restricted airspace at Camp Ripley (R-4301) provides enough area to conduct training for the current systems.	Yes. The current tactical strip will be removed for the construction of a MPTR. UAS commanders have requested a tactical strip for replacement that includes hard-stand buildings and electrical power. The Combat Readiness Training Center currently has a location selected that has power in close proximity to the existing tactical strip. Camp Ripley is one of the sites to receive $730,000 for construction of a UAS strip in the down-range area in FY 2013.	Yes
Camp Roberts	No.	Funding.	Yes

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Table 4.1—Continued

Base/Commands	Answer To Question E: Does Available Restricted Airspace Affect/Limit UAS Operations at Your Installation?	Answer To Question J: What Solutions Would You Recommend for Unsolved Issues?	Shadow Strips Planned for FY 2013
Fort Dix	Yes.	We have accommodated all downrange requests. However, the size restriction of the UAS in R-5001 limits operation of large UAS operations.	
Fort Hunter-Liggett	No, we use R-2513 airspace.	None.	
Fort McCoy	Yes, Current coutilization of Young Air Assault Ship, a 6,250-ft. C-17/C-130 landing strip in R-6901 B. The UAS operations at this landing strip affect Sparta/ Fort McCoy airport operations.	Yes. Hangers for Shadows and permanent facilities with commercial power, and asphalt. Standard design and funding required.	
Fort Campbell	Fort Campbell currently has two approved sites for Shadow Flight operation; both are located among numerous field artillery firing points, which requires de-confliction during launches and landings because the firing points have to check fire. As a result, UAS flight training is significantly reduced. However, an additional UAS strip is being constructed to alleviate this problem.	Yes. Permanent facilities with commercial power and utilities.	

SOURCE: Installation UAS survey responses from TRADOC Capability Manager—Live, as of November 21, 2012.

Key Areas of Concern

As the war in Afghanistan draws to a close, the services must pay close attention not only to the training of UAS crews and support personnel but also to the routine exercise of these systems as part of combined arms training at home station and at the CTCs. This will require attention to a number of issues.

Beddown and Related Support Facilities

To facilitate the efforts described above, DoD should support current and future programs to develop ranges and beddown and support facilities similar to those in the Army's current programs. The Army has been implementing a robust program to establish Shadow beddown facilities—runways, shelters, and attendant support structures—on many of its installations, both active and National Guard. This will enable more opportunities both for UAS operators and for end users.

Airspace Considerations

As the responses reported in Table 4.1 suggest, the unique limitations of UASs pertaining to operations in the NAS can make integration into home station training difficult. Currently, UASs can operate only in restricted military airspace or, in the NAS, with certificates of authorization (COAs) from the FAA. In some cases, it should be possible to increase UAS training with ground forces (and with collocated manned aircraft units) without impinging in any significant way on the NAS. Although this will certainly require better coordination of restricted airspace at individual installations, better availability of restricted airspace will make better

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access to the NAS less of a key element in supporting training strategies, at least as they pertain to home-station or local training of ground forces. However, less-cumbersome procedures for NAS access will, among other things, facilitate opportunities for units to employ larger UASs, such as Gray Eagle, Predator, and Reaper, in home-station training events.[9]

Air Force

The Army and the Air Force have significantly different concepts for employment of UASs. The Air Force uses a remote split operations concept to employ its UASs. Under this approach, the Air Force flies UASs from home station using satellite or other relay links. It maintains only small deployed footprints at consolidated operating locations to launch, recover, and maintain the aircraft.[10] This approach enables the deployment of the vast majority of its systems, yet the majority of the personnel who operate Air Force UASs do so from home station and require no reconstitution following deployments. By using remote split operations, 85 percent of the Air Force's UASs would be forward deployed for combat operations. The remaining 15 percent would support training at each operational base. The Air Force employment concept, however, does not facilitate integrated operations with Army tactical-level units during training at Army home stations. Once deployed, Army brigades, battalions, and SOF must learn to work with Air Force TACPs to coordinate UAS operations.

Training for Pilots, Operators, and Support Personnel

The Air Force uses a crew of one pilot and one sensor operator to man each UAS mission.[11] The pilots are officers and are either rated pilots who graduated from undergraduate pilot training or UAS-only pilots who graduated from a new program called undergraduate remotely piloted aircraft training.[12] UAS-only pilots have the 18X Air Force Specialty Code (AFSC) and will be discussed in more detail later. Following the structure of the training pipelines for other platforms, the training is broken into three phases: IQT, mission qualification training (MQT), and crew mission ready training. Air Education and Training Command conducts IQT and MQT, with the latter taking place in a formal training unit (FTU).

[9] In some cases, basing for the larger systems, especially Gray Eagle, will be contiguous with the training areas in which they are needed; Fort Hood, Texas, is an example. But this will not always be possible. The larger systems require longer and better runways and larger and more-sophisticated beddown and support facilities. It may be more cost-effective to move these UASs to support training where they are needed, rather than establishing beddown facilities in a large number of additional locations.

[10] The 432nd Wing at Creech AFB operates MQ-1 Predators and MQ-9 Reapers from seven forward bases overseas. Maintainers at forward bases serve four-month rotations in theater.

[11] Many more people are involved in RPA operations, including the mission intelligence commander. Also, there is a weapon school course for advanced training of RPA operations. For this research, we were primarily interested in the initial training of pilots and sensor operators.

[12] Some Air Force navigators who had commercial instrument qualifications have been allowed to train as pilots for the RQ-4. This avenue for sourcing RQ-4 pilots closed in spring 2011.

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Pilots

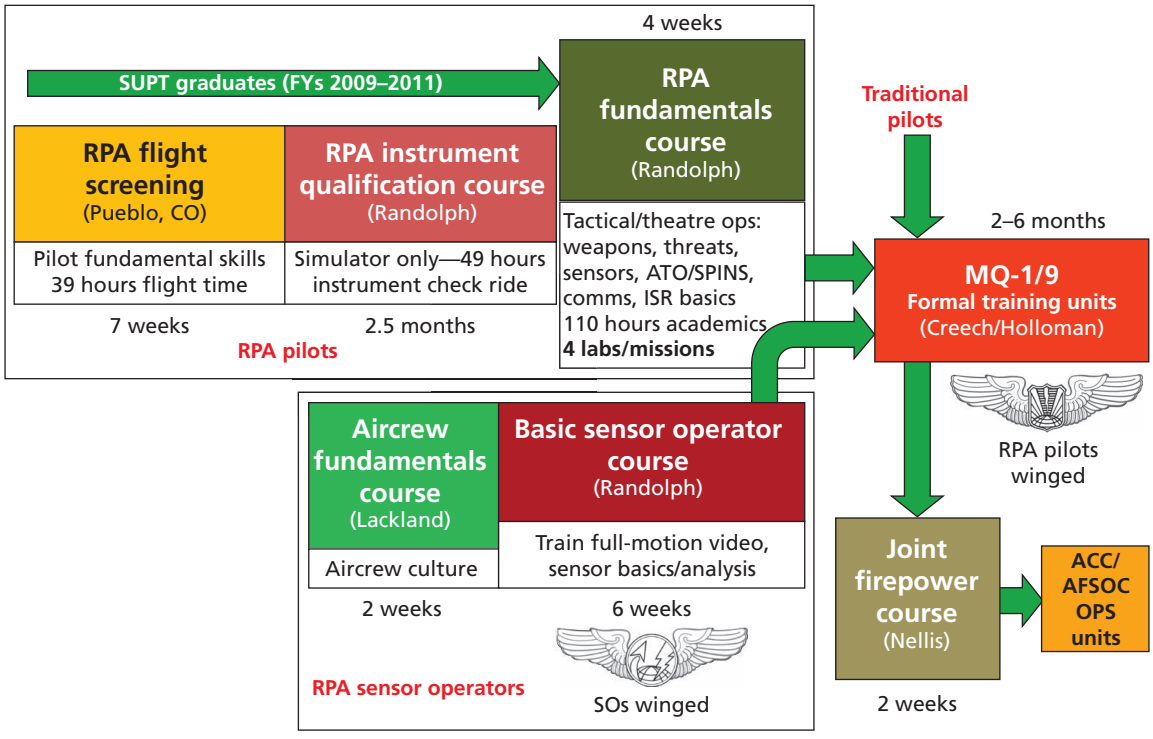
Reaper and Predator

In response to the need to reach and sustain the manpower to fulfill Reaper and Predator requirements, the Air Force initiated a new program to produce RPA pilots.[13] Currently, Reaper training takes place at Hancock Field Air National Guard Base in Syracuse, and Predator training takes place at Holloman AFB. New RPA pilots have attained the foundational skills to conduct RPA missions and are qualified to operate in the NAS or International Civilian Aviation Organization airspace. Figure 4.5 outlines the training pipeline. Figure 4.6 shows the UASs.

Global Hawk

Currently, most Global Hawk pilots are traditional Air Force pilots who volunteered for a tour in the Global Hawk (see Figure 4.7), a majority of whom are qualified to fly multiengine transport aircraft. Prior to 2011, navigators who also had commercial pilot licenses and had completed commercial instrument qualifications were allowed to become Global Hawk pilots; however, the Air Force has not decided whether to retain navigators who are currently Global Hawk pilots in the community or return them to navigator duties. The third source of Global Hawk pilots is the 18X career field, UAS-only pilots who have graduated from undergraduate remotely piloted aircraft training. After finishing the three preparatory courses, candidate Global Hawk pilots head to the RQ-4 FTU, the 1st Reconnaissance Squadron at Beale AFB.

Figure 4.5
Air Force UAS Pilot and Sensor Operator Pipeline



RAND *RR440-4.5*

[13] The Air Force uses the term *RPA* to refer to unmanned aircraft systems. The accepted joint terminology is *UAS*.

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Figure 4.6
Reaper (top) and Predator UASs



SOURCE: U.S. Air Force.



SOURCE: DoD.
RAND *RR440-4.6*

Once at the FTU, pilots are trained first on simulators designed for pilots with an instructor pilot. Then, they participate in on-the-job training, flying live missions with an instructor pilot in the mission control element.

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Figure 4.7
Global Hawk UAS



SOURCE: DoD.
RAND *RR440-4.7*

Sensor Operators

Reaper and Predator

Enlisted sensor operators for Reaper and Predator are either trained into a new career field or cross-trained from another AFSC (1U00X). After graduating from the Air Force's basic training or being reclassified, they attend a two-week course at Lackland AFB, Texas, with other aircrew AFSCs. Then they go to Randolph AFB, Texas, for a six-week basic sensor operator course. After completion, they go to the appropriate FTU for the system they will be flying.

Global Hawk

Sensor operators for the Global Hawk are trained differently from those for other UASs. Sensor operators for the Global Hawk come from the intelligence imagery analyst career field (1N1XXs). They receive MQT at Beale AFB, where they learn to use the Global Hawk system. After one tour as sensor operators (approximately three years), they move on to other imagery analyst assignments; therefore, it is difficult to maintain expert sensor operators for the Global Hawk.

Maintenance

Training for those who maintain Air Force UASs takes place at three locations.[14] The fundamentals are taught at the maintenance schoolhouse at Sheppard AFB, Texas. Initial skills training and advanced skills training take place at the unit.

[14] Contractors provide certain UAS maintenance, for example, depot-level maintenance.

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Operational Training

Given the emphasis on current operations and the Air Force's remote split operations concept for employing UASs, few opportunities exist to support ground troops either during home-station or CTC training. In general, with a few limited exceptions, Air Force UAS crews do not train in exercises or other training events in CONUS and do not support training in CONUS of Army or Marine Corps units at either their home stations or at the CTCs. Air Force UAS crews do conduct operational missions in theater, and these missions frequently are the chief or even the only way deployed Army and Marine Corps units get an opportunity to work directly with Air Force UAS crews. Thus, most elements of the UAS force in theater often have no experience working together before they have to do so in combat operations.

The result of not working with ground troops either at home station or the CTC is that ground units generally do not integrate Air Force UAS capabilities into their planning. RAND's conversations with the training community, including trainers at the NTC, as well as what officials told the GAO, confirmed that the

> effective integration of UAS in training exercises, like the integration of other types of joint air assets, depends on the priority that ground units place on developing training objectives that require the participation of joint air assets and their ability to plan for the use of these assets in the exercise. … [As a result], Army combat brigades often focus UAS training objectives during exercises on integrating their Shadow UAS and do not emphasize planning for and employing Air Force UAS.[15]

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[15] Independent RAND team visits also confirmed what the Air Force told the GAO, that

> unmanned aircraft are deployed to support overseas operations except for those that are supporting the initial training of UAS personnel or the testing of aircraft." These officials [from the 432 Wing] stated that in the event that additional aircraft were made available, the wing's personnel levels are insufficient to support additional training events because the unit does not have adequate personnel to support projected operational commitments and greater numbers of training exercises. Second, Army and Air Force officials told us that when Air Force UASs are at the training center, these aircraft are not always available to support ground unit training because a considerable portion of the UAS flight time is dedicated to accomplishing Air Force crewmember training tasks. Officials told us that the Army and Air Force have reached an informal agreement to allot about half of the time that an Air Force UAS is flying at the training center to support Army ground unit training objectives and the other half to accomplish Air Force training tasks. Air Force officials pointed out that although they try to align their crewmember training syllabi with ground unit training objectives at the National Training Center, training new personnel to operate these aircraft is their priority. Third, UASs may not be available during certain hours to support ground unit training, which during exercises goes on 24 hours a day. For example, Predator UASs from the California Air National Guard are available to support ground units only during daylight hours. To travel to the training center, these aircraft must pass through segments of national airspace that are not restricted for DOD's use and therefore must rely on a ground-based observer or on chase aircraft to follow them to and from the training center. Because of this reliance on ground or airborne observers, flights to and from the training center must be accomplished during daylight hours and are necessarily more expensive as well.
>
> As a result of the limited number of unmanned Air Force assets that are available to support ground unit training at the National Training Center and the Joint Readiness Training Center, Army ground units conducting training exercises have frequently relied on manned aircraft to replicate the capabilities of the Air Force's Predator and Reaper UAS. Officials told us that the use of manned aircraft in this role permits ground units to practice the process to request and integrate the capabilities provided by Air Force UASs in joint operations. However, this practice is not optimal, as the manned aircraft do not replicate all of the capabilities of the Predator and Reaper aircraft, such as longer dwell times.

GAO, 2010a, p. 26.

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Key Areas of Concern

We note above that, as the war in Afghanistan draws to a close, the services must pay close attention not only to the training of UAS crews and support personnel but also to routinely including these systems in combined arms training at home station and at the CTCs. This will require attention to a number of issues.

Beddown and Related Support Facilities

Discussions with officers of the 432d Wing suggest an Air Force future much like the past: flying in support of COCOM requirements worldwide. If this comes about, there will continue to be limited opportunities for the Air Force to support Army or Marine Corps training at the home station or CTCs. Alternatively, if providing such training becomes a priority, the Air Force's current basing and beddown posture will become a problem.

Airspace Considerations

The unique limitations of UASs pertaining to operations in the NAS make integration into home-station training difficult. Currently, UASs can operate only in restricted military airspace or, in the NAS, with COAs from the FAA. These COAs can often be prohibitive to participating in joint training. For example, the MQ-1 FTU from March ARB tried to participate in training with the Marines at Twentynine Palms. Unfortunately, the COA requires a manned chase plane and, given the geography, the contracted chase plane cannot fly the shortest route. The only option is to fly through the restricted airspace between Fort Irwin and Twentynine Palms, which is prohibitively long because the COA permits operations only during daylight hours. These limitations restrict where UASs can be used because an installation must have access to a significant amount of restricted airspace. Other limitations include the basing expense of sprinkling UASs across the country to embed with Army or Marine units at home station.

Several different possibilities could be considered to help increase joint training opportunities. The Air Force could consider the location of Army hubs when choosing where to base its UAS fleet. A location that is near Army maneuver elements might make airspace access less of a restriction or at least make COAs more practical. Proximity might provide more opportunities for training UAS integration throughout the entire mission planning process.

Alternatively, the Air Force could permanently leave a small number of UASs at a training location and remotely operate these from Holloman AFB, Creech AFB, or other locations. These systems are designed to employ remote split operations, in which the crew operating the platform need not be colocated with the platform. The various Air Force units could get flying time by cycling through these dedicated aircraft. This option would provide Air Force crews—including launch and recovery crews—practice integrating with ground forces and would simultaneously support the ground forces' need for integrated training. This plan would also reduce the issue of airspace access because the aircraft would be located within the restricted airspace in which they would be used or at an auxiliary airfield close enough that a COA would be practical.

A promising development that enhances UAS training is the advancement of ground-based sense-and-avoid (GBSAA) and airborne sense-and-avoid (ABSAA) technologies. These may open up regions of civil airspace for properly equipped UASs to operate safely in accordance with the FAA's mandate to "do no harm" without requiring FAA issuance of COAs. In particular, GBSAA has recently completed a series of successful demonstrations, and the

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Army is planning to GBSAA equip a number of its UAS training bases to extend their current military airspace with adjoining civil airspace to increase UAS training capacity by 2015. The Army is the lead for the development of GBSAA, but GBSAA has been designed for the use of all the services. Each service, like the Army, would use one of its existing ground based radars in implementing GBSAA. ABSAA's implementation uses UAS-borne sensors and electronics, including those not currently on UASs. Current development of all-weather ABSAA that could operate without FAA COAs is restricted to Global Hawk, with plans to scale down to Reaper. ABSAA availability is not known at this time but will be some years after GBSAA becomes available.

Navy

Relative to the Air Force and Army, the Navy has had limited experience with UASs. To date, Navy ships have employed the Scan Eagle, a non–program of record UAS, fielded through a rapid-acquisition program (see Chapter Two). Scan Eagles are flown from frigates. The Navy has also operated BAMS-D,[16] which is scheduled to be replaced by the MQ-4C, Triton.[17] The Navy is acquiring the Fire Scout (MQ-8B). While we limited most of our study effort to the period through FY 2012, the Navy's most recent experience is the best example of the evolution of UASs and their implications for operational capabilities. In early May 2013, the Navy launched an X-47B experimental drone from the nuclear powered aircraft carrier USS *George H.W. Bush* as it operated off the coast of Virginia (Vergakis, 2013). This launch represented the latest step in introducing a disruptive technology into the operating forces and helped mark a paradigm shift in warfare because this particular UAS is capable of autonomous flight.

The Navy's approaches to integrating UASs and to training and developing UAS operators differ significantly from those of the Army and Air Force. Generally, Navy UASs are being incorporated into existing fleet aviation units and organizations, and the personnel who will operate them are, to a large extent, the same personnel who will operate traditional aircraft assigned to these organizations. In this way, the Navy is addressing several problems often seen when disruptive technologies are introduced. The Navy approach has emphasized the complementarity of the systems, rather than pitting the new technology and its proponents against the old technology and its proponents. In addition, the Navy will reduce cost by capitalizing

[16] While the Air Force has conducted Global Hawk UAS operations since 2001, the Navy has just recently pursued using the system. The Navy purchased Global Hawk airframes from the Air Force and is using them to test operational concepts and technologies. The aim for the Global Hawk maritime demonstration program, BAMS-D, is to better understand maritime surveillance with UASs that fly at high altitude. The goal is to improve the fleet's operational understanding of the battlespace, and the Navy deployed BAMS-D in 2009.

[17] The Navy's BAMS UAS (MQ-4C), now called Triton, is a persistent maritime intelligence, surveillance, and reconnaissance system. As a persistent airborne asset, Triton's sensors will support increased situational awareness for naval forces. The imagery and data provided by the airframe's sensors will be directly available within federated networks, allowing Navy, joint, allied, and coalition exploitation centers to use MQ-4C UAS data.

While the Navy is currently operating only BAMS-D (in FY 2012), it plans to purchase a total of 68 Triton MQ-4C UAS airframes from FY 2014 through FY 2026. This acquisition plan will increase deployment of BAMS to operational commanders throughout the world. The current concept of operations includes plans for the Navy to operate Triton UASs in five separate geographic locations. These operations would provide continuous maritime surveillance, with persistent ISR support 24 hours a day, seven days a week, out to ranges of 2,000 nautical miles from the deployed location. (Derived from Department of the Navy, 2010.)

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on investments already made in personnel aviation training. For example, the Fire Scout UAS will be embedded in Navy H-60 squadrons.[18] This enables taking advantage of H-60 pilots' training and experience, because they will also pilot the Fire Scout. The flying skills of the H-60 pilot are utilized for both airframes and minimize the potentially disruptive effects of this new technology. Similarly, Triton, the follow-on to BAMS-D, is intended to complement Navy P-3/8 aircraft with its long loitering capability and sensors. The Navy plans to have P-3/8 officers both be in tactical command of the UAS and pilot the Triton UAS. These officers will first serve and qualify in the P-3/8 aircraft, rotate to a UAS training unit, then assume duties in a UAS squadron. The Triton UAS capabilities complement the capabilities of the P-8 aircraft. The training construct the Navy is pursuing will capitalize, complement, and exploit the capabilities of both aircraft and the personnel assigned to them.

Training for Operators and Support Personnel

Scan Eagle

Qualification training for personnel directly associated with UAS operations is not yet well established for the Navy. Currently, contractors operate the Scan Eagle UAS. (See Figure 4.8.)

Fire Scout

The Navy will have two approaches for Fire Scout operator training—one for littoral combat ship (LCS) employment and another for SOF support. The majority of Fire Scouts will be flown from the LCS. (See Figure 4.8.)

Littoral Combat Ship Employment

The aviation detachment that will deploy with the LCS will consist of one H-60R helicopter and two Fire Scouts and will have 23 assigned personnel. The training these personnel will need is similar to that for deploying with H-60 detachments on guided missile destroyers today (normally, two H-60 helicopters deploy with a guided missile destroyer). In the future, ships will deploy with a mix of H-60s, and Fire Scout and aviation detachment personnel will fly both aircraft depending on mission requirements.

The skills needed to operate and maintain the Fire Scout are complementary to those needed for the H-60. The operators and maintainers of Fire Scout will be the same as for the H-60, with some additional training on the Fire Scout. An H-60 fleet replacement squadron's (FRS's) Fire Scout fleet introduction team will provide this training to the AVOs and MPOs en route. The AVO course for H-60 pilots lasts five weeks. This initial and all sustainment training for the Fire Scout will be conducted via simulator.

Fire Scout Support for Special Operations Forces

The Navy is establishing dedicated units to support SOF, rather than integrating Fire Scout into existing units. The first of these units, Unmanned Helicopter Reconnaissance Squadron One, will be both a training and an operational squadron. The Navy's plan is to organize each such squadron to have nine detachments, each consisting of three Fire Scout airframes, seven to eight AVOs, eight MPOs, and 16 maintenance and support personnel. The Fire Scouts that will be flown off LCSs will be piloted by commissioned officers. The Fire Scouts supporting

[18] The Fire Scout will greatly contribute to increased mission readiness and response by conducting persistent ISR operations immediately around seaborne task forces, as well as over the horizon. The persistence, range, sensors, and data sharing of UASs extend the ISR reach of Navy ships and increase situational awareness.

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Figure 4.8
Scan Eagle (top) and Fire Scout UASs



SOURCE: DoD.



SOURCE: DoD.

RAND *RR440-4.8*

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SOF units will be piloted by enlisted AVOs. Initially, these AVOs will be air warfare operators who have completed tours as MPOs with an LCS Fire Scout.

Fire Scout Maintainers

The Fire Scout maintainers consist of four Navy specialties. Enlisted aviation machinist mates and aviation structural mechanics will take the mechanical course for LCS Fire Scout. Enlisted aviation electronics technicians and aviation electrician's mates will take an electronic technical course for LCS Fire Scout. The maintenance and support skills needed for the Fire Scout are complementary skills for Navy enlisted technicians.

Triton

Operator Training

The MQ-4C Triton UAS is composed of several systems: the airframe; a suite of mission payloads; communications systems; a mission control system (MCS) used for mission planning, control, and execution; and a support system. The Triton UAS will be deployed as an adjunct system to P-3/8 squadrons. The MCS will be based at a main operating base in CONUS, and BAMS maintenance and launch and recovery operations will take place at a forward location.

The Triton watch organization will consist of a mission commander (P-8 naval flight officer),[19] one AVO (officer, P-8 pilot), and two mission payload (enlisted) air warfare operators. Training plans for the Triton watch organization are being developed, and the initial operating capability of Triton will be in FY 2016. The Navy plans to use P-3/8 pilots as tactical coordinators and AVOs on the Triton. Future aviators will first go through flight school, earn wings on the P-3/8 aircraft, then perform an initial operational tour on the P-3/8.[20] After that, aviators will rotate to the FRS for training on Triton before reporting to their squadrons. Designated FRS for BAMS is Patrol Squadron 30 (VP-30), located at Naval Air Station Jacksonville, Florida. FRS training provides initial and refresher qualification training for personnel who will be assigned to Triton units.

Maintenance personnel and the pilot who launches and recovers the airframe are located at the forward operating base. The Navy plans to rotate personnel through the forward base every several months.

A simulation training capability will be built into the MCS. Initial Navy manning plans indicate that there will be eight to ten crews per squadron. The crews will be flying real missions that will sustain their proficiency. Triton UASs are flown via point and click; there is no stick and rudder. VP-30 is developing the tailored Naval Air Training and Operating Procedures Standardization requirements for the Triton; the final training and readiness manual for Triton is due in 2013.

Maintenance Training

The Triton airframe, engines, and associated equipment are different from the P-3/8; one is a UAS and the other a manned aircraft. Separate training will thus be necessary. When the

[19] The mission control officer is a naval flight officer who is responsible for the mission planning and the overall tactical employment of the airframe. The AVO is a naval aviator, responsible for flight planning and safety of flight, and is the pilot in command of the airframe. The MPOs are enlisted air warfare operators, responsible for the operation and employment of the sensors and the detection and analysis of targets.

[20] The notional pilot training track for P-3/8 pilots is (1) attend and graduate from flight school, (2) attend FRS for P-8 training, and (3) conduct an operational P-8 squadron tour.

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Triton UAS is introduced into the fleet, the Chief of Naval Air Technical Training will stand up a technical school to train enlisted personnel to perform Triton maintenance.

Operational Training

BAMS/Triton

The P-8A's missions overlap with those of Triton. The missions the two have in common include maintaining the maritime common operational picture and the classification, identification, detection, and tracking of surface units. The P-8A, however, has missions that the Triton does not perform (e.g., antisubmarine warfare) and vice versa. However, the increased utilization and cross training of P-8A and Triton crews over time can and is expected to increase understanding and employment of these systems in support of the warfighter.

While the Navy was operating only BAMS-D in FY 2012,[21] the Navy has plans to purchase a total of 68 Triton MQ-4Cs UAS airframes from FY 2014 through FY 2026. This acquisition plan will increase deployment of Triton UAS to operational commanders throughout the world. The current concept of operations includes plans for the Navy to operate Triton UAS in five geographic locations. These operations would provide continuous maritime surveillance, with persistent ISR support 24 hours a day, seven days a week, out to ranges of 2,000 nautical miles from the deployed location (Department of the Navy, 2010). The LCS does not have the Navy Continuous Training Environment (NCTE) synthetic training capability, and Fire Scouts assigned to the LCS will have no capability to train in the NCTE. Integrated training plans for Fire Scout are being developed.

Integrated Training

Triton's MCS will be configured so that it can participate in fleet training exercises synthetically via NCTE. Fleet synthetic training events for BAMS-D and Triton are being developed.

Key Areas of Concern

Airspace Considerations

Airspace planning is a critical requirement when conducting UAS operations but is less of a constraint for UASs in naval operations. The FAA controls the airspace up to the 12-mile limit from land. Navy surface ships with Scan Eagle and Fire Scout can embark the UASs, travel 12 nautical miles out to sea to a naval operating area, then conduct UAS training.

BAMS-D and Triton use special use airspace and fly at altitudes higher than commercial airlines do. They file instrument flight rules flight plans. However, BAMS-D and Triton do not incorporate sense-and-avoid technology, and conflicts can exist with visual flight rules aircraft in the airspace. Airspace issues exist at some Navy training installations as well. For example, along the North Carolina coast, the expeditionary readiness group must work with the FAA to route commercial aircraft around the established restricted operating zone units.

[21] BAMS-D has participated in CSG training events in the Virginia Capes operating area, including combined training unit exercises and joint task force exercises. Navy officials emphasized that Triton is a tactical asset and will respond to the requirements of the task force.

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The Need for Interoperability

So far, this report has emphasized that home-station training is not as effective as it should be, thus reducing the effectiveness of multiservice, or interoperability, training at CTCs and during joint exercises. The importance of interoperability training is stressed in Chairman of the Joint Chiefs of Staff Guide 3501 (2012, pp. B-2 and B-3), which notes that the

> ability of systems, units, or forces to operate in synergy in the execution of assigned tasks is critical to successful operations. This ability to operate effectively together describes interoperability. From a joint training perspective, interoperability is a Service component responsibility. Interoperability training is based on joint doctrine, or where no joint doctrine exists, on Service or [SOF] doctrine to prepare forces or staffs from more than one Service component to respond to operational and tactical requirements deemed necessary by CCDRs [combatant commanders] to execute their assigned missions. Interoperability training involves forces of two or more Service components (including SOF) with no interaction with a CCDR or subordinate JFC [joint force commander] or joint staff.

The publication in 2011 of the MTTP for UASs was designed to address the problem of interoperability. As designed, it is

> a single source, descriptive reference guide to ensure effective planning, integration, and utilization of multi-service UAS capability. It provides commanders, operational staffs, requestors, and UAS operators with a comprehensive resource for planning and employing unmanned aircraft . . . . US Air Force (USAF) uses the term [RPA] for the air vehicle component of a UAS. (MTTP, 2011, p. i)

To date, interoperability training at the NTC and the Joint Readiness Training Center has been limited.[22] GAO (2005, p. 2) cited two significant challenges for improving interoperability training: (1) "establishing effective partnerships with program stakeholders through comprehensive communication and coordination and (2) developing joint training requirements that meet combatant commanders' needs," with particular emphasis on tactical level training (GAO, 2005, p. 2).[23] To meet this challenge, DoD established the Training Transformation Implementation Plan (Director, Readiness and Training Policy and Programs, 2006), giving the Office of the Under Secretary of Defense for Personnel and Readiness overall responsibility and giving the Deputy Under Secretary of Defense for Readiness executive agent responsibility for training transformation planning, programming, budgeting, and execution progress.

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[22] GAO, 2005, p. 1, found that

> U.S. forces are conducting significantly more complex operations, requiring increased interoperability between and among the military services, combatant commands, and other DOD and non-DOD organizations. In the past, military services experienced some joint operations training during joint exercises, but most service training focused on individual service competencies with limited joint context.

[23] GAO, 2005, p. 18, noted that,

> in the past, joint training tasks were primarily focused at the command level and were identified through DOD authoritative processes that built requirements by translating command combat commanders inputs into training requirements. Training transformation has expanded joint training requirements to include those at the tactical level in addition to joint command level training.

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While RAND did not assess interoperability training in detail, discussions with the Army's training community, as noted above and as reported in GAO, 2010a, p. 26, suggest that such opportunities have been limited by the lack of Air Force assets, particularly the Predator, due to pressing operational requirements in Iraq and Afghanistan. The problem of transiting Air Force UAVs from Creech AFB to the NTC at Fort Irwin through FAA controlled airspace is often cited. Permanently stationing Air Force UAVs at the NTC would, of course, negate that problem, much as the Marine Corps has done by basing UASs at the MCAGCC at Twentynine Palms, California, to support training there. However, the experience of the Marine Corps suggests that the mere presence of UASs will not ensure that the forces are properly trained. The forces must prepare at their home stations for such training. In addition, given the common MTTP, forces trained to operate with their own services' UASs should find working with UASs from the other services less challenging.

Simulators

Congress has pressed for information on the role that simulators might play in a UAS training strategy, seeking an informed balance between live training and simulated training. In addition, the GAO reported that the

> military services lacked simulators that were capable of supporting training that is intended to build proficiency in skills required of UAS vehicle and sensor operators and prepare these personnel to conduct UAS combat missions. … [And] the Air Force and the Army have not fully developed comprehensive plans that address long-term UAS simulator requirements and associated funding needs. (GAO, 2010a, pp. 27–28)

Implicit in the GAO's comments is an assumption that simulators should play an important role in the future of UAS training. Our review questions that conclusion.

DoD has historically viewed simulator training and joint use of training facilities as an exercise in cost reduction. It is first necessary to understand how simulation better enables the introduction of the technology and, similarly, how joint use of the disruptive technology enables more effective military operations. For the purposes of this report, we have clearly focused on these aspects of simulation and jointness, which must be understood before the more-traditional perspectives of resource allocation can be applied. Currently, the usual significant savings that the department has garnered from simulators in the past do not appear to obtain in this instance. The danger is that, if the department starts with a savings orientation, it will not fully capitalize on the capabilities UASs represent.

For traditional aircraft systems, one major appeal of using simulators, rather than live flying, is the cost differential. For example, a RAND study of the trade-off between live and simulated training for manned aircraft noted that "the Marines and British are starting to give greater recognition to use of simulators as they seek either to reduce the high costs of live training or conserve the limited life of operational aircraft" (Schank et al., 2002, p. 49). In this case, the cost of flying the strike fighter aircraft they were discussing was many times greater than the cost of using a simulator, and the procurement cost of the aircraft itself was also significantly greater than that of the simulator. That said, they also noted that,

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> [t]o increase that use, several improvements must happen to integrate simulators more fully into their unit training. The fidelity and availability of simulators must increase to the point that fighter pilots see their benefit in training. This requires additional funding for simulators. (Schank et al., 2002, p. 49)

The report further argues that, even given the cost advantage of simulators for strike fighter aircraft training, simulators are a complement to live training, not a substitute for it.

The same point was made to us concerning UAS simulators. Officials of the 432d Wing also noted that simulators were not very good for training on landings. Moreover, a substantial investment in new simulator technology would be necessary to improve the realism of UAS simulators to the point it could prove useful for training UAS crews and ground forces. For example, GAO, 2010a, p. 28, found that currently Air Force and Army simulators did not have the ability

> to replicate all UAS procedures and to enable the integration of UAS training with other types of aircraft, [e.g.,] … the Army's Shadow Institutional Mission Simulator is not currently capable of replicating system upgrades that are being fielded directly to ongoing combat operations, such as a laser target designator and communications relay equipment. … Air Force and Army simulators are also … incapable of providing virtual, integrated training opportunities between manned and unmanned aircraft because of interoperability and information security concerns.

The conditions that make a compelling case for simulators for the training of fighter pilots are largely absent when it comes to UAS training:

- First, UAS flying hours are much less expensive than flying hours for manned aircraft. By one account, the flying hour cost of Shadow was $705; a comparable figure for Gray Eagle was $4,275.[24] By comparison, the Air Force told the GAO that "the live training cost of one F-15E flight hour is approximately $17,449" (Pickup, 2012, pp. 15–16). Other sources peg the flying hour costs of manned aircraft much higher.[25]
- Second, the kinds of operational activities that need more training emphasis, in particular, air-ground coordination, are generally not activities in which simulators *per se* can substitute for live flying. A good example of both the limitations and the value of simulators can be found at the digital air-ground integration ranges the Army operates today. On these ranges, only the weapon system engagement is simulated. Everything else—planning, coordination, UAS operation, ground unit and/or manned aircraft activity, target acquisition—is live.
- Third, while simulators are inherent in the systems used for initial training of pilots and sensor operators,[26] they are not well suited (and not designed) for training operating

[24] Ron Moring, UAS cost per flying hours, personal communication, April 5, 2013. The cost for the Gray Eagle is similar to the costs the Air Force reported for Predator at $3,679 and Reaper at $4,762, as reported by Mark Thompson, "Costly Flight Hours," *Time*, April 2, 2013.

[25] Recently, the Air Force comptroller's office told *Time* that the flying hour cost for the F-15C was $41,921. Other aircraft had considerably higher flying hour costs; e.g., the cost of flying an F-22 for one hour was reported to be $68,362. See Thompson, 2013.

[26] See Shawn Johnson, DAMO-TRC Army Flying Hour Program, "UAS cost per flying hours," personal communication, with Joan Vandervort, Office of the Office USDP&R, April 10, 2013.

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forces on the full spectrum of UAS capabilities. Simulators may be useful as a supplement to live training of pilots and crews but do not replicate the myriad activities and stimuli that a live training environment provides well for maneuver forces.
- Fourth, as noted previously, simulators at best complement rather than substitute for live training. Given the current state of UAS fielding, first priority must be given to building the live-flying infrastructure. Then, and only then, might funds be used to undertake the research and development that must precede any consideration of fielding the kind of interactive UAS air-ground simulators that could train both UAS crews and ground troops.

In the future, the services should reevaluate the need for virtual training using a cost and effectiveness analysis (COEA) including developmental costs for simulators, the savings based on the costs of flying UASs, and the critical availability of air space for training. Given current budget limitations and the importance of fully developing the opportunities for live training and the relatively low cost of such training, diversion of funds to a research and development program to develop higher-fidelity UAS-ground simulators is not appropriate at this time.

Summary

This chapter presented an overview of UAS training in 2012. Our focus was on service-specific and interoperability training. The training framework presented in Chapter Three was our starting point, with an emphasis on preparing forces for joint training and deployment. We looked at ground, air, and sea forces. Insights came from a wide variety of sources but mainly through visits to selected service bases, where we talked with operators and support personnel, those who train operators and associated team members, and those who train and observe the forces who employ UASs. In general, the RAND team found that qualification training in all the services for designated UAS-specific MOSs is well established. The critical issue is being able to train with ground forces at home station. The experience of the Marine Corps illustrates the importance of such opportunities. The Marine Corps has Shadow squadrons based at the MCAGCC at Twentynine Palms, California, where the restricted airspace is adequate both for maintaining crew proficiency and for supporting ground forces. However, both the ground trainers and squadron personnel the RAND team interviewed reported that the ground forces are not adequately trained at home station to integrate UAS capabilities into their operations. This required starting with what amounted to "remedial" training at Twentynine Palms, and trainees thus did not achieve the level of proficiency desired. This suggests that the biggest challenge in developing and implementing a training strategy for UASs is gaining and maintaining proficiency on the part of end users or "supported units"—the leaders and staffs who will integrate UAS capabilities into their operations.

Thus, as the war in Afghanistan draws to a close, the services must pay close attention not only to training UAS crews and support personnel but also to routinely exercising these systems during combined arms training at home station and at the CTCs. We addressed a number of issues for this, including beddown and support facilities and airspace considerations.

We found that home station training is generally not as effective as it should be, thus reducing the potential effectiveness of multiservice or "interoperability" training at CTCs and during joint exercises. We noted that, to date, interoperability training at the CTCs has been

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limited by the lack of Air Force assets, particularly the Predator, due to pressing operational requirements in Iraq and Afghanistan. However, given the common MTTP, forces trained to operate with their own service UASs should find working with UASs from the other services less challenging.

Finally, we considered the case for UAS simulators. Currently, such simulators do not appear to offer the significant savings that the Department has usually garnered from simulation in the past. We concluded that, given current budget limitations and the importance of fully developing the opportunities for live training and the relatively low cost of such training, diversion of funds to a research and development program to develop higher fidelity UAS-ground simulators would be unwise at this time.

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CHAPTER FIVE

Implications and Recommendations

The Guiding Principle: "Train As We Fight"

DoD has been under some pressure from Congress and such organizations as GAO for the lack of central control and the lack of the development of a joint DoD strategy for training. For example, "DOD Lacks a Comprehensive, Results-Oriented Strategy to Resolve UAS Training Challenges," was the summary title of a section of a recent GAO report (GAO, 2010a, p. 29). The Joint Unmanned Aircraft System Center of Excellence was established to support the joint operator and the services by facilitating the development and integration of common unmanned aircraft system operating standards, capabilities, concepts, technologies, doctrine, tactics, techniques, procedures, and training. The center, however, was disestablished in May 2011, and its UAS oversight function was reassigned to the Joint Staff Force Structure, Resources, and Assessment Directorate (J8), with some responsibilities assigned to the UAS Task Force. However, the 2011 publication of the MTTP for UASs addressed the problem of interoperability, and the services have agreed to incorporate the MTTP in their training.
While the services have agreed to a common set of TTP, each service continues to develop its own UASs to meet its own requirements. Moreover, the GAO (2010a, p. 25) has well documented that the opportunity for joint training is limited. While the GAO identified a number of organizations and initiatives addressing UAS training challenges, only one of the eight organizations and initiatives it listed were led by the services. Given the current maturation of UAS platforms, this emphasis is misplaced; the military services employs their UASs in very different ways. Today, the services are still struggling with how to incorporate these new systems. The appropriate strategy for UAS training is to encourage each service to solve its own UAS training problems, then to coordinate the resulting TTPs by updating the MTTP to achieve a high level of interoperability.

Commanders and operators from the bottom up are discovering and adapting to the revolutionary operational changes that UASs have brought about. The most apparent changes are in the persistence and responsiveness of UASs relative to other platforms in the permissive threat environments in which they are currently operating. These characteristics help develop valuable shared situational awareness between UASs and the supported forces and also make ISR capabilities more responsive and immediately available. Processing, exploitation, and dissemination concepts for UAS-generated information, however, are still evolving. In addition, armed UASs provide strike capabilities similar in some ways to those of CAS; the evolution of UASs from pure ISR platforms to small, lightly armed ISR platforms, to bigger, more heavily armed, faster, and even stealthier reconnaissance-strike platforms has crossed operational and cultural seams. This has lead to the need for continual resolution of disputes between intelli-

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gence and operations staffs over priorities for UASs and their implications for mission planning and execution.

To date, the services have, in a variety of important ways, been "training *while* they fight." Iraq and Afghanistan have served as de facto training ranges, as well as an active theater of war. For example, Air Force Predator and Reaper pilots and sensor operators have frequently gone straight from flight instruction and certification to flying real-world missions, learning and adapting as they support operations. Army and Marine Corps units have also learned in theater how to capitalize on the robust set of capabilities UASs provide.

The demonstrated ability of the services to learn on the fly should be cause for optimism about continued success in UAS training as operations wind down. But that continued success will depend on preserving training opportunities in an environment in which training is not an incidental by-product of operational requirements. Operational experiences, for example, typically do not suffer from the inherent limitations of CONUS training venues, such as limited area, limited time, and limited fidelity. Because of such limitations, it has been harder to train as we fight in CONUS. Infrastructure and other limitations currently make it difficult or impossible to train at night or in bad weather, to train with live or dummy munitions, or to train in a communications environment that represents the environment and demands of actual operations in theater. Preservation of the current levels of proficiency, improvement where needed, and adaptation to changing circumstances will not come without effort; they will require overcoming or at least alleviating the limitations mentioned here.

Elements of a Strategic Training Plan

To *train as we fight*, the DoD training strategy must

- engender better appreciation of UAS capabilities throughout the chain of command
- address organizational, structural, and infrastructure and support issues
- enable training as we fight in collective unit training
- enable training as we fight in larger exercises.

Engender Better Appreciation of UAS Capabilities

Many ground force commanders and their battle staffs today do not fully recognize the potential benefits UASs bring to the fight and, as a result, are not in a position to benefit from them in circumstances that would improve units' warfighting capabilities. This is traceable in part to limited use of UASs in home-station and CTC training but also to other inherent limitations, such as a shortage of experienced personnel and UAS assets and airspace and infrastructure limitations. Overcoming these limitations will enable more opportunities to foster better understanding and improve integration. Training guidance should emphasize the value of UASs, using examples of how units have benefited by preparing themselves to use such systems through training and attending familiarization courses. Such vignettes can be inserted into professional education and training materials to share positive experiences working with UASs.

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Address Organizational, Structural, and Training Infrastructure and Support Issues

Organization and Structure

UASs are a disruptive technology, and their introduction can create tensions between operations and intelligence staffs on the right balance between using UASs to collect intelligence or launch strikes. In the Army, for example, one could ask, is Gray Eagle an ISR asset or an armed reconnaissance system? Doctrine development efforts should produce a doctrine flexible enough to allow changes in allocation and organizational balances and address the attendant training issues accordingly.

Also, in the Army, the organizational placement of UASs remains a challenge, as illustrated by the fact that the assignment of responsibilities for the Raven is still being worked out. A more-systematic approach to monitoring and maintaining Raven operator qualifications will better enable integration of the system into maneuver forces and thus improve overall training and help develop better appreciation of the system's capabilities and limitations. In addition, the Army is currently examining alternatives for placing Shadow platoons in the headquarters company of a brigade combat team or consolidating them in the developing full-spectrum combat aviation brigade. Resolution of these organizational issues will likewise aid in training integration.

Training Infrastructure, Training Support Issues, and Related Factors

Some of the most important ways in which shortfalls can detract from UAS training are

- incompatible or different communications capabilities
- airspace restrictions
- inability to train at night or in bad weather
- inability to use live or dummy munitions
- UAS unavailability
- insufficient time.

These shortfalls cannot always be fully corrected. Some, such as differences in communications capabilities, are inherent but can be alleviated to some extent. The full correction of others may be unaffordable, but partial correction should still be possible. Inability to train at night or in bad weather, for example, is to some extent a result of FAA restrictions on when Air Force UASs can fly from their bases to the NTC. Basing Air Force UASs at the NTC would significantly reduce the effect of these restrictions and might also make it possible for the UASs to use live or dummy munitions, further improving realism for both customers and operators.

Research suggests that airspace restrictions, while sometimes nettlesome, need not pose a serious obstacle to most UAS training at a unit's home station, either for operators or end users. Nevertheless, efforts to gain more access to airspace should continue with the research and development of the joint program for GBSAA systems, led by the Army's program manager for UAS. This system uses ground-based radars to provide an extra layer of airspace safety, which could enable the FAA to make the use of civil airspace adjacent to UAS training airspace less restrictive and thus expand the airspace available for UAS training. A promising initial demonstration with Gray Eagle took place in summer 2011, but GBSAA is not expected to be certified for use until 2015.

The insufficient number of UASs for training should be alleviated to some extent as some systems redeploy from overseas theaters and also by the recent decision to increase the number

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of Predator/Reaper CAPs from 61 available today to 85 in the future. Similarly, the Operation Enduring Freedom drawdown will likely free up more RPA trainers, alleviating the shortfall.

Enable Training as We Fight in Unit Collective Training

To facilitate home station training, the following steps need to be taken:

- Training must make full use of units' UASs and must use simulation or surrogates, despite their limitations, when live use is not possible.
- Training should include the systems of other services and their associated joint tactical air controllers (JTACs) and air liaison officers (ALOs) to the extent possible.
- Air Force preparation training of JTACs and ALOs should be available for support of unit-level training, as well as for larger exercises.
- After-action reviews and reports should be expanded to reinforce lessons learned; they can also provide a sound basis for continued measurable improvements. Over time, the reports growing out of these documents should become more detailed and should incorporate measures of performance and effectiveness, so that these metrics can drive future improvements.

Enable Training as We Fight in Larger Exercises

By design, larger exercises like those at maneuver CTCs provide considerable opportunities for more-realistic training. They are thus already better postured to provide training on the use and integration of UAS. However, more can be done to enhance the use of training opportunities in such large exercises to further the goal of better UAS integration in the force. Specifically, we recommend

- continued stress on training realism
- including live UASs and their associated JTACs and ALOs as much as possible
- including the CAS-like and ISR missions that UASs, especially Air Force UASs, will be performing in theater
- providing a small paved air strip to base RPAs, launch and recovery elements (LREs), and support crews at the maneuver CTCs to avoid the NAS constraints associated with remote operation
- continued efforts to integrate additional Creech AFB–based UASs into CTC training, when needed.

Initiatives with Likely Near-Term Payoffs

Other things can be done that should provide near-term payoffs:

- **Increase exposure to the capabilities and limitations of UAS—**Continue to expose appropriate commanders to UAS operations through short (one- to two-day) familiarization courses, such as those the Air Force offers at various UAS squadrons' locations (e.g., Creech AFB, Beale AFB, and March ARB). These also need to be introduced as part of the joint training curriculum in a more formal and standardized fashion across the force. The proliferation of Air Force UAS squadrons geographically within CONUS should provide ready access for ground units whatever their home station.

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- **Harness the lessons-learned process to guide the development of service and joint doctrine and TTP—**Formalize and standardize these processes as appropriate, and share best practices more extensively across services and regions. Right now, most extended learning is done "on the job," with lessons learned shared informally among operators and trainers. Different UAS elements tend to focus support on different ground units, each with geographical and other mission differences. Best practices across these geographic and mission boundaries need to be understood to inform joint doctrine and, hence, responsive training requirements.
- **Address well-known but underresourced training infrastructure shortfalls—**Consider this issue in light of our previous discussions of basing. UASs can be based at maneuver CTCs to minimize the impact of FAA restrictions. If this is done as a part of the drawdown and redeployment of RPA units to CONUS, this should not be too disruptive or expensive; many details remain to be worked out, but military construction and other costs appear to be manageable. Communications infrastructure and C2 organizations and processes at the ranges can be enhanced to better mirror operational capabilities.

Institutionalizing Training for UAS Capabilities over the Longer Term

Institutionalizing UAS training over the longer term will naturally depend on continued support for the specific programs and initiatives and others like them that we outlined earlier. Institutionalization will also require more-general efforts, falling into three broad categories: acculturation, professional development of the UAS force (operators, maintainers, and a UAS chain of command), and integration of the UAS community (a subprofession, if you will) into the aviation profession. These three are somewhat interwoven, and the third depends on the first two. Finally, institutionalization over the longer term will require adaptation: The strategies must be designed to be adaptive, and those who develop and implement them must be willing to adapt them.

Acculturation

The RAND team heard from many sources that many end users do not yet have a well-developed appreciation of the capabilities UASs can bring to an operation. In some cases, this lack of appreciation has derived from negative experiences. Some of these experiences resulted from inexperienced operators, some from mechanical failures, some from sheer bad luck (e.g., weather). The need to deconflict airspace and the need to do so, even when using restricted airspace reserved for military use, often led to utilization problems and contributed to negative impressions about the value of UAS. First impressions do count, and avoiding bad ones is much easier than overcoming them later.

Professional Development

All the services need to maintain professional development strategy for the UAS force. The services are developing a professional force of operators for UASs, both systems and payloads, consisting of enlisted soldiers, noncommissioned officers, and warrant and commissioned officers, although the Army currently has no UAS officer specialty. It is important to develop a cadre of UAS professionals with hands-on experience in all echelons of UAS operation; the Army may

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wish to consider a career pipeline for such officers, perhaps with an additional skill identifier. Such a professional cadre is a key element in full integration of UAS capabilities.

Integration

The services are making significant efforts to integrate UASs into their force structures. Army efforts would be aided by more access during training to the operational and even strategic capabilities of Air Force UASs. These efforts will be aided by better acculturation and an institutionalized UAS career field that, over time, develops professionals with a more-complete understanding of UAS capabilities and limitations and sufficient rank, technical expertise, and operational experience to enable better integration of the capabilities into the overall operations of the end users. Related issues include integration of UAS capabilities with other ISR systems and with the intelligence warfighting function more generally, the tension between those who value the strike capabilities of UASs and those who value the intelligence collection capabilities, and the further tensions likely to emerge as UAS capabilities widen further. As UAS capabilities grow and broaden, integrating them into other warfighting functions will also present challenges.

Adaptation

The training strategy must adapt to future technical innovations and changes in operational demands. To enable this adaptability, those concerned with overall training strategy development will need to remain cognizant of and to guide the following, where possible:

- evolution of the roles of UASs in the full range of military operations, and the speed and breadth of the expansion of those roles
- surfacing and resolving UAS doctrinal issues (In particular, how will the requirements of intelligence and operations be integrated and deconflicted? How will both organic and nonorganic systems be better integrated to support ground forces, and which warfighting functions will they support? How will technological advances and changes in expected operational conditions influence decisions regarding these roles and missions?)
- service adjustments of force structures and personnel management processes to accommodate the disruptive technology effects of UASs
- influence of the above and related issues on the development, promulgation, and adaptation of joint and service doctrines so these doctrines can continue to form a solid basis for UAS training.

Summary of Findings and Recommendations

Our findings and recommendations are summarized as follows:

1. The proper strategy for DoD at this time is to encourage each service to solve its own UAS training problems, rather than to constrain any one service under the guise of joint operations.
2. DoD should support current and future programs to develop ranges and beddown and support facilities similar to those in the Army's current programs.

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3. In spite of the demands of deploying units and sustaining combat operations in Afghanistan, Army trainers indicate that Army units are better at maintaining qualification for Shadow qualification than for Raven. Nevertheless, not all units have been able to maintain high Shadow qualification rates—some units arrive at the NTC with one-half or fewer of their operators qualified. Better tracking of operators and their sustainment training is needed, particularly but not exclusively for Ravens.
4. If joint training becomes a priority, the Air Force's current basing and beddown posture will become more of a problem. The Air Force could consider the location of Army hubs when choosing where to base its UAS fleet. A location that is near Army maneuver elements might make airspace access less of a restriction or at least make COAs more practical. Proximity might provide more opportunities for training UAS integration throughout the entire mission planning process.
5. Given current budget limitations and the importance of fully developing the opportunities for live training and the relatively low cost of such training, diversion of funds to a research and development program to develop higher fidelity simulators would seem unwise at this time.

Path to the Future

We have presented and discussed a multitude of means for setting up UAS training strategies for success. These means include support for ongoing facilities and basing initiatives; expansion of such facilities, where possible, to enable wider availability of UASs to support collective training; and efforts to increase the use of UASs—the complete UAS package, including JTACs and other coordinating elements—in collective training, both local and in larger exercises. We have noted the need to support continuing efforts to resolve airspace access issues, observing as we did so that there are ways to keep such restrictions from imposing serious limitations on much of the UAS training envisioned here. Similarly, we have discussed the potential for simulators to add value in training, now and perhaps more in the future. But we have also cautioned that simulators, in their current state, are not a good substitute for live use of UASs in collective training.

The path to the future for UAS strategies starts now, with support for ongoing initiatives that will continue the trends towards better training integration and thus better ability on the part of end users to employ the multiple capabilities of UASs in their operations. The path continues, using that foundation, with longer-term efforts to add to acculturation of end users, professionalization of the UAS community, and integration of the two to harmonize the capabilities of UASs as key elements of overall force effectiveness.

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APPENDIX A

Current Major DoD UAS Programs in FY 2012

The following pages come directly from a Congressional Research Service report on U.S. UASs (Gertler, 2012, pp. 31–46).

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Current Major DOD UAS Programs

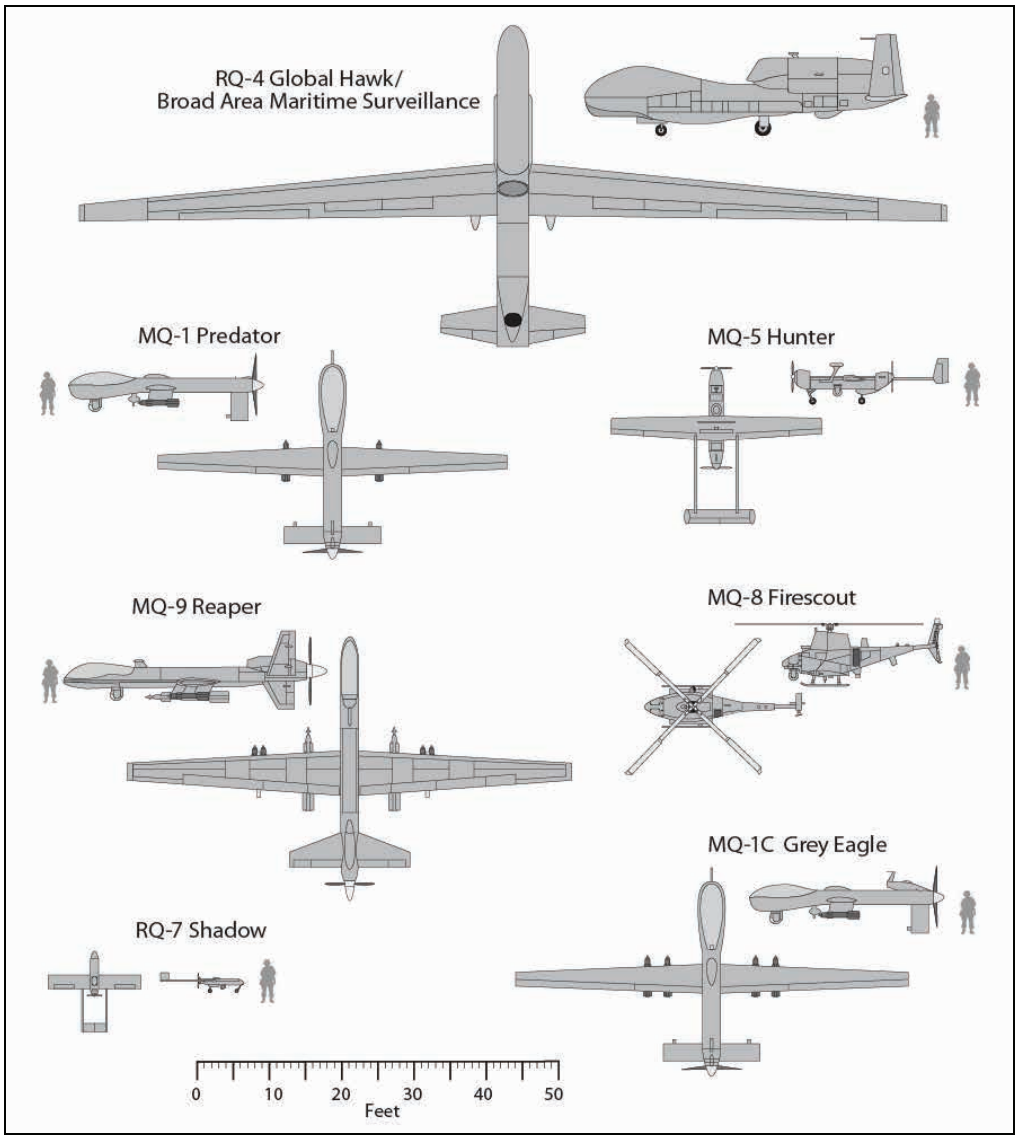
This section addresses the program status and funding of some of the most prominent UAS programs being pursued by DOD, and most likely to compete for congressional attention. This section does not attempt to provide a comprehensive survey of all UAS programs, nor to develop a classification system for different types of UAS (e.g., operational vs. developmental, single mission vs. multi mission, long range vs. short range). One exception is a short subsection below titled "Small UAVs." The UAVs described in this section are distinguished from the proceeding UAVs by being man-portable and of short range and loiter time. These smaller UAVs are not currently, and are unlikely to be, weaponized. The services do not provide as detailed cost and budget documentation for these UAVs as they do for major UAS programs. Individually, these UAVs appear very popular with ground forces, yet do not necessarily demand as much congressional attention as larger UAS programs like Predator or Global Hawk. As a whole, however, these small, man-portable UAVs appear likely to increasingly compete with major UAS programs for congressional attention and funding.

Table 6. Characteristics of Selected Tactical and Theater-Level Unmanned Aircraft

System	Length (ft)	Wingspan (ft)	Gross weight (lbs)	Payload capacity (lbs)	Endurance (hours)	Maximum altitude (ft)
Predator	27	55	2,250	450	24+	25,000
Grey Eagle	28	56	3,200	800	40	25,000
Reaper	36	66	10,500	3,750	24	50,000
Shadow	11	14	375	60	6	15,000
Fire Scout	23	28	3,150	600	6+	20,000
Global Hawk	48	131	32,250	3,000	28	60,000
BAMS	48	131	32,250	3,200	34+	60,000

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Figure 5. U.S. Medium-Sized and Large Unmanned Aircraft Systems



Source: Congressional Budget Office, *Policy Options for Unmanned Aircraft Systems*, Publication 4083, Washington, DC, June 2011.

Notes: All aircraft are drawn to the same scale. The silhouette figure is a 6-foot-tall soldier, also drawn to scale.

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Table 7. Acquisition Cost of Medium-Sized and Large Unmanned Aircraft Systems Under the Department of Defense's 2012 Plan

(Millions of 2011 dollars)

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total, 2011-2020
Air Force											
RQ-4 Global Hawk	1,200	1,060	890	790	810	710	1,160	530	80	60	7,290
MQ-1 Predator	30	10	10	10	[a]	[a]	[a]	[a]	[a]	[a]	60
MQ-9 Reaper	1,700	1,550	1,740	1,440	1,350	1,150	1,060[b]	1,040[b]	1,030[b]	1,010[b]	13,070
Army											
MQ-1C Grey Eagle	870	1,060	1,040	740	220	90	[a]	[a]	[a]	[a]	4,020
RQ-7 Shadow	610	250	270	200	300	280	[a]	[a]	[a]	[a]	1,910
Navy and Marine Corps											
RQ-4 Broad Area Maritime Surveillance	530	560	760	880	900	1,010	1,230	1,260	1,130	1,130	9,390
MQ-8 Fire Scout	60	70	60	80	80	90	130	160	150	150	1,030
RQ-7 Shadow	90	10	10	10	[a]	[a]	[a]	[a]	[a]	[a]	120
All services											
	5,090	4,570	4,780	4,150	3,660	3,330	3,580	2,990	2,390	2,350	36,890

Source: Congressional Budget Office based on data from the Department of Defense's budget request for 2012, Selected Acquisition Reports for December 2010, and Aircraft Procurement Plan: Fiscal Years 2012-2041 (submitted with the 2012 budget, March 2011).

Notes: Acquisition cost includes the cost of procuring air vehicles, sensors, and grounds stations, plus the cost for research. development, test, and evaluation. The services' cost data have been adjusted using CBO's projection of inflation and rounded to the nearest $10 million.

a. The Department of Defense has no plans to acquire or modify the specified system in these years.

b. The cost is for the follow-on aircraft the Air Force plans to acquire instead of the Reaper.

MQ-1 Predator

Through its high-profile use in Iraq and Afghanistan and its multi-mission capabilities, the MQ-1 Predator has become the Department of Defense's most recognizable UAS. Developed by General Atomics Aeronautical Systems in San Diego, CA, the Predator has helped to define the modern role of UAS with its integrated surveillance payload and armament capabilities. Consequently, Predator has enjoyed accelerated development schedules as well as increased

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procurement funding. The wide employment of the MQ-1 has also facilitated the development of other closely related UAS (described below) designed for a variety of missions.

System Characteristics. Predator is a medium-altitude, long-endurance UAS. At 27 feet long, 7 feet high and with a 48-foot wingspan, it has long, thin wings and a tail like an inverted "V." The Predator typically operates at 10,000 to 15,000 feet to get the best imagery from its video cameras, although it has the ability to reach a maximum altitude of 25,000 feet. Each vehicle can remain on station, over 500 nautical miles away from its base, for 24 hours before returning home. The Air Force's Predator fleet is operated by the 15th and 17th Reconnaissance Squadrons out of Creech Air Force Base, NV; the 11th Reconnaissance Squadron provides training. A second control station has been established at Whiteman AFB, MO.[104] Further, "[t]here are plans to set up Predator operations at bases in Arizona, California, New York, North Dakota, and Texas."[105] The Air Force has about 175 Predators;[106] the CIA reportedly owns and operates several Predators as well.

Mission and Payload. The Predator's primary function is reconnaissance and target acquisition of potential ground targets. To accomplish this mission, the Predator is outfitted with a 450-lb surveillance payload, which includes two electro-optical (E-O) cameras and one infrared (IR) camera for use at night. These cameras are housed in a ball-shaped turret that can be easily seen underneath the vehicle's nose. The Predator is also equipped with a Multi-Spectral Targeting System (MTS) sensor ball which adds a laser designator to the E-O/IR payload that allows the Predator to track moving targets. Additionally, the Predator's payload includes a synthetic aperture radar (SAR), which enables the UAS to "see" through inclement weather. The Predator's satellite communications provide for beyond line-of-sight operations. In 2001, as a secondary function, the Predator was outfitted with the ability to carry two Hellfire missiles. Previously, the Predator identified a target and relayed the coordinates to a manned aircraft, which then engaged the target. The addition of this anti-tank ordnance enables the UAS to launch a precision attack on a time sensitive target with a minimized "sensor-to-shoot" time cycle. Consequently, the Air Force changed the Predator's military designation from RQ-1B (reconnaissance unmanned) to the MQ-1 (multi-mission unmanned).[107] The air vehicle launches and lands like a regular aircraft, but is controlled by a pilot on the ground using a joystick.

MQ-1C Grey Eagle

A slightly larger, longer-endurance version of the Predator, the Army's MQ-1C Grey Eagle entered low-rate initial production on March 29, 2010.[108] The Grey Eagle can remain aloft for 36 hours, 12 hours longer than its Air Force sibling.

An Army platoon operates four aircraft with electro-optical/infrared and/or laser rangefinder/designator payloads, communications relay equipment, and up to four Hellfire

[104] Phillip O'Connor, "Drones seeking terrorists guided from Missouri air base," *St. Louis Post-Dispatch*, May 10, 2011.

[105] P.W. Singer, *Wired for War* (New York: The Penguin Press, 2009), p. 33.

[106] Congressional Budget Office, *Policy Options for Unmanned Aircraft Systems*, Pub. No. 4083, June 2011, p. 5.

[107] Glenn W. Goodman, Jr., "UAVs Come of Age," *The ISR Journal*, July 2002, p. 24.

[108] Department of Defense, *Selected Acquisition Report (SAR), MQ-1C UAS Gray (sic) Eagle*, DD-A&T(Q&A)823-420, Washington, DC, December 31, 2010.

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missiles. Each platoon includes two ground control stations, two ground data terminals, one satellite communication ground data terminal, one portable ground control station, one portable ground data terminal, an automated takeoff and landing system, two tactical automatic landing systems, and ground support equipment. In total, the program will be 124 aircraft, plus 21 attrition aircraft and 7 schoolhouse aircraft, for a total of 152 aircraft. The average procurement unit cost of a Grey Eagle system is $114.1 million.[109]

MQ-9 Reaper

The MQ-9 Reaper, formerly the "Predator B," is General Atomics' follow-on to the MQ-1. The Reaper is a medium- to high-altitude, long-endurance Predator optimized for surveillance, target acquisition, and armed engagement. While the Reaper borrows from the overall design of the Predator, the Reaper is 13 feet longer and carries a 16-foot-longer wingspan. It also features a 900 hp turboprop engine, which is significantly more powerful than the Predator's 115 hp engine. These upgrades allow the Reaper to reach a maximum altitude of 50,000 feet, a maximum speed of 225 knots, a maximum endurance of 32 hours, and a maximum range of 2,000 nautical miles.[110] However, the feature that most differentiates Reaper from its predecessor is its ordnance capacity. While the Predator is outfitted to carry 2 100-pound Hellfire missiles, the Reaper now can carry as many as 16 Hellfires, equivalent to the Army's Apache helicopter, or a mix of 500-pound weapons and Small Diameter Bombs.

As of February 4, 2011, General Atomics Aeronautical Systems had delivered 65 of 399 planned Reapers, 43 of which are operationally active.[111]

The MQ-9 is operated by the 17th Reconnaissance Squadron and the 42nd Attack Squadron, both at Creech Air Force Base, NV, and the 29th Attack Squadron at Holloman AFB, NM.[112]

Program Status. Predator–family UAS are operated as part of a system, which consists of four air vehicles, a ground control station, and a primary satellite link. The unit cost in FY2009 for one Predator system was approximately $20 million,[113] while the average procurement unit cost for a Reaper system was $26.8 million.[114]

[109] Ibid.

[110] OSD, *UAS Roadmap 2005-2030*, August 2005, p. 10.

[111] Department of Defense, *Selected Acquisition Report (SAR), MQ-9 UAS Reaper*, DD-A&T(Q&A)823-424, Washington, DC, December 31, 2010.

[112] U.S. Air Force, *Fact Sheet: MQ-9 Reaper*, August 18, 2010.

[113] U.S. Air Force, *Fact Sheet: MQ-1 Predator*, July 20, 2010.

[114] Department of Defense, *Selected Acquisition Report (SAR), MQ-9 UAS Reaper*, DD-A&T(Q&A)823-424, Washington, DC, December 31, 2010.

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Table 8. Predator and Reaper Combined Funding

($ in Millions)

		Procurement	RDT&E
FY11			
Request	62 air vehicles	1600.0	
	Mods	31.8	
Appropriations Conference	12 air vehicles	176.6	83.2
	Mods	31.8	
FY12			
Request	9 air vehicles	125.5	61
	Mods	30.2	

RQ-4 Global Hawk

Northrop Grumman's RQ-4 Global Hawk has gained distinction as the largest and most expensive UAS currently in operation for the Department of Defense. Global Hawk incorporates a diverse surveillance payload with performance capabilities that rival or exceed most manned spy planes. However, Pentagon officials and Members of Congress have become increasingly concerned with the program's burgeoning cost, which resulted in Nunn-McCurdy breaches in April 2005 and April 2011.[115] Also, the RQ-4B Block 30 was deemed "not operationally suitable" due to "low air vehicle reliability" by the office of Operational Test and Evaluation in May 2011.[116]

System Characteristics. At 44 feet long and weighing 26,750 lbs, Global Hawk is about as large as a medium sized corporate jet. Global Hawk flies at nearly twice the altitude of commercial airliners and can stay aloft at 65,000 feet for as long as 35 hours. It can fly to a target area 5,400 nautical miles away, loiter at 60,000 feet while monitoring an area the size of the state of Illinois for 24 hours, and then return. Global Hawk was originally designed to be an autonomous drone capable of taking off, flying, and landing on pre-programmed inputs to the UAV's flight computer. Air Force operators have found, however, that the UAS requires frequent intervention by remote operators.[117] The RQ-4B resembles the RQ-4A, yet features a significantly larger airframe. In designing the B-model, Northrop Grumman increased the Global Hawk's length from 44 feet to 48 feet and its wingspan from 116 feet to 132 feet. The expanded size enables the RQ-4B to carry an extra 1000 pounds of surveillance payload.

[115] Amy Butler, "USAF Declares Second Major Global Hawk Cost Breach," Aerospace Daily, April 13, 2011. The 2005 breach stemmed from costs in transitioning from the Block 10 Global Hawk to the larger Block 30; the 2011 breach was attributed primarily to reduced procurement quantities rather than issues with the program.

[116] J. Michael Gilmore, *RQ-4B Global Hawk Block 30* , OSD Director, Operational Test and Evaluation, Operational Test and Evaluation Report, May 2011. John T. Bennett, "Pentagon testers slam aerial spy drone as unfit for operations," *The Hill*, June 7, 2011.

[117] Jeff Morrison, "USAF No Longer Viewing Global Hawk As An Autonomous System, Official Says," *Aerospace Daily*, December 3rd, 2005.

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Mission and Payload. The Global Hawk UAS has been called "the theater commander's around-the-clock, low-hanging (surveillance) satellite."[118] The UAS provides a long-dwell presence over the battlespace, giving military commanders a persistent source of high-quality imagery that has proven valuable in surveillance and interdiction operations. The RQ-4A's current imagery payload consists of a 2,000-lb integrated suite of sensors much larger than those found on the Predator. These sensors include an all-weather SAR with Moving Target Indicator (MTI) capability, an E-O digital camera and an IR sensor. As the result of a January 2002 Air Force requirements summit, Northrop Grumman expanded its payload to make it a multi-intelligence air vehicle. The subsequent incarnation, the RQ-4B, is outfitted with an open-system architecture that enables the vehicle to carry multiple payloads, such as signals intelligence (SIGINT) and electronic intelligence (ELINT) sensors. Furthermore, the classified Multi-Platform Radar Technology Insertion Program (MP-RTIP) payload will be added in order to increase radar capabilities. These new sensor packages will enable operators to eavesdrop on radio transmissions or to identify enemy radar from extremely high altitudes. Future plans include adding hyper-spectral sensors for increased imagery precision and incorporating laser communications to expand information transfer capabilities.[119] The end goal is to field a UAS that will work with space-based sensors to create a "staring net" that will prevent enemies from establishing a tactical surprise.[120] In August 2003, the Federal Aviation Administration granted the Global Hawk authorization to fly in U.S. civilian airspace, which further expanded the system's mission potential.[121] This distinction, in combination with the diverse surveillance capabilities, has led many officials outside the Pentagon to consider the Global Hawk an attractive candidate for anti-drug smuggling and Coast Guard operations.[122]

Program Status. Developed by Northrop Grumman Corporation of Palmdale, CA, Global Hawk entered low-rate initial production in February 2002. The Air Force has stated that it intends to acquire 51 Global Hawks, at an expected cost of $6.6 billion for development and procurement costs. As of November 2009, the Air Force possessed 7 RQ-4As and 3 RQ-4Bs.[123] Another 32 Global Hawks had been authorized and appropriated through FY2011.[124] According to the most recent Selected Acquisition Report, the current average procurement unit cost for the Global Hawk has reached $140.9 million in current dollars.[125]

In April 2005, the Air Force reported to Congress that the program had overrun by 18% as a result of an "increasing aircraft capacity to accommodate requirements for a more sophisticated, integrated imagery and signals intelligence senor suite."[126] A Government Accountability Office report in December 2004 noted that the program had increased by nearly $900 million since 2001 and recommended delaying the purchase of future Global Hawks until an appropriate

[118] Glenn W. Goodman, Jr., "UAVs Come Of Age," *The ISR Journal*, July 2002.

[119] David A. Fulghum, "Global Hawk Shows Off Updated Package of Sensors," *Aviation Week & Space Technology,* September 08, 2003.

[120] Ibid.

[121] Sue Baker, "FAA Authorizes Global Hawk Flights," Aeronautical Systems Center Public Affairs, August 21, 2003.

[122] Ron Laurenzo, "Global Hawk Scouts Ahead for Other UAVs," *Defense Week*, September 2, 2003.

[123] U.S. Air Force, *Fact Sheet: RQ-4 Global Hawk*, November 19, 2009.

[124] Department of Defense, *Department of Defense Fiscal Year 2012 Budget Estimates, Aircraft Procurement, Air Force*, February 2011.

[125] OSD, *Selected Acquisition Report,* December 31, 2010, p. 29.

[126] James R. Asker, "Global Hawk 18% Over Budget," *Aviation Week & Space Technology*, April 25, 2005.

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development strategy could be implemented.[127] The rising costs of the UAV and accusations of Air Force mismanagement have caused concern among many in Congress and in the Pentagon as well as facilitating an overall debate on the Air Force's development strategy.[128]

Following a 2010 Defense Acquisition Board review of the Global Hawk program,

> Air Force acquisition executive David Van Buren told reporters that he is "not happy" with the pace of the program, both on the government and the contractor side. Chief Pentagon arms buyer Ashton Carter also criticized the program, saying that it was "on a path to being unaffordable."[129]

In April 2011, a reduction in the number of Global Hawk Block 40 aircraft requested in the FY2012 budget from 22 to 11 caused overall Global Hawk unit prices to increase by 11%, again triggering Nunn-McCurdy.[130]

In its markup of the FY2011 defense authorization bill, the House Armed Services Committee expressed concern "that differing, evolving service unique requirements, coupled with Global Hawk UAS vanishing vendor issues, are resulting in a divergence in each service's basic goal of maximum system commonality and interoperability, particularly with regard to the communications systems." The bill report directs the Under Secretary of Defense for Acquisition, Technology, and Logistics to certify and provide written notification to the congressional defense committees by March 31, 2011, that he has reviewed the communications requirements and acquisition strategies for both Global Hawk and BAMS. The subcommittee wants assurance that the requirements for each service's communications systems have been validated and that the acquisition strategy for each system "achieves the greatest possible commonality and represents the most cost effective option" for each program.[131]

A May 20, 2011, report from the Air Force Operational Test and Evaluation Center found the Global Hawk Block 20/30 to be "effective with significant limitations ... not suitable and partially mission capable." The report cited "lackluster performance of the EISS imagery collector and ASIP sigint collectors at range" rather than issues with the Global Hawk airframe itself.[132]

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[127] United States Government Accountability Office, GAO-05-6 *Unmanned Aerial Vehicles[:] Changes in Global Hawk's Acquisition Strategy Are Needed to Reduce Program Risks,* November 2004, p. 3-4.

[128] See H.Rept. 109-89. House Armed Service Committee "National Defense Authorization Act for the Fiscal Year 2006." May 20, 2005, p. 91.

[129] Marina Malenic, "Air Force, Navy Pledge Greater Global Hawk-BAMS Cooperation," *Defense Daily*, July 2, 2010.

[130] The Nunn-McCurdy provision requires DOD to notify Congress when cost growth on a major acquisition program reaches 15%. If the cost growth hits 25%, Nunn-McCurdy requires DOD to justify continuing the program based on three main criteria: its importance to U.S. national security; the lack of a viable alternative; and evidence that the problems that led to the cost growth are under control. For more information, see CRS Report R41293, *The Nunn-McCurdy Act: Background, Analysis, and Issues for Congress* , by Moshe Schwartz.

[131] U.S. Congress, House Committee on Armed Services, *National Defense Authorization Act for Fiscal Year 2011*, Report to accompany H.R. 5136, 111th Cong., May 21, 2010, H.Rept. 111-491, p. 178.

[132] Amy Butler, "Poor Testing Results Latest Hurdle for Global Hawk," *Aviation Week/Ares blog*, June 3, 2011.

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Table 9. Global Hawk Funding

($ in Millions)

	Quantity	Procurement	RDT&E	Advance Procurement
FY11				
Request	4	649.6	251.3	90.2
Authorization Conference[a]	N/A	N/A	N/A	N/A
Appropriations Conference	4	503.0	220.3	72.3
FY12				
Request	3	323.9		71.5

a. As passed, H.R. 6523, the Ike Skelton National Defense Authorization Act For Fiscal Year 2011, did not include program-level detail, so no amounts were specified for these program elements.

BAMS

The Navy's Broad Area Maritime Surveillance system is based on the Global Hawk Block 20 airframe but with significantly different sensors from its Air Force kin. This, coupled with a smaller fleet size, results in a higher unit cost. "The air service's drone costs $27.6 million per copy, compared to an expected $55 million per BAMS UAV, including its sensors and communications suite…. At 68 aircraft, the BAMS fleet will be the world's largest purchase of long-endurance marinized UAVs."[133]

System Characteristics and Mission. "BAMS ... provides persistent maritime intelligence, surveillance, and reconnaissance data collection and dissemination capability to the Maritime Patrol and Reconnaissance Force. The MQ-4C BAMS UAS is a multi-mission system to support strike, signals intelligence, and communications relay as an adjunct to the MMA/P-3 community to enhance manpower, training and maintenance efficiencies worldwide."[134]

"The RQ-4 ... features sensors designed to provide near worldwide coverage through a network of five orbits inside and outside continental United States, with sufficient air vehicles to remain airborne for 24 hours a day, 7 days a week, out to ranges of 2000 nautical miles. Onboard sensors will provide detection, classification, tracking and identification of maritime targets and include maritime radar, electro-optical/infra-red and Electronic Support Measures systems. Additionally, the RQ-4 will have a communications relay capability designed to link dispersed forces in the theater of operations and serve as a node in the Navy's FORCEnet strategy."[135]

[133] Gayle S. Putrich, "Northrop selected to build BAMS drone," *Navy Times*, April 22, 2008.

[134] Northrop Grumman, "MQ-4C BAMS UAS," press release, http://www.as.northropgrumman.com/products/bams/index.html.

[135] Department of Defense, *Department of Defense Fiscal Year 2012 Budget Estimates, Research, Development, Test & Evaluation, Navy*, Budget Activity 7, February 2011.

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"The drones ... will collect information on enemies, do battle-damage assessments, conduct port surveillance and provide support to Navy forces at sea. Each aircraft is expected to serve for 20 years."[136]

Program Status. The Administration's FY2012 budget request documents place Milestone C for BAMS in the third quarter of FY2013, with initial operational capability in the first quarter of 2016. "Since Milestone B for the Navy BAMS UAS program, identifying opportunities for the RQ-4-based BAMS and Global-Hawk programs has been a significant interest item for the UAS TF and has been well documented within the Department."[137] In one effort to integrate development, on June 12, 2010, the Navy and Air Force concluded a Memorandum of Agreement (MOA) regarding their Global Hawk and BAMS programs, which use a common airframe. "Shared basing, maintenance, command and control, training, logistics and data exploitation are areas that could be ripe for efficiencies, says Lt. Gen David Deptula, Air Force deputy chief of staff for intelligence, surveillance and reconnaissance…. Also, a single pilot and maintenance training program is being established at Beale AFB, Calif., for both fleets."[138] However, issues still exist over common control stations and whether one service's pilots should be able to operate the other service's aircraft.

MQ-8B Fire Scout

Now in deployment, the Fire Scout was initially designed as the Navy's choice for an unmanned helicopter capable of reconnaissance, situational awareness, and precise targeting.[139] Although the Navy canceled production of the Fire Scout in 2001, Northrop Grumman's vertical take-off UAV was rejuvenated by the Army in 2003, when the Army designated the Fire Scout as the interim Class IV UAV for the future combat system. The Army's interest spurred renewed Navy funding for the MQ-8, making the Fire Scout DOD's first joint UAS helicopter.

System Characteristics and Mission. Northrop Grumman based the design of the Fire Scout on a commercial helicopter. The RQ-8B model added a four-blade rotor to reduce the aircraft's acoustic signature.[140] With a basic 127-pound payload, the Fire Scout can stay aloft for up to 9.5 hours; with the full-capacity sensor payload, endurance diminishes to roughly 6 hours. Fire Scout possesses autonomous flight capabilities. The surveillance payload consists of a laser designator and range finder, an IR camera and a multi-color EO camera, which when adjusted with specific filters could provide mine-detection capabilities.[141] Fire Scout also currently possesses line-of-sight communication data links. Initial tests of an armed Fire Scout were conducted in 2005, and the Navy expects to add "either Raytheon's Griffin or BAE's Advanced Precision Kill Weapon System" small missiles to currently deployed Fire Scouts soon.[142] Discussions of future missions

[136] Gayle S. Putrich, "Northrop selected to build BAMS drone," *Navy Times*, April 22, 2008.

[137] Under Secretary of Defense (Acquisition, Technology and Logistics), *Department of Defense Report to Congress on Addressing Challenges for Unmanned Aircraft Systems*, September 2010.

[138] Amy Butler, "U.S. Navy/Air Force UAV Agreement Raises Questions," *Aerospace Daily*, July 6, 2010.

[139] "RQ-8A Fire Scout, Vertical Take Off and Landing Tactical Unmanned Aerial Vehicle (VTUAV)," GlobalSecurity.org, http://www.globalsecurity.org/intell/systems/vtuav.htm, April 26th, 2004.

[140] David A. Fulghum, "Army Adopts Northrop Grumman's Helicopter UAV," *Aviation Week & Space Technology*, October 20th, 2003.

[141] Northrop Grumman Corp. Press Release, "Northrop Grumman's Next-Generation Fire Scout UAV on Track," June 23rd, 2005.

[142] Joshua Stewart, "Navy plans to arm Fire Scout UAV with missiles," *Navy Times*, August 18, 2011.

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have also covered border patrol, search and rescue operations, medical resupply, and submarine spotting operations.

Program Status. Six production MQ-8 air vehicles have been delivered to date.[143] The Pentagon's 2009 UAS Roadmap estimates a future inventory of 131 RQ-8Bs for the Navy to support the Littoral Combat Ship class of surface vessels.[144] The Army had intended to use the Fire Scout as the interim brigade-level UAV for its Future Combat System program,[145] but canceled its participation in January, 2010.[146]

A Fire Scout attracted media attention in August 2010, when it flew through Washington, DC, airspace after losing its control link. "A half-hour later, Navy spokesmen said, operators re-established control and the drone landed safely."[147]

FIRE-X/MQ-8C

The FIRE-X project, recently designated MQ-8C but continuing the Fire Scout name, is a developmental effort to adapt the Fire Scout software and navigation systems to a full-size standard helicopter. The Navy "is to award Northrop Grumman a contract to supply 28 MQ-8C Fire Scout ... to be fielded by the first quarter of 2014 to meet an urgent operational requirement."[148]

> Fire Scout can fly for 8 hours with a maximum range of 618 nautical miles? Well, Fire-X will fly for 15, with a max range of 1227. Fire Scout tops out at 100 knots? Fire-X can speed by at 140. Fire-X will carry a load of 3200 lbs. to Fire Scout's 1242. All this talk from a drone helicopter that just took its first flight in December.... Fire-X isn't going to be a big departure from Fire Scout, though. The BRITE STAR II and other radars will remain on board, as will its software for relaying information to a ship.[149]

RQ-170 Sentinel

Although publicly acknowledged to exist, most information about the Lockheed Martin RQ-170 Sentinel is classified. First photographed in the skies over Afghanistan, but also reportedly in operation from South Korea,[150] the RQ-170 is a tailless "flying wing" stealthier than other current

[143] Department of the Navy, *Fiscal Year (FY) 2012 Budget Estimates, MQ-8 UAV*, February 2011.

[144] Northrop Grumman Corp. Press Release, "Northrop Grumman's Next-Generation Fire Scout UAV on Track," June 23rd, 2005. *FY2009–2034 Unmanned Systems Integrated Roadmap*, p. 66.

[145] The Army intended to field four different classes of UAVs as part of its Future Combat System (FCS): Class I for platoons, Class II for companies, Class III for battalions, and Class IV for brigades. See CRS Report RL32888, *Army Future Combat System (FCS) "Spin-Outs" and Ground Combat Vehicle (GCV): Background and Issues for Congress*, by Andrew Feickert and Nathan J. Lucas, for more information.

[146] April M. Havens, "U.S. Army wants to cancel Fire Scouts (sic) program," *The Mississippi Press*, January 15, 2010, As presented on http://www.gulflive.com.

[147] Elisabeth Bumiller, "Navy Drone Violated Washington Airspace," *The New York Times*, August 26, 2010.

[148] Graham Warwick, "U.S. Navy Goes Ahead With Bell 407-Based Fire Scout UAV," *Aerospace Daily*, September 8, 2011.

[149] Spencer Ackerman, "Navy Upgrades Its Spying, Drug-Sniffing Robot Copter," *Wired.com/Danger Room blog*, April 11, 2011.

[150] Bill Sweetman, "Beast Sighted In Korea," *Aviation Week/Ares blog*, February 16, 2010.

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U.S. UAS. An RQ-170 was reported to have performed surveillance and data relay related to the operation against Osama bin Laden's compound on May 1, 2011. The government of Iran claimed on December 2, 2011, to be in possession of an intact RQ-170 following its incursion into Iranian airspace.

System Characteristics. Built by Lockheed Martin, the RQ-170 has a wingspan of about 65 feet and is powered by a single jet engine. It appears to have two sensor bays (or satellite dish enclosures) on the upper wing surface. Although an inherently low-observable blended wing/fuselage design like the B-2, the RQ-170's conventional inlet, exhaust, and landing gear doors suggest a design not fully optimized for stealth.[151]

Potential Mission and Payload. "The RQ-170 will directly support combatant commander needs for intelligence, surveillance and reconnaissance to locate targets."[152]

Program Status. "The RQ-170 is a low observable unmanned aircraft system (UAS) being developed, tested and fielded by the Air Force."[153] No further official status is available.

Other Current UAS Programs

RQ-5A Hunter/MQ-5B Hunter II

Originally co-developed by Israel Aircraft Industries and TRW (now owned by Northrop Grumman) for a joint U.S. Army/Navy/Marine Corps short-range UAS, the Hunter system found a home as one of the Army's principal unmanned platforms. The service has deployed the RQ-5A for tactical ISR in support of numerous ground operations around the world. At one time, the Army planned to acquire 52 Hunter integrated systems of eight air vehicles apiece, but the Hunter program experienced some turbulence. The Army canceled full-rate production of the RQ-5A in 1996, but continued to use the seven systems already produced. It acquired 18 MQ-5B Hunter IIs through low-rate initial production in FY2004 and FY2005. The MQ-5B's design includes longer endurance and the capability to be outfitted with anti-tank munitions. Both variants are currently operated by the 224th Military Intelligence Battalion out of Fort Stewart, GA; by the 15th Military Intelligence Battalion out of Ft. Hood, TX; and by 1st Military Intelligence Battalion out of Hohenfels, Germany.

System Characteristics. The RQ-5A can fly at altitudes up to 15,000 feet, reach speeds of 106 knots, and spend up to 12 hours in the air. Weighing 1,600 pounds, it has an operating radius of 144 nautical miles. The MQ-5B includes an elongated wingspan of 34.3 feet up from 29.2 feet of the RQ-5A and a more powerful engine, which allows the Hunter II to stay airborne for three extra hours and to reach altitudes of 18,000 feet.[154] The Hunter system consists of eight aircraft, ground control systems and support devices, and launch/recovery equipment. In FY2004, the final year of Hunter procurement, a Hunter system cost $26.5 million.

[151] U.S. Air Force, *Fact Sheet: RQ-170 Sentinel*, December 2, 2010. and CRS analysis of available RQ-170 photography.

[152] U.S. Air Force, *Fact Sheet: RQ-170 Sentinel*, December 2, 2010.

[153] Ibid.

[154] OSD, *UAS Roadmap 2005-2030*, August 2005, p. 7

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Mission and Payload. The Army has mostly used the Hunter system for short- and medium-range surveillance and reconnaissance. More recently, however, the Army expanded the Hunter's missions, including weaponization for tactical reconnaissance/strike operations with the GBU-44/B Viper Strike precision guided munition, which can designate targets either from the munition's laser, from another aerial platform, or from a ground system. This weapon makes the Hunter the Army's first armed UAS. "Also, in 2004, the Department of Homeland Security, Customs and Border Protection Bureau, and Office of Air and Marine utilized Hunter under a trial program for border patrol duties. During this program, the Hunter flew 329 flight hours, resulting in 556 detections."[155]

Program Status. The Army halted Hunter production in 2005. As of May 2011, 45 Hunter UAVs were still in operation and periodically receiving upgrades and modifications. In August 2005, the Army awarded General Atomics' Warrior UAS (which later became Grey Eagle) the contract for the Extended Range-Multi Purpose UAS program over the Hunter II.[156]

RQ-7 Shadow

The RQ-7 Shadow found a home when the Army, after a two-decade search for a suitable system, selected AAI's close range surveillance platform for its tactical unmanned aerial vehicle (TUAV) program. Originally, the Army, in conjunction with the Navy explored several different UAVs for the TUAV program, including the now-cancelled RQ-6 Outrider system. However, in 1997, after the Navy pursued other alternatives, the Army opted for the low-cost, simple design of the RQ-7 Shadow 200. Having reached full production capacity and an IOC in 2002, the Shadow has become the primary airborne ISR tool of numerous Army units around the world and is expected to remain in service through the decade.

The Administration's FY2011 budget request did not include funding for Shadow aircraft, although it did include continued RDT&E funding for Shadow.[157]

System Characteristics. Built by AAI Corporation (now owned by Textron), the Shadow is 11 feet long with a wingspan of 13 feet. It has a range of 68 nautical miles, a distance picked to match typical Army brigade operations, and average flight duration of five hours. Although the Shadow can reach a maximum altitude of 14,000 feet, its optimum level is 8,000 feet. The Shadow is catapulted from a rail-launcher, and recovered with the aid of arresting gear. The UAS also possesses automatic takeoff and landing capabilities. The upgraded version, the RQ-7B Shadow, features a 16-inch greater wingspan and larger fuel capacity, allowing for an extra two hours of flight endurance.

Mission and Payload. The Shadow provides real-time reconnaissance, surveillance, and target acquisition information to the Army at the brigade level. A potential mission for the Shadow is the perilous job of medical resupply. The Army is considering expanding the UAS's traditional missions to include a medical role, where several crucial items such as blood, vaccines, and fluid

[155] Kari Hawkins, "Pioneer platform soars to battlefield success," *www.army.mil*, May 19, 2011.

[156] Jefferson Morris, "Army More Than Doubles Expected Order for ERMP with General Atomics Win," *Aerospace Daily & Defense Report,* August 10th, 2005.

[157] Todd Harrison, *Analysis of the FY 2011 Defense Budget* (Washington, DC: Center for Strategic & Budgetary Assessments, 2010), p. 38.

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infusion systems could be delivered to troops via parachute.[158] For surveillance purposes, the Shadow's 60-pound payload consists of an E-O/IR sensor turret, which produces day or night video and can relay data to a ground station in real-time via a line-of-sight data link. As part of the Army's Future Combat System plans, the Shadow will be outfitted with the Tactical Common Data Link currently in development to network the UAS with battalion commanders, ground units, and other air vehicles.[159] The Marine Corps is considering how to arm Shadow.[160]

Program Status. The Army and Marine Corps currently maintain an inventory of 364 Shadow UAVs.[161] The program cost for a Shadow UAV system—which includes four vehicles, ground control equipment, launch and recovery devices, remote video terminals, and High Mobility Multipurpose Wheeled Vehicles for transportation—reached $11.1 million in current year dollars for FY2008.[162] The Army procured 102 systems through 2009.[163] In FY2012, the Army requested $25 million for 20 Shadow aircraft to replace combat losses, and approximately $200 million for payload upgrades.

"Small UAVs"

RQ-14 Dragon Eye

AeroVironment's Dragon Eye is a backpack-carried, battery-operated UAV employed by the Marines at the company level and below for reconnaissance, surveillance, and target acquisition. Dragon Eye features a 3.8-foot rectangular wing, twin propellers, and two camera ports each capable of supporting day-light electro-optical cameras, low-light TV cameras, and infrared cameras. The compact and lightweight design of the UAV allows an operational endurance of 45 minutes and can travel as far as 2.5 nautical miles from the operator. Low-rate-initial-production of 40 aircraft began in 2001. After a 2003 operational assessment, the Marine Corps awarded AeroVironment a contract to deliver approximately 300 systems of full-rate-production Dragon Eyes.[164] However, that contract was later revised to acquire Raven UAS instead. One Dragon Eye system consists of three air vehicles and one ground station. The final Marine Corps procurement budget request in FY2006 anticipated the current unit cost per Dragon Eye system as $154,000.[165]

FQM-151 Pointer

Although procurement of this early UAS began in 1990, the electric-powered Pointer has seen service in Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF). Pointer is a

[158] Erin Q. Winograd, "Army Eyes Shadow UAVs Potential For Medical Resupply Missions," *InsideDefense.com*, December 20, 2002, p.14.

[159] "Upgraded Shadow UAV Rolls Off Production Line," *Defense Today*, August 5, 2004.

[160] Paul McCleary, "Marines Want a Big Bang From a Small Package," *Aviation Week/Ares blog*, October 26, 2010.

[161] OSD, *UAS Roadmap 2005-2030*, August 2005, p. 8.

[162] Department of the Army, Army Procurement OPA 02: Communications and Electronics FY2009, February 2008, TUAS (B00301), Item No. 61, p. 18 of 23.

[163] Department of the Army, *Committee Staff Procurement Backup Book, Fiscal Year 2012 Budget Estimate, Aircraft Procurement, Army, RQ-7 UAV MODS*, Washington, DC, February 2011, p. 1 of 10.

[164] Peter La Franchi, "Directory: Unmanned Air Vehicles," *Flight International*, June 21st, 2005, p. 56.

[165] Department of the Navy, FY2006-FY2007 Budget Estimate - Marine Corps Procurement, February 2005, BLI No. 474700, Item 44, p. 20 of 22.

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short-range reconnaissance and battlefield surveillance UAV developed by AeroVironment. Its flight endurance (two hours) is greater than most similar small UAVs, in part due to its relatively large, 9-foot wingspan. That wingspan decreases portability of the 8.5-pound Pointer, and as a result, transportation of a Pointer system (two air vehicles and a ground control unit) requires two personnel. Although superseded by the Raven (below), Pointer remains a valued short-range ISR asset for the Air Force and Special Operations Command.

RQ-11 Raven

Engineered from the basic design of the Pointer, the Raven is two-thirds the size and weight of its predecessor, with a much smaller control station, making the system man-portable.[166] "The RQ-11A is essentially a down-sized FQM-151 *Pointer*, but thanks to improved technology can carry the same navigation system, control equipment, and payload."[167] The Raven provides Army and SOCOM personnel with "over-the-hill" reconnaissance, sniper spotting, and surveillance scouting of intended convoy routes. The electric motor initiates flight once hand-launched by a running start from the ground operator. The vehicle is powered by an electric battery that needs to be recharged after 90 minutes, but deployed soldiers are equipped with four auxiliary batteries that can be easily charged using the 28 volt DC outlet in a Humvee. The vehicle lands via a controlled crash in which the camera separates from the body, which is composed of Kevlar plating for extra protection. Like the Pointer, the Raven can carry either an IR or an E-O camera and transmits real-time images to its ground operators. The relatively simple system allows soldiers to be trained in-theater in a matter of days. Raven systems can either be deployed in three-aircraft or two-aircraft configurations. "Raven was adopted as the US Army's standardised short range UAV system in 2004 with a total of 2469 air vehicles (including older RQ-11A series models) in operational service by mid 2007."[168] "The US Army has an ongoing acquisition objective for about 2,200 Raven systems and has taken delivery of more than 1,300 to date."[169] A three-aircraft system costs approximately $167,000.[170]

ScanEagle

Developed by the Insitu Group (owned by Boeing) as a "launch-and-forget" UAV, the ScanEagle autonomously flies to points of interest selected by a ground operator.[171] The ScanEagle has gained notice for its long endurance capabilities and relative low cost. The gasoline-powered UAV features narrow 10 foot wings that allow the 40-pound vehicle to reach altitudes as high as 19,000 feet, distances of more than 60 nautical miles, and a flight endurance of almost 20 hours. Using an inertially stabilized camera turret carrying both electro-optical and infrared sensors, ScanEagle currently provides Marine Corps units in Iraq with force-protection ISR and is also used by Special Operations Command. ScanEagle operations began in 2004,[172] and continue

[166] Peter La Franchi, "Directory: Unmanned Air Vehicles," *Flight International*, June 21st, 2005, p. 57.

[167] Andreas Parsch, "AeroVironment RQ-11 Raven," *Directory of U.S. Military Rockets and Missiles*, September 12, 2006.

[168] "UAV Directory - Aircraft Specification AeroVironment - RQ-11A Raven," *FlightGlobal.com*, (2011).

[169] "UAV Directory - Aircraft Specification AeroVironment - RQ-11B Raven," *FlightGlobal.com*, (2011).

[170] The FY2012 budget request includes $70.8 million for 424 systems and supporting equipment. Department of Defense, *Department of Defense Fiscal Year 2012 Budget Estimates, Aircraft Procurement, Army*, February 2011.

[171] Jim Garamone, "ScanEagle Proves Worth in Fallujah Fight," *American Forces Press Service*, January 11th, 2005.

[172] Insitu, "Backgrounder: ScanEagle® Unmanned Aircraft System," press release, September 22, 2011, (continued...)

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today. Although ScanEagle was expected to cost about $100,000 per copy, the Navy and SOCOM have contracted for operations instead of procurement, with Boeing providing ISR services utilizing ScanEagle under a fee-for-service arrangement.[173]

ScanEagle is also in use by non-military organizations for surveillance purposes, including tracking whale migrations.[174]

Small Tactical Unmanned Aerial System (STUAS)

In July 2010, the Department of the Navy awarded Insitu a two-year, $43.7 million contract for the design, development, integration, and test of the Small Tactical Unmanned Aircraft System (STUAS) for use by the Navy and Marine Corps to provide persistent maritime and land-based tactical reconnaissance, surveillance, and target acquisition (RSTA) data collection and dissemination. "For the USMC, STUAS will provide the Marine Expeditionary Force and subordinate commands (divisions and regiments) a dedicated ISR system capable of delivering intelligence products directly to the tactical commander in real time. For the Navy, STUAS will provide persistent RSTA support for tactical maneuver decisions and unit-level force defense/force protection for Navy ships, Marine Corps land forces, and Navy Special Warfare Units."[175]

Payloads include day/night video cameras, an infrared marker, and a laser range finder, among others. STUAS can be launched and recovered from an unimproved expeditionary/urban environment, as well as from the deck of Navy ships.[176]

STUAS uses Insitu's Integrator airframe, which uses common launch, control, and recovery equipment with ScanEagle. STUAS has a takeoff weight of up to 125 pounds with a range of 50 nautical miles. However, STUAS will be procured and operated by the services rather than operated on a fee-for-service basis because "the Scan Eagle's current fee-for-service contract limits the way the UAS is deployed ... with Boeing/Insitu employees usually operating the aircraft in the field due to liability issues." Procuring the system will allow the services to train their own operators. Initial operating capability is expected in the fourth quarter of FY2013.[177]

(...continued)

http://www.boeing.com/bds/mediakit/2011/ausa/pdf/bkgd_scaneagle.pdf.

[173] See, inter alia, Boeing, "Boeing Awarded Navy Contract for ScanEagle Services," press release, June 6, 2008, http://www.boeing.com/news/releases/2008/q2/080606a_nr.html and Insitu, "Boeing Wins $250M Special Ops Contract for ScanEagle ISR Services," press release, May 22, 2009, http://www.insitu.com/print.cfm?cid=3774.

[174] Boeing, " From saving soldiers to saving whales," undated press release, http://www.boeing.com.au/ViewContent.do?id=61784&aContent=ScanEagle.

[175] Naval Air Systems Command, *Aircraft and Weapons: Small Tactical Unmanned Aircraft System*, http://www.navair.navy.mil/index.cfm?fuseaction=home.display&key=4043B5FA-7056-4A3A-B038-C60B21641288.

[176] Ibid.

[177] Gayle Putrich, "Insitu wins long-awaited US Navy STUAS deal," *FlightGlobal.com*, July 30, 2010.

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APPENDIX B

The Department of Defense's Traditional Acquisition System

Overview

The DAS is a structured and deliberate process for establishing requirements and planning and resourcing the procurement of new capabilities. The need for accountability and oversight in the allocation of national resources has led to the buildup over decades of a large bureaucratic apparatus around the DAS. The complexity of the process can be seen in Figure B.1.

This bureaucracy has many virtues. It provides for a structured process governed by regulations and accountable authorities and includes provisions for relatively stable funding over system life cycles. Such provisions are far from perfect. For example, observers have long noted that the process can be slow and unresponsive to the immediate needs of warfighters. Such concerns have led, as will be discussed below, to evolving roles for the combatant commanders in resource allocation processes. Another concern is that provision of training and sustainment considerations, while formally required, is an afterthought to the acquisition and fielding of new equipment. Both concerns will be discussed below.

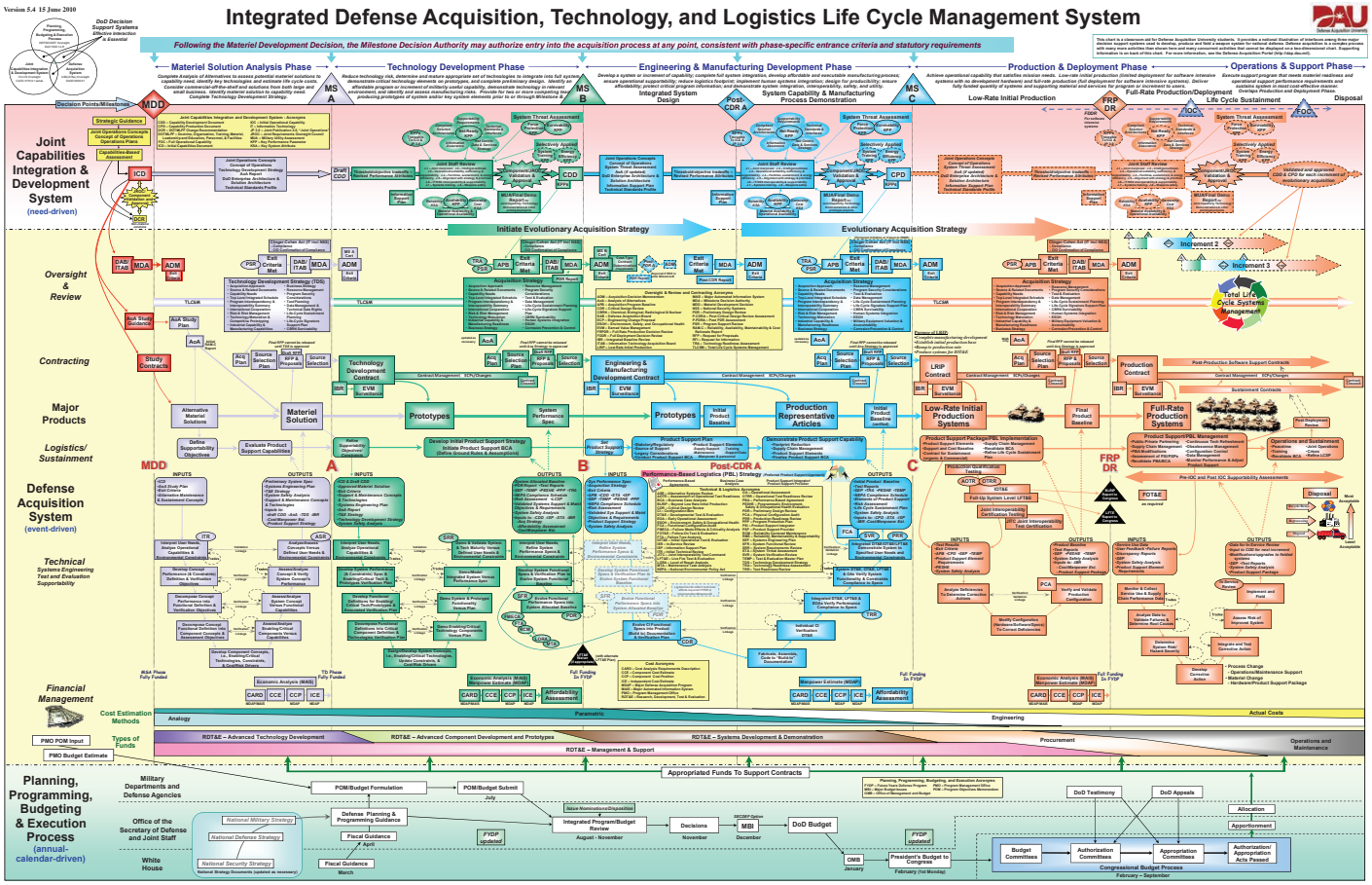
Role of Combatant Commanders in Traditional Acquisition

To meet current warfighter needs, the DoD has in recent years advanced changes to some existing acquisition processes and relationships. As a result, the roles of the COCOMs in the traditional system have evolved. For example, the Secretary of Defense approved a "streamlined and refocused" integrated priority list process to better support the development of service program objective memorandums (Hicks et al., 2008, p. 59). In November 2005, the Vice Chairman of the Joint Chiefs of Staff launched a process by which the Joint Requirements Oversight Council, in consultation with the COCOMs, identified a list of "most pressing" military issues to support resourcing and planning decisions (Hicks et al., 2008, p. 59). In 2006 the Senior Warfighters Forum, consisting of COCOM deputies, began meeting every four to six weeks to discuss coordination issues, and the Vice Chairman of the Joint Chiefs of Staff began coordinating regular trips to the COCOMs with critical PPBE decision points to better represent the COCOM position in resourcing decisions (Hicks et al., 2008, p. 60). Furthermore, SOCOM's traditional acquisition activities have increased, and its budget has grown significantly (GAO, 2007b, p. 1).

The COCOMS do not lead the process, but their ability to participate in acquisition, particularly in identifying requirements, has expanded. An emphasis on warfighting in recent years has given new weight to the capabilities and solutions that the COCOMs identify as

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Figure B.1
Defense Acquisition System



SOURCE: Defense Acquisition University, June 2010.

RAND *RR440-B.1*

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required. Beyond the current fight, however, observers argue that the nature of future challenges and the technology necessary to meet them are so dynamic that fundamental acquisition relationships need to be rethought. As the commander of SOUTHCOM recently wrote:

> We are living in an age of rapid change facilitated by advancing technologies and increasingly networked systems, societies, and economies. In order for security agencies to be successful in this complex environment, those organizations must be flexible, open and forward-thinking. (Stavridis, 2010, p. xxii)

Leadership of traditional acquisition processes is vested in the military departments (the force providers) rather than the combatant commanders (the force users). The DAS consists of the interrelationship between the establishment of requirements (Joint Capabilities Integration and Development), the process of providing solutions, and the allocation of resources (PPBE). All processes are primarily driven by the military departments, with some inputs from the COCOMs. The logic behind the vesting of acquisition authority in the military departments reflects both Title 10 responsibilities and unique competencies for acquisition. The division of labor has traditionally been that the COCOMs provide inputs to the determination of requirements, and the services lead on providing solutions. A recent RAND assessment concluded that it "is the job of those in Washington, D.C., to reach out to the COCOMs and demonstrate that their needs are being addressed, rather than turn the process over to them" (Blickstein and Nemfakos, 2009, p. 7). Traditionally, the COCOMs are viewed as best suited to fighting wars, while the military departments are best suited to balancing other priorities and managing resource decisionmaking.

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APPENDIX C

Military Value Analysis of Unmanned Aircraft System Training Bases

Training Locations

The information on specific training locations included in this appendix is drawn from RAND interviews, service presentations to congressional oversight committees, and Army surveys and consolidated snapshots of selected Army bases compiled in November 2012.

Initial training for UAS operators and sensor operators is concentrated at a few locations. The Air Force uses Beale AFB for training its Global Hawk crews and primarily Holloman AFB for its Predator crews.[1] The Navy plans to leverage the similarities between the Global Hawk and BAMS by having some joint training at Beale AFB. The Army conducts all its initial UAS training at Fort Huachuca, Arizona. The Marine Corps trains its Shadow crews with the Army.[2] Current and continuing pressures on the defense budget are likely to result in further changes. We limited our efforts to analyze military value in depth to activities that any training base would more certainly include, regardless of budget reductions. After we gain a fuller understanding of the results of Secretary of Defense decisions on the content of the FY 2014 and FY 2015 programs, we will renew our efforts to complete this military value analysis.

The approach to the *military value analysis of training bases* presented here is based on the Department of the Navy's 1995 Base Realignment and Closure documents. These categories and a brief description are listed below:

- flight training areas and airspace—covers access to special use airspace, availability of training areas, etc.
- airfield and maintenance facilities—includes facilities available for housing and maintaining the aircraft
- expansion potential—any comments on future plans for expansion or capacity for expansion
- training and training facilities—includes classrooms or other similar infrastructure and equipment required for training
- military and general support mission—any impacts of the other military missions housed at the same installation

[1] The training for the LRE is separate from the FTU and takes place at Creech AFB, Nevada.

[2] The Marines will also operate the RQ-20A Puma. We do not discuss the training for that SUAS.

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- weather—any impacts of weather on training capacity
- location—description of the where the installation is located
- base loading—comments on consolidation of training.

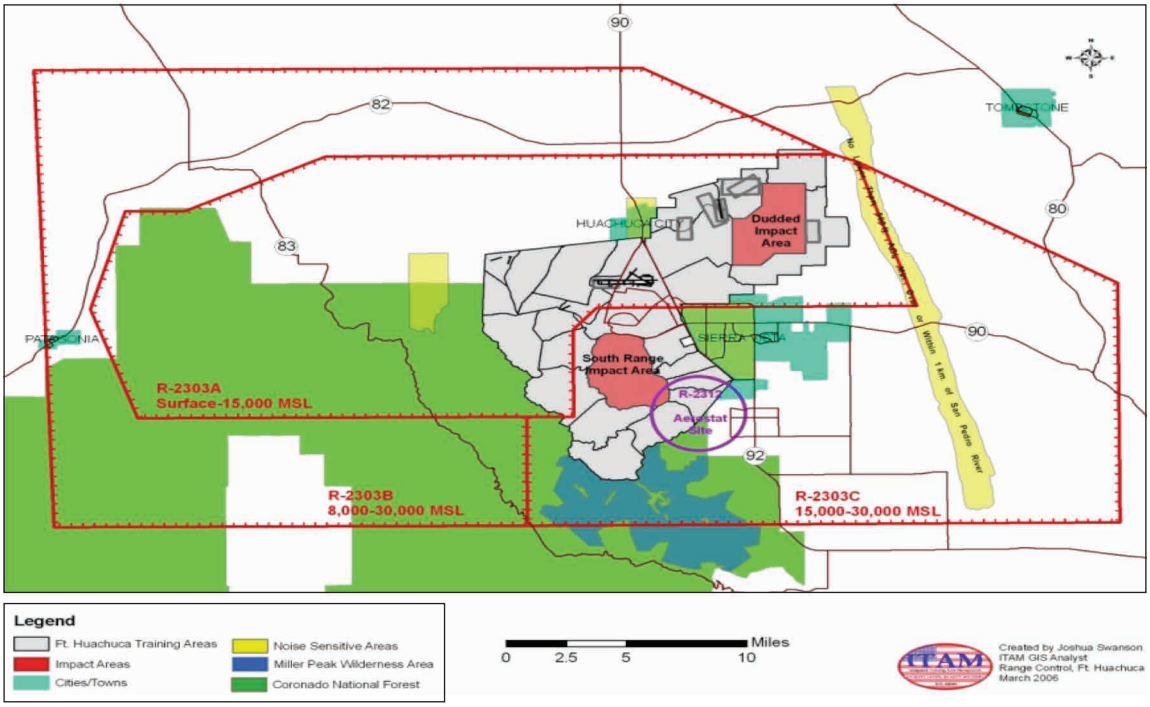
Army RQ-7 and MQ-1C Training IQT Fort Huachuca, Arizona

Fort Huachuca, Arizona, is home to the 2-13th Aviation Regiment (formally the Unmanned Aircraft Systems Training Battalion). The 2-13th trains operators and maintainers for the RQ-7 Shadow, the Warrior Alpha, and the MQ-1C Gray Eagle. The training pipeline for each of these was described in the body of this report.

Flight Training Areas and Airspace

See Figure C.1. R-2303 is a major operational area used for airspace manned and unmanned operations, Army and joint service training along with Department of Homeland Security border security operations. Fort Huachuca is the controlling authority and so can activate this restricted use airspace on demand, at any time. It covers 850 mi^2 of land outside Fort Huachuca and encompasses 4,600 mi^3 of airspace from the surface to 30,000 feet, much of it over private land. The FAA has issued several waivers to ensure the safe operations of manned and unmanned traffic. The area also has unencumbered radio frequency spectrum for the foreseeable future.

Figure C.1
Airspace Surrounding Fort Huachuca



RAND *RR440-C.1*

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Airfield and Maintenance Facilities

See Figure C.2. UAS operations split between the Libby Army Airfield and Black Tower. Shadow and Hunter training takes place at Black Tower. There are dedicated maintenance facilities as well as hangers and airstrips. Gray Eagle training takes place at Libby Army Airfield.

Expansion Potential

The IQT common core and the course for Shadow are currently running 24-hour operations. It would be difficult to expand the student capacity without committing more resources. The Gray Eagle course is just beginning, and the Hunter course is winding down. There is enough infrastructure for the planned capacity. Any expansion would require more resources.

Training and Training Facilities

Most UAS training operations take place at the Black Tower complex. Gray Eagle and Warrior Alpha vehicles are flown out of Libby Army Airfield.

Military and General Support Mission

Fort Huachuca is home to the military intelligence schoolhouse. This proximity could provide a unique opportunity for collective training between the two schoolhouses. Huachuca is also home to the Buffalo Soldier Electronic Testing Range.

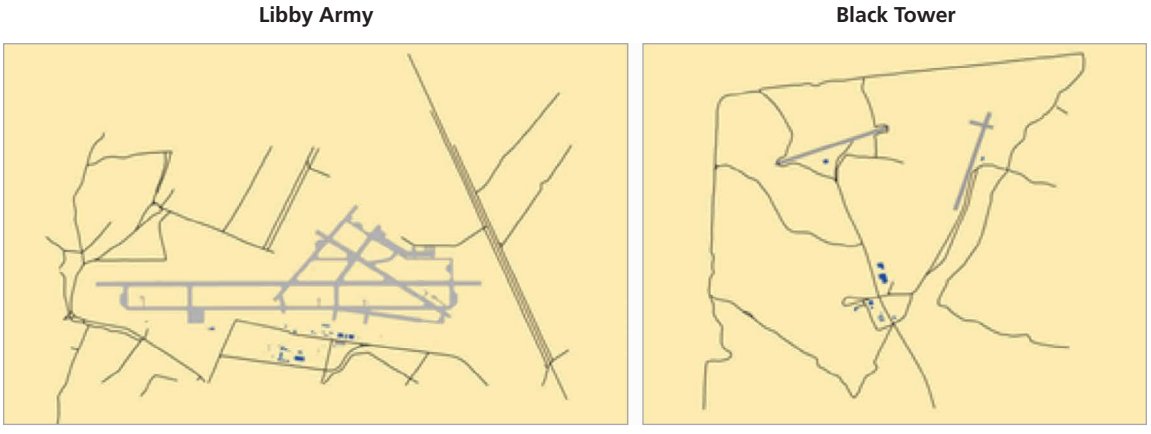
Weather

Fort Huachuca has excellent weather for UAS operations. It has approximately 270 training days a year.

Location

See Figure C.3. Fort Huachuca is situated in southeastern Arizona, near the town of Sierra Vista. There are approximately 60,000 people at Fort Huachuca.

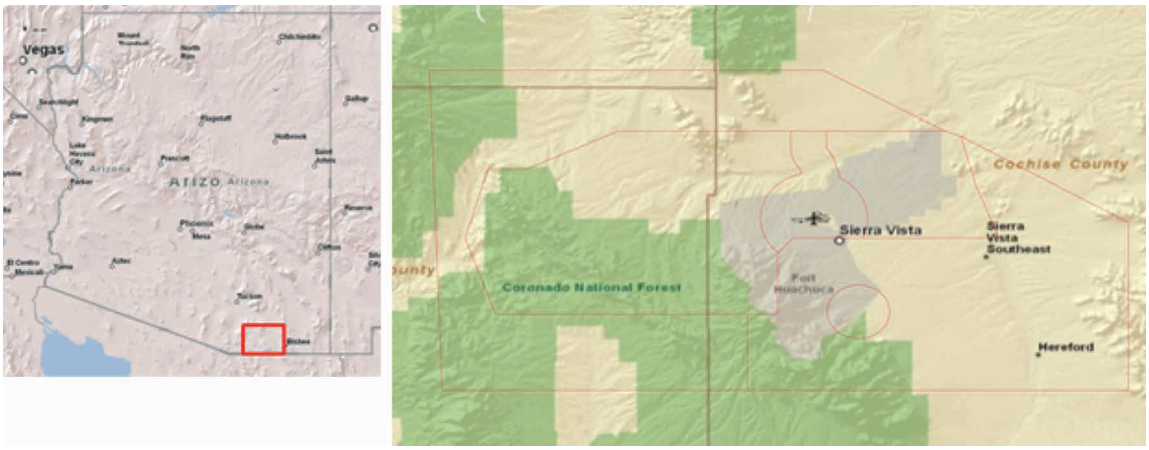
Figure C.2
Airfield and Maintenance Facilities at Fort Huachuca



RAND *RR440-C.2*

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Figure C.3
Location of Fort Huachuca



RAND *RR440-C.3*

Base Loading

Fort Huachuca is the hub for Army UAS training. This consolidation could be both good and bad. The lack of redundancy elsewhere limits the ability to expand operations when needed. For example, if one of the runways were damaged, the entire Army UAS training capability could be severely affected.

Air Force Active Duty MQ-1/9 Formal Training Unit—Holloman AFB, New Mexico

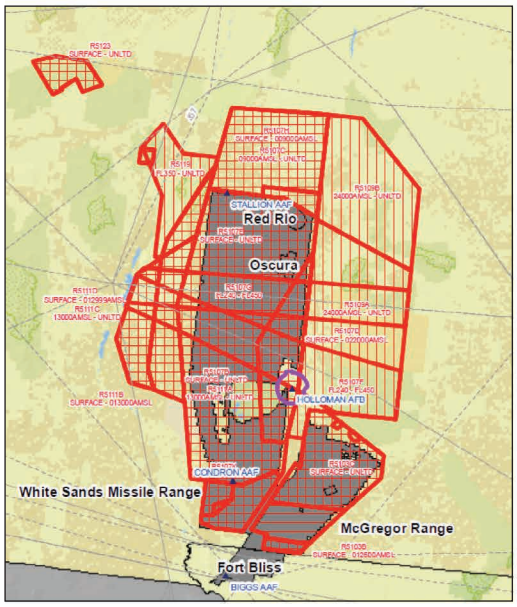
Flight Training Areas and Airspace

See Figure C.4. Holloman AFB has access to the restricted airspace areas within the White Sands Missile Range (WSMR) and McGregor airspace. It is possible to reach both ranges without leaving restricted airspace. While competition for airspace is fierce, WSMR supports flying RPA operations out of Holloman AFB. The current plan is for MQ1/MQ9 to depart Holloman AFB northbound for WSMR airspace and to remain totally within R-5107 B/C/D/H. An alternative is to depart Holloman AFB southbound and climb to FL-180 in R-5107D. There is a three-way memorandum of understanding in place, but the testing mission at WSMR occasionally conflicts with RPA training. A few other areas near Holloman AFB have potential for RPA operations, although they require COAs from the FAA.

The MQ-1/9 FTU completed the transition from Creech AFB to Holloman AFB. Plans call for an additional FTU, bringing a total of five MQ-1/9 training squadrons, including one maintenance squadron, to Holloman AFB. These squadrons will fall under the 49th Wing and bring in an additional 200 officers, 250 enlisted, and 150 contractors. Two hundred students are expected to cycle through in three-month training periods. Holloman AFB would have 28 MQ-1s and 10 MQ-9s. To operate the aircraft, they would have 12 common ground stations, four Predator Primary Satellite Links, two LREs, and five mission control elements. They expect to fly approximately 2,800 sorties a year, 540 at night.

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Figure C.4
Restricted and Non–Joint Use Class D Airspace near Holloman AFB



	Altitudes		Hours of Use	
	Minimum	Maximum	From	To
Airspace				
Beak A MOA	12,500 feet MSL	UTBNI FL180	0600	Sunset
Beak B MOA	12,500 feet MSL	UTBNI FL180	0600	Sunset
Beak C MOA	12,500 feet MSL	UTBNI FL180	0600	Sunset
Beak A/B/C ATCAAs	FL180	UTBNI FL230	As scheduled and coordinated	
Ancho A/B/C ATCAAs	FL180	UTBNI FL230	As scheduled and coordinated	
Cowboy A/B/C ATCAAs	FL230	FL600	As scheduled and coordinated	
Talon High East MOA	12,500 feet MSL	FL180	Sunrise	Sunset
Talon High West MOA	12,500 feet MSL	FL180	Sunrise	Sunset
Talow Low MOA	300 FEET AGL	UTBNI 12,500 feet MSL	Sunrise	Sunset
Talon High East and West ATCAAs	FL180	FL600	As scheduled and coordinated	
Valmont ATCAA	FL180	FL600	As scheduled and coordinated	
Restricted Area				
R-5103B (McGregor)	Surface	Unlimited	0700†	2000†
R-5103C (McGregor)	Surface	Unlimited	0700†	2000†
R-5107A (Ft Bliss)	Surface	Unlimited	Continuous	
R-5107B (WSMR)	Surface	Unlimited	Continuous	
R-5107C (WSMR)	9,000 feet MSL	Unlimited	Continuous Monday - Friday 12 hours in advance††	
R-5107D (WSMR)	Surface	FL220	Continuous	
R-5107E (WSMR)	Surface	Unlimited	By NoTAM 12 hours in advance	
R-5107F (WSMR)	FL240	FL450	Continuous M-F; 12 hours in advance pm weekends	
R-5107G (WSMR)	FL240	FL450	Continuous M-F; 12 hours in advance pm weekends	
R-5107H (WSMR)	Surface	UTBNI 9,000 feet MSL	By NoTAM 12 hours in advance	
R-5107J (WSMR)	Surface	UTBNI 9,000 feet MSL	Continuous Mon-Fri 12 hours in advance ††	
R-5109A	24,000 feet MSL	Unlimited	Intermittent by NoTAM	
R-5109B	24,000 feet MSL	Unlimited	Intermittent by NoTAM	
R-5111A (WSMR)	13,000 feel MSL	Unlimited	By NoTAM 12 hours in advance	
R-5111B (WSMR)	Surface	UTBNI 13,000 feet MSL	By NoTAM 12 hours in advance	
R-5111C (WSMR)	13,000 feel MSL	Unlimited	By NoTAM 12 hours in advance	
R-5111D (WSMR)	Surface	13,000 feet MSL	By NoTAM 12 hours in advance	

Notes: † – other times by NOTAM, †† – other times by NOTAM, 12 hours in advance
UTBNI = Up to, but not including; AGL = above ground level; FL = Flight level. FL 180 is approximately 18,000
Feet MSL; MSL= mean sea level; NOTAM = Notice to Airmen
Source: U.S. Air Force 2006

RAND *RR440-C.4*

Airfield and Maintenance Facilities

These are included with the training facilities.

Expansion Potential

The second MQ-9 FTU is scheduled to open in FY 2013, making Holloman home to three MQ-1/MQ-9 FTUs. There is currently a year lag in infrastructure to be able to support a third FTU. The new facilities were supposed to have been finished prior to the standup of the new FTU; however, construction is running approximately a year behind schedule. It is difficult to comment on the ability to meet the required capacity as the capacity requirement is in flux.

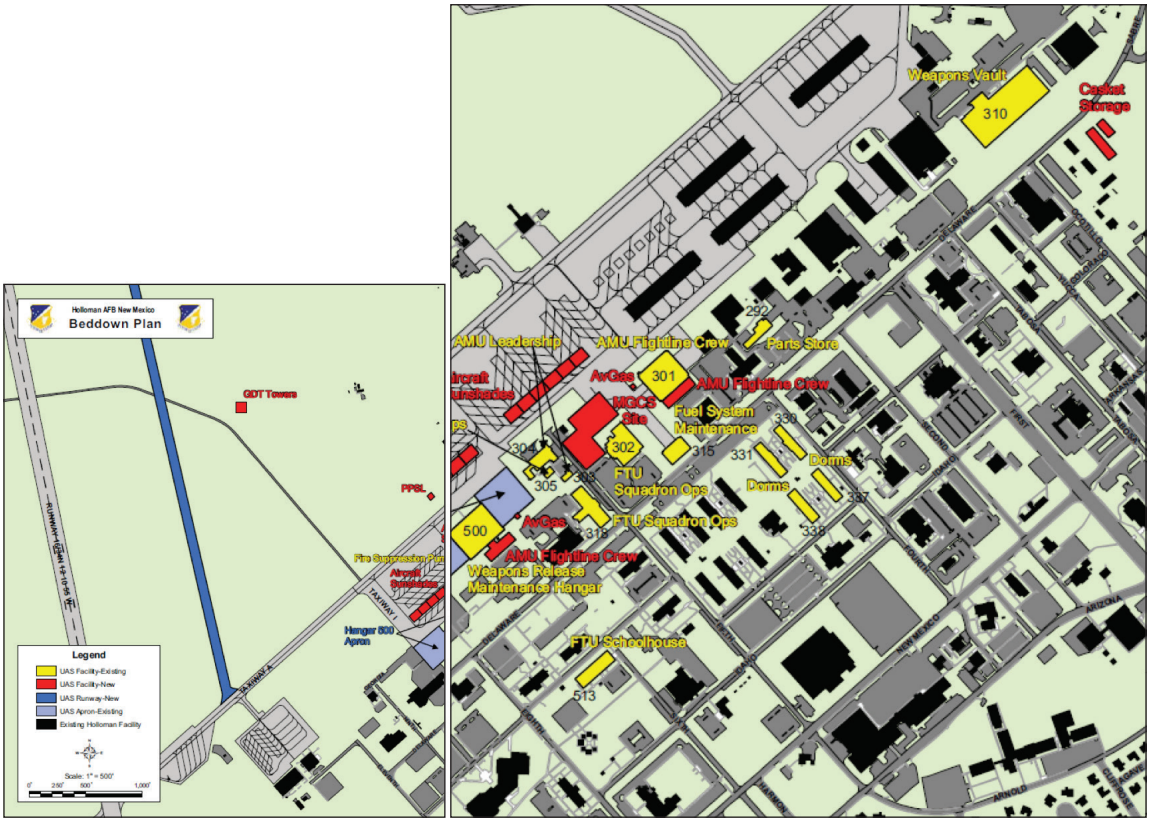
Training and Training Facilities

See Figure C.5. Holloman AFB has 200,000 ft^2 of existing and open facilities, including office space and hangars that could accommodate the FTUs with minor renovations. The map in Figure C.5 shows where new facilities would be located and identifies existing facilities.

Table C.1 shows the space required to start up the unit, as well as the required final bed-down space, as defined by military construction. Table C.2 shows the facility plan for each functional requirement.

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Figure C.5
MQ-1/MQ-9 Beddown Plan



RAND *RR440-C.5*

Military and General Support Mission

Other aircraft flown at Holloman currently include the T-38, MQ-1, MQ-9, the QF-4, and the German Tornado.[3] There are plans to move at least a portion of the F-16 FTUs from Luke AFB, Arizona, to Holloman AFB. This could affect the availability of airspace access.

Location

Holloman AFB is located in southern New Mexico, near the town of Alamogordo. The base encompasses about 59,600 acres and has a population of about 21,000 military, civilian, and families.

Base Loading

Moving the FTUs from Creech AFB to Holloman AFB freed up some capacity at the former and allowed the latter to focus purely on training.[4] There is some redundancy with the Air National Guard FTU at March ARB; however, that FTU is much smaller and primarily trains

[3] A German training unit is stationed at Holloman AFB. The F-22s will be transitioning from the base. Air Combat Command and the Air Staff are deciding what to put in place of the F-22 squadron.

[4] The LRE training is a separate course from the FTU and still taught at Creech.

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Table C.1
Beddown Plans

Function/Activity	Space Required for	
	Initial Startup	Final Beddown
Parking apron (000 ft^2)	30	60
Squadron operations facility (000 ft^2)	16	48
FTU schoolhouse	20	50
(classrooms and simulators) (000 ft^2)	11	11
MCE facility (000 ft^2)	12	24
Aircraft maintenance unit (000 ft^2)	30	70
Munitions PGM shop (000 ft^2)	2	Unknown
Munitions storage (000 ft^2)	3	Unknown
Aircraft parts store (000 ft^2)	10	10
Weapon load trainer (bays)	1 bay	1 bay[a]
Casket storage (000 ft^2)	8	16
Bulk fuel storage (gal)	32	32
Lodging (rooms)	60	200
All backshops (000 ft^2)	24	24

[a] Use maintenance bay.

Air National Guard operators. March ARB currently has adequate infrastructure and capacity for its training mission.

Air Force RQ-4 Formal Training Unit—Beale AFB, California

Flight Training Areas and Airspace

Because of the altitude at which RQ-4s conduct their primary mission, airspace access is manageable at Beale AFB. A cylinder is used to access Class A airspace. The FAA provides a standing window for flights into this cylinder of 10 hours a day, every weekday. Requests outside this window are handled individually and have not been a limitation.

Airfield and Maintenance Facilities

Beale AFB has dedicated airfield and maintenance facilities.

Expansion Potential

There is enough capacity for expanding the training mission of RQ-4s at Beale AFB. There are plans to include some portion of the operator or maintenance training for the Navy's MQ-4 BAMS at Beale, but this would be several years from now.

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Table C.2
Facility Requirements

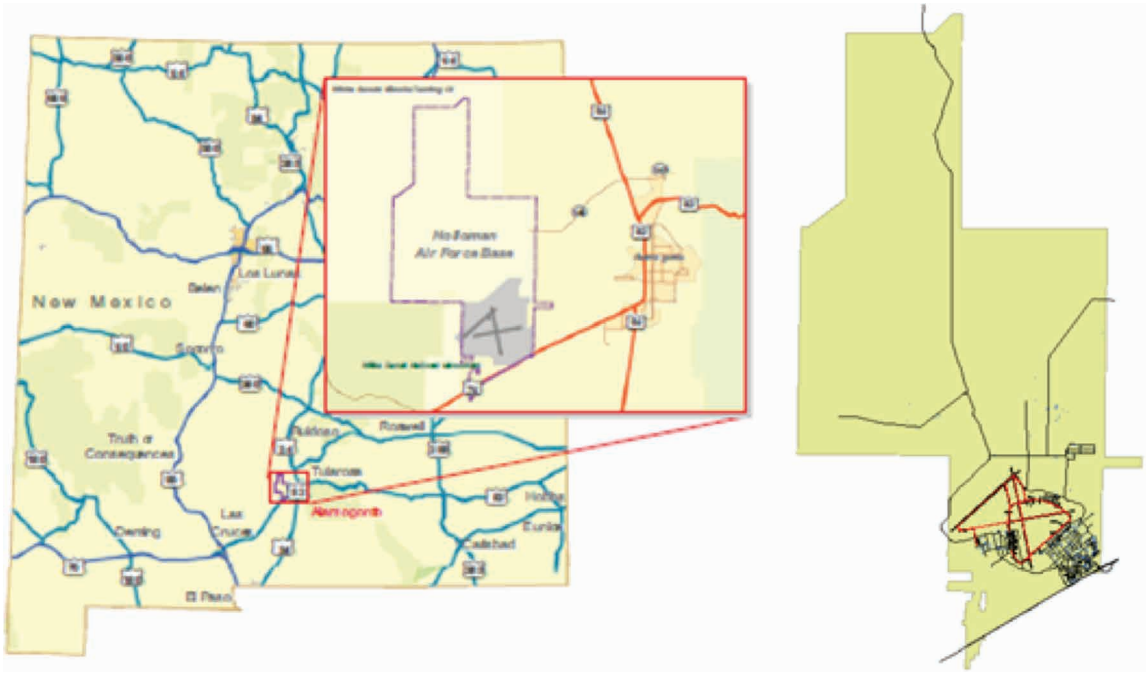
Function Description	Remarks
Flightline pavement	Use main ramp.
Live ordnance load area	Construct new LOLA on taxiway Echo.
Maintenance hangar (new FTU)	Use building 500.
Maintenance hangar (3 FTU squadrons)	Use building 301.
FTU squadron operations (new FTU)	For initial capability, use building 513 and a portion of building 302; when project is complete, transition from building 513 into building 318.
FTU squadron operations (Creech UAS)	If there are two FTU squadrons, use building 318; a third FTY squadron can occupy all of building 302 after F-22A transition is complete.
Aircraft maintenance unit (new FTU)	Initially locate leadership team in building 303 and operate flightline crews out of building 301 until completion of building 500 new construction (10,000 ft^2).
Aircraft maintenance unit (3 FTU squadrons)	If two units, locate both leadership teams in building 303 and flightline crews of the second unit in building 301. If three units, locate third leadership team in building 302 and locate flightline crew in building 302. New construction for building 301 can also be considered for the third crew.
Fuel system maintenance	Use building 315.
Precision guided munitions facility	Construct two maintenance bays and administration.
Munitions storage	Construct 26-by-120-ft Hayman igloo (possibly two 60-ft sections).
Aircraft parts store (new FTU)	Use existing contract support or shared building 292 (T-38 parts store).
Aircraft parts store (3 FTU squadrons)	If T-38 mission relocates, use building 292. If no relocation, add space to building 292.
Weapon release shop	Use each respective maintenance bay (building 500 for one and building 302 for two).
Casket storage	Construct 50-by-800-ft covered storage pad in logistics readiness squadron yard. Requirement may grow, depending on quantity of MQ-9 caskets on hand.
Bulk fuel storage	Construct two 8,000-gallon tanks adjacent to hangars 301 and 500 (for aviation gas) for MQ-1 and use existing JP-8 capacity for MQ-9.
Various backshops	Construct 5,000-ft^2 addition on building 500. Building 301 may require new additional space.

Training and Training Facilities

Beale AFB has adequate training space. There are several different aspects of training: classroom, simulation, and live flights. There is enough classroom space available for both the sensor operator training and the pilot training. The pilots use a pilot simulator to cover emergency procedures and aircraft operation. This simulator is very limited in its ability to mimic real-life contingencies. The sensor operators train on Data Analysis Workstations. These two simulators are not compatible, so there is no true crew simulator. Such a simulator has been

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Figure C.6
Location of Holloman AFB



RAND *RR440-C.6*

programmed but is still eight to ten years away.[5] Crew training takes place on live missions, with instructors flying the mission with students.

Military and General Support Mission

Beale AFB is home to several other aircraft, including the MC-12, the U-2, and the T-38. The RQ-4 fits well with the mission of other aircraft at Beale since it was designed to eventually replace the U-2. RQ-4 pilots are also doing tours in the MC-12. There was some talk of maintaining dual currency in the two platforms, but the status of that plan is unknown.

Location

Beale AFB is located in northern California, approximately one hour outside Sacramento. The nearest town is Marysville, California.

Base Loading

Beale AFB is the hub for high-altitude surveillance. The installation is extremely large, with plenty of room for growth.

[5] We understand this decision to be based on resources since on-the-job training on live missions is available.

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Unmanned aircraft systems (UASs) have become increasingly prevalent in and important to U.S. military operations. Initially serving only as reconnaissance or intelligence platforms, they now carry out such other missions as attacking enemy forces. The swift expansion in their numbers and in the demand for their employment has, however, significantly increased demands on logistics and training systems. The challenge is not simply training system operators but also training operational forces and their commanders to integrate the systems into combat operations. Much of that aspect of training has thus far happened as units employ the systems in actual operations—essentially, on-the-job training. UAS training, particularly for the employment of UASs, now needs to be integrated more formally and cost-effectively into service and joint training programs. This report develops a general concept for training military forces in employment of UASs and a framework for addressing the training requirements and discusses the limits of existing infrastructure in supporting UAS training. Interoperability among services is another issue, because services have thus far mainly developed training suitable for their own needs. But the services have established a set of multiservice tactics, techniques, and procedures for UASs, which should facilitate interoperability training. At present, units are not always ready for joint training, so the focus should be on improving training at the unit level in the employment of UAS capabilities, with the overall guiding principle being to "train as we fight."



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UNMANNED SYSTEMS IN PERSPECTIVE

A Monograph

by

Major David F. John

United States Air Force



School of Advanced Military Studies
United States Army Command and General Staff College
Fort Leavenworth, Kansas

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Unmanned systems have become a vital component of US military operations in the twenty-first century. They are here to stay, and their utility will continue to expand. Nevertheless, uninformed beliefs and biases continue to skew the discourse regarding unmanned systems. These systems do not constitute a fundamental change in the nature or character of warfare. Policymakers, strategists, or operators who attempt to use unmanned systems in place of human prudence will be profoundly disappointed with the results. They are not a revolution in military affairs, nor do they provide easy answers to the challenges of war. While all of the Services have developed and fielded unmanned systems, the US Air Force's evolution of unmanned aircraft since 2001 is particularly illuminating for future endeavors.

Rather than pursue robotic autonomy, the US military must cultivate professional service members with the skill and discipline to wield unmanned systems adeptly. The Services must fully integrate the tactics and technology of unmanned systems with manned components of the force, as both will be crucial in future endeavors. Leaders should never allow technology to dictate policy or strategy; unmanned systems must always fit into legitimate and comprehensive plans.

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The opinions and conclusions expressed herein are those of the student author, and do not necessarily represent the views of the US Army Command and General Staff College or any other government agency. (References to this study should include the foregoing statement.)

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ABSTRACT

UNMANNED SYSTEMS IN PERSPECTIVE, by Major David F. John, United States Air Force, 94 pages.

Unmanned systems have become a vital component of US military operations in the twenty-first century. They are here to stay, and their utility will continue to expand. Nevertheless, uninformed beliefs and biases continue to skew the discourse regarding unmanned systems. These systems do not constitute a fundamental change in the nature or character of warfare. Policymakers, strategists, or operators who attempt to use unmanned systems in place of human prudence will be profoundly disappointed with the results. They are not a revolution in military affairs, nor do they provide easy answers to the challenges of war. While all of the Services have developed and fielded unmanned systems, the US Air Force's evolution of unmanned aircraft since 2001 is particularly illuminating for future endeavors.

Rather than pursue robotic autonomy, the US military must cultivate professional service members with the skill and discipline to wield unmanned systems adeptly. The Services must fully integrate the tactics and technology of unmanned systems with manned components of the force, as both will be crucial in future endeavors. Leaders should never allow technology to dictate policy or strategy; unmanned systems must always fit into legitimate and comprehensive plans.

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ACRONYMS

AOC	Air Operations Center
ATC	Air Traffic Control
CAP	Combat Air Patrol
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DODD	Department of Defense Directive
FCS	Future Combat System
FMV	Full-motion Video
GPS	Global Positioning System
ICBM	Intercontinental Ballistic Missile
IED	Improvised Explosive Device
ISR	Intelligence, Surveillance, and Reconnaissance
JFACC	Joint Force Air Component Commander
JTAC	Joint Terminal Air Controller
LCS	Littoral Combat Ship
PTSD	Posttraumatic Stress Disorder
ROE	Rules of Engagement
RPA	Remotely Piloted Aircraft
RSO	Remote Split Operations
SA	Situational Awareness
SATCOM	Satellite Communications
SEAL	Sea, Air, Land
SIGINT	Signals Intelligence
SR-UAV	Short-Range Unmanned Aerial Vehicle
TTP	Tactics, Techniques, and Procedures

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UAS	Unmanned Aircraft System(s)
UAV	Unmanned Aerial Vehicle
UCAS	Unmanned Combat Air System(s)
UGS	Unmanned Ground System(s)
UGV	Unmanned Ground Vehicle
UMS	Unmanned Maritime System(s)
UN	United Nations
USAF	United States Air Force
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle

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INTRODUCTION

Technology alone has never won a war. Genghis Khan's stirrups, Hernán Cortés's firearms, and America's atomic bombs all gave their users critical advantages, but they were pivotal only because they fit into situations and strategies that suited their use. Unmanned systems today fall into the same category. Though many see so-called "drones" as a revolutionary, ominous development in warfare, in fact they are nothing of the sort. Unmanned systems do not constitute a fundamental change in the nature or character of warfare. Policymakers, strategists, or operators who attempt to use unmanned systems in place of human prudence will be profoundly disappointed with the results.

Two explanations exist for the burgeoning interest in military unmanned systems over the past decade. The first is the most obvious: they are multiplying across the globe. Advances in technology, cost considerations, and persistent conflicts waged by modern societies fuel this proliferation. Unmanned systems satisfy numerous requirements for policymakers and combatants. Their utility will continue to expand.

The second explanation for the prevalence of unmanned systems in public discourse is more subjective—they impassion people across a wide spectrum of beliefs and interests. Engineers envision marvelous new creations. Futurists and philosophers contemplate the implications of autonomous robots. The defense industry sees a profitable market. Military budgeters imagine billions of dollars in savings. Commanders clamor for solutions to extend their situational awareness (SA) and control of the battlespace.[1] Soldiers, sailors, airmen, and Marines

[1]"Situational Awareness: The perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the future." Department of Defense, *Unmanned Systems Safety Guide for DoD Acquisition,* Version .96 (Washington, DC: Department of Defense, January 2007), http://www.ndia.org/Divisions/Divisions/Robotics/Documents/Content/ContentGroups/Divisions1/Robotics/UMS_SafetyPolicyVer096_Released.pdf (accessed 1 March 2014), 16.

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(and their loved ones) envision war without friendly casualties. Meanwhile, pacifists proclaim that drones are slaughtering innocents, and conspiracy theorists think the movie *The Terminator* is now a reality.[2]

In other words, assertions about unmanned systems often depend more on a speaker's beliefs than on the facts, and these biases distort the collective discussion. The critical thinker must endeavor to minimize these inevitable shades, but one cannot eliminate them. The following analysis just as surely reflects the author's own biases. He is a United States Air Force (USAF) senior pilot of both manned and unmanned aircraft, and holds dual master's degrees in military history and military operational art and science. This background suggests an opportunity for contextual accuracy that many voices in the debate may lack.

This project consists of five parts. Section I examines the evolution of unmanned systems into the types currently employed by the US military. Section II analyzes the ways in which the USAF has integrated unmanned aircraft systems (UAS) into the modern battlefield.[3] Section III addresses the false notion that unmanned systems are a revolution in military affairs (RMA), and debunks flawed assumptions regarding the development and employment of this technology. Section IV delves into the realm of policy to demonstrate that unmanned systems change neither the nature nor the rules of armed conflict. Finally, Section V presents three recommendations for the further development and operation of military unmanned systems: professional discipline, comprehensive integration, and prudent strategy.

The lexicon surrounding unmanned systems remains in a state of flux (so it goes with military jargon). This project will adhere to the terminology contained within Joint Publication 1-

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[2]Nick Turse and Tom Engelhardt, *Terminator Planet: The First History of Drone Warfare, 2001-2050* (Lexington, KY: Dispatch Books, 2012), 4.

[3]The term Unmanned Aerial Vehicle (UAV) refers to an aircraft per se, while Unmanned Aircraft System (UAS) denotes the collection of components that make up a complete package, to include aircraft, control station, launch and recovery equipment, communications relays, etc.

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02 and the Department of Defense (DOD) *Unmanned Systems Integrated Roadmap FY2011-2036*, but direct quotes will preserve authors' original phrasing and abbreviations. The expression "unmanned system(s)" will remain unabbreviated throughout this discussion. The inaccurate and pejorative term "drones" will appear only by exception.

I – UNMANNED SYSTEMS PAST AND PRESENT

Humanity has been on a quest to increase standoff distance in warfare ever since an early hominid first thought to hurl a rock instead of bludgeoning his enemy. While the intercontinental ballistic missile (ICBM) and its younger sibling the cruise missile are the ultimate weapons in distance warfare, the military technically does not regard them as unmanned systems. The *Unmanned Systems Safety Guide* defines an unmanned system as such:

> An electro-mechanical system that is able to exert its power to perform designed missions and includes the following: (1) there is no human operator aboard and (2) the system is designed to return or be recoverable. The system may be mobile or stationary. [Unmanned Systems] include unmanned ground vehicles [UGVs], unmanned aerial vehicles [UAVs], unmanned underwater vehicles [UUVs], unattended munitions, and unattended ground sensors. Missiles, rockets and their submunitions, and artillery are not considered [unmanned systems].[4]

The development of unmanned systems spanned the twentieth century. In 1898, Nicola Tesla built a radio-controlled boat, which he envisioned as a potential weapon. Western militaries developed remote-controlled aircraft and torpedoes during World War I, but none proved particularly successful.[5] Further development occurred during the interwar years but reliability and accuracy remained problematic. During World War II, Japan experimented with unmanned air, sea, and ground vehicles, but ultimately it addressed the accuracy problem by resorting to the kamikaze. Germany actually deployed several thousand UGVs called *Goliath*, but their slow

[4]Department of Defense, *Unmanned Systems Safety Guide*, 1.

[5]Armin Krishnan, *Killer Robots: Legality and Ethicality of Autonomous Weapons* (Burlington, VT: Ashgate, 2009), 15-16; Jeremiah Gertler, *U.S. Unmanned Aerial Systems* (Washington, DC: Congressional Research Service, 3 January 2012), http://fpc.state.gov/documents/organization/180677.pdf (accessed 1 March 2014), 1.

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speed, unwieldy cable link, and lack of a camera (forcing operators to remain within eyesight) made them impractical in combat.[6] The Allies remained largely disinterested in unmanned systems during the war, notwithstanding the tragic crash of an experimental remotely controlled B-24 bomber that claimed the life of Joseph P. Kennedy Jr., the future president's older brother.[7]

Following World War II, the US military's interest in unmanned systems began to grow. The US Navy used unmanned maritime systems (UMS) to conduct minesweeping operations and to take radioactivity samples after nuclear tests.[8] In the late 1960s, the USAF first experimented with manned-unmanned teaming by remotely controlling AQM-34 UAVs from an airborne C-130 aircraft.[9] Most UAVs during the Cold War flew as practice targets, as decoys for enemy radars, or for limited intelligence collection.[10] Concurrently, the US military made great strides with precision-guided weapons and satellite technology, both of which proved crucial to future unmanned endeavors.[11]

The 1990s heralded the modern age of unmanned systems with the arrival of the General Atomics RQ-1 Predator, which flew reconnaissance missions over the conflicts in the Balkans from 1995 onward.[12] The National Defense Authorization Act of 2001 gave the DOD the goal to

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[6]Krishnan, 16-18.

[7]Ibid., 18-19. The crew flew the takeoff and initial navigation of the bomber before setting the autopilot, arming the payload, and preparing to bail out. Unfortunately, the explosives detonated prematurely.

[8]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036* (Washington, DC: Department of Defense, 2011), http://www.defenseinnovationmarketplace.mil/resources/UnmannedSystemsIntegratedRoadmapFY2011.pdf (accessed 1 March 2014), 25.

[9]Ibid., 82.

[10]Gertler, 1.

[11]Krishnan, 19-22.

[12]Christopher Drew, "Drones are Weapons of Choice in Fighting Qaeda," *The New York Times*, 16 March 2009, http://www.nytimes.com/2009/03/17/business/17uav.html (accessed 1 March 2014). The coalition did deploy several variants of UAS during the 1991 Gulf War for reconnaissance and gunnery spotting purposes. See Gertler, 2.

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convert one third of its deep strike aircraft into unmanned systems within a decade.[13] In the first half of 2001, the US military began test firing AGM-114 Hellfire missiles from Predator aircraft.[14] The anti-tank Hellfire's lightweight design, laser-guided precision, and modifiable warhead made it a flexible weapon for a wide array of potential targets.

The events of 11 September 2001 (i.e. 9/11) accelerated the weaponization of unmanned systems. On 7 October 2001, the United States first flew an armed Predator over Afghanistan,[15] and on 4 February 2002, a Predator launched the first Hellfire in combat. The alleged target was a tall Saudi expatriate wanted for the recent murder of 3,000 American civilians. The identification proved erroneous, and Osama bin Laden survived for another nine years before his death at the hands of US Navy SEALs.[16] By the end of the first year of Operation Enduring Freedom, Predator crews had launched Hellfires at 115 targets in Afghanistan.[17]

In December 2002, the USAF conducted an on-the-job experiment with unmanned air-to-air combat by loading AIM-92 Stinger missiles on its Predators flying over Iraq. One Predator fired a Stinger at an attacking Iraqi MiG-25 fighter, but it missed—the MiG did not.[18]

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[13]National Defense Authorization Act, Fiscal Year 2001, Appendix. 106th Cong., 30 October 2000. Public Law 106-398, http://www.gpo.gov/fdsys/pkg/PLAW-106publ398/pdf/PLAW-106publ398.pdf (accessed 1 March 2014), 1654A-38; Gertler, 2.

[14]George Tenet, "Written Statement for the Record of the Director of Central Intelligence before the National Commission on Terrorist Attacks Upon the United States," 24 March 2004, http://www.9-11commission.gov/hearings/hearing8/tenet_statement.pdf (accessed 1 March 2014), 15.

[15]Ibid., 16.

[16]Thom Shanker and James Risen, "A Nation Challenged: Raid's Aftermath; U.S. Troops Search for Clues to Victims of Missile Strike," *The New York Times,* 11 February 2002, http://www.nytimes.com/2002/02/11/world/nation-challenged-raid-s-aftermath-us-troops-search-for-clues-victims-missile.html (accessed 1 March 2014).

[17]P. W. Singer, *Wired for War: The Robotics Revolution and Conflict in the Twenty-first Century* (New York, NY: Penguin Press, 2009), 35.

[18]Matt J. Martin and Charles W. Sasser, *Predator: The Remote-Control Air War over Iraq and Afghanistan: A Pilot's Story* (Minneapolis, MN: Zenith Press, 2010), 21; David A. Fulghum, "Predator's Progress," *Aviation Week and Space Technology* 158, no. 9 (3 March 2003): 48.

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Unmanned Aircraft in the US Military

The Predator is the best-known UAS, but it is only one of many unmanned systems currently flying over conflict zones. The growth of UAS in the past two decades brings to mind the development and proliferation of manned aircraft in the years immediately prior to and during World War II.[19] In the United States, the late 1930s and early 1940s saw the progression of fighter aircraft from outdated monoplanes into the venerable P-51 Mustang and jet prototypes, while twin-engine bombers paved the way for the mighty B-29 Superfortress. Likewise, UAS operated by the US military have burgeoned from simple prototypes into a wide array of sizes and capabilities.

The DOD categorizes its operational UAS into five groups.[20] Group 1 consists of short-range unmanned aerial vehicles (SR-UAVs). SR-UAVs in the current DOD inventory are unarmed and communicate via direct line-of-sight (LOS) signals. These platforms, currently flown by all the Services, include hand-launched UAVs like the RQ-11 Raven. The Raven provides "over the hill" situational awareness (SA) to troops in the field. These troops can manually fly the SR-UAV, or program it via Global Positioning System (GPS) waypoints, out to a range of seven to ten miles. Its camera, which sends live video back to the operator, includes both electro-optical (i.e. television) and infrared modes. The WASP III, also known as the Battlefield Air Targeting Micro Air Vehicle (BATMAV), is an even smaller UAV used by Special Operations Command and the US Marines. It has a range of three miles with electro-optical and infrared capabilities similar to the Raven's sensors.[21]

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[19]Gertler, 6.

[20]Each of the Services groups its UAS into tiered systems that do not always correspond to the other Services' categories; the DOD's five-group methodology is one attempt to rectify this confusion.

[21]Headquarters, United States Air Force, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047* (Washington, DC: Headquarters, United States Air Force, 18 May 2009), www.govexec.com/pdfs/072309kp1.pdf (accessed 1 March 2014), 25-26.

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Group 2 consists of the Scan Eagle, an albatross-sized UAS launched via catapult, to include mounts on US Navy ships. The Scan Eagle can fly via preprogrammed waypoints out to sixty miles for up to twenty hours. The Navy and Marines plan to replace their Scan Eagles with a new Small Tactical Unmanned Aerial System (STUAS), with similar real-time intelligence, surveillance and reconnaissance (ISR) capabilities.[22]

Group 3 contains the slightly larger RQ-7 Shadow and the MQ-5 Hunter. These UAS fly higher, faster, longer, and farther than the UAS in Groups 1 and 2, but they remain tethered to a LOS data link.[23] While the RQ-7 is unarmed, the US Army has equipped several of its MQ-5s with small laser-guided bombs (the "M" designates multi-role, i.e. weapon carrying, versus the unarmed "R," for reconnaissance).[24]

Group 4 is the domain of the MQ-1 (formerly RQ-1) Predator. It can carry up to two Hellfire missiles and pilots can fly it using LOS signals or via satellite communications (SATCOM). Because SATCOM introduces approximately a two-second roundtrip delay between an operator's input and the visible aircraft response, USAF crews launch the Predator via LOS. They then transfer control to a geographically separated crew that uses SATCOM to fly missions that can last over twenty-two hours. Remote split operations (RSO) is the term for this collaboration.[25] Also included in Group 4 is the US Army's MQ-1C Gray Eagle, a Predator variant that the Army continues to improve and field in greater numbers, and the MQ-8 Fire Scout unmanned helicopter.[26] The latter currently is in testing to carry small laser-guided

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[22]Gertler, 45-46.

[23]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 21.

[24]Army Technology, "Hunter RQ-5A / MQ-5B/C UAV, United States of America," *Army-Technology.com*, n.d., http://www.army-technology.com/projects/hunter (accessed 1 March 2014).

[25]United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 26.

[26]Tamir Eshel, "Improving the Army's Gray Eagle," *Defense Update*, 30 July 2013, http://defense-update.com/20130730_improving-the-armys-gray-eagle-mq-1c.html (accessed 1 March 2014).

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rockets.[27] The Navy's Unmanned Combat Air System (UCAS), presently in the initial stages of development, will be the subject of further analysis below.[28]

Group 5 consists of the largest UAS in today's inventory: the MQ-9 Reaper, RQ-4 Global Hawk, and RQ-170 Sentinel. The Reaper is essentially the Predator's big sibling. It can carry up to 3,000 pounds of weapons, currently a combination of Hellfires and 500-pound laser- or GPS-guided bombs. It also can mount payloads like synthetic aperture radar, wide-angle cameras, and other signals intelligence (SIGINT) equipment.[29] Reapers eventually will supplant Predators in the USAF inventory, though the timing of this phased replacement remains in flux.[30]

Dwarfing the Reaper is the RQ-4 Global Hawk, which boasts a 130-foot wingspan. It is significantly larger than the U-2 spy plane of Cold War fame that it was designed to replace (both aircraft remain in service today). The RQ-4 has a 60,000-foot ceiling, 28-hour endurance, a range of 8,700 miles, and cruises at over 300 knots using a turbofan jet engine.[31] In 2001, one flew nonstop from the United States to Australia.[32] The Global Hawk uses RSO similar to the Predator and Reaper, though pilots typically fly it using preplanned autopilot routes rather than manually.[33] The unarmed Global Hawk's missions are ISR and battlefield communication support.[34]

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[27]Dave Majumdar, "AUVSI: Northrop Close to Completing Firescout Weapon Tests," *Flightglobal*, 14 August 2013, http://www.flightglobal.com/news/articles/auvsi-northrop-close-to-completing-firescout-weapon-tests-389492 (accessed 1 March 2014)

[28]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 21.

[29]United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 27.

[30]Stephen Daggett and Pat Towell, *FY2013 Defense Budget Request: Overview and Context* (Washington, DC: Congressional Research Service, 20 April 2012), http://www.fas.org/sgp/crs/natsec/R42489.pdf (accessed 1 March 2014), 10.

[31]US Air Force, "RQ-4 Global Hawk," *Air Force Fact Sheets*, 16 October 2008, http://www.af.mil/ AboutUs/FactSheets/Display/tabid/224/Article/104516/rq-4-global-hawk.aspx (accessed 1 March 2014).

[32]James C. Dawkins, Jr., "Unmanned Combat Aerial Vehicles: Examining the Political, Moral, and Social Implications" (monograph, School of Advanced Air and Space Studies, 2005), 15; Gertler, 5.

[33]Singer, *Wired for War*, 36; Gertler, 36.

[34]US Air Force, "RQ-4 Global Hawk"; United States Air Force, *USAF Unmanned Aircraft*

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The United States acknowledges the existence of the RQ-170 Sentinel, but details of the program remain mostly classified.[35] The RQ-170's "flying-wing" design resembles a B-2 bomber. It has a sixty-five-foot wingspan and a single jet engine. Reports claim an RQ-170 provided ISR and data relay for the US Navy SEAL raid that killed Osama bin Laden in Abbottabad, Pakistan, on 1 May 2011.[36] In December 2011, Iran's government claimed that it downed an RQ-170 after the aircraft violated Iranian airspace, but details of the incident remain unclear.[37]

Although many voices in the UAS community continue to advocate for a future of boundless technological expansion, American UAS growth and development is slowing. As late as 2009, the USAF's *UAS Flight Plan* included a timeline for the development of autonomous aircraft, lethal miniature "swarming" robots, unmanned refueling aircraft, three types of advanced tactical UAS, and next-generation long-endurance ISR platforms.[38] Fiscal constriction and the United States' withdrawal from Iraq and drawdown in Afghanistan have forced the DOD to reorient its vision for unmanned systems toward more realistic objectives. In 2009, it cancelled an advanced satellite project to improve military SATCOM bandwidth.[39] The Fiscal Year 2013

Systems Flight Plan 2009-2047, 27.

[35]US Air Force, "RQ-170 Sentinel," *Air Force Fact Sheets*, 10 December 2009, http://www.af.mil/AboutUs/ FactSheets/Display/tabid/224/Article/104547/rq-170-sentinel.aspx (accessed 1 March 2014).

[36]Gertler, 41-42.

[37]Gertler, 42; Spencer Ackerman, "Exclusive Pics: The Navy's Unmanned, Autonomous 'UFO'," *Wired*, 31 July 2012, http://www.wired.com/dangerroom/2012/07/x47b (accessed 1 March 2014); Christian Malis, "New Extrapolations: Robotics and Revolution in Military Affairs," in *Robots on the Battlefield: Contemporary Perspectives and Implications for the Future*, eds. Ronan Douaré, Didier Danet, Jean-Paul Hanon, and Gérard de Boisboissel (Fort Leavenworth, Kansas: Combat Studies Institute Press, 2014), http://usacac.army.mil/CAC2/cgsc/carl/download/csipubs/FrenchRobots.pdf (accessed 1 March 2014), 36.

[38]David Deptula and Eric Mathewson, "United States Air Force Unmanned Aircraft Systems (UAS) Flight Plan 2009-2047," (PowerPoint presentation, Washington, DC: Headquarters, United States Air Force, 23 July 2009), http://www.globalsecurity.org/intell/library/news/2009/intell-090723-dod01.htm (accessed 1 March 2014), slide 15, slide 20; United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 38; Theodore A. Langstroth, "Unmanned Aerial Refueling: Increasing Combat Effectiveness of the Tanker Fleet," *USAF Weapons Review* (Summer 2008): 41; Krishnan, 64-65.

[39]Gertler, 17.

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defense budget halted procurement of new USAF Global Hawks (energetic lobbying is likely to restore funding for the program in the 2015 budget, however).[40] The DOD has slowed the acquisition of Reapers and delayed the Predator's retirement to cover the shortfall.[41] The USAF has canceled plans for a stealthy "MQ-X" and halted progress on further medium-sized UAS designs.[42] The Defense Advanced Research Projects Agency (DARPA) continues to promote UAS research and development, but for the time being the true driver of military technology—defense appropriations—is decelerating.[43]

Unmanned Ground Systems and Mission Command

The US Army had big plans for unmanned ground systems (UGS). In October 1999, the Army began work on a three-decade modernization known as the Future Combat System (FCS). This project envisioned a network of "manned, unmanned, and robotic" vehicles and support equipment designed to enable the Army to prevail on modern and future battlefields.[44] The unmanned projects in the FCS included several variants of UGV, unattended ground sensors, and two new UAVs: a hovering miniature air vehicle and a Fire Scout variant.[45] The most novel technology was an armed UGV, operated remotely, which could be equipped with a wide array of

[40]Daggett and Towell, 10; Aaron Mehta, "Global Hawk Wins in 2015 Request, Sources Say," *Defense News*, 26 January 2014, http://www.defensenews.com/article/20140126/DEFREG02/301260027/Global-Hawk-Wins-2015-Request-Sources-Say (accessed 1 March 2014).

[41]Daggett and Towell, 10. Swarming microbots remain conspicuously absent from the budget.

[42]Lawrence Spinetta and M. L. Cummings, "Unloved Aerial Vehicles," *Armed Forces Journal* (November 2012), http://www.armedforcesjournal.com/unloved-aerial-vehicles (accessed 1 March 2014).

[43]DARPA-BAA-13-28, *Broad Agency Announcement: Tactically Exploited Reconnaissance Node (TERN) Program* (Arlington, VA: Defense Advanced Research Projects Agency, 13 March 2013), https://www.fbo.gov/utils/view?id=c7856332d425ee0e7ff54ea0fe061bff (accessed 1 March 2014).

[44]Andrew Feickert and Nathan Jacob Lewis, RL32888, *Army Future Combat System (FCS) 'Spin-Outs' and Ground Combat Vehicle (GCV): Background and Issues for Congress* (Washington, DC: Congressional Research Service, 30 November 2009), https://opencrs.com/document/RL32888 (accessed 1 March 2014), 1-2.

[45]Feickert and Lewis, 12-14; Scott Gourley, "Army Establishes Structured Approach to BCT Modernization," *Defense Systems*, 24 July 2012, http://defensesystems.com/Articles/2012/07/24/Cover-Story-Brigade-Combat-Team-Modernization.aspx (accessed 1 March 2014).

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lethal (and nonlethal) payloads.[46] While the production model remained in development, in 2007 the Army actually deployed three armed prototypes of the Talon UGV, called SWORDS (Special Weapons Observation Reconnaissance Detection System), to Iraq.[47] The Army appeared on the verge of a major shift toward reliance on unmanned systems, to include lethal UGS.

A decade of sustained land combat and significant program setbacks led to the demise of the FCS before any of its revolutionary unmanned systems ever hit the field. While Soldiers battled irregular insurgents and improvised explosive devices (IEDs) in Iraq and Afghanistan, the FCS program suffered repeated delays and cost overruns. In April 2009, Defense Secretary Robert Gates began dismantling the FCS program by recommending the cancellation of its manned ground vehicle.[48] In January 2010, the Army stopped procurement of the larger UAV, followed by the demise of the smaller one in early 2011 (though several dozen prototypes did see service in the field). Then it stopped development of the unattended ground sensors. Finally, it canceled the UGV.[49] The SWORDS prototypes that deployed to Baghdad never fired a shot, and the Army chose not to purchase more of these systems.[50]

Cost overruns tarnished the FCS, but the program's demise also stemmed from a conscious decision by the US Army and Marines to move away from technological solutions in favor of human ones. These Services have reoriented their focus toward "mission command," the concept of empowering commanders and subordinates to exercise disciplined initiative,

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[46]Krishnan, 73.

[47]Krishnan, 28-29; Singer, *Wired for War*, 30.

[48]Robert M Gates, *Duty: Memoirs of a Secretary at War* (New York, NY: Alfred A. Knopf, 2014), 320; Feickert and Lewis, 1.

[49]Kate Brannen, "Army kills off MULE unmanned vehicle," *Army Times*, 15 August 2011, http://www.armytimes.com/article/20110815/NEWS/108150336/Army-kills-off-MULE-unmanned-vehicle (accessed 1 March 2014).

[50]Erik Sofge, "Inside Story of the SWORDS Armed Robot 'Pullout' in Iraq: Update," *Popular Mechanics*, 1 October 2009, http://www.popularmechanics.com/technology/gadgets/4258963 (accessed 1 March 2014).

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underpinned by shared understanding and mutual trust.[51] This philosophy is fundamentally about human minds and decision-making, but unmanned systems do still factor into its implementation. FCS-envisioned networking capabilities continue to make progress, improving mission command on the battlefield.[52] The military also continues to experiment with UGS as an extension of—not a replacement for—human capabilities. Spatial disorientation, task saturation, and frequency congestion in crowded urban environments remain problematic when remotely controlling ground vehicles.[53] Nevertheless, numerous UGS prototypes have made their way into the hands of deployed troops, who have developed innovative methods to use them. The initiative of these Soldiers and Marines exemplifies the mission command philosophy.

The Army's most beloved unmanned systems are the UGVs it uses for explosive ordnance disposal. Remote-operated Talons, as well as a smaller vehicle called the PackBot, have saved countless lives—both military and civilian—by defusing IEDs and other explosives that formerly required human technicians to neutralize them.[54] The US military has used between 5,000 and 6,000 UGVs to defuse tens of thousands of IEDs in Iraq and Afghanistan.[55]

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[51]Headquarters, Department of the Army, ADP 3-0, *Unified Land Operations* (Washington, DC: Headquarters, Department of the Army, 10 October 2011), 6, 13; Headquarters, United States Marine Corps, Department of the Navy, MCDP 1-0, *Marine Corps Operations* (Washington, DC: Headquarters, United States Marine Corps, Department of the Navy, 9 August 2011), 7-5.

[52]Gourley.

[53]Skye L. Pazuchanics, Roger A. Chadwick, Merrill V. Sapp and Douglas G. Gillian, "Robots in Space and Time: The Role of Object, Motion and Spatial Perception in the Control and Monotoring of Uninhabited Ground Vehicles," in *Human-Robot Interactions in Future Military Operations,* eds. Michael Barnes and Florian Jentsch (Burlington, VT: Ashgate, 2010), 88; Tal Oron-Gilad and Yaniv Minkov, "Remotely Operated Vehicles (ROVs) from the Bottom-Up Operational Perspective," in *Human-Robot Interactions in Future Military Operations*, 223; Chris Jansen and Jan B. F. van Erp, "Telepresence Control of Unmanned Systems," in *Human-Robot Interactions in Future Military Operations*, 266; Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 61.

[54]Singer, *Wired for War*, 20.

[55]Krishnan, 28; Antonin Tisseron, "Robotic and Future Wars: When Land Forces Face Technological Developments," in *Robots on the Battlefield: Contemporary Perspectives and Implications for the Future*, 3.

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The Army is also fielding a 5.5-pound UAV known as the Switchblade, which sports a grenade-sized warhead designed for precision engagement of small targets.[56] Medea Benjamin of Code Pink calls it a "robotic suicide bomber . . . an unmanned kamikaze."[57] She fails to account for the fact that a human remains in control of its maneuvering and lethal employment. In context, the Switchblade sounds far less ominous—and certainly more discriminating—than the ballistic artillery shells responsible for the majority of violent deaths in modern warfare.[58] The Army and Marines will continue to develop unmanned systems, but they do not appear whatsoever interested in relinquishing lethal discretion to autonomous robots.

Unmanned Maritime Systems

The US Navy's recent experience with unmanned systems is similar to that of the Army: while a massive modernization program flounders, discreet technologies are finding their way into operational use. In 2002, the Navy began a program to develop and field an advanced warship called the Littoral Combat Ship (LCS). The Navy wanted the LCS for combat operations in coastal regions. Designers promised an affordable, modular solution to difficult problems like minesweeping, detection of stealthy submarines, and defense against small-boat threats.[59] The Navy planned to use a plethora of unmanned systems to enable a drastic reduction in LCS

[56]UAS Vision, "AeroVironment New US Army Orders for Switchblade Tactical Missile Systems Now Total $37M," *UAS Vision*, 12 September 2013, http://www.uasvision.com/2013/09/12/aerovironment-gets-37m-new-us-army-orders-for-switchblade-tactical-missile-systems (accessed 1 March 2014).

[57]Medea Benjamin, *Drone Warfare: Killing by Remote Control* (New York, NY: Verso, 2013), 36-37.

[58]Otto Kreisher, "IEDs Replace Artillery as Battlefield's Biggest Killer, JIEDDO Director Says," *Breaking Defense*, 17 October 2012, http://breakingdefense.com/2012/10/ieds-replace-artillery-as-battlefields-biggest-killer-jieddo-g (accessed 1 March 2014).

[59]Todd Harrison, "Analysis of the FY 2012 Defense Budget," *Center for Strategic and Budgetary Assessments*, 15 July 2011, http://www.csbaonline.org/publications/2011/07/analysis-of-the-fy2012-defense-budget (accessed 1 March 2014), 51; Otto Kreisher, "Littoral Combat Ship (LCS)," *Naval Forces* 30, no. 2 (2009): 28.

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crewmembers: just forty Sailors per ship, as opposed to over three hundred on a modern cruiser.[60] The LCS would deploy unmanned surface vehicles (USVs), unmanned underwater vehicles (UUV), and UAS including the Fire Scout helicopter.[61] The Navy originally asked for seventy LCS hulls, but ultimately settled on fifty-two.[62] Two competing ship designs, one from Lockheed Martin and the other from General Dynamics/Austal, began concurrent development. As the LCS program got underway, worldwide contingency operations prompted a number of smaller experiments under real-world conditions.

During the 2003 Iraq War, the Navy deployed the Spartan Scout, a remotely operated USV equipped with sensors and communication gear, to inspect civilian boats in the Arabian Gulf.[63] Unmanned seaborne operations proved more challenging than airborne ones for many reasons. Ship-mounted antennas limited LOS range for remote surface operations to roughly six nautical miles, although SATCOM capabilities or a relay vehicle could mitigate this shortcoming.[64] Autonomous USVs might use GPS to maneuver at greater range, but without a link to the ship, their utility would be limited. Roiling seas, adverse weather, and corrosive saltwater wreaked havoc on sensitive technology.[65] One Navy study determined that USVs were

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[60]Michelle Mackin, GAO-13-530, *Navy Shipbuilding: Significant Investments in the Littoral Combat Ship Continue Amid Substantial Unknowns About Capabilities, Use, and Cost*, Report to Congressional Requesters, (Washington, DC: United States Government Accounting Office, July 2013), http://www.gao.gov/assets/660/656107.pdf (accessed 1 March 2014), 3; Kreisher, "Littoral Combat Ship (LCS)," 28.

[61]Mackin, 31.

[62]Kreisher, "Littoral Combat Ship (LCS)," 28; Mackin, 1.

[63]Singer, *Wired for War*, 115. The Spartan Scout in 2003 was unarmed—weapons testing began the following year. The Navy has tested a .50-caliber gun on it, but has not deployed an armed variant in real-world operations to date. See Matthew Richter, "Operational Manning Considerations for Spartan Scout and Sea Fox Unmanned Surface Vehicles (USV)," (master's thesis, Naval Postgraduate School, 2006), http://www.dtic.mil/dtic/tr/fulltext/u2/a457242.pdf (accessed 1 March 2014), 40.

[64]Richter, 38.

[65]Singer, *Wired for War*, 114-115.

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more manpower-intensive than manned vessels due to their many intricate systems.[66] Spartan Scout testing ended in 2006, whereupon further USV research became part of the LCS program.[67]

Another unmanned system that made its military debut in 2003 was the Remote Environmental Monitoring Unit, or REMUS. This torpedo-shaped UUV, adapted from an existing civilian model, conducted minesweeping operations in the Arabian Gulf harbor of Um Qasr.[68] Its preprogrammed movements and navigation sensors alleviated the need for a cable link to send commands, meaning it truly acted autonomously. Like the Spartan Scout, REMUS was a precursor to equipment that will be integral to the LCS and other naval vessels in the future.

While Sailors and Marines have spent the last decade experimenting with unmanned systems under combat conditions, the LCS program has become a quagmire. Originally promised at $220 million each, the Fiscal Year 2012 budget listed the per-unit cost of an LCS at over $1.8 billion.[69] The first two prototypes arrived two years behind schedule.[70] Minesweeping modules are four years late, with estimated completion in 2017.[71] The ships will not finish full operational testing until 2019 at the earliest.[72] Poor management, requirements creep, and real-world developments have hamstrung the LCS program.

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[66]Richter, 1-2.

[67]US Navy, "SPARTAN Scout Unmanned Surface Vehicle," US Navy, ODUSD Advanced Systems and Concepts, 2006, http://www.dtic.mil/dtic/pdf/ success/SSUSV20080908.pdf (accessed 1 March 2014), 1.

[68]Woods Hole Oceanographic Institution, "REMUS," *Woods Hole Oceanographic Institution*, 2013, http://www.whoi.edu/main/remus (accessed 1 March 2014); Singer, *Wired for War*, 37-38.

[69]Kreisher, "Littoral Combat Ship (LCS)," 27; Chris Hellman, "Analysis of the Fiscal Year 2012 Pentagon Spending Request," *National Priorities Project*, 14 February 2011, http://nationalpriorities.org/ pressroom/articles/2011/02/14/analysis-of-the-fiscal-year-2012-pentagon-spending (accessed 1 March 2014).

[70]Mackin, 18.

[71]Ibid., 29

[72]Ibid., 48.

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The problems with the LCS point to a broader conclusion: at present, unmanned systems cannot replace most humans at sea. One of the costliest modifications to the LCS has been a twenty-five percent increase in crew size to alleviate workload and fatigue, and this number is likely to increase.[73] Space aboard the LCS is tight: if crew requirements grow too large, the viability of both competing ship designs may come into question. Tests on several of the LCS's unmanned systems have revealed unacceptable failure rates and unforeseen complications that corroborate the increased staffing requirements for the Spartan Scout USV.[74] In July 2013, the Government Accountability Office issued this scathing pronouncement: "Current LCS weapon systems are under-performing and offer little chance of survival in a combat scenario."[75] Unlike the Army's defunct FCS, the LCS continues to survive on life-support, but the future of the program remains uncertain. In the meantime, the Navy is pursuing one more noteworthy foray into the world of unmanned systems.

The Navy currently operates proven UAS of many shapes and sizes, but it also is developing and testing a potential game-changer: the X-47B UCAS.[76] The Navy adapted its design from a joint UCAS program that the DOD cancelled in 2006.[77] The stealthy X-47B has a sixty-two-foot wingspan (comparable to a Reaper or an RQ-170), uses jet propulsion, and includes weapons bays for up to two 2,000-pound bombs.[78] On 14 May 2013, the X-47B made its first successful catapult launch from the deck of the U.S.S. *George H.W. Bush* (it landed ashore,

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[73]Mackin, 20, 44-45.

[74]Mackin, 32-34; Richter, 1-2.

[75]Mackin, 42.

[76]Once operational, the UCAS will be renamed the Unmanned Carrier Launched Airborne Surveillance and Strike System, or UCLASS. Dave Majumdar, "Navy Restarts X-47B Carrier Testing," *USNI News*, 11 November 2013, http://news.usni.org/2013/11/11/navy-restarts-x-47b-carrier-testing (accessed 1 March 2014).

[77]Gertler, 47.

[78]Ackerman.

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as planned). Two months later, it made its first carrier landing.[79] Concurrently, the Navy began testing unmanned aerial refueling from manned tanker aircraft, using a Learjet modified for autonomous flight with human pilots onboard to override any glitches.[80]

The Navy plans to grant unprecedented levels of autonomy to the X-47B. Although current tests involve multiple redundant human controls (pilots, deck officers, and tower personnel all have the ability to wave-off the aircraft from a bad approach), ultimately the Navy envisions a UAS that can fly missions all on its own.[81] However, as Captain Jaime Engdahl, the UCAS program manager, confesses: "We are in the crawl-walk-run stage of autonomous systems."[82] The Navy is emphatic that the UCAS is simply a demonstration, and a limited one at that. Originally, it planned to retire the X-47Bs after the July carrier tests. Under pressure from politicians and the defense industry, the Navy conceded to continued experiments. It has allocated a further $20 to $25 million to keep the program alive while it determines how to proceed.[83] The Navy does not anticipate fielding an operational X-47B before 2019.[84]

Accompanying the Navy's embryonic experiments with autonomy is the notion that a carrier-based, stealthy UCAS could alleviate host-nation basing requirements for UAS. Elimination of forward bases might reduce the perceived need to gain foreign approval for combat operations.[85] Then again, USAF B-2 bombers (which fly intercontinental missions from

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[79]NAVAIR, "Unmanned X-47B makes historic landing aboard USS George H.W. Bush," *NAVAIR,* 10 July 2013, http://www.navair.navy.mil/index.cfm?fuseaction=home.NAVAIRNewsStory &id=5417 (accessed 1 March 2014).

[80]NAVAIR, "Navy Autonomous Aerial Refueling Tests Underway," *NAVAIR,* 11 September 2013, http://www.navair.navy.mil/index.cfm?fuseaction=home.NAVAIRNewsStory&id=5451 (accessed 1 March 2014).

[81]Majumdar, "Navy Restarts X-47B Carrier Testing."

[82]Ackerman.

[83]Majumdar, "Navy Restarts X-47B Carrier Testing."

[84]Ackerman.

[85]Micah Zenko, *Reforming U.S. Drone Strike Policies,* Council on Foreign Relations, Special

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Missouri), carrier-launched manned aircraft, and other ISR assets have conducted military operations without basing rights for decades.

Despite various methods of controlling unmanned systems, a human remains "in-the-loop" and responsible for their safe operation at all times (with the exception of the innocuous REMUS UUV). No autonomous robots are out conducting combat missions unsupervised while their human monitors leave the controls for a lunch break. More importantly, humans remain entirely in charge of every decision to launch lethal munitions, just as they do in manned platforms. While the Army and Marines operate most unmanned systems as an additional duty for conventional troops, the USAF requires rated pilots to fly its Group 4 and 5 platforms.[86] The next section will discuss how these airmen employ UAS in today's conflicts. While all of the Services continue to develop tactics, techniques, and procedures (TTP) for unmanned systems, the USAF's experience over the past twelve years provides the clearest assessment of the realities of unmanned systems in modern warfare.

II – AVIATORS AND INNOVATORS

The USAF calls its unmanned systems Remotely Piloted Aircraft (RPAs) for a reason. The airmen who fly these platforms are no "cubicle warriors": while they are not physically located inside their airframes, they are connected intimately to the battlefield. Over the past decade, determined RPA crews have toiled to integrate new capabilities into the complex and

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Report No. 65 (January 2013), http://www.cfr.org/wars-and-warfare/reforming-us-drone-strike-policies/p29736 (accessed 1 March 2014), 23.

[86]Gertler, 26; United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 26-27; Singer, *Wired for War*, 37. According to AFI 11-401, "A rated aircrew member is a commissioned officer who holds a USAF aeronautical rating. The USAF considers rated officers to be in career aviation status and awards ratings only to pilots, RPA pilot, CSOs [Combat System Operators], ABMs [Air Battle Managers], observers, and flight surgeons." See AF/A3O-AT, Air Force Instruction 11-402, *Aviation and Parachutist Service, Aeronautical Ratings and Aviation Badges* (13 December 2010, certified current 5 February 2013), http://www.e-publishing.af.mil (accessed 1 March 2014), 129.

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evolving battle spaces of America's conflicts.[87] They have managed this feat despite a tempo of constant surge operations, 24 hours a day for 365 days a year. Many RPA crewmembers have deployed to active combat zones to conduct LOS launch and recovery operations.[88] Their innovations have produced remarkable advances in the way the USAF supports the achievement of strategic objectives, operational successes, and tactical victories.

RPAs have become indispensable assets for US military operations. Stated succinctly, "RPAs benefit from a long loiter time, the ability to provide armed over watch and armed reconnaissance with precision-guided munitions, extensive reach-back capabilities, and the ability to have the [full-motion video] FMV feed exploited real-time."[89] They are ideal for military missions including ISR, interdiction, close air support, force protection, and maritime patrol. By replacing low-fuel RPAs with fresh ones and swapping out crews multiple times per sortie, squadrons can extend their persistence indefinitely. While pilots and sensor operators handle the immediate tactical tasks, analysts worldwide simultaneously work round-the-clock to convert FMV and sensor reports into actionable intelligence. RPAs also benefit from low acoustic

[87]For the remainder of this discussion, the term "RPA crew" will refer to the rated pilot, enlisted sensor operator, and mission support personnel in direct support of a particular aircraft. They represent only the spearhead of up to 170 people who can be involved in the maintenance and exploitation of a single RPA. See Gertler, 26.

[88]Depending on the scale and intensity of operations, up to one tenth of a typical RPA squadron is deployed for launch and recovery operations at any given time. Major Eric Hendrickson, USAF, e-mail message to author, 8 November 2013.

[89]Timothy W. Ford, "MQ-1/-9 Integration with Ground Control Station for Strike Coordination and Reconnaissance," *USAF Weapons Review* (Winter 2012): 25.

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signatures.[90] Audible concealment is vital for lethal engagements, but it also aids in the building of comprehensive SA that often leads to a decision *not* to use deadly force.[91]

These capabilities did not arrive overnight. The rapid deployment of immature UAS technology into dynamic war zones following 9/11 complicated the command, control, and coordination of RPAs with other assets. The operational-level Air Operations Center (AOC) repeatedly clashed with tactical personnel in-theater over RPA allocation and tasking. Many times, manned aircraft and joint terminal air controllers (JTACs) had no idea an RPA even was in their vicinity, much less whether it could assist in an active mission.[92] As one expert RPA pilot noted, problems arose from "incomplete understanding of MQ-1/-9 capabilities and systemic perception of RPAs as the 'just-in-case' tactical employment option."[93] These growing pains reprised the US military's repeated battles over the use of airpower at large since World War I.

The USAF's burgeoning RPA community struggled to overcome these deficiencies. The strain of nonstop surge operations initially hampered the development of planning and coordination TTPs to suit remote operations, but these have improved significantly.[94] Networked computer systems, internet relay chat, e-mail, video teleconferencing, and telephones (both secure and unclassified) enable RPA crews to prepare for the geographically separated missions they

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[90]Tamara L. Barlette, "Optimizing the MQ-1/9 in Close Air Support" (student paper, United States Air Force Weapons School, 12 December 2009), 20; Albert F. Scaperotto, "MQ-1 / MQ-9 Remote Split Operations Mission Planning and Execution Cell (MPEC)" (student paper, United States Air Force Weapons School, 11 December 2010), 14; Mike Scorsone, "Fighter-Unmanned Aerial System Integration in Close Air Support Operations," *USAF Weapons Review* (Winter 2008): 12; Martin and Sasser, 276.

[91]Luther S. Turner, Jason Adair and Louis Hammel, "Optimizing Deadly Persistence—Armed UAV Integration in the Joint Tactical Fight," *USAF Weapons Review* (Summer 2009): 48.

[92]Brandon E. Baker, "Increasing the Combat Effectiveness of the RQ-4," *USAF Weapons Review* (Summer 2008): 39-40; Scorsone, 9, 14; Ford, 24; Martin and Sasser, 293-294; Gertler, 16.

[93]Preston L. Rhymer, "MQ-1/-9 Hellfire IIP Buddy Lase for Fixed Wing" (student paper, United States Air Force Weapons School, 12 December 2009), 1.

[94]Scaperotto, 1-2.

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face.[95] Nothing can replace face-to-face planning and debriefing, but disjunction is not only an issue for unmanned systems: it is a reality for troops deployed across modern, dispersed battlefields. It also represents nothing new. US Navy aviators have conducted dislocated mission planning at sea for decades. They have developed efficient communications and TTPs that enable them to support distant operations.[96] The RPA community is finally gaining the leeway to free up experienced aviators and intelligence personnel for comprehensive mission planning.[97] This emphasis is critical to optimizing the capabilities RPAs bring to the fight.

Real-time video may be the most coveted asset on RPAs, but their capabilities as a communications bridge are invaluable as well. RPA crews can leverage multiple voice and data links to contact any echelon, from troops-in-contact all the way to national-level authorities. Rather than waiting to return to base in a manned aircraft, an RPA crew can pass immediate, high fidelity mission reports, battle damage assessments, and other in-flight messages to operations centers and commanders. Likewise, they can pass detailed tactical and administrative data forward to other aircraft and ground troops.[98] A rated pilot in the driver's seat puts an "airman's perspective" on tactical messages, thus enhancing their utility to warfighters.[99] Real-time communications are also important for RPA survival: because current models lack onboard threat detectors or countermeasures, crews rely on off-board cues to evade hostile fire.[100]

RPA crews can employ their own Hellfires and laser-guided bombs with surgical precision, but they also can pinpoint targets for manned aircraft with heavier firepower. The persistent, stable perspective of an RPA with multifaceted connectivity is a boon to low-flying

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[95]Ford, 28.

[96]Scaperotto, 6-7.

[97]Ibid., 8-9, 21.

[98]Barlette, 10-11.

[99]Ibid., 16.

[100]Ford, 29.

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helicopters or fast-moving jets with limited loiter time.[101] An RPA crew may describe visible features in the terrain to guide another aircrew's eyes. The crew also can make use of GPS-derived coordinates, or use the RPA's infrared illuminator or laser designator to cue the sensors of other aircraft, expediting correct target acquisition.[102] The Predator's and the Reaper's lasers are compatible with the targeting pods and laser-guided weapons carried by US (and most allied) aircraft. Use of an RPA to "buddy-lase," in which its laser guides a munition fired from another aircraft or vice-versa, often is the most expeditious and precise method to employ weapons.[103] Ground personnel likewise can use laser designators and infrared pointers to cue aircraft sensors and weapons. Laser guidance also enables an aircrew to shift weapons in flight away from the intended target if noncombatants enter the impact zone or other extenuating circumstances occur—a rare occurrence, since crews thoroughly scan target surroundings before firing.[104]

Tactical data links have become an indispensable component of modern warfare. The RPA community has labored to integrate its aircraft into the primary coalition network, known as Link 16 or the Joint Tactical Information Distribution System (JTIDS). This system communicates position, status, and mission management information regarding friendly assets, detected threats, and potential targets. Link 16 enables diverse platforms to work together across the battle space, increasing SA and enhancing overall effectiveness. These days, an aircraft flying in an active area of operations without Link 16 can be more of a liability than a benefit. Lamentably, RPAs operated in combat zones for years without this essential capability, and this shortcoming hampered their integration with other aircraft.[105] Ultimately, airmen and engineers

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[101]Scorsone, 13.

[102]Barlette, 17.

[103]Rhymer, 4.

[104]Zenko, *Reforming U.S. Drone Strike Policies*, 6.

[105]Nicholas R. Pederson, "Integrating MSCT to Enhance MQ-1/9 Link 16 Operations" (student paper, United States Air Force Weapons School, 12 June 2010), 5.

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devised workarounds to provide basic Link 16 capabilities for Predators and Reapers.[106] USAF RPAs are set to attain full Link 16 capability within a couple years.[107] Future data links must fully include RPAs and other unmanned systems from Day One.

Link 16 connectivity enhances the crucial two-way flow of information needed to maximize the effective integration of RPAs with other assets. When friendly ground troops are nearby, aircrews require clearance from a qualified JTAC or equivalent controller in order to release weapons. Using Link 16, a JTAC can pass digital targeting information to an RPA crew, rather than relying on voice or chat messages (the RPA crew still must visually identify the target and get confirmation from the JTAC before weapons launch).[108] Likewise, a Link 16-equipped RPA with high SA on a target can send detailed information to ground forces and other aircraft instantly and without transmission errors.[109] RPA crewmembers recognize that they are personally responsible for the accuracy and timeliness of target coordinates and information—erroneous or obsolete data could result in fratricide or civilian casualties.[110]

In situations where friendly ground troops do not physically deploy, such as during Operation Unified Protector over Libya in 2011, RPA crews are ideal controllers for strike coordination and reconnaissance.[111] The persistence of an RPA allows crews to build detailed SA over extended periods, as compared to intermittent coverage from manned aircraft following a

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[106]As initially implemented, RPA positional tracks updated less often than the tracks of full link participants. In addition, all of the aircraft in an RPA squadron operated on a single merged server with one identifier, which necessitated clear, standardized communication procedures to avoid confusion. David M. Martinez, "Digitally Aided CAS in the MQ-1/9" (student paper, United States Air Force Weapons School, 10 December 2011), 2-4, 9; Pederson, 4.

[107]Pederson, 22-23.

[108]Martinez, 5, 14.

[109]Pederson, 4.

[110]Ibid., 17.

[111]Ford, 24. Initial US operations over Libya carried the code name Operation Odyssey Dawn. The North Atlantic Treaty Organization (NATO)'s Operation Unified Protector replaced this moniker after 12 days.

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traditional air tasking order. RPAs also can leverage support from myriad coalition assets both inside and outside the theater. An RPA control station can receive cueing information from ISR platforms like the RC-135 Rivet Joint, E-8 JSTARS, E-3 AWACS, U-2, Global Hawk, national-level assets, and tactical aircraft, with scores of analysts in the loop to exploit collected data and intelligence products.[112] Persistent RPAs can pass this SA to arriving aircraft while others depart.

In certain scenarios, RPAs may be the only assets available. Although the USAF initially employed them as single aircraft, RPA crews have developed TTPs to fight as teams. This synergy is similar to manned aircraft flying in formation, but instead of close visual formations, RPA crews can use precise timing and coordination to mass sensors and firepower.[113] This capability is not limited to aircraft from the same squadron. By leveraging the multiple communication methods available in their control stations, geographically separated crews can link up, establish a coordinated game plan, and accomplish a tasking without ever meeting face-to-face.[114] The key to successful execution is the development of shared understanding, based on rigorous training and common tactical standards across RPA squadrons.[115] By practicing and adhering to these innovative TTPs, disciplined crews can transform a few tenuous RPAs into a formidable expression of modern American airpower.

Positive identification of hostile targets in modern combat zones is challenging, but essential.[116] Many enemy combatants do not wear uniforms, and even professional militaries employ deception and camouflage to confuse modern sensors, as the Serbs did by using dummy

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[112]Ford, 30. JSTARS stands for Joint Surveillance Target Attack Radar System and AWACS stands for Airborne Warning and Control System.

[113]Kristin A. Wozniak, "MQ-1/9 Multi-ship Operations in OCO" (Student Paper, Nellis Air Force Base, NV: United States Air Force Weapons School, 11 June 2011), 13, 15.

[114]Ibid., 1-2.

[115]Ibid., 21.

[116]Ford, 31.

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tanks during the conflict in Kosovo.[117] Clear, stable FMV from an RPA can be the most important tool in accurately identifying a suspected enemy target. While crews benefit from a team of professional analysts who aid them in making the right decisions, an RPA pilot employing lethal ordnance bears ultimate responsibility for compliance with the rules of engagement (ROE).

In the event of a friendly aircraft crash, an RPA's persistence may be the decisive factor in successful combat search and rescue. MQ-1 and MQ-9 pilots train to act as on-scene commanders for search and rescue, just like other pilots. They can communicate instantly and comprehensively with rescue coordinators at the operations center.[118] Their watchful gaze enables them to direct additional assets to the site—and their precision weapons can target threats to an isolated survivor—without risking additional aircrew.[119] The roar of friendly jet engines, though transitory, may be the ultimate emotional comfort for a downed aviator—but 24-hour overhead cover from an armed RPA realistically offers the best chance for a successful rescue.[120]

III – A REVOLUTION IN MILITARY AFFAIRS?

Definitions abound as to what constitutes a revolution in military affairs (RMA), but the notion of discontinuity is common to all. Andrew Marshall argues that an RMA is "a major change in the nature of warfare brought about by the innovative application of new technologies which, combined with dramatic changes in military doctrine and operational and organizational concepts, fundamentally alters the character and conduct of military operations."[121] An RMA

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[117]Michael Ignatieff, *Virtual War: Kosovo and Beyond* (New York, NY: Metropolitan Books, 2000), 105.

[118]Scorsone, 14; Michael Lewis, "MQ-1/-9 Role in the Combat Search and Rescue Mission," *USAF Weapons Review* (Summer 2010): 24.

[119]Lewis, 24, 30, 32.

[120]Norton Schwartz, "U.S. Drone Program is Fatally Flawed," *Intelligence Squared Debates*, transcript, 10 September 2013, http://intelligencesquaredus.org/debates/past-debates/item/905-the-us-drone-program-is-fatally-flawed (accessed 1 March 2014), 43.

[121]Jeffrey McKitrick, et al., "The Revolution in Military Affairs," in *Battlefield of the Future: 21st*

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means more than new gadgets: it represents a fundamental shift that permanently alters the way humans fight. Technology plays a decisive role in nearly all commonly acknowledged RMAs. Specific lists vary, but several episodes tend to feature prominently: the introduction of gunpowder, the Industrial Revolution, the Napoleonic way of war (an exception to the technological impetus), powered flight, blitzkrieg, nuclear weapons, and the Information Revolution of the 1990s.[122] Many believe the time has come to announce yet another RMA.

The Pitfalls of Believing in RMAs

A number of analysts believe unmanned systems constitute an RMA. As P.W. Singer exclaims, "humans' 5,000-year-old monopoly over the fighting of war is over . . . the introduction of unmanned systems to the battlefield doesn't change simply how we fight, but for the first time changes who fights at the most fundamental level."[123] He recalls perusing gadgets in a *Sharper Image* catalog and then reading reports of drone strikes. This juxtaposition convinces him that humanity has arrived at a point of singularity whereupon robots will replace humans on the battlefield.[124] Other writers decry a coming age of "suicide drones," evidently unaware of the irony of the phrase.[125] Admiral Dennis Blair, former US Director of National Intelligence, dismisses the hype. He acknowledges the "novelty factor" of unmanned systems, but believes the

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Century Warfare Issues, eds. Barry R. Schneider and Lawrence E. Grinter (Maxwell Air Force Base, AL: Air University Press, 1998), 65. Andrew Marshall has been the director of the Office of Net Assessments in the Office of the Secretary of Defense since 1973.

[122]Joseph S. Nye, Jr., *The Future of Power* (New York, NY: PublicAffairs, 2011), 36; McKitrick, et al., "The Revolution in Military Affairs," in *Battlefield of the Future*, 65-68; Thomas C. Graves, "Al-Qaeda, the Revolution in Military Affairs, and the Future of Warfare," in *Short of General War: Perspectives on the Use of Military Power in the 21st Century*, ed. Harry R. Yarger, 23-38 (Carlisle, PA: Strategic Studies Institute, United States Army War College Press, April 2010), http://www.strategicstudiesinstitute.army.mil/pubs/display.cfm?pubID=983 (accessed 1 March 2014), 26-27.

[123]Singer, *Wired for War*, 194.

[124]Ibid., 10. Singer defines a singularity as "a state in which things become so radically different that the old rules break down and we know virtually nothing." Ibid., 102.

[125]Turse and Engelhardt, 57; Benjamin, 36-37.

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ensuing sense of sinister "overwhelming force" is erroneous.[126] When discussing an RMA, it is critical to examine reality—not to speculate what could theoretically occur. If militaries ultimately imbue robots with the capability and authority to employ autonomous lethal force, then humanity may indeed experience a discontinuity in history.[127] However, that day has not arrived.

The entire RMA concept is misleading because it compartmentalizes and distorts the past, equating newfangled innovations with momentous historical developments. P.W. Singer compares unmanned systems to "fire, gunpowder, the steam engine or the computer."[128] It took humans thousands of years to tame fire. Gunpowder gradually entered the battlefield in an evolutionary process over hundreds of years. Industrial mechanization may have begun in the eighteenth century, but it continues to evolve to this day. Computer technology has progressed exponentially, but its contribution to warfare has not followed a correspondingly inexorable path. Steven Metz explains: "Even in revolutionary times, continuity outweighs change. . . . War will always involve a dangerous and dynamic relationship among passion, hate, reason, chance and probability."[129] True believers in technology would be wise to heed his insight.

RMA proponents of the 1990s focused on new information technologies, like GPS and networking, that helped the United States and its allies defeat Iraq in 1991, but they downplayed the significance of context. Decades beforehand, General William Westmoreland promoted the concept of the "electronic battlefield" in Vietnam. He envisioned a day when "enemy forces [would] be located, tracked and targeted almost instantaneously through the use of data-links,

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[126]Dennis Blair, "U.S. Drone Program is Fatally Flawed," 41-42.

[127]Michael Contratto, "The Decline of the Military Ethos and Profession of Arms: An Argument Against Autonomous Lethal Engagements" (research paper, Air War College, February 2011), 1; Krishnan, 166.

[128]P.W. Singer, foreword to "Game Changers: Disruptive Technology and U.S. Defense Strategy," by Shawn Brimley, Ben FitzGerald and Kelley Sayler, *Center for a New American Security*, 27 September 2013, http://www.cnas.org/game-changers (accessed 1 March 2014), 4.

[129]Steven Metz, *Armed Conflict in the 21st Century: The Information Revolution and Post-Modern Warfare* (Carlisle Barracks, PA: Strategic Studies Institute, US Army War College, 2000), xiv-xv.

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computer-assisted intelligence evaluation and automated fire control."[130] Technological superiority did not solve Westmoreland's problems in Southeast Asia. The United States lost in Vietnam and won in Desert Storm because the situations and the strategies were different—not because an RMA occurred in the intervening years. Subsequent American misadventures in Iraq would underscore this fact.

Belief in an RMA can be more than misleading. It can be downright disastrous. America's military ventures in the 1990s concluded with an air war over Kosovo without a single friendly combat fatality.[131] Meanwhile, al-Qaeda sought ways to merge audacity, low-tech weaponry, and internet connectivity to confound a militarily superior United States.[132] In 2001, Washington responded to the attacks of 9/11 with military intervention in Afghanistan. Special operations forces backed up by precision ISR and airstrikes (including armed UAS) enabled the Northern Alliance to rout al-Qaeda and the Taliban, seemingly validating the transformational nature of modern technology. As the United States prepared to invade Iraq in 2003, Defense Secretary Donald Rumsfeld fostered the notion that "[w]ith the help of technology . . . a U.S. intervention could be speedy *and* lethal."[133] American confidence in "information superiority" crashed against jagged rocks of poor assumptions and strategic blunders in Iraq, repudiating the purported RMA of the 1990s.[134] Technology enhanced the warfighting capabilities of the US

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[130]William C. Westmoreland, quoted in Krishnan, 19.

[131]Ignatieff, 161.

[132]Graves, 24-25; Michael R. Gordon and Bernard E. Trainor, *Cobra II: The Inside Story of the Invasion and Occupation of Iraq* (New York, NY: Pantheon Books, 2006), 30; Office of the US Air Force Chief Scientist, *Technology Horizons: A Vision for Air Force Science and Technology 2010-2030* (Maxwell AFB, AL: Air Force Research Institute, 2011), http://www.defenseinnovationmarketplace.mil /resources/AF_TechnologyHorizons2010-2030.pdf (accessed 1 March 2014), 39.

[133]Gordon and Trainor, 53 (emphasis original).

[134]Krishnan, 26; Metz, 39; Singer, *Wired for War*, 184, 188.

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military, but it did not bestow victory. As Joseph Nye concluded, "Americans were not mistaken to invest in the revolution in military affairs; they were wrong to think it was sufficient."[135]

Despite their novelty, unmanned systems in all their present forms do not constitute an RMA. As Section I recounted, their development began before the Wright Brothers' first flight. They lie upon a continuum, not astride a singularity. As Michael Ignatieff explains, "the battlefield has been emptying for centuries," transitioning from massed troops to dispersed elements as humans have developed weapons with increased range and precision.[136] Debate over the morality of distance warfare predates unmanned systems by hundreds of years: medieval knights derided longbow archers as un-chivalric cowards, and Japan's samurai culture shunned firearms until the 1850s. Unmanned systems' utility in armed conflict remains entirely dependent on the situation and the strategy chosen. The author is not alone in the opinion that unmanned systems are not an RMA. Medea Benjamin, no fan of unmanned systems, instead argues that they represent a "progressive evolution" in surveillance and killing, not a revolutionizing force.[137]

The USAF's greatest achievements with UAS have come through iterative, collaborative approaches and adaptations—not via technological wizardry. This is not a new story. By the end of World War I, military airplanes already were flying every type of mission that they do today, with the exception of nuclear bombing. In the interwar period, premier airpower advocates such as Giulio Douhet and William "Billy" Mitchell were themselves aviators. These days, the most strident voices on unmanned systems hail from academia or industry.[138] P.W. Singer is one of the leading authorities on unmanned systems, but he tips his hand when he uses catchy terms like

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[135]Nye, 35.

[136]Ignatieff, 169.

[137]Benjamin, 219. Instead, she fears that they represent a slippery slope to rampant murder.

[138]P. W. Singer, "What Churchill Can Teach Us About the Coming Era of Lasers, Cyborgs and Killer Drones," *Foreign Policy*, 22 October 2013, http://www.foreignpolicy.com/articles/2013/10/22/winston_churchill_military_technology_lasers_cyborgs_drones (accessed 1 March 2014); Singer, *Wired for War*, 138.

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"killer application" to describe them.[139] Robotic independence would constitute a significant leap, perhaps akin to the advent of nuclear weapons (the only plausible RMA to date, in this author's opinion), but the US military is not moving inexorably toward this fate.

There is no "Red Button of Death"

One of the most prevalent misconceptions distorting the discourse on unmanned systems is the illusion of an instantaneous kill-chain: a "red button" of death that allows national leaders to kill capriciously.[140] Micah Zenko, another respected authority on unmanned systems, claims that they provide "a near-instantaneous 'find-fix-finish' loop."[141] He contrasts this responsiveness with the time required to plan and execute the 1998 cruise missile strikes that targeted Osama bin Laden. The problem with this argument is that it compares the prompt fly-out of a Hellfire to the extended flight of a Tomahawk cruise missile, without acknowledging the unseen mountains of deductive effort behind the decision to launch either. The FMV recording from a Predator that one might glimpse on *WikiLeaks* is but a fraction of the intelligence collection, analysis, and exploitation that goes into operations involving unmanned systems.[142]

To some degree, the US military has been its own worst enemy in this regard. Top commanders with access to FMV have tended to become overly involved in tactical operations.[143] Micromanagement undermines the mutual trust that is vital to the military chain of command. It also leads to unnecessary delays, as commanders overloaded with information endeavor to make all of the decisions, rather than letting their subordinates exercise the initiative inherent in mission

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[139]Singer, foreword to "Game Changers," 4.

[140]Benoit Royal, "Military Robots and Ethics: Ethical Problems for European Industrial, Political, and Military Leaders," in *Robots on the Battlefield*, 126.

[141]Zenko, *Reforming U.S. Drone Strike Policies*, 6.

[142]Medea Benjamin notes that, as of 2010, the USAF processed almost 1,500 hours of FMV and 1,500 images daily, requiring approximately nineteen analysts per UAS. See Benjamin, 21.

[143]Singer, *Wired for War*, 349-350.

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command.[144] This problem is not new. In May 1975, President Gerald Ford himself intervened in an ongoing operation to recover the crew of the *Mayaguez*, a US ship hijacked by the Khmer Rouge. He and his advisors repeatedly questioned tactical decisions and prohibited Navy planes from disabling a hostage-laden enemy ship at sea, resulting in a disastrous island assault during which forty US Marines died.[145] Real-time intelligence from unmanned systems only increases a commander's temptation to meddle, but instant responsiveness, in most cases, is an illusion.

The exception to the myth of the "instant kill" further strengthens the case for decentralized execution with regard to unmanned systems. RPAs providing direct support to friendly ground units can enable rapid decisions regarding lethal force within the constraints of strict ROE.[146] In Iraq and Afghanistan, a common insurgent tactic has been to emplace mortar tubes or IEDs and then activate them remotely, while the combatants disappear into the civilian landscape. When empowered by their commanders, UAS crews can detect, confirm, and engage these hostile targets more effectively than calling in a manned airstrike or artillery barrage.[147] This responsiveness exists only because multiple individuals have done their homework. The process of identifying patterns of life, tracking enemy movements, identifying likely ambush spots, detecting hostile activity, confirming target coordinates, avoiding noncombatants, and then guiding weapons all the way to impact, is a team effort. Moreover, the team is legally (and morally) responsible if something ever goes wrong.[148]

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[144]Singer, *Wired for War*, 354-355.

[145]Dawkins, 22-24.

[146]Martin and Sasser, 238.

[147]Martin and Sasser, 131-132; Ralph Peters, *Fighting for the Future: Will America Triumph?* (Mechanicsburg, PA: Stackpole Books, 1999), 107; Dawkins, 28.

[148]Christopher Drew, "Study Cites Drone Crew in Attack on Afghans," *New York Times*, 10 September 2010, http://www.nytimes.com/2010/09/11/world/asia/11drone.html (accessed 1 March 2014); Martin and Sasser, 131, 269.

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Total Situational Awareness is an Illusion

The myth of instant responsiveness couples with the notion that unmanned systems finally offer a path to "battlespace awareness," which is another term for *total* SA. The US military's experiences in Iraq and Afghanistan should have taught its commanders and strategists that these phrases represent metaphors, not tangible goals. Nevertheless, the belief persists that technology can clear away the fog of war, despite decades of contradictory evidence.[149]

During the Kosovo conflict, state-of-the-art NATO aircraft expended tons of ordnance on dummy tanks and other decoys that appeared real from fifteen thousand feet.[150] Modern UAS might have been better at discerning fact from fiction, but this simply would have prompted the Serbs to devise alternate countermeasures (increased use of human shields, perhaps). Moreover, Serbian air defenses would have taken a significant toll on exposed UAS. In the decade preceding the 2003 Iraq War, the USAF flew numerous U-2 missions over Iraq that transmitted plentiful SIGINT and imagery to analysts, but decision-makers still lacked accurate information regarding Saddam Hussein's weapons programs.[151] Furthermore, technical data could not answer the subjective questions about Iraqi society that led to insurgency there once the regime collapsed. If the United States had possessed a fleet of UAS at the time, they would have collected more information than U-2s and orbiting satellites provided. Would it have made a difference? Perhaps, but information and intelligence are two different things.

The data links that have proven so vital to operations in Iraq and Afghanistan also tend to convince commanders that their SA is higher than it actually is. Modern US ground forces deploy

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[149]Singer, *Wired for War*, 184-5. The metaphors of the "fog" and "friction" of war originally derive from Carl von Clausewitz, *On War*, ed. Michael Howard and Peter Paret (Princeton, NJ: Princeton University Press, 1984), 119, 140.

[150]Ignatieff, 105.

[151]Micah Zenko, *Between Threats and War: U.S. Discrete Military Operations in the Post-Cold War World* (Stanford, CA: Stanford University Press, 2010), 41-42.

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with "blue force trackers" to communicate friendly positions and movements. These reports aid in command and control, but they say nothing about enemy intentions. Blue force trackers, Link 16, and other networks can transmit detected enemy activity, but no amount of collected data equates to a true "red force tracker."[152] Irregular adversaries also tend to emit fewer of the SIGINT transmissions that advanced ISR technology can detect and exploit.

Persistent, real-time FMV and SIGINT from UAS mitigate some of these intelligence holes, but they also increase "fog" in two ways: they limit contextual awareness while simultaneously overloading data collection resources. A common analogy equates monitoring an FMV feed to looking through a "soda straw": focused clarity of a small space with zero peripheral vision. One study equated remote operation to driving at night, as contextual information normally available to a daytime driver (i.e. a manned system) is missing.[153] If individual Predator feeds actually represented the sum of intelligence on their targets, then such discomfort would be appropriate. Fortunately, this almost never is the case.

UAS cameras and sensors continue to improve from the grainy black-and-white footage of a decade ago, but even high-definition pictures can be enigmatic without proper context. Many pundits argue that a truck full of fruit looks the same as a truck full of weapons.[154] This would be true if the observer viewed the truck in isolation—unaware of its origin, destination, or additional contributing factors. Persistent UAS can address these gaps in SA, if crews receive the time and corroboration needed for accurate characterization. This attention to detail helps explain why only one incident of fratricide has occurred in over a decade of armed UAS operations. On 6 April 2011, a Predator strike killed a Marine and a Navy specialist during a firefight in which the

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[152]Singer, *Wired for War*, 189-190.

[153]Laurel Allender, "A Cognitive Systems Engineering Approach for Human-Robot Interaction: Lessons from an Examination of Temporal Latency," in *Human-Robot Interactions*, 321.

[154]Benjamin, 27; Singer, *Wired for War*, 223.

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ground commander mistook them for the enemy.[155] One fratricide still is too many. Compared to historical friendly fire rates, however, this is a remarkable record.

In the quest to build persistent SA across a dynamic battlefield, military forces most often demand improved technology and ever more unmanned systems. What they really need is an improved concept of operations. UAS units in support of American campaigns have had to juggle competing demands from multiple parties. Because its data can go to any facility that has approved access and connectivity, one UAV may simultaneously be supporting several teams of analysts.[156] This system works when all are examining the same target, but it creates conflict when disparate parties each want a single aircraft to observe different things.[157] One proposed technological solution to the "soda straw" conundrum was a multiple-camera pod for the MQ-9 Reaper called Gorgon Stare. Despite a "do not field" recommendation from RPA test pilots who found it impractical, several Gorgon Stare pods made it to operational units. Subsequently, in the spring of 2013, the USAF cut funding for the program.[158]

Failed enterprises like Gorgon Stare indicate that the problem is not the capability to collect FMV and SIGINT, but rather the ability to process and interpret all of the information. Under current procedures, while RPA crews conduct real-time missions, distributed analysts require hours or even days to review reams of data.[159] DARPA and other agencies continue to pursue automated collection and processing capabilities, hoping to use technology to distill

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[155]Benjamin, 28.

[156]United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 66.

[157]Martin and Sasser, 254, 293-294; Baker, 40.

[158]Major Landon Quan, USAF, e-mail message to author, 20 February 2014; Maggie Ybarra, "Air Force Pulls Plug on Gorgon Stare Funds, May Freeze Increment 2 Pods," *Inside The Air Force*, 9 May 2013, http://insidedefense.com/Inside-the-Air-Force/Inside-the-Air-Force-05/10/2013/air-force-pulls-plug-on-gorgon-stare-funds-may-freeze-increment-2-pods/menu-id-151.html (accessed 1 March 2014).

[159]Major Landon Quan, USAF, e-mail message to author, 20 February 2014.

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needles of clarity from haystacks of data.[160] Their initiatives obscure the true problem: human interpretation is required to convert information into actionable intelligence. More UAS are not the answer to information overload, especially not swarms of miniature robots that many writers portend.[161] The solution is the development of a strategy that utilizes focused, persistent ISR—not a quest for omnipresent battlespace awareness. Joint planners and operators must know how to ask the right questions, prioritize limited assets, and adapt to changing and unexpected circumstances. Section V addresses this integrated approach.

Proliferation is not Exponential

The exponential growth of unmanned systems in recent years leads many to claim that future development will follow a similar trend. P.W. Singer invokes Moore's Law (which postulates that semiconductor technology doubles roughly biennially) across a broad spectrum of military-related technology including microchips, data storage, wireless networks, and internet bandwidth. He associates this process with the progressive emptying of battlefields due to increasingly precise and lethal modern weapons, but military developments do not follow his logic.[162] Battlefields may be emptying, but unmanned systems have neither alleviated the need for deployed forces nor eliminated the deadly risks of combat. For example, note the number of American ground troops in Kosovo in 1999 (zero) versus the number that invaded Iraq in 2003 (150,000).[163] Destructive potential is not ever increasing, either: the Soviet Union tested the world's most powerful nuclear bomb in 1961, but nuclear weapon yields and arsenals since have

[160]Singer, *Wired for War*, 291; US Air Force Chief Scientist, *Technology Horizons*, xxi; Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 62.

[161]Brimley, FitzGerald and Sayler, "Game Changers," 20.

[162]Singer, *Wired for War*, 98-100.

[163]Gordon and Trainor, 555. NATO troops did occupy portions of Kosovo and Serbia following the ceasefire, and several thousand remain there to this day.

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shrunk drastically. Context matters—warfare does not follow mathematical projections. Nevertheless, the DOD's statistics on UAS growth are startling indeed.

The increase in the number of hours flown by UAS followed an exponential curve until 2011. Between 1995 and May 2007, UAS crews logged approximately 250,000 hours. They flew another 250,000 hours in the subsequent eighteen months, between May 2007 and November 2008.[164] In 2009 alone, UAS logged nearly 500,000 hours, and by mid-2010, they had surpassed 1,000,000 total flight hours.[165] Between 2001 and 2008, ISR flight time rose by 1,431 percent.[166] In 2004, the USAF could maintain five simultaneous 24-hour Predator combat air patrols (CAPs).[167] In 2009, the Secretary of Defense gave the USAF the objective of supporting fifty Predator and Reaper CAPs, and by July of that year, the USAF had thirty-four CAPs in operation.[168] Washington subsequently raised the target to sixty-five CAPs by mid-2014. The USAF was up to sixty-one simultaneous CAPs by 2013, just four short of the ultimate goal.[169]

In order to accomplish this unprecedented growth, the USAF had to strain its rated pilot force. The USAF's cadre of approximately fifty RPA pilots in the late 1990s had to multiply in response to worldwide commitments post-9/11, and shortages were inevitable.[170] By mid-2007, the USAF had begun to extend the length of pilots' assignments in RPA squadrons. It augmented their ranks with a round of involuntary transfers, forcing many young pilots to transition from

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[164]Deptula and Mathewson, slide 43.

[165]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 22.

[166]Deptula and Mathewson, slide 34.

[167]Turse and Engelhardt, 36.

[168]United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 76; Deptula and Mathewson, briefing transcript.

[169]Bradley T. Hoagland, *Manning the Next Unmanned Air Force: Developing RPA Pilots of the Future* (Washington, DC: The Brookings Institution, Federal Executive Fellows Policy Paper 17, 6 August 2013), http://www.brookings.edu/research/papers/2013/08/06-air-force-drone-pilot-development-hoagland (accessed 1 March 2014), iv.

[170]Ibid., 2.

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manned aircraft to unmanned squadrons before their previous tours were up. Then it further extended assignments, lengthened mobilization periods for Air National Guard and Air Force Reserve RPA pilots, curtailed RPA flight testing, and delayed the opening of the new RPA Weapons School squadron to fulfill operational demands.[171] In 2010, the USAF initiated RPA-only pilot training for officers without prior flying experience, speeding up the pipeline and reducing training costs.[172] As of 2013, the USAF had approximately 1,300 RPA-qualified pilots (8.5 percent of total USAF pilots), projected to increase to 1,650 pilots by 2017.[173]

Something interesting has happened in the last three years: the numbers have leveled off. Since 2010, the US military's UAS flight hours have begun to normalize at roughly 500,000 to 600,000 a year—still an astounding number, but no longer a runaway statistic.[174] USAF pilot shortfalls likewise are stabilizing. Over the past three years, UAS have been busy in the Middle East, Asia, and Africa, but the US military also has departed from Iraq. Future UAS operations in Afghanistan will depend on the ultimate security agreement between the American-led coalition and the Afghan government, but America's footprint there will certainly diminish. According to one analyst, "drawdown is all but inevitable; the USAF simply does not need to maintain 65 combat air patrols unless there are major ground combat operations underway."[175]

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[171]Deptula and Mathewson, slide 35.

[172]Lawrence Spinetta, "The Glass Ceiling for Remotely Piloted Aircraft," *Air & Space Power Journal* (July-August 2013), http://www.airpower.maxwell.af.mil/article.asp?id=155 (accessed 1 March 2014), 102.

[173]Hoagland, 3.

[174]General Atomics, "Predator Family UAVs Pass 2 Million Flight Hours," *Defence Talk*, 26 September 2012, http://www.defencetalk.com/predator-family-uavs-pass-2-million-flight-hours-44758/ (accessed 1 March 2014). This statistic includes Predator, Reaper, and Gray Eagle hours, which represent the overwhelming majority of statistically tracked UAS flight hours.

[175]Dave Majumdar, "USAF: Current Unmanned Aircraft Irrelevant in the Pacific," *Flightglobal*, 6 December 2012, http://www.flightglobal.com/news/articles/usaf-current-unmanned-aircraft-irrelevant-in-the-pacific-379839 (accessed 1 March 2014).

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Hence the answer to every security problem is not always "more unmanned systems." When alarmists lament that growth to date "undoubtedly means . . . more countries with drones flying over them, more drone bases, more crashes, more mistakes," they are begging the question.[176] Continued escalation is not a certainty; there is no perpetual motion machine inexorably replicating "drones." The future growth—or retrenchment—of unmanned systems depends on a host of factors, chiefly policymakers' decisions concerning the use of force and the composition of the military. As discussed in Section I, DOD-wide belt-tightening already is revising future UAS plans. Sections IV and V examine policy dynamics in detail.

Are Unmanned Systems Really "More Bang for the Buck?"

In times of constrained budgets, unmanned systems appeal to governments and militaries because they seem cheaper than manned alternatives. The DOD has acknowledged this belief in writing—its *Unmanned Systems Integrated Roadmap FY2011-2036* states: "affordability [will] be treated . . . like a Key Performance Parameter (KPP) such as speed, power, or data rate."[177] Predators and Reapers certainly are cheaper than F-22 Raptors and F-35 Joint Strike Fighters. However, as with the issue of escalation, past performance is not a guarantee of future returns. The cost equation of unmanned systems is more complex than it seems.

The US military rushed the development and deployment of many unmanned systems to satisfy urgent requests from commanders in the field. This nontraditional approach concealed many of these systems' expenses and shortcomings. Funding for many unmanned systems came from wartime contingency appropriations, as opposed to the traditional budget process.[178] Initially, commercial off-the-shelf technology like the Predator or the Talon UGV provided rapid

[176]Turse and Engelhardt, 156

[177]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, v.

[178]United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 63.

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solutions at remarkably low cost. However, as operations continued and the need grew for these systems to integrate with other combat capabilities, problems surfaced. As the *Unmanned Systems Integrated Roadmap* explains, "each unmanned system was procured as a vertically integrated, vendor-proprietary solution . . . this resulted in an inhibition to innovation; increased vulnerability to threats . . . increased complexity . . . [and] increased costs."[179] The DOD is revising the acquisition process for unmanned systems to match traditional practices, and demanding interoperability and open architecture in future designs.[180]

UAS may be cheaper than manned fighters and bombers, but many still cost tens of millions of dollars each, particularly when the cost of ground control stations and communications equipment is included.[181] In 2012 dollars, a Reaper system of four aircraft, ground control station, and satellite uplink costs $30.9 million. A Gray Eagle platoon of four aircraft and all support equipment costs $153.1 million, and a single Global Hawk costs $222.7 million.[182] "They are not expendable, they are very expensive," states General Mike Hostage, commander of Air Combat Command.[183] The Congressional Budget Office agrees: "Although a pilot may not be on board, the advanced sensors carried by unmanned aircraft systems are very expensive and cannot be viewed as expendable."[184] Each crash reduces combat capability.

Regrettably, many such crashes have occurred—but raw numbers are misleading. In 2007, the USAF determined that it had lost 50 percent of its Predators.[185] By 2010, thirty-eight

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[179]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 33.

[180]Ibid., 15, 34.

[181]Gertler, 13.

[182]Michael J. Sullivan, *Defense Acquisitions: Assessments of Selected Weapon Programs*, report to Congressional Committees, GAO-13-294SP (Washington, DC: United States Government Accounting Office, March 2013), http://www.gao.gov/ assets/660/653379.pdf (accessed 1 March 2014), 101, 105, 113.

[183]Majumdar, "USAF: Current Unmanned Aircraft Irrelevant in the Pacific."

[184]Gertler, 4.

[185]Krishnan, 127.

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Predators and Reapers had crashed in Iraq and Afghanistan, at a cost of $3.7 to $5 million each. Nine others had crashed stateside. Ostensibly, the USAF's RPAs were crashing themselves out of existence.[186]

Mishap rates have decreased significantly over the past several years. The 2009 accident rate for the Predator was comparable to that of the F-16 fighter at that aircraft's same stage of development, and better than that of single-engine private planes in the United States. Crash rates for aircraft in general tend to be highest during development and initial operations. The US military accepted the risks associated with deploying untested unmanned systems because the capabilities they provided were worth the cost. Mishap rates for manned aircraft have declined markedly over the past fifty years due to improvements in designs and training, and today unmanned systems are aligning with this trend.[187]

Developers identify modularity as a key affordability factor for future unmanned systems, envisioning a "standardized, low-cost, small- to medium-sized, remotely piloted airframe able to carry mission-specific payloads."[188] This concept (aside from the remote pilot) sounds remarkably like the DOD's original vision for the F-35 Joint Strike Fighter. The Pentagon wanted the F-35 to be an affordable aircraft whose three variants would answer the respective needs of the USAF, Navy, and Marines for decades to come. After years of requirements creep, cost overruns, and broken deadlines, the price tag for each F-35 now stands at $135 million.[189]

The F-35's skyrocketing price tag is no surprise to USAF Lieutenant Colonel Lawrence Spinetta, an experienced pilot and former RPA squadron commander. He notes, "[w]ithout

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[186]Gertler, 17-18.

[187]Ibid., 18-19.

[188]US Air Force Chief Scientist, *Technology Horizons*, 83.

[189]Harrison, 43. This number comes from the 2012 Defense Budget. In the 2013 Budget, the DOD cut the production rate of the F-35 to reduce total program cost. This move further increases per-unit price, as research and development costs are shared across a smaller fleet. Daggett and Towell, 10.

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exception, every generation of bomber and fighter aircraft since the Wright Flyer has been an order of magnitude more expensive than its predecessor."[190] However, his claim that "[u]nmanned aircraft . . . offer so much capability for so little money that they represent a way out of the service's force structure death spiral" is either prescience—or fallacy.[191] The exorbitant Global Hawk and the Navy's UCAS certainly challenge such an assertion.

General Hostage's assertion that unmanned systems are nonexpendable is not universal. The *Unmanned Systems Integrated Roadmap* envisions a future in which commanders habitually make decisions to expend (i.e. destroy) robotic vehicles in order to accomplish their missions.[192] It notes, "[i]n order to be expendable, which is often the intent of building an unmanned system, the vehicle must be low-cost."[193] The *Roadmap* does not mention an associated requirement: in order to be expendable, commanders must have enough units that sacrificing them does not exhaust available reserves. Cost equals price-per-unit times the total number of systems purchased. Future designs may be expendable, but this does not mean the total bill will be low. The *Roadmap* is correct to regard affordability as important, but when the same document highlights the need to "protect the defense industrial base," one begins to surmise the intended audience.[194] Unmanned systems can be cost effective only if the US military resists the siren song of cheap, quick fixes perpetually emanating from the purveyors of armaments.

More Machines, Fewer Humans: the Wrong Answer

Personnel costs are a significant component of military budgets. If technology could decrease the ratio of crews-to-vehicles, then unmanned systems might reduce this expense

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[190]Spinetta and Cummings, "Unloved Aerial Vehicles."

[191]Ibid.

[192]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 7.

[193]Ibid., 14.

[194]Ibid., 64.

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without sacrificing combat effectiveness. The USAF presently uses one pilot and one sensor operator to control each RPA. This two-to-one ratio does not include the scores of additional personnel involved in the support and intelligence exploitation of each aircraft.

In the mid-2000s, the USAF tested a system called Multi-Aircraft Control (MAC), which allowed one ground control station to manage up to four airborne RPAs during benign operations like transit or holding patterns. The *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047* set a goal to implement MAC on a wider scale by late 2010, envisioning 56 percent in manpower savings across the RPA fleet.[195] Such developments prompted drone alarmists to forecast omnipotent puppet masters singlehandedly directing squadrons of lethal drones to incinerate clusters of (presumably innocent) people in distant lands.[196] In actuality, such marionette-like manipulation turned out to be more difficult than expected.

At first glance, MAC may appear analogous to air traffic control (ATC), in which each controller can manage multiple airborne aircraft. However, human factors experts call this analogy "fallacious for projecting the safe human-robot ratio because it ignores the Pilot-in-Command role. . . . If a manned air vehicle encounters difficulties, the ATC does not assume control of the aircraft; the Pilot on board remains in charge of each individual aircraft."[197] The interplay between controllers and pilots is what makes ATC function, particularly when the unexpected occurs. The author's personal experience as a flight leader, instructor pilot, and mission commander in the F-15C Eagle, F-22 Raptor, MQ-1 Predator, and MQ-9 Reaper corroborates this finding. In dynamic situations, flying one's own aircraft while simultaneously directing a formation of four or more fighters is extremely demanding. Proficiency requires years

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[195]United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 18, 55; Deptula and Mathewson, slide 11.

[196]Turse and Engelhardt, 43.

[197]Robin R. Murphy and Jennifer L. Burke, "The Safe Human-Robot Ratio," in *Human-Robot Interactions*, 47.

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of training and constant practice. It relies on rigorous tactical standards and prudent delegation to the qualified human aviators operating each additional aircraft.

Studies of multitasking have consistently shown that human performance deteriorates when a person attempts to do several things at once (text messaging while driving, for example). Experiments with unmanned systems have demonstrated that simultaneously controlling multiple vehicles engenders significant risks of lost SA, cognitive overload, and incorrect task prioritization.[198] P.W. Singer notes, "[j]ust having a human operator control two rather than one UAV at a time reduces their performance by an average of 50 percent."[199] One experiment with UGVs found that single operators controlling two vehicles detected less than 25 percent of their targets, but *adding* an additional operator to each system improved detections up to 170 percent– in other words, more humans were the answer, not fewer.[200] Technological solutions that simplify inputs or make displays more intuitive may streamline a remote operator's changeover between the controls of multiple vehicles, but ergonomics cannot eradicate the pitfalls of multitasking.[201]

The USAF's MAC trial ended in 2011-2012 because aircrews found it infeasible and unreliable. One veteran RPA pilot lamented the "inability to build SA as you push into the target area" when flying multiple aircraft.[202] Another explained that MAC control did not suffice when there were "two targets to prosecute or two malfunctioning airplanes. That was more than one

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[198]Michael J. Barnes and A. William Evans III, "Soldier-Robot Teams in Future Battlefields: An Overview," in *Human-Robot Interactions*, 12, 21-22; Keryl Cosenzo, Raja Parasuraman, and Ewart de Visser, "Automation Strategies for Facilitating Human Interaction with Military Unmanned Vehicles," in *Human-Robot Interactions,* 104.

[199]Singer, *Wired for War*, 126.

[200]Florian Jenstch, A. William Evans III, and Scott Ososky, "Model World: Military HRI Research Conducted Using a Scale MOUT Facility," in *Human-Robot Interactions*, 422.

[201]Barnes and Evans, "Soldier-Robot Teams," in *Human-Robot Interactions*, 22; Jennifer M. Riley, et al., "Situation Awareness in Human-Robot Interaction: Challenges and User Interface Requirements," in *Human-Robot Interactions*, 178-179; Gloria Calhoun and Mark Draper, "Unmanned Aerial Vehicles: Enhancing Video Display Utility with Synthetic Vision Technology," in *Human-Robot Interactions*, 242.

[202]Major Landon Quan, USAF, e-mail message to author, 4 December 2013.

4719 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

pilot could handle."[203] These "targets" include not just lethal strikes, but any dynamic surveillance task, such as following a vehicle through crowded urban streets or tracking individuals in rugged terrain. A human-flown RPA with real-time FMV is the ideal platform for such volatile situations, but they require singular focus to be successful. The fog and friction of ground combat is even greater than that of airborne operations.[204] One Pentagon report determined, "[e]ven if the tactical commander is aware of the location of all his units, the combat is so fluid and fast-paced that it is very difficult to control them."[205] The Navy's plan to synchronize multiple types of unmanned systems from an LCS in hostile waters portends a multitasking nightmare.[206]

Multi-aircraft control may still be useful for scripted flight plans like those of the Global Hawk (although even its pilots frequently have to intervene manually), but for demanding, unpredictable situations, unmanned systems require one crew per vehicle.[207] Even if MAC could reduce personnel requirements during transit, the ratio of aircraft en route versus those on target would depend on the tactical scenario. A squadron would still need a full roster of pilots standing by to assume aircraft control during intense situations.[208] Only one factor might alter the equation. It is the most controversial subject in the debate over unmanned systems: what if technology could eliminate the need for human control altogether?

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[203]Martin and Sasser, 301.

[204]von Clausewitz, 119, 140.

[205]Singer, *Wired for War*, 126.

[206]Riley, et al., "Situation Awareness in Human-Robot Interaction," in *Human-Robot Interactions*, 176.

[207]Gertler, 36.

[208]Michael Lewis and Jijun Wang, "Coordination and Automation for Controlling Robot Teams," in *Human-Robot Interactions*, 415. Moreover, the MAC required a sensor operator to monitor each vehicle during transit, so there was no improvement to enlisted personnel requirements. See Michael Hoffman, "Are Enlisted Airmen Next to Pilot UAVs?" *Air Force Times*, 21 December 2008, http://www.airforcetimes.com/article/20081221/NEWS/812210319/Are-enlisted-airmen-next-to-pilot-UAVs (accessed 1 March 2014).

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Robotic Autonomy

If militaries develop and deploy fully autonomous lethal systems, the character of warfare will change in significant but unpredictable ways. As discussed above, fully autonomous systems to date exist only as experimental prototypes.[209] While academia, industry, and certain DOD entities continue to advocate for increased robotic autonomy, uniformed personnel at all levels remain opposed to relinquishing the human decision over the employment of deadly force.

Full autonomy is distinct from automation or semi-autonomy. An autonomous robot consists of several components: "sensors" to obtain information, "processors" to interpret it, and "effectors" to implement its decisions.[210] Autonomous systems are "self-directed toward a goal in that they do not require outside control, but rather are governed by laws and strategies that direct their behavior . . . [even in] unpredictable situations."[211] They must be capable of "complex decision making, including autonomous mission planning, and [have] the ability to self-adapt to the environment."[212] In contrast, an *automatic* system (an aircraft flying on autopilot with a human monitor, for example) "is not able to define the path . . . or to choose the goal."[213] Semi-autonomous systems implement even more automation, but still do not make decisions. "Fire and forget" missiles, radar-guided air defenses, and mines are semi-autonomous systems.[214]

Department of Defense Directive (DODD) 3000.09, *Autonomy in Weapon Systems,* dated 21 November 2012, spells out the US military's current stance on the subject:

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[209]Krishnan, 44.

[210]Singer, *Wired for War*, 67.

[211]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 43.

[212]US Air Force Chief Scientist, *Technology Horizons*, 53.

[213]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 43.

[214]Department of Defense, Directive 3000.09, *Autonomy in Weapon Systems* (Washington, DC: Department of Defense, 21 November 2012), http://www.dtic.mil/whs/directives/corres/pdf/300009p.pdf (accessed 1 March 2014), 14; Krishnan, 45. While a human does not select the specific target for a mine, one does select its (static) location and fusing function. The device only reacts to a direct stimulus—it does not make a "decision" to explode.

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> Commanders and operators [shall] exercise appropriate levels of human judgment over the use of force . . . in accordance with the law of war, applicable treaties, weapon system safety rules, and applicable rules of engagement (ROE). . . . Human-supervised autonomous weapon systems may be used . . . for local defense to intercept attempted time-critical or saturation attacks. . . . Autonomous weapon systems may be used to apply non-lethal, non-kinetic force such as some forms of electronic attack.[215]

The regulation permits the military to use semi-autonomous lethal weapon systems under human control, as it has for decades. Ancillary studies may make many assertions about the need for autonomy in future designs, but DODD 3000.09 is plain in its restrictions.[216] Speculation aside, "for the foreseeable future, decisions over the use of force . . . will be retained under human control in unmanned systems."[217]

DODD 3000.09 does not present novel concepts; the US military learned its lessons regarding human-supervised autonomy long ago. In 1960, the United States deployed a radar system designed to detect Soviet ICBM launches and trigger a rapid nuclear response sequence. Shortly after activation, the system lit up with warnings of an incoming attack. Its radar had picked up a large object rising above the horizon: the moon. The system worked as programmed—its designers simply had not taught it to distinguish a missile from a celestial object. An astute commander quickly spotted the error and ended the crisis.[218]

Forays into autonomy have not always ended bloodlessly. On 3 July 1988, a US Navy Aegis cruiser in the Arabian Gulf detected an unknown aircraft. The newly installed air defense system aboard the *Vincennes* misidentified a civilian airliner as an Iranian F-14 fighter. Despite situational evidence to the contrary, the crew trusted the computer and shot down the airliner,

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[215]Department of Defense, Directive 3000.09, 2-3.

[216]United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 33; Deptula and Mathewson, slide 21; Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, vi, 27, 45-46.

[217]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 17.

[218]"Moon Stirs Scare of Missile Attack," *New York Times*, 8 December 1960.

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killing all 290 passengers and crew.[219] The human-supervised autonomy of the *Vincennes* would have fit the defensive stipulations of DODD 3000.09, but the crew's actions would have violated the requirement always to exercise human judgment and apply ROE. Today, Phalanx ship-defense guns and the equivalent land-based C-RAM (Counter Rocket, Artillery, and Mortar) can operate under human-supervised autonomy, but only under strict, short-range constraints.[220]

The US military has built up a healthy mistrust of autonomous weapon systems. Nevertheless, academics, think tanks, and industry advocates continue to publish studies proclaiming that autonomy is not just desirable, but necessary and inevitable.[221] In 2011, the Office of the USAF Chief Scientist's *Technology Horizons* asserted, "[i]ncreasing levels of flexible autonomy will be needed for a wider range of Air Force functions."[222] A recent study from the Center for a New American Security concluded: "To realize their full game-changing potential, militaries may need to use more contentious concepts of operation including fully autonomous ISR or even combat missions."[223] Armin Krishnan believes that if Western armed forces "wish to retain their current military advantage in the long run they will need to increasingly substitute soldiers with technology, i.e. robots."[224] These statements all use the word "need" to characterize the importance of autonomy, but all come from sources outside the military chain of command.[225]

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[219]Mark Hagerott, "Robots, Cyber, History, and War," in *Robots on the Battlefield*, 25; Singer, *Wired for War*, 124-125.

[220]Singer, *Wired for War*, 38; 34. The C-RAM only targets incoming projectiles, not live adversaries. Hagerott, "Robots, Cyber, History, and War," in *Robots on the Battlefield*, 27.

[221]Krishnan, 34.

[222]US Air Force Chief Scientist, *Technology Horizons*, 53.

[223]Brimley, FitzGerald and Sayler, "Game Changers," 15.

[224]Krishnan, 2.

[225]US Air Force Chief Scientist, *Technology Horizons*, 166-169. The authors of *Technology Horizons* are all civilians except for two USAF colonels, both of whom have spent their careers in research and development, not operations.

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Vignettes that advocate for autonomous systems tend to sound contrived. The *Unmanned Systems Integrated Roadmap* presents a hypothetical scenario wherein friendly autonomous systems neutralize a rogue UUV and destroy a futuristic enemy UAV.[226] In both engagements, friendly actions promptly defeat a non-adaptive foe. Other studies further strain credulity. One proposal from 2006 addresses ROE concerns by suggesting that autonomous robots should "shoot to destroy hostile weapons systems, but not suspected combatants," as if aiming a missile at a vehicle rather than the driver inside changes the outcome.[227] Ronald Arkin, a leading advocate for robotic autonomy, envisions autonomous aircraft programmed to hold fire or select a smaller weapon if a hostile target passes near a hospital. He and his colleagues believe future autonomous systems could even wait to determine whether a person "seems ready to attack" before they shoot at him.[228] These appeals for autonomy casually disregard the reality of warfare in myriad ways. Guileful adversaries habitually leverage protected symbols and structures (i.e. hospitals and religious buildings) in far more complex and nefarious ways than simply driving past them. Determining a human's actual intentions remains squarely in the realm of science fiction.

Empirical evidence does not support lofty aspirations for autonomous weapons systems. To assess whether autonomous systems could replace human soldiers, scientists must develop scenarios that replicate the unpredictability of combat against a live, adaptive foe. As *Technology Horizons* explains, "it is the lack of suitable V&V [verification and validation] methods that prevents all but relatively low levels of autonomy from being certified for use."[229] Robotics

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[226]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 9-10.

[227]Singer, *Wired for War*, 128.

[228]Tara McKelvey, "Could We Trust Killer Robots?" *Wall Street Journal*, 19 May 2012, http://online.wsj.com/article/SB10001424052702303448404577410032825529656.html (accessed 1 March 2014).

[229]US Air Force Chief Scientist, *Technology Horizons*, xx.

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experts have determined that "[a]rtificial intelligence required for vehicle autonomy remains a disappointing technology despite exponential improvements in computing cost and density."[230]

Artificial intelligence can exceed human capacity in certain endeavors. For example, the computer *Deep Blue* beat human chess champion Gary Kasparov in 1997. Chess has relatively simple rules that an adroitly programmed machine can use to generate nearly infinite combinations.[231] Computers excel at chess because all possible moves take place within a "well-defined problem space."[232] Chess is a *complicated* game, with vast possible permutations that nevertheless operate in patterned and finite ways. War, on the other hand, is *complex*: it adapts based on diverse interactions and emergent properties that make it impossible to predict with certainty.[233] In war, a wise adversary hardly ever plays by the "rules." Instead, a deft combatant seeks victory through asymmetric and adaptive methods.

Computers falter when problems do not have clear boundaries. For example, it is difficult for a computer to tell the difference between an apple and a tomato without detailed analysis, as nearly all measures of comparison overlap in some regard (size, shape, color, etc.). Most humans can distinguish between an apple and a tomato—or between a Soviet ICBM and the moon—intuitively.[234] Experiments with teams of autonomous vehicles have found that robotic self-coordination quickly becomes "computationally intractable" because every decision spawns an ever-expanding set of possibilities.[235] Swarms of robots that resemble phenomena in nature are

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[230]Nancy J. Cooke and Roger A. Chadwick, "Lessons Learned from Human-Robotic Interactions on the Ground and in the Air," in *Human-Robot Interactions*, 361.

[231]Krishnan, 47; United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 41.

[232]Chris Jansen and Jan B. F. van Erp, "Telepresence Control of Unmanned Systems," in *Human-Robot Interactions*, 251.

[233]Gökçe Sargut and Rita Gunther McGrath, "Learning to Live with Complexity," *Harvard Business Review* 89, no. 9 (September 2011): 70-71.

[234]Singer, *Wired for War*, 76; "Moon Stirs Scare of Missile Attack."

[235]Lewis and Wang, "Coordination and Automation for Controlling Robot Teams," in *Human-*

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intriguing but impractical in unscripted scenarios.[236] Human intellect is imperfect, but it has evolved the ability to distill coherency from complex uncertainty without requiring a preprogrammed solution. This explains how pilots can wield formations of aircraft in unfamiliar situations where the research indicates that autonomous robots would quickly run out of ideas.

Autonomy at any level of the decision-making process affects the application of lethal force, even if a human ultimately pulls the trigger. Military operations demand trust and shared understanding, from tactical engagements all the way to strategic direction and planning. A program that could evaluate "up to 3,000 friendly COAs [courses of action] per minute" would be counterproductive because commanders and staffs never would learn why certain options did not make the cut.[237] Commanders and staffs develop courses of action and conduct wargames to focus their planning, not to arrive at perfect solutions (which do not exist).

Any autonomous ISR system designed to cull unnecessary data before sending it to human analysts would have to be pristine, as erroneous omissions could be disastrous.[238] Unfortunately, when autonomous systems are assigned tasks such as "making a prediction of enemy activity . . . the data upon which the diagnosis is based are fuzzy and uncertain. Hence a substantial error rate in diagnostic accuracy is anticipated."[239] Skepticism is critical in order to avoid "automation bias—an overreliance in which people treat information from the robot as fact

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Robot Interactions, 402.

[236]Tisseron, "Robotic and Future Wars," in *Robots on the Battlefield*, 13; Hagerott, "Robots, Cyber, History, and War," in *Robots on the Battlefield*, 30; George R. Lucas, Jr., "The Ethical Challenges of Unmanned Systems," in *Robots on the Battlefield*, 139-140.

[237]Krishnan, 54.

[238] Michel Yakovleff, "Battlefield Robotization: Toward a New Combat Ecosystem," in *Robots on the Battlefield*, 254; Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 49.

[239]Christopher D. Wickens, Brian Levinthal and Stephen Rice, "Imperfect Reliability in Unmanned Air Vehicle Supervision and Control," in *Human-Robot Interactions*, 194.

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without seeking additional information."[240] The crew of the *Vincennes* demonstrated automation bias in 1988 with tragic consequences.

Professional military members accept the personal responsibility inherent in the state sanction of lethal operations. Autonomy threatens to fracture this paradigm, which has legal and ethical implications, but advocates for autonomy are not depraved. Instead, they believe the military needs autonomous robots because future conflicts will demand split-second timing that exceeds human capabilities. The *Unmanned Systems Integrated Roadmap* envisions systems that can "adapt and learn . . . fast enough to provide benefits within the adversary's decision loop."[241] Aerial dogfights, cyber-attacks, and nuclear missile launches do demand near-instantaneous responsiveness, but it is irresponsible to invoke a metaphorical feedback loop to justify imbuing robots with decision-making authority.[242] Military operations as a rule require not reflexive action but rather prudent deliberation and an acceptance of responsibility for both intended effects and unintended consequences.[243] The following section will examine these challenges as they pertain to current policies and strategies involving unmanned systems.

IV – ARE UNMANNED SYSTEMS MAKING MORE TERRORISTS?

The preceding sections analyzed the development of unmanned systems into their present forms, and dissected persistent misconceptions regarding their character and promise. Unmanned

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[240]Lori Fister Thompson and Douglas J. Gillan, "Social Factors in Human-Robot Interaction," in *Human-Robot Interactions*, 70.

[241]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 48. This concept derives from the Observe-Orient-Decide-Act loop developed by USAF Colonel John Boyd, a fighter pilot and theorist, in the 1970s. RMA proponents of the 1990s and early 2000s borrowed this concept in their pursuit of technological solutions to the fog and friction of war. See Frans Osinga, *Science, Strategy, and War: The Strategic Theory of John Boyd* (New York, NY: Routledge, 2007), 1-3.

[242]United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 16.

[243]Hagerott, "Robots, Cyber, History, and War," in *Robots on the Battlefield*, 28; Dominique Lambert, "Autonomous Robots: The Irreducible and Complementary Place of Officer's Ethics," in *Robots on the Battlefield*, 132.

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systems provide remarkable proven—and potential—capabilities, but they are an amalgamated component of war's evolution, not a divergent path. Like any inanimate tool, unmanned systems themselves are neither legal nor illegal; neither moral nor immoral; neither right nor wrong. When wielded by professionals, they operate well within the accepted rules of warfare.[244] Conversely, if used carelessly or with ill intent, unmanned systems have the potential to explode the notion that warfare—though always regrettable—can be a legitimate, noble endeavor. Unmanned systems must not lower the threshold for when to employ force. The consequences of a cavalier attitude toward violence will be severe.

Too Seductive for Policymakers?

Some analysts believe that the apparent risk-free nature of unmanned systems facilitates the decision to resort to force, making violence a first resort rather than a last one.[245] The nature of risk is among the most complex subjects in warfare, particularly as technology has enabled greater distance and detachment between combatants. With regard to tactical risk, unmanned systems do increase the safety and security of their operators as compared to manned equivalents. In terms of their ability to produce mission success, or their potential to transfer danger to other friendly forces or civilians, unmanned systems are not a riskless proposition.[246]

Since the dawn of aviation, many airpower advocates claimed that aircraft could shatter existing paradigms of protracted warfare on land and at sea, providing shortcuts to victory by striking enemy leadership and economies directly. Their predictions always failed: against

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[244]Christof Heyns, "Report of the Special Rapporteur on Extrajudicial, Summary or Arbitrary Executions," Report A/68/382, submitted to the United Nations General Assembly, 13 September 2013, http://justsecurity.org/wp-content/uploads/2013/10/UN-Special-Rapporteur-Extrajudicial-Christof-Heyns-Report-Drones.pdf (accessed 1 March 2014), 4.

[245]Zenko, *Reforming U.S. Drone Strike Policies*, 8; Schwartz, "U.S. Drone Program is Fatally Flawed," 45.

[246]Benjamin, 212-213; Zenko, *Reforming U.S. Drone Strike Policies*, 8.

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Germany, Japan, North Korea, Vietnam, Iraq, and Serbia, US air attacks alone never broke enemy resistance.[247] Instead, they served as critical enablers for comprehensive approaches (with varying levels of success). Even the atomic bombing of Japan did not produce victory singlehandedly: it represented the final act of years of grueling combat on land, at sea, and in the air, including a strangling naval blockade and the entry of the Soviet Union into the Pacific theater. Nevertheless, despite the dearth of evidence, each technological advance in air combat spawned new pundits who insisted airpower finally could make warfare systematically winnable.[248]

Following the Gulf War and an ill-fated troop deployment to Somalia in 1993, the United States and its allies relied almost exclusively on airpower for a number of military operations. Policymakers chose this option because they did not want to risk ground forces, and because they believed aircraft could accomplish the desired missions. The two no-fly zones over Iraq minimized friendly casualties and contained Iraq at a cost of $1 billion per year, but they did not achieve the ultimate goal of eliminating the regime of Saddam Hussein.[249]

Military options that avoided placing personnel in harm's way altogether were even more attractive to policymakers, as demonstrated by the 1998 cruise missile strikes that (unsuccessfully) targeted Osama bin Laden and his associates. In this instance, the United States unleashed deadly force into Afghanistan and Sudan—nations with which it was not at war.[250] Cruise missile attacks alleviated the need for forward bases and involved zero risk of friendly casualties or prisoners-of-war. Unfortunately, they also failed to achieve their objectives. The United States' international prestige slipped, and the legend of bin Laden grew. The persistence

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[247]Turse and Engelhardt, 25. These are examples of American air campaigns, but other nations have tried similar approaches. The Luftwaffe's failure to subdue Britain during the *blitz* campaign is a prime example of resilience in the face of air attack.

[248]John A. Warden III, "Air Theory for the Twenty-First Century," in *Battlefield of the Future*, 121-122.

[249]Zenko, *Between Threats and War*, 29, 38, 49.

[250]Ibid., 52.

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and accuracy of modern unmanned systems may offer a higher probability of effective targeting than standoff weapons like cruise missiles, but precision does not equate to mission success.[251]

Contemporary American military leaders have been more reluctant to employ force than their civilian counterparts have, and the former tend to eschew simple martial solutions to difficult problems.[252] Sometimes the civilian leadership heeds their advice, and sometimes it rejects it. The no-fly zones over Iraq "were generally supported by senior civilian officials and opposed by senior military officials" (the latter viewed them as ineffective).[253] In the run-up to the 2003 invasion of Iraq, senior civilian leaders spurned top generals' recommendations for a larger force to mitigate risk, instead opting for an RMA-inspired invasion plan.[254] Conversely, in July 2013, Chairman of the Joint Chiefs of Staff Martin Dempsey's astute articulation of the risks of American intervention in Syria's civil war succeeded in mollifying hawkish political leaders.[255]

Unmanned systems appeal to casualty-averse politicians because they reduce the risk of friendly losses, but this factor does not make the decision to employ force an easy one. Every time a commander uses state-sanctioned violence to achieve an end, he or she injects a stimulus into a system that will create multiple-order effects, and the payoff had better be worth the potential cost. Nonetheless, once leaders make the decision to employ force, they are obliged to select tools that minimize risk to friendly forces and reduce collateral damage.[256] Unmanned systems—at times—may be the right answer. General Norton Schwartz, former Air Force Chief of Staff, cannot believe any responsible citizen "would prefer for the American military to absorb

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[251]Dawkins, 17-18, 21; Heyns, 4-5.

[252]Zenko, *Between Threats and War*, 26, 67-68.

[253]Ibid., 48-49.

[254]Gordon and Trainor, 101-103.

[255]Martin Dempsey, "Gen. Dempsey Responds to Levin's Request for Assessment of Options for Use of U.S. Military Force in Syria," 19 July 2013, http://www.levin.senate.gov/download/?id=f3dce1d1-a4ba-4ad1-a8d2-c47d943b1db6 (accessed 1 March 2014).

[256]Lucas, "The Ethical Challenges of Unmanned Systems," in *Robots on the Battlefield*, 136.

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casualties just for the purpose of making war less numbing to the political leadership."[257] Unmanned systems may seem particularly seductive for spying because they alleviate prisoner-of-war concerns in the case of a crash, but this precedent already exists. American satellites have been peering into other nations for more than half a century.

The words and phrases policymakers use to describe strategy directly influence the way nations conceive and fight wars. Use of the term "Global War on Terror" to define American military operations against al-Qaeda and its affiliates after 9/11 gave the impression that the nation was at war with an extensive, incorporated adversary. Consequently, the United States mobilized massive worldwide military and intelligence efforts, including the rapid proliferation of unmanned systems, in a conflict whose very title implied limitless commitment. In reality, those responsible for 9/11 numbered in the hundreds, and most other extremists worldwide had little or no connection with them; grievances tend to be local, not global. The notion that the United States had embarked on a so-called "long war" thus became a self-fulfilling prophecy.[258]

The Administration of President Barack Obama retired the Global War on Terror moniker, but it maintained the assertion that America is committed to a long-term conflict against persistent adversaries.[259] Many worry that the increased use of unmanned systems under the current administration "may lower social barriers in society against the deployment of lethal force," leading to an era of eternal conflict.[260] Speculation aside, this concern highlights the danger of seeking violent solutions to complex problems: absent a comprehensive approach to

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[257]Schwartz, "U.S. Drone Program is Fatally Flawed," 12.

[258]Benjamin, 97.

[259]White House, *The National Security Strategy of the United States of America* (Washington, DC: US Government Printing Office, May 2010), 19-21; Amnesty International, *Will I Be Next? US Drone Strikes in Pakistan* (London, UK: Amnesty International Publications, October 2013), http://www.amnestyusa.org/research/reports/will-i-be-next-us-drone-strikes-in-pakistan (accessed 1 March 2014), 48.

[260]Heyns, 5.

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solving the root causes of strife, lethal attacks tend to spread discontent and transfer risk. This metastasizing effect explains why new "al-Qaeda" offshoots seem to emerge daily.

Unmanned systems are tools that do not apply equally to all strategic, operational, and tactical problems. If, based on rigorous analysis and debate, the United States' government elects to target a legal combatant with lethal force, then the stealth, persistence, and precision of a UAS may be the appropriate solution. Still, experience to date demonstrates that simply eliminating one or a handful of individuals does not ensure victory. The 2011 *National Military Strategy of the United States* explains: "While such operations disrupt in the short-term, they cannot be decisive and do not constitute a viable long-term strategy for combating extremism."[261]

Policymakers must analyze every contingency specifically to determine how to proceed, rather than grouping distinct crises into a unitary, Cold War-like model. Fortunately, the available evidence indicates that this is what they at least endeavor to do. The latest *National Security Strategy of the United States* repeatedly emphasizes that lethal force is only one component of a comprehensive, interdependent approach to securing the safety and interests of the nation.[262] Technology has increased the global interconnectedness of America's allies and its adversaries alike, but leaders must always tailor decisions involving lethal force to fit specific situations.

Legality

Unmanned systems do not permit a nation to deviate from international laws and norms. During declared armed conflicts between states or between a state and a non-state actor, international humanitarian law applies. Under this framework, lethal attacks must be *proportional* (devastation must not outweigh the intended gain) and *discriminating* (they must target lawful

[261]Joint Chiefs of Staff, *The National Military Strategy of the United States* (Washington, DC: US Government Printing Office, 2011), 6.

[262]White House, *National Security Strategy of the United States*, 3-4, 8, 18, 20-22.

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combatants and not civilians, also called *distinction*).[263] Violence must reach a defined minimum level of intensity, and participants must be governmental authorities or organized armed groups.[264] Modern terrorists strain these guidelines by intentionally embedding their activities among civilian populaces, maintaining fluid organizational structures, and frequently switching between violent action and peaceful existence, but their flaunting of legal characterization does not make them immune from attack.

International humanitarian law presumes an individual is a noncombatant until proven otherwise. One can lose this protected status based upon "insignia or conduct."[265] Conduct such as propaganda, recruitment, finance, and logistical support to the enemy do not make an individual a targetable combatant.[266] Activities must indicate a "continuous combat function," meaning a person is a member of an armed group and actively participates by planning, commanding, or executing "operations amounting to direct participation in hostilities."[267] A lethal strike from an unmanned system can exemplify proportionality and distinction, or else it can be murder—as the United Nations (UN) Special Rapporteur explains, "[t]he legal test remains whether there is sufficient evidence."[268]

The United States asserts that it uses unmanned systems in a declared armed conflict that began the week after 9/11. On 18 September 2001, the US Congress passed the Authorization for the Use of Military Force. This act legitimated military action against "nations, organizations, or

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[263]Dawkins, 26, 30; Amnesty International, 27; Heyns, 14-16.

[264]Amnesty International, 45-47; Heyns, 12-14.

[265]Heyns, 14-15.

[266]Ben Emmerson, "Report of the Special Rapporteur on the Promotion and Protection of Human Rights and Fundamental Freedoms While Countering Terrorism," Report A/68/389, submitted to the United Nations General Assembly, 18 September 2013, http://msnbcmedia.msn.com/i/msnbc/sections/news/UN_Drones_Report.pdf (accessed 1 March 2014), 21; Benjamin, 133.

[267]Emmerson, 20.

[268]Heyns, 15.

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persons [that] planned, authorized, committed, or aided the terrorist attacks that occurred on September 11, 2001, or harbored such organizations or persons, in order to prevent any future acts of international terrorism against the United States by such nations, organizations or persons."[269] Concurrently, UN Security Council Resolutions 1368 and 1373 provided international justification for state self-defense against transnational threats like al-Qaeda.[270] The United States has carried out UAS strikes in Afghanistan, Pakistan, Yemen, and Somalia under these sanctions, while those in Iraq and Libya fell under other UN authorizations.[271]

Outside of armed conflict, international human rights law regulates violent action. This body of law is stricter: deadly force may only be a last resort to prevent immediate loss of life.[272] In addition, if an armed conflict diminishes below the aforementioned coherence and intensity, human rights law replaces humanitarian law as the accepted standard.[273] Some believe human rights law should apply during armed conflict as well, but this notion is naïve—deadly force is the defining feature of war, not a fallback option.[274] Due to the restrictive nature of human rights law, armed unmanned systems rarely, if ever, belong outside the realm of armed conflict.

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[269]Joint Resolution, S.J. Res. 23, 107th Cong., 18 September 2001. Public Law 107-40, http://www.gpo.gov/ fdsys/pkg/PLAW-107publ40/pdf/PLAW-107publ40.pdf (accessed 1 March 2014), 115 STAT. 224; Zenko, *Reforming U.S. Drone Strike Policies*, 16.

[270]Emmerson, 16; United Nations Security Council, Resolution 1368 (2001), 12 September 2001, S/RES/1368, http://www.un.org/docs/scres/2001/sc2001.htm (accessed 1 March 2014); United Nations Security Council, Resolution 1373 (2001), 28 September 2001, S/RES/1373, http://www.un.org/docs/scres/2001/sc2001.htm (accessed 1 March 2014).

[271]Benjamin, 129-130; Amnesty International, 48; Emmerson, 7-10; Zenko, *Reforming U.S. Drone Strike Policies*, 9.

[272]Emmerson, 17; Eric Pomes, "A Comparison of Drones and Military Unmanned Ground Vehicles (UGVs) in International Law," in *Robots on the Battlefield*, 93-94.

[273]Heyns, 14; Zenko, *Reforming U.S. Drone Strike Policies*, 16.

[274]Amnesty International, 23, 44; Heyns, 9.

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Civilian Casualties

War is deplorable even when it is justified, and the deaths of innocent civilians rank high among its horrors. In the past three centuries, wars have claimed the lives of approximately equal numbers of civilians and soldiers.[275] The deaths of noncombatants are tragic but they are legal as long as belligerents adhere to the laws of armed conflict and do not intentionally target or wilfully harm them.[276] Incidental civilian casualties may technically be permissible, but in an age of instant global connectivity, every innocent death risks derailing a nation's strategy and empowering its adversaries.

Civilians have died because of American UAS strikes.[277] In Afghanistan, The UN notes that unmanned systems have accounted for fewer civilian deaths than manned aircraft.[278] General Schwartz asserts that the ratio of civilians to combatants killed by UAS strikes in the Afghan theater is roughly one to seven, far below historical proportions.[279]

The remote, hostile nature of the regions where many UAS strikes take place obfuscates the debate over civilian casualties. In these areas, interloping militants intentionally embed themselves among civilian populations in defiance of humanitarian law.[280] Civilians live in constant fear of becoming collateral damage from an airstrike. The intruders terrorize the locals, murdering anyone suspected of spying.[281] Civilians seldom speak candidly with outsiders for fear

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[275]William Eckhardt, cited in Alexander B. Downes, "Desperate Times, Desperate Measures: The Causes of Civilian Victimization in War," *International Security* 30, no. 4 (Spring 2006): 152.

[276]Heyns, 16; Krishnan, 93.

[277]Amnesty International, 52.

[278]Emmerson, 7-8.

[279]Schwartz, "U.S. Drone Program is Fatally Flawed," 18.

[280]Amnesty International, 47; Krishnan, 94.

[281]Amnesty International, 14-15, 32-33.

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of retribution.[282] Owen Bennett-Jones, a British journalist who has spent extensive time in these treacherous regions, belies common perceptions with his assessment:

> The closer you get to the places where the drones are actually landing, the more support for them there is . . . the reason is that these Taliban commanders and fighters are causing absolute havoc in the tribal areas. They are going around killing people, beheading them. They are cutting people's limbs off, writing graffiti in blood from severed limbs . . . people are terrified of them. And these drones come along and kill them.[283]

Marauding terrorists cause far more devastation than American unmanned systems, but this disproportion does not mitigate the costs of civilian deaths due to UAS strikes. The precision of a UAS makes it a far more discriminating weapons system than artillery or other unguided munitions, and its persistence enables crews to wait for shot opportunities that avoid collateral damage.[284] Nevertheless, mistakes have occurred and likely will occur in the future.

Some observers, including Amnesty International and UN Special Rapporteur Christof Heyns, imply that not all civilian deaths are unintentional. They recount follow-up UAS strikes that appeared to target first responders and medical personnel trying to aid victims of an initial attack. If true, these strikes would constitute war crimes.[285] In the author's experience with missions in Afghanistan, as soon as first responders showed up, the shooting was over. The US military does not practice such illegal and deplorable tactics.

Even if unmanned systems shrink the number of civilian casualties to a pittance, the psychological impact on those living underneath protracted air campaigns is severe. Despite their precision in targeting the wrongdoers that Bennett-Jones mentions above, UAS strikes also are alien and unexpected. Civilians fear that any stranger in their midst may be the target of the next

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[282]Amnesty International, 10, 34.

[283]Owen Bennett-Jones, "Tensions Continue To Rise Between US And Pakistan," interviewed by Robin Young, *Here & Now*, transcript, 5 November 2013, http://hereandnow.wbur.org/2013/11/05/tensions-us-pakistan (accessed 1 March 2014).

[284]Emmerson, 7; Blair, "U.S. Drone Program is Fatally Flawed," 19; Amnesty International, 16.

[285]Heyns, 15; Amnesty International, 27, 29-30.

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missile impact.[286] One RPA sensor operator empathized that it must be "horrible" to live under such an omnipresent threat.[287] Defense analyst Eliot Cohen believes this constant menace will demoralize America's enemies, but his argument is ahistorical.[288] Humans tend not to accept a feeling of powerlessness, and the notion that enemy militants will succumb to the psychological pressure is nonsense. If they cannot fight their foes on the battlefield, they will find new—often unexpected—ways of striking back elsewhere.[289] Attempting to subdue populations by deploying swarms of UGS to patrol streets and neighborhoods would engender even worse results.

The psychological impact of civilian casualties resulting from protracted campaigns counteracts the benefits of eliminating lawful enemy combatants. In other words, it is bad strategy. The senior commander's guidance in Afghanistan is unequivocal: "If we kill civilians or damage their property in the course of our operations, we will create more enemies than our operations eliminate."[290] Prolonged campaigns in remote areas generate opportunities for enemy propaganda that enrages millions, even if the facts on the ground contradict false claims that UAS strikes are indiscriminate and wanton.[291] When armed unmanned systems act as a component of a comprehensive strategy (comprising more than purely military means), a surgical strike on a high-value target may be a decisive achievement that contributes directly to strategic aims. The

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[286]Benjamin, 118; Turse and Engelhardt, 65.

[287]Matthew Power, "Confessions of a Drone Warrior," *GQ*, 23 October 2013, http://www.gq.com/news-politics/big-issues/201311/drone-uav-pilot-assassination (accessed 1 March 2014).

[288]Singer, *Wired for War*, 297-298.

[289]Singer, *Wired for War*, 312-313; Ahmed Rashid, "U.S. Drone Program is Fatally Flawed," 15.

[290]Letta Tayler, *Between a Drone and Al-Qaeda: The Civilian Cost of US Targeted Killings in Yemen*, eds. Andrea Prasow, Joe Stork, and Joseph Saunders (Human Rights Watch, October 2013), http://www.hrw.org/reports/2013/10/22/between-drone-and-al-qaeda-0 (accessed 1 March 2014), 27.

[291]John Donvan and John Kael Weston, "U.S. Drone Program is Fatally Flawed," 31-32, 48; Scott Shane, "C.I.A. Is Disputed on Civilian Toll in Drone Strikes," *International New York Times*, 11 August 2011, http://www.nytimes.com/2011/08/12/world/asia/12drones.html (accessed 1 March 2014); Royal, "Military Robots and Ethics," in *Robots on the Battlefield*, 122.

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alternative, which Admiral Blair has called a global game of "Whac-A-Mole" that costs approximately $20 million per terrorist each year, is not a viable approach to national security.[292]

Proliferation and Asymmetric Warfare

The policies governing unmanned systems remain controversial, but these systems' effectiveness in America's twenty-first-century conflicts to date is indisputable. Nonetheless, anyone who assumes that they provide an insurmountable advantage under any circumstances is mistaken. GPS signals, satellite links, and the various nodes that support remote operations all have vulnerabilities.[293] Individuals who participate directly in the employment of these systems—including civilian contractors—are lawful combatants regardless of their physical location.[294] On their own, contemporary UAS and other unmanned systems do not stand a chance against advanced militaries. Iran's questionable claim that it crashed an RQ-170 by hacking its control signal suggests that nations are working to develop non-kinetic options to defeat unmanned systems.[295] Increasing autonomy might allay vulnerabilities in communication links, but the costs of erroneous decisions and unintended consequences from autonomous vehicles operating in uncertain situations would far outweigh any gains.

Adversaries have found low-tech ways to confound or exploit vulnerabilities in unmanned systems. Militants in Iraq and Afghanistan used commercial software to intercept Predator video feeds, providing them with counterintelligence and early warning, before coalition forces discovered the breach and encrypted the signals. Pentagon officials knew this vulnerability existed but assumed adversaries would not know how to exploit it, and they did not want to spend

[292]Admiral Blair reached this figure by dividing the annual US intelligence budget of $80 billion by an estimated 4,000 al-Qaeda members worldwide. Benjamin, 209.

[293]Dawkins, 54-55; Singer, *Wired for War*, 199.

[294]Dawkins, 58.

[295]Gertler, 41-42; Ackerman.

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time and money to upgrade the systems.[296] In an al-Qaeda safe house in Timbuktu, Mali, investigators found a document detailing ways to counter or confuse unmanned systems. Much of its advice was farfetched but certain tactics were remarkably prudent.[297] Taliban fighters supposedly foiled some UGVs simply by tipping them over.[298] Future systems likewise will be susceptible to asymmetric methods: a simple mosquito net would be a significant impediment for a swarm of insect-sized microbots. Nature also gets a vote. Severe weather can keep an entire fleet of UAS grounded regardless of operational needs.[299] Military personnel learn always to have a backup plan, and unmanned systems do not alter this wisdom.

The United States has been the most prolific user of unmanned systems in combat to date, and some critics wish the nation could rewind the clock and reverse what they perceive as an inexorable slide toward robotic war.[300] The belief that the spread of unmanned systems is America's fault, or that the nation singlehandedly could prevent their proliferation, is specious. At last count, eighty-seven countries have unmanned systems, and more than forty are developing robotic weapons.[301] Cultures perceive concepts like autonomy in different ways: P.W. Singer finds that some Asian nations have little antipathy toward autonomous weapons.[302] Much of the technology underpinning unmanned systems is inexpensive and available on the commercial

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[296]Siobhan Gorman, Yochi J. Dreazen and August Cole, "Insurgents Hack U.S. Drones," *Wall Street Journal*, 17 December 2009, http://online.wsj.com/news/articles/SB126102247889095011 (accessed 1 March 2014).

[297]Abdullah bin Mohammed, "The Al-Qaida Papers – Drones," *AP*, 17 June 2011, http://hosted.ap.org/specials/interactives/_international/_pdfs/al-qaida-papers-drones.pdf (accessed 1 March 2014).

[298]Tisseron, "Robotic and Future Wars," in *Robots on the Battlefield*, 4.

[299]Martin and Sasser, 125.

[300]Turse and Engelhardt, 30-31.

[301]Singer, "What Churchill Can Teach Us"; Krishnan, 11.

[302]Singer, *Wired for War*, 168.

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market.[303] Nevertheless, advanced unmanned systems are not simple to develop and field. Micah Zenko notes that many countries have missed multiple deadlines in their unmanned projects.[304]

Precedents do have consequences, and the ways in which the United States uses its unmanned systems influence developments worldwide. The UN has emphasized that there is nothing illegal or immoral about unmanned systems per se—used properly, they are more discriminating and proportional than many other weapons.[305] To set the example, and to retain the authority to condemn others' transgressions, the United States must employ unmanned systems within internationally recognized laws and norms of armed conflict.[306] Collaborative consensus, not gadgetry or expedience, must be the catalyst for any changes to existing frameworks.[307] As Central Intelligence Agency Director John Brennan says, "[i]f we want other nations to use these technologies responsibly, we must use them responsibly."[308] Countries will continue to develop some weapons in secret, as they always have, but international sales demand transparency and regulation.[309] These measures will enable the United States and its allies to use unmanned systems effectively while retaining the license to dissuade violations by less scrupulous actors.[310]

International frameworks do not change the fact that asymmetry is a fundamental component of warfare: no military wants a "fair fight."[311] Combatants always work to maximize

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[303]US Air Force Chief Scientist, *Technology Horizons*, xvii.

[304]Zenko, *Reforming U.S. Drone Strike Policies*, 18, 20.

[305]Heyns, 4-5; Emmerson, 7, 23.

[306]Zenko, *Reforming U.S. Drone Strike Policies*, 4, 24-25.

[307]Emmerson, 5.

[308]John Brennan, quoted in Zenko, *Reforming U.S. Drone Strike Policies*, 5.

[309]Amnesty International, 55; Krishnan, 158; Zenko, *Reforming U.S. Drone Strike Policies*, 19; Heyns, 23; Eric Germain, "Stakeholders and Issues: Outlook for Change in the International Legal Framework for the Use of Military Robotics," in *Robots in the Battlefield*, 69.

[310]Rashid, "U.S. Drone Program is Fatally Flawed," 14, 49; Benjamin, 145-146; Turse and Engelhardt, 165.

[311]Dawkins, 35-36.

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their advantages while confounding those of their enemies.[312] Technology can provide a temporary edge but overconfidence is perilous, for opponents always devise ways to counterbalance one-sided advantages.[313] America must not assume that its enemies' answer to unmanned systems will be corresponding machines of their own. For example, terrorists to date have not been particularly interested in unmanned systems as weapons of choice.[314] Likewise, the notion that superior unmanned systems are the only way to defeat hostile unmanned vehicles is myopic. The US military must employ tactics, technologies, and strategies that can adapt to evolving and unexpected situations.[315] The final section of this project will discuss three ways the United States can enhance the utility of unmanned systems as instruments of national security.

V – WHERE TO GO FROM HERE

Unmanned systems do not fundamentally alter the nature or character of warfare. They are tools whose effectiveness depends on the ways a nation chooses to perceive and utilize them. The US military must select, educate, and equip professionals who can wield unmanned systems with the skill and discipline that the profession of arms demands. The Services must fully integrate the tactics and technology of unmanned systems with manned components of the force, as both will be crucial in future endeavors. Leaders should never allow technology to dictate policy or strategy; unmanned systems must always fit into legitimate and comprehensive plans.

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[312]Metz, 22; Tisseron, "Robotic and Future Wars," in *Robots on the Battlefield*, 14.

[313]Singer, *Wired for War*, 240, 321.

[314]Krishnan, 147; Zenko, *Reforming U.S. Drone Strike Policies*, 21.

[315]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 4; Richard Szafranski, "Parallel War and Hyperwar: Is Every Want a Weakness?" in *Battlefield of the Future*, 135; Singer, *Wired for War*, 201.

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Professionalism

Just as unmanned systems do not alter the nature of warfare, they do not change what it means to serve as a member of the profession of arms. The fact that one is not at mortal risk while controlling an unmanned system does not mean that one will never face danger in the course of a career. Thousands of service members who originally performed support roles have deployed to Iraq and Afghanistan since 9/11, and many have experienced battle firsthand. Like other forward-positioned personnel, deployed RPA operators routinely endure mortar and rocket attacks within yards of their duty stations.[316] In the author's experience, RPA pilots and sensor operators are every bit as committed to military service as fighter pilots or infantrymen. In today's military, some "will close with the enemy while others will not. Regardless of the nature of the weapons system, the end result is still the same."[317] Volunteers for military service must understand that this vocation entails participation in organized violence, regardless of one's current job description. One who is "never prepared to take a life" should not enlist in the first place.[318]

All of the Services identify a "warrior ethos" as essential to military service, but what they actually demand is a "professional military ethos."[319] Americans want a military culture that espouses not belligerence but rather traits like "sacrifice, courage, bravery, aggressiveness and discipline."[320] Critics claim that unmanned systems eliminate the need for valor.[321] Colonel Eric Matthewson, a highly experienced USAF RPA pilot, retorts that valor need not always involve physical danger: "Valor is doing what is right. Valor is about your motivations and the ends that

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[316]For example, Major Eric Hendrickson recalled "around five mortars and one rocket land within 100 yards of me, while performing my duties as an RPA pilot." Major Eric Hendrickson, USAF, e-mail message to author, 15 February 2014.

[317]Dawkins, 60.

[318]Power, "Confessions of a Drone Warrior."

[319]Dawkins, 44.

[320]Ibid., 40.

[321]Benjamin, 87, 174; Weston and Schwartz, "U.S. Drone Program is Fatally Flawed," 21.

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you seek. It is doing what is right for the right reasons."[322] Unmanned systems operators who understand that they are integral to national security—and who receive recognition for their deeds—will be poised to exercise the restraint and judgment that their profession requires.[323]

The profession of arms also entails accountability for one's actions, and unmanned systems do not change this fact. The legal and ethical implications of killing do not vary based on one's proximity to the violence.[324] In February 2010, misleading communication from a Predator crew led to an airstrike that killed twenty-three Afghan civilians. An investigation of the incident led to disciplinary sanctions for the USAF RPA operators and several US Army officers who were also involved in the event.[325] Section III explained why robotic autonomy is infeasible from a pragmatic standpoint. The legal and ethical demands of military service further condemn the concept of robot warfare: if no human were accountable for lethal force, then the links between intent, action, and consequence that characterize state-sanctioned violence would be broken.[326]

Military service members understand that their profession involves killing, but this knowledge does not eliminate the traumatic nature of violence, even violence experienced remotely. A December 2011 study of six hundred USAF RPA pilots found 42 percent reporting "moderate to high operational stress," with 20 percent reporting "burnout."[327] Instances of posttraumatic stress disorder (PTSD) among unmanned systems operators are unfortunate but unsurprising. The intimate view provided by unmanned systems gives their operators a visceral

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[322]Turse and Engelhardt, 50.

[323]Hoagland, 14; Singer, *Wired for War*, 394.

[324]Singer, *Wired for War*, 407.

[325]Dexter Filkins, "Operators of Drones are Faulted in Afghan Deaths," *New York Times*, 29 May 2010, http://www.nytimes.com/2010/05/30/world/asia/30drone.html (accessed 1 March 2014); Drew, "Study Cites Drone Crew in Attack on Afghans"; Emmerson, 8.

[326]Contratto, 2, 15-16, 19; Singer, *Wired for War*, 432; Krishnan, 87; Ronan Doaré, "The Legal Aspects of Military Ground Robots," in *Robots on the Battlefield*, 74-75.

[327]Power, "Confessions of a Drone Warrior."

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link with the enemy that a fighter pilot, sailor, or artillery crewmember may never experience.[328] The author can attest that the seconds between pulling the trigger and a Hellfire missile's impact seem to last an eternity, even when the target is definitely hostile. The sounds and sights of distant comrades under fire provoke equally gut-wrenching emotions.[329] PTSD is a predictable reaction to the horror of war. Unmanned systems do not remove it—nor should they. The US military has a sworn duty to care for traumatized service members, but it must not imagine that it can eliminate the fundamental causes of PTSD. Anyone who believes technology can make war painless has no business in its commission.

To maintain the professionalism and readiness that leads to success in war, units that operate unmanned systems require capable leadership, vibrant esprit, and robust training—not gadgetry. It is past time to retire the insulting label of "cubicle warriors" that totally misrepresents the way forces employ unmanned systems today.[330] America needs talented, experienced, prudent individuals in control of its military unmanned systems. The Services must cultivate and appoint commanders who can focus their units on mission success without neglecting the strains of remote combat on personnel and their families. Amid the challenges of nonstop operations, units must nourish the camaraderie and shared identity that sustain all successful military forces.

As troops redeploy from Afghanistan, the operating tempo should slacken for many units that operate unmanned systems.[331] Units must utilize this leeway to implement continuous training programs that emphasize the tactical proficiency and practical expertise needed in unfamiliar situations. These programs also groom future instructors and leaders.[332] In 2009, the

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[328]Martin and Sasser, 52; Benjamin, 90; Power, "Confessions of a Drone Warrior."

[329]Drew, "Drones are Weapons of Choice in Fighting Qaeda"; Power, "Confessions of a Drone Warrior"; Singer, *Wired for War*, 332.

[330]Singer, *Wired for War*, 329; Turse and Engelhardt, 54-55.

[331]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 29, 74.

[332]Ryan Cross, "MQT to IP: A Roadmap for MQ-1/-9 Pilots," (student paper, United States Air

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USAF Weapons School, which develops elite tacticians for all major USAF weapons systems, inaugurated a squadron for RPA pilots.[333] The other Services would benefit from similar programs. Simulator-based training is useful, but it does not replace hands-on instruction and mentorship.[334] The skills needed to wield unmanned systems may differ from those that are ideal for manned platforms, but the obligation to train and promote talented individuals is the same.[335]

The current environment supports the normalization of assignments and careers involving unmanned systems. America's massive military endeavors following 9/11 obliged the DOD to generate combat power in various caustic ways. Involuntary assignments to unmanned systems ostensibly represented punishment tours and career-enders.[336] This era is concluding. As unmanned systems gain legitimacy, assignment to them no longer equates to a hardship tour. Enlisted Army UAS operators currently promote at higher-than-average rates.[337] Conversely, promotion and command opportunities for USAF RPA pilots lag behind those of other career tracks. Besides involuntary assignments, constant surge operations prevented many of these individuals from attending professional military education or other career broadening opportunities, leading to a lower promotion rate for RPA pilots as compared to their peers.[338] This inequity must improve commensurate to the emerging balance between manned and unmanned

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Force Weapons School, 1 June 2013), 1, 4, 5, 12.

[333]Daniel Turner, "USAF Weapons School Activates the 26th Weapons Squadron MQ-1/-9 Weapons Instructor Course," *USAF Weapons Review* (Winter 2008): 7-8. The USAF Weapons School is equivalent to the Navy's "Top Gun" program.

[334]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 75; United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 82.

[335]Hoaglund, 5-6; Singer, *Wired for War*, 370; Schwartz, "U.S. Drone Program is Fatally Flawed," 6; E.W. Powers, "Developing and Integrating Unmanned Systems for Military Operations," in *Robots on the Battlefield*, 197.

[336]Spinetta, "Glass Ceiling for Remotely Piloted Aircraft," 103; Dawkins, 42-43; Krishnan, 37.

[337]Hoffman.

[338]Spinetta, "Glass Ceiling for Remotely Piloted Aircraft," 102; Hoaglund, 11-12.

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platforms.[339] The Services should cultivate service members with distinct aptitude for remote operations, but they also must develop individuals with broader experience.[340] Leaders with expertise in both manned and unmanned operations will be vital to future force development and integration.

Unmanned systems designed for pure troop support in benign skies do not require rated pilots, but platforms capable of participating in complex air campaigns will continue to demand officer aviators with the requisite qualifications and authority.[341] UAS operations since 2001 have occurred under an umbrella of friendly air supremacy. This condition masks the challenges of joint operations in the event an adversary does not cede total control of the airspace and frequency spectrum. Contested air operations will remain the domain of specialized, rated aviators for the foreseeable future.

Integrated Technology and Tactics

In order to prevail in future conflicts, the US military must fully integrate the technology and tactics of unmanned systems with the other components of national defense. This is not an "either-or" dilemma: manned and unmanned systems both have important roles to play. The nation's wartime experiences since 1991 have furthered a misleading sense of American dominance in conventional military operations, prompting some to presume this lead is so

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[339]For a comprehensive discussion of the need to update the USAF's command and promotion system to account for unmanned systems, see Spinetta, "Glass Ceiling for Remotely Piloted Aircraft" and Hoaglund.

[340]Hoaglund, v, 4, 7, 19; Cooke and Chadwick, "Lessons Learned from Human-Robotic Interactions on the Ground and in the Air," in *Human-Robot Interactions* 366; United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 49, 59, 81.

[341]David R. Buchanan, "Joint Doctrine for Unmanned Aircraft Systems: The Air Force *and* the Army Hold the Key to Success" (student paper, Naval War College, 3 May 2010), http://www.dtic.mil/dtic/tr/fulltext/u2/a525266.pdf (accessed 1 March 2014), 14-15; Hoffman; United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 28-30; Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 72.

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insurmountable that advanced weapons are simply boondoggles.[342] This assumption is myopic. America cannot assume air supremacy in future wars, nor can it expect unfettered access to the electromagnetic spectrum, and both are critical elements for unmanned operations.[343] Modern air defenses would annihilate most existing UAS platforms that entered their engagement zones without additional support.[344] Kinetic weapons are not the only threats: future adversaries will use electronic warfare and cyber-attacks to blunt US military endeavors.[345] Simple malfunctions and unintentional radio jamming by friendly forces already have spoiled many UAS missions.[346]

Technology can help address these challenges without resorting to autonomous killing robots. The USAF's use of Link 16 and laser weapon guidance to integrate RPAs with manned platforms is archetypal. Against advanced foes, technological solutions that enable seamless integration among disparate platforms ensure adaptability and resilience.[347] Compression and encryption techniques can reduce the ever-increasing strain on frequency bandwidth.[348] The US military should equip unmanned systems with defensive countermeasures and a wider array of weapons, including air-to-air capable UAS. Unmanned systems may still falter against advanced defenses and severe electronic jamming, but this does not mean they are irrelevant in these

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[342]Turse and Engelhardt, 61; Peters, 21.

[343]Paul Madsen, "Network Centric Warfare," *USAF Weapons Review* (Winter 2009): 31-32; Majumdar, "USAF: Current Unmanned Aircraft Irrelevant in the Pacific."

[344]Majumdar, "USAF: Current Unmanned Aircraft Irrelevant in the Pacific"; Turse and Engelhardt, 150.

[345]Singer, *Wired for War*, 201.

[346]Martin and Sasser, 44; Power, "Confessions of a Drone Warrior."

[347]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 3, 30-31; US Air Force Chief Scientist, *Technology Horizons*, 43. Unmanned systems are not the only platforms that have struggled with integration. The F-22's original designers assumed the advanced Raptor would not want to risk electronic detection in order to collaborate with other platforms, so they did not include the ability to transmit via Link 16. The author spent two years testing multimillion-dollar workarounds to provide this critical (and still unfinished) capability.

[348]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 28, 67-68.

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arenas.[349] Remote vehicles that lose communications can be configured to loiter or transit through contested zones, rather than automatically returning to base, until friendly forces regain the airwaves.[350] Unmanned systems must be able to communicate via multiple links.[351] In order to prevail against a fully integrated US military, an enemy would need to defeat every component simultaneously, not just block a single network or frequency band.

Technology is effective only when optimally employed. The US military has made great strides integrating unmanned systems under combat conditions. It must build upon these successes with rigorous joint training. As historical precedents reveal, innovative thinking, comprehensive evaluation, and constant practice are more important than technology alone. In the 1930s, traditionalists in Britain and America resisted the integration of tanks into their armies, while Germany developed the combined tactics that became blitzkrieg.[352] The Allies learned to integrate mechanized ground forces, bombers, and fighters only after bloody experiences on the battlefields of Europe and the Pacific.[353] In order to set the conditions for optimal integration of manned and unmanned systems, the nation must maintain robust military training facilities. It also must open national airspace to UAS flights that adhere to strict safety regulations.[354] The Services must practice realistic scenarios that replicate advanced adversaries, and they always must train to fight as a joint team—just as they have on the battlefield for more than a decade.[355]

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[349]Madsen, 35-36; Majumdar, "USAF: Current Unmanned Aircraft Irrelevant in the Pacific."

[350]Krishnan, 39.

[351]United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 43-44; Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 66, 69.

[352]Singer, "What Churchill Can Teach Us"; Singer, *Wired for War*, 252.

[353]Thomas A. Hughes, *Overlord: General Pete Quesada and the Triumph of Tactical Air Power in World War II* (New York, NY: The Free Press, 1995), 186-191.

[354]Department of Defense, *Unmanned Systems Integrated Roadmap FY2011-2036*, 53-55, 57-58.

[355]Madsen, 36; United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 14, 46.

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The final piece of the integration puzzle is the establishment of adaptable joint doctrine to govern the command and control of unmanned systems. America must prepare for multiple contingencies with varying levels of intensity and simultaneity. UGS, UMS, and small UAS will remain under the direct control of their respective ground units or ships, but larger, highly capable unmanned systems need more flexibility to shift rapidly between missions. Army UAS operators deploy with ground forces to preserve continuity and esprit, but this setup is far less effective than the USAF's satellite-enabled remote split operations (RSO). One study found that, assuming a baseline of 132 UAVs, USAF RSO could maintain thirty-four 24-hour CAPs while the Army's model could sustain only twelve.[356] The Army should consider adopting the RSO model, and trust its capable troops to build camaraderie and unity of effort despite the distance.[357]

UAS that fly above five hundred feet need to be included in the Joint Force Air Component Commander's (JFACC's) purview.[358] In exchange for this overarching authority, the JFACC and his AOC must be willing to delegate varying levels of tactical control to forward-deployed echelons commensurate with a given situation. Accordingly, the Services have begun to utilize the Air Component Coordination Element, a forward-positioned air liaison that represents the JFACC, to address prior frustrations regarding over-centralization of air assets.[359] An intense air campaign versus a robust adversary will require different command and control than

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[356]Deptula and Mathewson, slide 28; Singer, *Wired for War*, 217; "Air Force vs. Army Concepts for UAV Employment," Arlington, VA: Air Force Association, n.d., http://secure.afa.org/grl/UAV_CONOPS.pdf (accessed 1 March 2014); Buchanan, 1, 5, 10-11, 13.

[357]Buchanan, 19.

[358]Deptula and Mathewson, slide 40.

[359]Mike Hostage, "A Seat at the Table," *Air & Space Power Journal* (Winter 2010), http://www.airpower.maxwell.af.mil/airchronicles/apj/apj10/win10/2010_4_05_hostage.pdf (accessed 1 March 2014), 18-20; United States Air Force, *USAF Unmanned Aircraft Systems Flight Plan 2009-2047*, 53-54; Buchanan, 18-19.

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counterinsurgency operations.[360] Joint doctrine must evolve to address both effectively. Mutual trust among the Services is the linchpin.

Manned and unmanned aircraft recently demonstrated the value of integration. In March 2013, a flight of Iranian F-4 Phantoms attempted to intercept an MQ-1 Predator in the Arabian Gulf. The Iranian pilots quickly changed their minds when an F-22 Raptor suddenly appeared in their formation and radioed them that they "really ought to go home."[361] Unmanned systems may be on the rise, but advanced manned weapons systems remain vital for deterrence and domain superiority.

Prudent Policy and Comprehensive Strategy

If policies that include unmanned systems are defective, professional human control and effective force integration will not be enough to produce favorable results. The US government must never compromise its reputation as a law-abiding, responsible global actor for the sake of expedience or opportunity.[362] Policies driven by fear lead to dark places—they lead to waterboarding, Abu Ghraib, and errant UAS strikes. Diligent analysis and multinational collaboration are the real catalysts of US national security. It is time to dismiss all notions of a global conflict against monolithic terrorism and properly articulate ongoing American efforts for what they truly are: discrete operations against specific adversaries.[363] In order to reinforce

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[360]Buchanan, 4, 6, 8, 15.

[361]General Mark D. Welsh, quoted in Matthew Cox, "Welsh: F-22 Flew to Drone's Rescue off Iran Coast," *Military.com*, 17 September 2013, http://www.military.com/daily-news/2013/09/17/welsh-f22-flew-to-drones-rescue-off-iran-coast.html (accessed 1 March 2014).

[362]Benjamin, 198-199; Turse and Engelhardt, 117.

[363]White House, Office of the Press Secretary, "Fact Sheet: U.S. Policy Standards and Procedures for the Use of Force in Counterterrorism Operations outside the United States and Areas of Active Hostilities," 23 May 2013, http://www.whitehouse.gov/the-press-office/2013/05/23/fact-sheet-us-policy-standards-and-procedures-use-force-counterterrorism (accessed 1 March 2014); Emmerson, 18-19; Heyns, 14; Turse and Engelhardt, 92-93.

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America's commitments to justice and human rights worldwide, Washington should make good on its promises to increase transparency and accountability regarding unmanned systems.[364]

Unmanned systems exist within conceivable approaches to warfare—they are not iconoclastic. They are tools to support strategy, which Colin Gray defines as "the bridge that relates military power to political purpose."[365] Knowledge of tactical options is important for the strategist, but a comprehensive approach to national challenges never depends upon a single tactic or technology.[366] For instance, nuclear weapons may have underpinned the Cold War strategy of containment, but they were just one of many amalgamated approaches to oppose communism.

While strategy is a never-ending quest for enduring relative advantage, actual military operations must have achievable end states and not endure perpetually. Like airpower to date, unmanned systems alone will not be decisive in warfare.[367] Furthermore, they do not appear to deter prospective enemies.[368] Unmanned systems do not make prolonged, continuous armed conflict desirable; warfare is too complex and adversaries are too adaptable. Neither do unmanned systems offer an instantaneous riposte to unexpected threats. At the strategic level, prudent analysis trumps reflexive reaction every time.

Good strategy advantageously influences the mind and will of both opponents and allies. The ultimate purpose of armed unmanned systems, like other weapons, is to kill people and break things. They are not tools to build nations or prevent state collapse. At best, a lethal UAS strike

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[364]Kimberly Dozier, "Brennan Defends Drone Strikes, Even on Americans," *Yahoo News*, 7 February 2013, http://news.yahoo.com/brennan-defends-drone-strikes-even-americans-224334056--politics.html (accessed 1 March 2014); Shane; Steve Inskeep and Carrie Johnson, "DOJ Paper: When it's OK to Kill Americans in Al-Qaida," *NPR.org*, 5 February 2013, http://www.npr.org/2013/02/05/171138329/doj-paper-when-its-ok-to-kill-americans-in-al-qaida (accessed 1 March 2014); Amnesty International, 9, 35, 49; Heyns, 20-21, 23; Emmerson, 11-13.

[365]Colin Gray, *Modern Strategy* (Oxford, UK: University Press, 1999), 17.

[366]Rashid, Weston, and Donvan, "U.S. Drone Program is Fatally Flawed," 13, 34.

[367]Metz, 16.

[368]Zenko, *Between Threats and War*, 88-89.

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can create maneuvering space for comprehensive efforts to achieve strategic goals—at worst, an errant or ill-timed attack could ruin years of collaboration.[369] Likewise, nonlethal ISR from unmanned systems can inform and influence prudent decisions, or else it can deceive its users while enraging others by invading their privacy. US strategy must meld precision targeting with "*psychological* precision . . . shaping a military operation so as to attain the desired attitudes, beliefs, and perceptions on the part of both the enemy and other observers."[370]

A final vignette from recent operations in Afghanistan offers a microcosm of the way in which unmanned systems can support strategic objectives. In 2008, UAS participated in combined US-Canadian operations in the Kandahar region. Precision strikes from UAS

> represented the culminating point of a rigorous, multidisciplined (intelligence, operations, information operations) process and cumulative understanding of our environment that evolved throughout the deployment. They reduced risk to friendly forces, minimized collateral damage and dislocated the enemy, reducing his freedom of action while marginalizing his strength in the eyes of the population—the key terrain.[371]

The tactical advantages that persistent, precise unmanned systems supplied to joint, multinational forces directly contributed to long-term strategic goals of destabilizing insurgents and securing friendly populations.[372] Disciplined professionals worked tirelessly to integrate unmanned systems into a well-conceived and carefully orchestrated plan. Afghanistan remains a nation in peril, but this example reveals the right way to use unmanned systems within a broader strategy.

Conclusion

Unmanned systems have become instrumental to the national security of the United States. They will continue to evolve as innovators across the planet develop novel ways to

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[369]Bennett-Jones; Blair, Schwartz, Weston and Donvan, "U.S. Drone Program is Fatally Flawed," 16-17, 33, 44; Martin and Sasser, 81; Zenko, *Between Threats and War*, 117.

[370]Metz, 77-78 (emphasis original).

[371]Turner, Adair and Hammel, "Optimizing Deadly Persistence," 43.

[372]Ibid., 44, 46, 49.

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employ them. Unmanned systems are here to stay—the issue remains how best to use them. Autonomous killing robots, despite marginal showings to date, are possible. Human ingenuity, especially when stimulated by the contest of warfare, makes many things possible. However, just because something is possible does not mean it is desirable. History is replete with ideas that seemed foolproof in concept but resulted in catastrophe when attempted. Autonomy is a mistake.

Technological improvements should make future unmanned systems easier to operate and incorporate with other military assets. The skillsets required to wield them will evolve. Nevertheless, technology will never replace human perception and judgment in warfare. War is a chimera that transforms before one's eyes. Successful militaries cultivate professional soldiers and leaders with the prudence to comprehend uncertainty and adapt accordingly. Optimal strategy clearly defines its approach and ultimate goals before choosing its means, and it continuously adjusts to suit the environment and the adversary. Wise policy upholds legitimacy and discretion in order to engender support from likeminded allies and marginalize malefactors. Unmanned systems, properly regarded and employed, are integral to all of these concepts.

In 1999, when the author was a cadet at the United States Air Force Academy, then-Brigadier General Mark D. Welsh (now General Welsh, USAF Chief of Staff) gave his first address as Cadet Wing Commandant. He concluded with these words: "War is a horrible, horrible, horrible thing. There is nothing good about it. But it is sometimes necessary. And so somebody better be good at it."[373] No technology—manned or unmanned—will ever alter this timeless wisdom.

[373]Mark D. Welsh, "Commandant's Address to the Cadet Wing" (United States Air Force Academy, CO, 26 August 1999), http://www.usna.org/bgwelshspeech.html (accessed 1 March 2014).

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Selected Acquisition Report (SAR)

RCS: DD-A&T(Q&A)823-420



MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle)

As of FY 2015 President's Budget

Defense Acquisition Management
Information Retrieval
(DAMIR)

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1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
DEC 2013		**00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle)	5b. GRANT NUMBER
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	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

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Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Selected Acquisition Report-SAR

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**48**	

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Common Acronyms and Abbreviations

Acq O&M - Acquisition-Related Operations and Maintenance
APB - Acquisition Program Baseline
APPN - Appropriation
APUC - Average Procurement Unit Cost
BA - Budget Authority/Budget Activity
BY - Base Year
DAMIR - Defense Acquisition Management Information Retrieval
Dev Est - Development Estimate
DoD - Department of Defense
DSN - Defense Switched Network
Econ - Economic
Eng - Engineering
Est - Estimating
FMS - Foreign Military Sales
FY - Fiscal Year
IOC - Initial Operational Capability
$K - Thousands of Dollars
LRIP - Low Rate Initial Production
$M - Millions of Dollars
MILCON - Military Construction
N/A - Not Applicable
O&S - Operating and Support
Oth - Other
PAUC - Program Acquisition Unit Cost
PB - President's Budget
PE - Program Element
Proc - Procurement
Prod Est - Production Estimate
QR - Quantity Related
Qty - Quantity
RDT&E - Research, Development, Test, and Evaluation
SAR - Selected Acquisition Report
Sch - Schedule
Spt - Support
TBD - To Be Determined
TY - Then Year
UCR - Unit Cost Reporting

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Program Information

Program Name
MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle)

DoD Component
Army

Responsible Office

Responsible Office		
Colonel Timothy R. Baxter Unmanned Aircraft Systems (UAS) Project Office Building 5300 Redstone Arsenal, AL 35898 timothy.r.baxter.mil@mail.mil	**Phone** **Fax** **DSN Phone** **DSN Fax** **Date Assigned**	256-313-5327 256-313-5445 897-5327 897-5445 July 1, 2011

References

SAR Baseline (Production Estimate)
Defense Acquisition Executive (DAE) Approved Acquisition Program Baseline (APB) dated March 25, 2011

Approved APB
Defense Acquisition Executive (DAE) Approved Acquisition Program Baseline (APB) dated September 12, 2013

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Mission and Description

The MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle) provides the Division Commander a dedicated, assured, multi-mission Unmanned Aircraft System for the tactical fight assigned to the Combat Aviation Brigade in each Division and supports the Division Fires, Battlefield Surveillance Brigades, and Brigade Combat Teams based upon the Division Commander's priorities. The MQ-1C Gray Eagle will also be assigned to Army Special Operations Forces and the Aerial Exploitation Battalions. MQ-1C Gray Eagle provides reconnaissance, surveillance, and target Acquisition; command and control; communications relay; signals intelligence; electronic warfare; attack; detection of weapons of mass destruction; battle damage assessment; and manned-unmanned teaming capabilities.

The unit of measure for a MQ-1C Gray Eagle is balanced platoons, each with four aircraft and associated support equipment and payloads to include: Electro-Optical/Infrared/Laser Range Finder/Laser Designator, communications relay, and up to four Hellfire Missiles. The Common Sensor Payload and STARlite Synthetic Aperture Radar Ground Moving Target Indicator are one per aircraft. Ground equipment per Platoon includes: two Universal Ground Control Stations, three Universal Ground Data Terminals, one Satellite Communication Ground Data Terminal, one Mobile Ground Control Station per Company, an Automated Take Off and Landing System which includes two Tactical Automatic Landing Systems and ground support equipment to include Ground-Based Sense and Avoid.

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Executive Summary

The MQ-1C Gray Eagle program continues with development, integration, testing, training, production and deployment while supporting the warfighter with two MQ-1C Gray Eagle Quick Reaction Units (four aircraft each and associated support equipment) and a full-up MQ-1C Gray Eagle Company (12 aircraft and 128 Soldiers) deployed in support of combat operations in Afghanistan.

MQ-1C Gray Eagle Initial Operational Test and Evaluation completed in August 2012. Developmental testing in 4th Quarter FY 2013 and 1st Quarter FY 2014 focused on incorporating the Universal Ground Control Station (UGCS) and Universal Ground Data Terminal (UGDT). Testing consisted of transportability and mobility, electromagnetic environmental effects, and software development. Environmental and Developmental Tests are planned for the 2nd and 3rd Quarter FY 2014. Formal Software Qualification Testing will be performed in 4th Quarter FY 2014 to prove out software functionality. These tests will assure technical maturity for a Follow-on Test and Evaluation (FOT&E) planned for June 2015.

On February 5, 2013, the Chief of Staff of the Army approved an Executive Order (EXORD) changing the MQ-1C Gray Eagle fielding configuration to provide greater capability across the Army. The EXORD directs fielding of MQ-1C Gray Eagle companies to ten Army Divisions, one to the National Training Center (NTC), two Army Special Operations Forces (ARSOF) units, and two to the Aerial Exploitation Battalions (AEB) for a total of 15 companies. The two ARSOF companies will be configured with 12 aircraft each (24 total) and the 13 units assigned to Army Divisions, NTC and the AEB's will be fielded with nine aircraft each (117 total) while Continental United States (CONUS) based. Seven aircraft are assigned to the institutional training base at Fort Huachuca, Arizona. The four remaining aircraft are for attrition. When a company or AEB assigned to a division deploys Outside the Continental United States (OCONUS), the Army will reassign equipment, as required, to bring the company to full Gray Eagle System equipment strength (12 aircraft and associated ground support equipment). All EXORD requirements will be met without exceeding the procurement objective of 152 aircraft and ground support equipment and Program of Record funding.

Each company will be integrated with the following payloads: Electro-Optical/Infrared, Laser Range Finder/Laser Designator, Synthetic Aperture Radar/Ground Moving Target Indicator, communications relay, and four HELLFIRE missiles. Ground support equipment for a 12 aircraft company includes six UGCS, seven UGDT, three Satellite Communication Ground Data Terminals, one Mobile Ground Control Station, and the Automated Take Off and Landing System consisting of six Tactical Automatic Landing System-Tracking Subsystem and ground support equipment.

The Full Rate Production (FRP) Defense Acquisition Board (DAB) completed June 14, 2013 and an Acquisition Decision Memorandum (ADM) approved procurement of up to 49 unmanned aircraft and associated ground support equipment which brings the total program quantity to 152 aircraft. The approved quantity satisfies 100-percent of the total procurement objective for the MQ-1C Gray Eagle program. The ADM changed the program classification from ACAT ID to ACAT IC.

An updated APB based on the DAB approved cost estimate was approved on September 12, 2013. Although the fielding strategy has evolved with the Chief of Staff EXORD, the Army will continue to use the 31 platoon metric to determine program APUC and PAUC. MQ-1C Gray Eagle has demonstrated meeting six of seven Key Performance Parameters (KPP). For the Net Ready KPP, Link-16 has not fully demonstrated meeting the threshold requirement. The Army approved deferring meeting this capability to FOT&E which is planned for June 2015.

Major contracting actions completed since the 2012 SAR include:

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- Initial FRP1 contract. FRP1 is a Firm Fixed Price (FFP) contract for 15 aircraft and associated ground equipment.
- FRP1 also includes a priced option for four aircraft and associated ground equipment. The option was exercised December 6, 2013 using FY 2014 funds.
- Award of a Cost Plus Fixed Fee (CPFF)/Cost Plus Incentive Fee contract for Pre-Planned Product Improvement (P3I) which allows for development efforts for FOT&E.
- Award of a CPFF Engineering Services contract (FY 2013 - FY 2017) which allows for integration, inspection, analysis and corrective action, test and evaluation for system hardware, software, and components and support of the MQ-1C Gray Eagle systems allocated among Base Engineering Service Memoranda.
- Modification to the Performance Based Logistics contract for performance from May 2013 to May 2014.

The FY 2014 RDT&E appropriation funds MQ-1C Gray Eagle at the FY 2014 PB request of $10.9M. However, a Congressional reduction of $81.3M from the Aircraft Procurement, Army budget request of $518.5M has resulted in a deferral of the planned production and incorporation of Ka-band (military) satellite communications.

Additionally, the FY 2014 appropriation did not include funding for the four war replacement aircraft in the Overseas Contingency Operations (OCO) request. The change in fielding strategy within the existing 152 programmed aircraft reduced the number of attrition aircraft from 21 to four, making the impact of the OCO reduction more significant.

There are no significant software-related issues with this program at this time.

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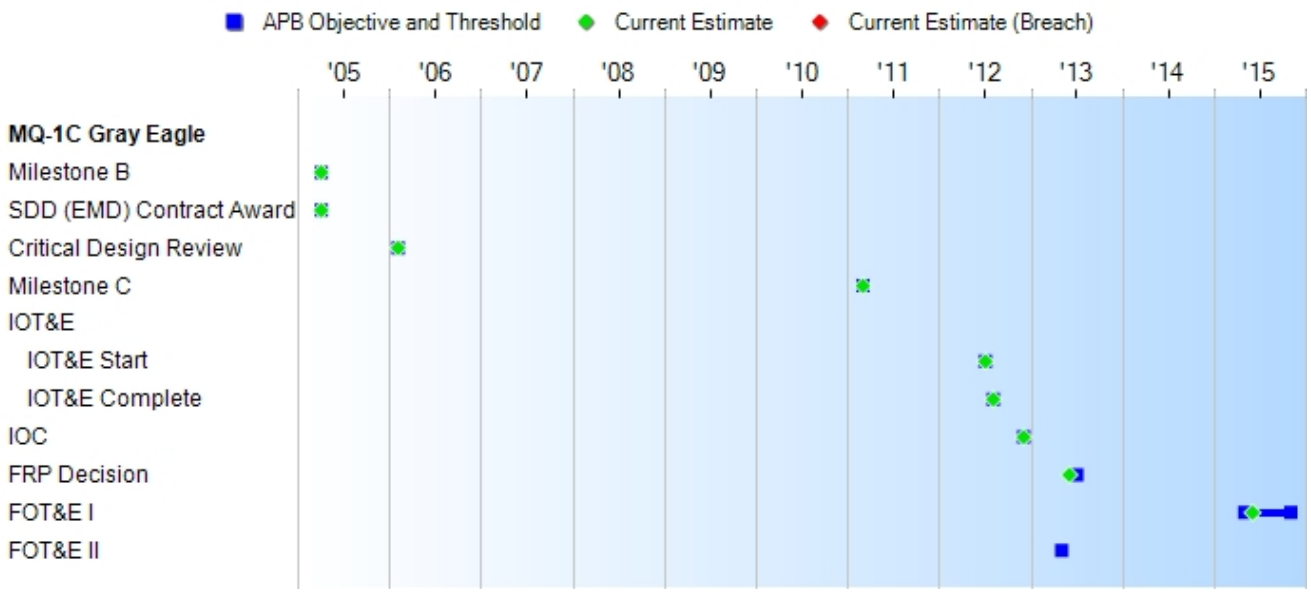
Threshold Breaches

APB Breaches		
Schedule		☐
Performance		☐
Cost	RDT&E	☐
	Procurement	☐
	MILCON	☐
	Acq O&M	☐
O&S Cost		☐
Unit Cost	PAUC	☐
	APUC	☐

Nunn-McCurdy Breaches		
Current UCR Baseline		
	PAUC	None
	APUC	None
Original UCR Baseline		
	PAUC	None
	APUC	None

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Schedule



Milestones	SAR Baseline Prod Est	Current APB Production Objective/Threshold		Current Estimate	
Milestone B	APR 2005	APR 2005	APR 2005	APR 2005	
SDD (EMD) Contract Award	APR 2005	APR 2005	APR 2005	APR 2005	
Critical Design Review	FEB 2006	FEB 2006	FEB 2006	FEB 2006	
Milestone C	MAR 2011	MAR 2011	MAR 2011	MAR 2011	
IOT&E					
IOT&E Start	SEP 2011	JUL 2012	JUL 2012	JUL 2012	
IOT&E Complete	OCT 2011	AUG 2012	AUG 2012	AUG 2012	
IOC	JUN 2012	DEC 2012	DEC 2012	DEC 2012	
FRP Decision	APR 2012	JUL 2013	JUL 2013	JUN 2013	(Ch-1)
FOT&E I	AUG 2012	MAY 2015	NOV 2015	JUN 2015	(Ch-2)
FOT&E II	MAY 2013	N/A	N/A	N/A	

Change Explanations

(Ch-1) The current estimate for FRP Decisions was changed from May 2013 to June 2013 to reflect the date of the FRP Defense Acquisition Board.

(Ch-2) The current estimate for FOT&E changed from April 2015 to June 2015 to allow synchronization with the planned NTC unit rotation schedule.

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Acronyms and Abbreviations

EMD - Engineering and Manufacturing Development
FOT&E - Follow-On Test and Evaluation
FRP - Full Rate Production
IOT&E - Initial Operational Test and Evaluation
NTC - National Training Center
SDD - System Development and Demonstration

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Performance

Characteristics	SAR Baseline Prod Est	Current APB Production Objective/Threshold		Demonstrated Performance	Current Estimate	
Net Ready	The system must fully support execution of all operational activities identified in the applicable joint and system integrated architectures and the system must satisfy the technical requirements for Net-Centric military operations to include 1) DISR mandated GIG IT standards and profiles identified in the TV-1, 2) DISR mandated GIG KIPs identified in the KIP declaration table, 3) NCOW RM Enterprise Services 4) IA requirements including	The system must fully support execution of all operational activities identified in the applicable joint and system integrated architectures and the system must satisfy the technical requirements for Net-Centric military operations to include 1) DISR mandated GIG IT standards and profiles identified in the TV-1, 2) DISR mandated GIG KIPs identified in the KIP declaration table, 3) NCOW RM Enterprise Services 4) IA requirements including	The system must fully support execution of joint critical operational activities identified in the applicable joint and system integrated architectures and the system must satisfy the technical requirements for transition to Net-Centric military operations to include 1) DISR mandated GIG IT standards and profiles identified in the TV-1, 2) DISR mandated GIG KIPs identified in the KIP declaration table, 3) NCOW RM Enterprise Services 4) IA requirements	Met threshold at IOT&E, LINK16 will be demonstrated at FOT&E	The system must fully support execution of all operational activities identified in the applicable joint and system integrated architectures and the system must satisfy the technical requirements for Net-Centric military operations to include 1) DISR mandated GIG IT standards and profiles identified in the TV-1, 2) DISR mandated GIG KIPs identified in the KIP declaration table, 3) NCOW RM Enterprise Services 4) IA requirements including	(Ch-1)

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	availability, integrity, authentica-tion, confident-iality, and non-repudiation, and issuance of an ATO by the DAA, and 5) Operationally effective information exchanges; and mission critical performance and IA attributes, data correctness, data availability, and consistent data processing specified in the applicable joint and system integrated architecture views. The system must be able to enter and be managed in the network, and exchange data in a secure manner.	availability, integrity, authentica-tion, confident-iality, and non-repudiation, and issuance of an ATO by the DAA, 5) Operationally effective information exchanges; and mission critical performance and IA attributes, data correctness, data availability, and consistent data processing specified in the applicable joint and system integrated architecture views.	including availability, integrity, authentica-tion, confident-iality, and non-repudiation, and issuance of an IATO by the DAA, 5) Operationally effective information exchanges; and mission critical performance and IA attributes, data correctness, data availability, and consistent data processing specified in the applicable joint and system integrated architecture views.		availability, integrity, authentica-tion, confident-iality, and non-repudiation, and issuance of an ATO by the DAA, 5) Operationally effective information exchanges; and mission critical performance and IA attributes, data correctness, data availability, and consistent data processing specified in the applicable joint and system integrated architecture views.	
Multi Payload/Weight Capability	The aircraft is capable of simultan-	UA will be capable of simultan-	UA will be capable of simultan-	Met threshold at IOT&E	UA will be capable of simultaneousl	(Ch-2)

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	eously carrying two payloads with a combined minimum weight of 300 lbs.	eously carrying three or more payloads with a combined minimum weight of 300 lbs.	eously carrying two payloads with a combined minimum weight of 200 lbs.		y carrying three or more payloads with a combined minimum weight of 300 lbs.	
Airframe Sensors Payload Capability	The aircraft will be capable of accepting payloads that are: EO/IR/LD capable of providing a 90% PD of a military target from the aircraft's operational altitude out to a minimum of 30km slant range. EO/IR/LD capable of providing a 90% PR of a military target, from the aircraft's operational altitude, out to a minimum of 10km slant range. SAR/GMTI Sensor capable of providing 85% PD of a military target, from the aircraft's operational	MQ-1C UA will be capable of accepting payloads that are: EO/IR/LD capable of providing: 90% PD of a military target, from the UA's operational altitude out to a minimum of 30 km slant range; 90% PR of a military target, from the UA's operational altitude, out to a minimum of 10 km slant range; SAR/GMTI sensor capable of providing 85% PD of a military target, from the UA's operational altitude, out to a minimum of	EO/IR/LD capable of providing: 90% PD of a military target, from the UA's operational altitude out to a minimum of 25 km slant range; 90% PR of a military target, from the UA's operational altitude out to a minimum of 9 km slant range.	Met objective, verified CSP during Production Prove-Out Test.	MQ-1C UA will be capable of accepting payloads that are: EO/IR/LD capable of providing: 90% PD of a military target, from the UA's operational altitude out to a minimum of 30 km slant range; 90% PR of a military target, from the UA's operational altitude, out to a minimum of 10 km slant range; SAR/GMTI sensor capable of providing 85% PD of a military target, from the UA's operational altitude, out to a minimum of	(Ch-2)

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	altitude, out to a minimum 10km slant range in clear weather	10 km slant range in clear weather.			10 km slant range in clear weather.	
Sustainment	The aircraft system must maintain a combat Ao of 90%.	MQ-1C must maintain a combat Ao of 90%.	MQ-1C must maintain a combat Ao of 80%.	Met updated threshold KPP at IOT&E	MQ-1C must maintain a combat Ao of 90%.	(Ch-2)
Aircraft Propulsion	The aircraft engine will be powered by DoD/NATO standard heavy fuel (JP8 Fuel).	UA engine will be powered by DoD/NATO standard heavy fuel (JP8 Fuel).	UA engine will be powered by DoD/NATO standard heavy fuel (JP8 Fuel).	Met objective	UA engine will be powered by DoD/NATO standard heavy fuel (JP8 Fuel).	(Ch-1)
Weapons Capable	The aircraft shall be capable of engaging traditional and non-traditional ground moving, stationary, and water borne moving targets with the AGM-114P-4A and AGM-114N-4 and other AGM-114 variants or similar future AGMs and small light weight precision munitions.	MQ-1C must be capable of engaging traditional and non-traditional ground moving and stationary and water borne moving and stationary targets with the AGM-114P-4A and AGM-114N-4 and other AGM-114 variants or similar future AGMs and small light weight precision munitions.	MQ-1C must be capable of engaging traditional and non-traditional ground moving and stationary targets with the AGM-114P-4A and AGM-114N-4.	Met threshold; (35) Hellfire shots DT/OT; (100+) Hellfire shots in OIF/OEF	MQ-1C must be capable of engaging traditional and non-traditional ground moving and stationary and water borne moving and stationary targets with the AGM-114P-4A and AGM-114N-4 and other AGM-114 variants or similar future AGMs and small light weight precision munitions.	(Ch-1)
Survivability and Force Protection	The GCS-V3 will be mounted onto an Army standard	The GCS will be mounted onto an Army standard tactical	The GCS will be mounted onto an Army standard tactical	Met objective	The GCS will be mounted onto an Army standard tactical	(Ch-1)

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	tactical vehicle with the ability to be up armored.	vehicle with the ability to be up armored.	vehicle with the ability to be up armored.		vehicle with the ability to be up armored.

Requirements Source

Capability Production Document (CPD) dated March 24, 2009

Change Explanations

(Ch-1) The KPP description in the February 28, 2012 APB was not verbatim from the 2009 JROC approved CPD. The wording in the current APB (APB Change 2) was updated to reflect the exact verbiage from the 2009 JROC approved CPD.

(Ch-2) Updated current estimate parameter to align with September 12, 2013 APB.

Acronyms and Abbreviations

% - Percent
AGMs - Air-to-Ground Missiles
Ao - Operational Availability
ATO - Approval to Operate
CPD - Capability Production Document
DAA - Designated Approval Authority
DISR - Department of Defense Information Technology Standards Registry
EO/IR/LD - Electro-Optical/Infrared/Laser Designator
GCS-V3 - Ground Control Station Version Three
GIG IT - Global Information Grid Information Technology
IA - Information Assurance
IATO - Interim Approval to Operate
JROC - Joint Requirements Oversight Council
KIP - Key Interface Profile
km - Kilometers
KPP - Key Performance Parameter
lbs - Pounds
NATO - North Atlantic Treaty Organization
NCOW RM - Net Centric Operations Warfare Reference Model
PD - Probability of Detection
PR - Probability of Recognition
SAR/GMTI - Synthetic Aperature Radar/Ground Moving Target Indicator
TV - Technical View
UA - Unmanned Aircraft

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Track to Budget

RDT&E

Appn		BA	PE		
Army	2040	07	0305204A		
	Project		**Name**		
	D09		Research, Development, Test and Evaluation, Army		(Sunk)
	Notes:		FY 2005 - FY 2010		
Army	2040	07	0305219A		
	Project		**Name**		
	MQ1		Research, Development, Test and Evaluation, Army		
	Notes:		Beginning FY 2011		

Procurement

Appn		BA	PE		
Army	2031	02	0305219A		
	Line Item		**Name**		
	A00020		MQ-1 Payload	(Shared)	(Sunk)
Army	2031	01	0305219A		
	Line Item		**Name**		
	A0005		MQ-1 UAV		
	Notes:		FY 2010 - FY 2036		
Army	2031	02	0313400A		
	Line Item		**Name**		
	A01001		MQ-1 Payload	(Shared)	
	Notes:		Beginning in FY 2015		
Army	2035	02	0030500A		
	Line Item		**Name**		
	00305000		Other Procurement, Army		(Sunk)
	Notes:		FY 2007 - FY 2009		

The MQ-1C Gray Eagle program baseline includes the Common Sensor Payload (CSP) procurement, which is part of the MQ-1 Payloads Aircraft Procurement, Army budget line. The funding line is shared with the CSP, Synthetic Aperture Radar, Ground Moving Target Indicator. and the Tactical SIGINT Payload.

MILCON

Appn		BA	PE
Army	2050	02	0202096A

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Project	Name
069830	Military Construction, Army

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Cost and Funding

Cost Summary

Total Acquisition Cost and Quantity

	BY2010 $M			BY2010 $M	TY $M		
Appropriation	SAR Baseline Prod Est	Current APB Production Objective/Threshold		Current Estimate	SAR Baseline Prod Est	Current APB Production Objective	Current Estimate
RDT&E	895.3	931.7	1024.9	925.7	896.3	945.3	936.1
Procurement	3364.7	2988.0	3286.8	2909.6	3572.0	3217.3	3103.6
Flyaway	--	--	--	2157.9	--	--	2297.7
Recurring	--	--	--	1903.5	--	--	2028.8
Non Recurring	--	--	--	254.4	--	--	268.9
Support	--	--	--	751.7	--	--	805.9
Other Support	--	--	--	484.1	--	--	523.9
Initial Spares	--	--	--	267.6	--	--	282.0
MILCON	992.0	578.5	636.4	597.7	1080.7	640.2	658.2
Acq O&M	0.0	0.0	--	0.0	0.0	0.0	0.0
Total	5252.0	4498.2	N/A	4433.0	5549.0	4802.8	4697.9

Confidence Level for Current APB Cost 50% -

The Independent Cost Estimate (ICE) to support the MQ-1C Gray Eagle program Milestone C decision, like all life cycle cost estimates previously performed by the Cost Assessment and Program Evaluation (CAPE) office, is built upon a product-oriented work breakdown structure, based on historical actual cost information to the maximum extent possible, and, most importantly, based on conservative assumptions that are consistent with actual demonstrated contractor and government performance for a series of acquisition programs in which the Department has been successful.

The confidence level for the Full Rate Production-aproved Acquisition Program Baseline (APB) is 50% and is based on the May 9, 2013, approved Army Cost Position and are in accordance with Army cost guidance, Army Regulations (AR) 11-18. It is difficult to calculate mathematically the precise confidence levels associated with life cycle cost estimates prepared for Major Defense Acquisition Programs (MDAPs). Based on the rigor in methods used in building estimates, the strong adherence to the collection and use of historical cost information, and the review of applied assumptions, we project that it is about equally likely that the estimate will prove too low or too high for execution of the program described.

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Quantity	SAR Baseline Prod Est	Current APB Production	Current Estimate
RDT&E	2	2	2
Procurement	29	29	29
Total	31	31	31

The unit of measure for a MQ-1C Gray Eagle is balanced Platoons, each with four aircraft and associated support equipment and payloads to include: Electro-Optical/Infrared/Laser Range Finder/Laser Designator, communications relay, and up to four Hellfire Missiles. The Common Sensor Payload and STARlite Synthetic Aperture Radar Ground Moving Target Indicator are one per aircraft. Ground equipment per Platoon includes: two Universal Ground Control Stations, three Universal Ground Data Terminals, one Satellite Communication Ground Data Terminal, one Mobile Ground Control Station per Company, an Automated Take Off and Landing System which includes two Tactical Automatic Landing Systems and ground support equipment to include Ground-Based Sense and Avoid.

Although the Army’s fielding strategy has evolved, the Army will continue to use the 29 platoon metric to determine APUC and the 31 platoon metric to determine PAUC. A balanced platoon contains four aircraft and ground support equipment and is the historic metric used to determine APUC and PAUC.

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Cost and Funding

Funding Summary

Appropriation and Quantity Summary
FY2015 President's Budget / December 2013 SAR (TY$ M)

Appropriation	Prior	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	To Complete	Total
RDT&E	878.7	10.9	46.5	0.0	0.0	0.0	0.0	0.0	936.1
Procurement	2330.2	466.3	199.0	49.3	52.2	6.5	0.1	0.0	3103.6
MILCON	437.2	36.0	124.0	22.0	39.0	0.0	0.0	0.0	658.2
Acq O&M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PB 2015 Total	3646.1	513.2	369.5	71.3	91.2	6.5	0.1	0.0	4697.9
PB 2014 Total	3777.3	652.4	266.2	35.0	43.8	113.6	0.6	0.0	4888.9
Delta	-131.2	-139.2	103.3	36.3	47.4	-107.1	-0.5	0.0	-191.0

Quantity	Undistributed	Prior	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	To Complete	Total
Development	2	0	0	0	0	0	0	0	0	2
Production	0	23	4	2	0	0	0	0	0	29
PB 2015 Total	2	23	4	2	0	0	0	0	0	31
PB 2014 Total	2	25	3	1	0	0	0	0	0	31
Delta	0	-2	1	1	0	0	0	0	0	0

4784 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Cost and Funding

Annual Funding By Appropriation

Annual Funding TY$
2040 | RDT&E | Research, Development, Test, and Evaluation, Army

Fiscal Year	Quantity	End Item Recurring Flyaway TY $M	Non End Item Recurring Flyaway TY $M	Non Recurring Flyaway TY $M	Total Flyaway TY $M	Total Support TY $M	Total Program TY $M
2005	--	--	--	--	--	--	54.3
2006	--	--	--	--	--	--	90.6
2007	--	--	--	--	--	--	123.7
2008	--	--	--	--	--	--	103.4
2009	--	--	--	--	--	--	61.8
2010	--	--	--	--	--	--	135.1
2011	--	--	--	--	--	--	119.2
2012	--	--	--	--	--	--	121.9
2013	--	--	--	--	--	--	68.7
2014	--	--	--	--	--	--	10.9
2015	--	--	--	--	--	--	46.5
Subtotal	**2**	**--**	**--**	**--**	**--**	**--**	**936.1**

4785 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding BY$
2040 | RDT&E | Research, Development, Test, and Evaluation, Army

Fiscal Year	Quantity	End Item Recurring Flyaway BY 2010 $M	Non End Item Recurring Flyaway BY 2010 $M	Non Recurring Flyaway BY 2010 $M	Total Flyaway BY 2010 $M	Total Support BY 2010 $M	Total Program BY 2010 $M
2005	--	--	--	--	--	--	58.8
2006	--	--	--	--	--	--	95.5
2007	--	--	--	--	--	--	127.3
2008	--	--	--	--	--	--	104.4
2009	--	--	--	--	--	--	61.6
2010	--	--	--	--	--	--	132.7
2011	--	--	--	--	--	--	114.8
2012	--	--	--	--	--	--	115.5
2013	--	--	--	--	--	--	63.9
2014	--	--	--	--	--	--	9.9
2015	--	--	--	--	--	--	41.3
Subtotal	**2**	**--**	**--**	**--**	**--**	**--**	**925.7**

4786 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding TY$
2031 | Procurement | Aircraft Procurement, Army

Fiscal Year	Quantity	End Item Recurring Flyaway TY $M	Non End Item Recurring Flyaway TY $M	Non Recurring Flyaway TY $M	Total Flyaway TY $M	Total Support TY $M	Total Program TY $M
2010	6	247.3	67.7	73.0	388.0	100.1	488.1
2011	6	243.2	57.7	92.9	393.8	110.3	504.1
2012	6	305.2	85.6	25.5	416.3	196.0	612.3
2013	4	198.0	110.6	54.2	362.8	87.6	450.4
2014	4	278.3	84.4	19.9	382.6	83.7	466.3
2015	2	131.8	8.4	2.4	142.6	56.4	199.0
2016	--	--	3.4	0.5	3.9	45.4	49.3
2017	--	--	4.8	0.5	5.3	46.9	52.2
2018	--	--	4.5	--	4.5	2.0	6.5
2019	--	--	--	--	--	0.1	0.1
Subtotal	**28**	**1403.8**	**427.1**	**268.9**	**2099.8**	**728.5**	**2828.3**

4787 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding BY$
2031 | Procurement | Aircraft Procurement, Army

Fiscal Year	Quantity	End Item Recurring Flyaway BY 2010 $M	Non End Item Recurring Flyaway BY 2010 $M	Non Recurring Flyaway BY 2010 $M	Total Flyaway BY 2010 $M	Total Support BY 2010 $M	Total Program BY 2010 $M
2010	6	240.8	65.9	71.1	377.8	97.5	475.3
2011	6	232.5	55.2	88.8	376.5	105.5	482.0
2012	6	286.6	80.4	23.9	390.9	184.2	575.1
2013	4	182.0	101.6	49.8	333.4	80.5	413.9
2014	4	250.8	76.1	17.9	344.8	75.4	420.2
2015	2	116.5	7.4	2.1	126.0	49.9	175.9
2016	--	--	2.9	0.4	3.3	39.4	42.7
2017	--	--	4.1	0.4	4.5	39.9	44.4
2018	--	--	3.7	--	3.7	1.7	5.4
2019	--	--	--	--	--	0.1	0.1
Subtotal	**28**	**1309.2**	**397.3**	**254.4**	**1960.9**	**674.1**	**2635.0**

4788 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding TY$
2035 | Procurement | Other Procurement, Army

Fiscal Year	Quantity	End Item Recurring Flyaway TY $M	Non End Item Recurring Flyaway TY $M	Non Recurring Flyaway TY $M	Total Flyaway TY $M	Total Support TY $M	Total Program TY $M
2007	--	--	--	--	--	9.7	9.7
2008	--	--	31.4	--	31.4	24.3	55.7
2009	1	151.2	15.3	--	166.5	43.4	209.9
Subtotal	**1**	**151.2**	**46.7**	**--**	**197.9**	**77.4**	**275.3**

4789 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding BY$
2035 | Procurement | Other Procurement, Army

Fiscal Year	Quantity	End Item Recurring Flyaway BY 2010 $M	Non End Item Recurring Flyaway BY 2010 $M	Non Recurring Flyaway BY 2010 $M	Total Flyaway BY 2010 $M	Total Support BY 2010 $M	Total Program BY 2010 $M
2007	--	--	--	--	--	9.9	9.9
2008	--	--	31.6	--	31.6	24.5	56.1
2009	1	150.2	15.2	--	165.4	43.2	208.6
Subtotal	**1**	**150.2**	**46.8**	**--**	**197.0**	**77.6**	**274.6**

4790 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding TY$
2050 | MILCON | Military Construction, Army

Fiscal Year	Total Program TY $M
2011	102.0
2012	228.0
2013	107.2
2014	36.0
2015	124.0
2016	22.0
2017	39.0
Subtotal	**658.2**

4791 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding BY$
2050 | MILCON | Military Construction, Army

Fiscal Year	Total Program BY 2010 $M
2011	96.5
2012	212.4
2013	98.1
2014	31.9
2015	107.6
2016	18.7
2017	32.5
Subtotal	**597.7**

4792 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Low Rate Initial Production

	Initial LRIP Decision	Current Total LRIP
Approval Date	3/29/2010	7/3/2012
Approved Quantity	2	6
Reference	Milestone C ADM	LRIP III ADM
Start Year	2010	2012
End Year	2011	2015

The Current Total LRIP Quantity is more than 10% of the total production quantity due to Milestone Decision Authority directed the LRIP quantities to facilitate the MQ-1C Gray Eagle capability entrance into theater as quickly as possible.

Initial LRIP Decision
The original LRIP quantity was two MQ-1C Gray Eagle systems which equates to six platoon sets (24 aircraft).

Current Total LRIP
The Current Total LRIP quantity is six MQ-1C Gray Eagle systems which equates to 18 platoon sets and includes LRIP I (24 aircraft and two attrition aircraft), LRIP II (24 aircraft and five attrition aircraft) and LRIP III (29 aircraft).

4793 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Foreign Military Sales

MQ-1C Gray Eagle has one inquiry for Pricing and Availability from the Government of Poland. There are no other inquiries or international activity at this time.

Nuclear Costs

None.

4794 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Unit Cost

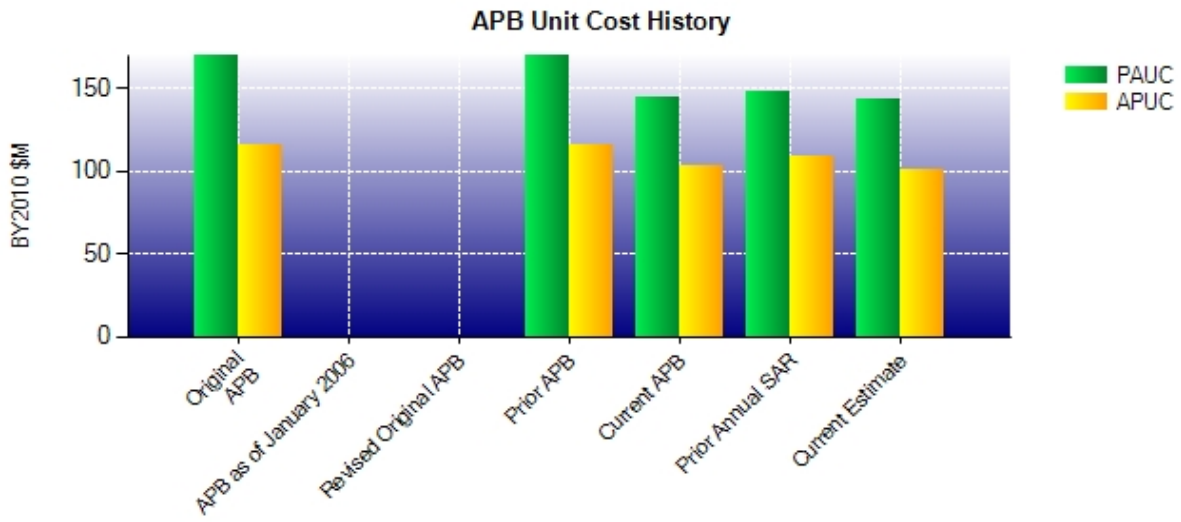
Unit Cost Report

Unit Cost	BY2010 $M Current UCR Baseline (SEP 2013 APB)	BY2010 $M Current Estimate (DEC 2013 SAR)	BY % Change
Program Acquisition Unit Cost (PAUC)			
Cost	4498.2	4433.0	
Quantity	31	31	
Unit Cost	145.103	143.000	-1.45
Average Procurement Unit Cost (APUC)			
Cost	2988.0	2909.6	
Quantity	29	29	
Unit Cost	103.034	100.331	-2.62

Unit Cost	BY2010 $M Original UCR Baseline (MAR 2011 APB)	BY2010 $M Current Estimate (DEC 2013 SAR)	BY % Change
Program Acquisition Unit Cost (PAUC)			
Cost	5252.0	4433.0	
Quantity	31	31	
Unit Cost	169.419	143.000	-15.59
Average Procurement Unit Cost (APUC)			
Cost	3364.7	2909.6	
Quantity	29	29	
Unit Cost	116.024	100.331	-13.53

4795 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Unit Cost History



		BY2010 $M		TY $M	
	Date	PAUC	APUC	PAUC	APUC
Original APB	MAR 2011	169.419	116.024	179.000	123.172
APB as of January 2006	N/A	N/A	N/A	N/A	N/A
Revised Original APB	N/A	N/A	N/A	N/A	N/A
Prior APB	FEB 2012	169.419	116.024	179.000	123.172
Current APB	SEP 2013	145.103	103.034	154.929	110.941
Prior Annual SAR	DEC 2012	147.829	108.852	157.706	117.314
Current Estimate	DEC 2013	143.000	100.331	151.545	107.021

SAR Unit Cost History

Initial SAR Baseline to Current SAR Baseline (TY $M)

Initial PAUC Dev Est	Changes								PAUC Prod Est
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
401.600	0.094	-242.537	-7.813	13.968	13.152	0.000	0.536	-222.600	179.000

Current SAR Baseline to Current Estimate (TY $M)

PAUC Prod Est	Changes								PAUC Current Est
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
179.000	1.768	0.000	0.139	0.810	-25.072	0.000	-5.100	-27.455	151.545

4796 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Initial SAR Baseline to Current SAR Baseline (TY $M)

Initial APUC Dev Est	Changes								APUC Prod Est
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
285.100	0.141	-177.121	0.000	14.931	-0.452	0.000	0.573	-161.928	123.172

Current SAR Baseline to Current Estimate (TY $M)

APUC Prod Est	Changes								APUC Current Est
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
123.172	1.341	0.000	0.148	-0.472	-11.717	0.000	-5.452	-16.152	107.021

SAR Baseline History

Item/Event	SAR Planning Estimate (PE)	SAR Development Estimate (DE)	SAR Production Estimate (PdE)	Current Estimate
Milestone A	N/A	N/A	N/A	N/A
Milestone B	N/A	APR 2005	APR 2005	APR 2005
Milestone C	N/A	FEB 2010	MAR 2011	MAR 2011
IOC	N/A	FEB 2012	JUN 2012	DEC 2012
Total Cost (TY $M)	N/A	5322.6	5549.0	4697.9
Total Quantity	N/A	13	31	31
Prog. Acq. Unit Cost (PAUC)	N/A	409.431	179.000	151.545

4797 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Cost Variance

Summary Then Year $M				
	RDT&E	Proc	MILCON	Total
SAR Baseline (Prod Est)	896.3	3572.0	1080.7	5549.0
Previous Changes				
Economic	+7.3	+61.3	+14.9	+83.5
Quantity	--	--	--	--
Schedule	--	+0.7	--	+0.7
Engineering	+38.8	-13.7	--	+25.1
Estimating	+34.8	-180.4	-586.0	-731.6
Other	--	--	--	--
Support	--	-37.8	--	-37.8
Subtotal	+80.9	-169.9	-571.1	-660.1
Current Changes				
Economic	-2.1	-22.4	-4.2	-28.7
Quantity	--	--	--	--
Schedule	--	+3.6	--	+3.6
Engineering	--	--	--	--
Estimating	-39.0	-159.4	+152.8	-45.6
Other	--	--	--	--
Support	--	-120.3	--	-120.3
Subtotal	-41.1	-298.5	+148.6	-191.0
Total Changes	+39.8	-468.4	-422.5	-851.1
CE - Cost Variance	936.1	3103.6	658.2	4697.9
CE - Cost & Funding	936.1	3103.6	658.2	4697.9

4798 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Summary Base Year 2010 $M				
	RDT&E	Proc	MILCON	Total
SAR Baseline (Prod Est)	895.3	3364.7	992.0	5252.0
Previous Changes				
Economic	--	--	--	--
Quantity	--	--	--	--
Schedule	--	--	--	--
Engineering	+32.1	-17.5	--	+14.6
Estimating	+30.9	-146.4	-524.3	-639.8
Other	--	--	--	--
Support	--	-44.1	--	-44.1
Subtotal	+63.0	-208.0	-524.3	-669.3
Current Changes				
Economic	--	--	--	--
Quantity	--	--	--	--
Schedule	--	--	--	--
Engineering	--	--	--	--
Estimating	-32.6	-133.7	+130.0	-36.3
Other	--	--	--	--
Support	--	-113.4	--	-113.4
Subtotal	-32.6	-247.1	+130.0	-149.7
Total Changes	+30.4	-455.1	-394.3	-819.0
CE - Cost Variance	925.7	2909.6	597.7	4433.0
CE - Cost & Funding	925.7	2909.6	597.7	4433.0

Previous Estimate: December 2012

4799 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

RDT&E	$M	
Current Change Explanations	**Base Year**	**Then Year**
Revised escalation indices. (Economic)	N/A	-2.1
Adjustment for current and prior escalation. (Estimating)	+1.7	+1.8
Army realigned resources to fully fund the program to the approved schedule. (Estimating)	+25.8	+29.0
Revised estimate due to sequestration reduction in FY 2013. (Estimating)	-5.5	-5.9
Revised estimate to align with FY 2015 PB which resulted in reduced RDT&E funding for future planned improvements. (Estimating)	-54.6	-63.9
RDT&E Subtotal	-32.6	-41.1

Procurement	$M	
Current Change Explanations	**Base Year**	**Then Year**
Revised escalation indices. (Economic)	N/A	-22.4
Adjustment for current and prior escalation. (Estimating)	+11.6	+13.0
Revised procurement profile due to FY 2013 Congressional reduction which delays procurement of four aircraft to FY 2015. (Schedule)	0.0	+3.6
Revised estimate for Common Systems Payload based on budget changes. (Estimating)	-13.0	-14.2
Revised estimate due to Congressional reduction in FY 2014 which defers Ka (military) Satellite Communications upgrade. (Estimating)	-51.2	-56.8
Revised estimate to align with FY 2015 PB which resulted in reduced Procurement funding for future planned modifications. (Estimating)	-87.2	-104.6
Revised estimate for Ground Equipment. (Estimating)	+6.1	+3.2
Adjustment for current and prior escalation. (Support)	+5.5	+5.6
Reduction in estimate for Initial Spares due to revised fielding plan. (Support)	-58.8	-65.2
Decrease in Other Support for Test and Evaluation, Software, Training/Devices and Modifications. (Support)	-60.1	-60.7
Procurement Subtotal	-247.1	-298.5

MILCON	$M	
Current Change Explanations	**Base Year**	**Then Year**
Revised escalation indices. (Economic)	N/A	-4.2
Adjustment for current and prior escalation. (Estimating)	+3.9	+4.2
Revised estimate that supports changes in Army baseline strategy for stationing and fielding the MQ-1C Gray Eagle. (Estimating)	+126.1	+148.6
MILCON Subtotal	+130.0	+148.6

4800 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Contracts

Appropriation: Acq O&M	
Contract Name	**Gray Eagle PBL**
Contractor	General Atomics - Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-12-C-0075, CPFF/CPIF
Award Date	May 08, 2012
Definitization Date	September 27, 2012

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
221.4	N/A	N/A	498.3	N/A	N/A	463.3	437.6

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to exercising the FY 2013 option.

Variance	Cost Variance	Schedule Variance
Cumulative Variances To Date (1/31/2014)	+6.3	-7.9
Previous Cumulative Variances	+6.3	-7.6
Net Change	+0.0	-0.3

Cost and Schedule Variance Explanations

The unfavorable net change in the schedule variance is due to Ground Control Equipment Spares that were impacted by technical issues associated with the Ground Data Terminal. An obsolete vendor component drove additional software analysis and impacted assembly.

4801 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Appropriation: Procurement	
Contract Name	**LRIP 3**
Contractor	General Atomics - Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-12-C-0057, FPIF
Award Date	July 06, 2012
Definitization Date	July 06, 2012

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
411.0	424.6	29	438.2	452.7	29	436.8	437.0

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to contract modifications P00001 through P00011 adding a platoon set of ground equipment and updated spares list.

Variance	Cost Variance	Schedule Variance
Cumulative Variances To Date (1/31/2014)	-1.8	-46.8
Previous Cumulative Variances	-0.9	+1.0
Net Change	-0.9	-47.8

Cost and Schedule Variance Explanations

The unfavorable net change in the cost variance is due to Work In Process on lower level assemblies. Performance on lower level assemblies will be claimed when production reaches Earned Value methodology thresholds.

The unfavorable net change in the schedule variance is due to late receipt of Universal Ground Data Terminal (UGDT), Initial Spares, and Tactical Control Data Link (TCDL). UGDT delayed by late receipt of hardware. Initial Spares delayed by lack of agreement on spares kits list with AAI Corporation and late deliveries from L-3 Communications. TCDL impacted by redesign of two Circuit Card Assemblies. The current schedule variance has no impact to the fielding schedule.

4802 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Appropriation: Procurement	
Contract Name	**LRIP II**
Contractor	General Atomics - Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-11-C-0099, FPIF
Award Date	April 08, 2011
Definitization Date	December 06, 2011

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
354.0	N/A	26	310.2	321.8	29	329.0	328.4

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to the Initial Contract Price Target being based on a Not To Exceed price.

Variance	Cost Variance	Schedule Variance
Cumulative Variances To Date (1/31/2014)	-7.0	-10.9
Previous Cumulative Variances	-1.8	-6.8
Net Change	-5.2	-4.1

Cost and Schedule Variance Explanations

The unfavorable net change in the cost variance is due to Integration, Assembly, Test and Checkout hours required during Phase 2 and Phase 3 flight line testing; including troubleshooting Government Furnished Equipment radios, incorporation of engineering changes, payloads, and rework tasks to support/correct critical engine related issues, and Ground Support Equipment line items that are in scope but were unplanned in the baseline.

The unfavorable net change in the schedule variance is due to delays for rework on Universal Ground Data Terminal Generation 3 modem Circuit Card Assemblies and delays related to software version 4.3.1.

Contract Comments

This contract is more than 90% complete; therefore, this is the final report for this contract.

Contract quantity 25 of 29 aircraft were delivered.

4803 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Appropriation: Procurement	
Contract Name	**LRIP-1**
Contractor	General Atomics - Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-10-C-0068, FPIF
Award Date	May 14, 2010
Definitization Date	February 28, 2011

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
242.5	287.9	26	292.6	317.3	26	289.1	286.3

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to contract modifications through P00074.

Variance	Cost Variance	Schedule Variance
Cumulative Variances To Date (1/31/2014)	+10.4	-0.7
Previous Cumulative Variances	+1.4	-1.3
Net Change	+9.0	+0.6

Cost and Schedule Variance Explanations

The favorable net change in the cost variance is due to overestimated support on Program Management and System Engineering.

The favorable net change in the schedule variance is due to completion of Ground Support Equipment, specifically Half Rack and Breakout Boxes that were originally delayed due to engineering changes.

Contract Comments

This contract is more than 90% complete; therefore, this is the final report for this contract.

Contract quantity 25 of 26 were delivered.

4804 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Appropriation: Procurement

Contract Name	**Full Rate Production (FRP)**
Contractor	General Atomics Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-13-C-0109, FFP
Award Date	September 13, 2013
Definitization Date	September 13, 2013

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
199.7	N/A	15	240.0	N/A	19	240.0	240.0

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to exercising an option established under initial contract award.

Cost and Schedule Variance Explanations

Cost and Schedule Variance reporting is not required on this FFP contract.

Contract Comments

This is the first time this contract is being reported.

4805 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Appropriation: RDT&E

Contract Name	**Engineering Services**
Contractor	General Atomics - Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-09-C-0136, CPFF
Award Date	September 30, 2009
Definitization Date	September 30, 2009

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
77.2	N/A	N/A	160.7	N/A	N/A	152.1	153.0

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to Contract Modifications through Mod P00099.

Variance	Cost Variance	Schedule Variance
Cumulative Variances To Date (1/31/2014)	+7.8	-1.8
Previous Cumulative Variances	+10.6	-0.9
Net Change	-2.8	-0.9

Cost and Schedule Variance Explanations

The unfavorable net change in the cost variance is due to efforts on a Sub-Engineering Services Memorandum (SESM) needing additional Electromagnetic Interference (EMI) testing and the purchase of new equipment to resolve compatibility issues.

The unfavorable net change in the schedule variance is due to efforts on a SESM needing additional EMI testing, delays in the alternator delivery, and design rework on the High Power Distribution Module.

Contract Comments

This contract is more than 90% complete; therefore, this is the final report for this contract.

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Appropriation: RDT&E

Contract Name	**Production Readiness Test Asset (PRTA)**
Contractor	General Atomics - Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-09-C-0151, CPIF
Award Date	April 28, 2009
Definitization Date	April 20, 2010

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
48.0	N/A	N/A	83.6	N/A	N/A	72.6	74.6

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to contract definitization at $40.60M with options exercised during Calendar Years 2010 - 2012, and Contract Modifications through P00063.

Variance	Cost Variance	Schedule Variance
Cumulative Variances To Date (1/31/2014)	+12.4	-1.1
Previous Cumulative Variances	+8.0	-2.2
Net Change	+4.4	+1.1

Cost and Schedule Variance Explanations

The favorable net change in the cost variance is due to overestimated support on Datalink Spares, Program Management, and System Engineering.

The favorable net change in the schedule variance is due to completion of Datalink Spares kits originally delayed by late material from subcontractor.

Contract Comments

This contract is more than 90% complete; therefore, this is the final report for this contract.

Contract W58RGZ-09-C-0151, Production Readiness Test Asset was included in the 2012 SAR and is listed in the 2013 SAR as a reference. This contract is not currently in the top six largest contracts. The contract is over 90 percent complete so this is the final report for this contract.

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Deliveries and Expenditures

Delivered to Date	Plan to Date	Actual to Date	Total Quantity	Percent Delivered
Development	2	2	2	100.00%
Production	10	10	29	34.48%
Total Program Quantity Delivered	12	12	31	38.71%

Expended and Appropriated (TY $M)			
Total Acquisition Cost	4697.9	Years Appropriated	10
Expended to Date	2210.6	Percent Years Appropriated	66.67%
Percent Expended	47.06%	Appropriated to Date	4159.3
Total Funding Years	15	Percent Appropriated	88.54%

The above data is current as of 1/31/2014.

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Operating and Support Cost

MQ-1C Gray Eagle

Assumptions and Ground Rules

Cost Estimate Reference:
The O&S Current Estimate is based on the June 14, 2013 Defense Acquisition Board (DAB) approved Full Rate Production (FRP) Army Cost Position (ACP). Operation and Maintenance cost was based on actual Unmanned Aircraft System (UAS) consumption data, analogy to Predator, O&S Management Information System (OSMIS) Blackhawk data. The cost is applied as steady state across the MQ-1C Gray Eagle program in accordance with the program schedule which includes a total approved procurement objective of 152 aircraft.

The unit of measure for a MQ-1C Gray Eagle is balanced Platoons, each with four aircraft and associated support equipment and payloads to include: Electro-Optical/Infrared/Laser Designator, communications relay, and up to four Hellfire Missiles. The Common Sensor Payload and STARlite Synthetic Aperture Radar Ground Moving Target Indicator are one per aircraft. Ground equipment per Platoon includes: two Universal Ground Control Stations, three Universal Ground Data Terminals, one Satellite Communication Ground Data Terminal, one Mobile Ground Control Station per Company, an Automated Take Off and Landing System which includes two Tactical Automatic Landing Systems and ground support equipment to include Ground-Based Sense and Avoid. A MQ-1C Gray Eagle Company is configured into three equal platoons and includes nine MQ-1C Gray Eagle aircraft for conventional companies (non-deployed) and when deployed, the Army will bring the company to full MQ-1C Gray Eagle System strength (12 aircraft and associated ground support equipment).

Sustainment Strategy:
The O&S cost is based on 15 MQ-1C Gray Eagle companies with a 20-year service plus one training base with a 27-year service life.

A Performance Based Logistics (PBL) contract was awarded May 8, 2012. The contract includes one base year plus two, one-year options. Soldiers will operate systems and perform 85% of the basic field maintenance. The Field Service Representative (FSR) will support remaining 15% of basic field maintenance through PBL efforts. Some of the Depot Level Reparables will be accomplished by organic depots through a Public Private Partnership (PPP) arrangement. The PPP with organic depot efforts will be determined through Cost Benefit Analysis and application of Title 10 USC 2426 and 50/50 rule.

Antecedent Information:
There is no antecedent to this program.

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Unitized O&S Costs BY2010 $M		
Cost Element	**MQ-1C Gray Eagle Average annual cost per company**	**No Antecedent (Antecedent) N/A**
Unit-Level Manpower	10.300	0.000
Unit Operations	1.300	0.000
Maintenance	3.460	0.000
Sustaining Support	3.750	0.000
Continuing System Improvements	0.360	0.000
Indirect Support	0.870	0.000
Other	2.460	0.000
Total	22.500	--

Unitized Cost Comments:
O&S unitized cost is based on 15 companies with a 20-year service life plus one training base with a 27-year service life. (15 companies x 20 year service life + one training base x 27 year service life = 327 Operational Systems).

The unitized average annual cost per system (Platoon) is $22.5M (BY$ 2010), ($7357.3M / 327 Operational Systems). The $2.460M Other cost is Operations and Maintenance related, Military Pay and Allowances (Medical & Morale, Welfare, Recreation).

	Total O&S Cost $M			
	Current Production APB Objective/Threshold		**Current Estimate**	
	MQ-1C Gray Eagle		**MQ-1C Gray Eagle**	**No Antecedent (Antecedent)**
Base Year	7357.3	8093.0	7357.3	N/A
Then Year	9950.8	N/A	9950.8	N/A

Total O&S Costs Comments:
HISTORICAL NOTES:

1) Prior to the FRP Decision, the average annual cost per MQ-1C Gray Eagle system was $31.84M.

2) Ownership Cost Key System Attribute was not required for post Milestone B documents per the March 10, 2007 Life Cycle Sustainment Outcome Metrics memorandum and the December 1, 2007 Guide to Sustainment Key Performance Parameter memorandum from the Deputy Under Secretary of Defense for Material Readiness and Maintenance Policy. After that time, the program was reclassified as an Acquisition Category ID Major Defense Acquisition Program.

O&S Cost Variance		
Category	**Base Year 2010 $M**	**Change Explanation**
Prior SAR Total O&S Estimate December 2012	11,904.0	
		Based on actual UAS consumption data, the June 2013 DAB

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Cost Estimating Methodology	-4546.7	approved ACP and analogy to Predator and OSMIS Blackhawk data.
Cost Data Update	0.0	
Labor Rate	0.0	
Energy Rate	0.0	
Technical Input	0.0	
Programmatic/Planning Factors	0.0	
Other	0.0	
Total Changes	-4546.7	
Current Estimate	7357.3	

Disposal Costs:

Lifecycle demilitarization/disposal costs are not included in the above estimate.

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Selected Acquisition Report (SAR)

RCS: DD-A&T(Q&A)823-420



MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle)

As of FY 2015 President's Budget

Defense Acquisition Management
Information Retrieval
(DAMIR)

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Report Documentation Page

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1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
DEC 2013		**00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle)	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of the Army,,Unmanned Aircraft Systems (UAS) Project Office,,Building 5300,,Redstone Arsenal,,AL,35898**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Selected Acquisition Report-SAR

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**48**	

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Common Acronyms and Abbreviations

Acq O&M - Acquisition-Related Operations and Maintenance
APB - Acquisition Program Baseline
APPN - Appropriation
APUC - Average Procurement Unit Cost
BA - Budget Authority/Budget Activity
BY - Base Year
DAMIR - Defense Acquisition Management Information Retrieval
Dev Est - Development Estimate
DoD - Department of Defense
DSN - Defense Switched Network
Econ - Economic
Eng - Engineering
Est - Estimating
FMS - Foreign Military Sales
FY - Fiscal Year
IOC - Initial Operational Capability
$K - Thousands of Dollars
LRIP - Low Rate Initial Production
$M - Millions of Dollars
MILCON - Military Construction
N/A - Not Applicable
O&S - Operating and Support
Oth - Other
PAUC - Program Acquisition Unit Cost
PB - President's Budget
PE - Program Element
Proc - Procurement
Prod Est - Production Estimate
QR - Quantity Related
Qty - Quantity
RDT&E - Research, Development, Test, and Evaluation
SAR - Selected Acquisition Report
Sch - Schedule
Spt - Support
TBD - To Be Determined
TY - Then Year
UCR - Unit Cost Reporting

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Program Information

Program Name
MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle)

DoD Component
Army

Responsible Office

Responsible Office		
Colonel Timothy R. Baxter Unmanned Aircraft Systems (UAS) Project Office Building 5300 Redstone Arsenal, AL 35898 timothy.r.baxter.mil@mail.mil	**Phone** **Fax** **DSN Phone** **DSN Fax** **Date Assigned**	256-313-5327 256-313-5445 897-5327 897-5445 July 1, 2011

References

SAR Baseline (Production Estimate)
Defense Acquisition Executive (DAE) Approved Acquisition Program Baseline (APB) dated March 25, 2011

Approved APB
Defense Acquisition Executive (DAE) Approved Acquisition Program Baseline (APB) dated September 12, 2013

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Mission and Description

The MQ-1C Gray Eagle Unmanned Aircraft System (MQ-1C Gray Eagle) provides the Division Commander a dedicated, assured, multi-mission Unmanned Aircraft System for the tactical fight assigned to the Combat Aviation Brigade in each Division and supports the Division Fires, Battlefield Surveillance Brigades, and Brigade Combat Teams based upon the Division Commander's priorities. The MQ-1C Gray Eagle will also be assigned to Army Special Operations Forces and the Aerial Exploitation Battalions. MQ-1C Gray Eagle provides reconnaissance, surveillance, and target Acquisition; command and control; communications relay; signals intelligence; electronic warfare; attack; detection of weapons of mass destruction; battle damage assessment; and manned-unmanned teaming capabilities.

The unit of measure for a MQ-1C Gray Eagle is balanced platoons, each with four aircraft and associated support equipment and payloads to include: Electro-Optical/Infrared/Laser Range Finder/Laser Designator, communications relay, and up to four Hellfire Missiles. The Common Sensor Payload and STARlite Synthetic Aperture Radar Ground Moving Target Indicator are one per aircraft. Ground equipment per Platoon includes: two Universal Ground Control Stations, three Universal Ground Data Terminals, one Satellite Communication Ground Data Terminal, one Mobile Ground Control Station per Company, an Automated Take Off and Landing System which includes two Tactical Automatic Landing Systems and ground support equipment to include Ground-Based Sense and Avoid.

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Executive Summary

The MQ-1C Gray Eagle program continues with development, integration, testing, training, production and deployment while supporting the warfighter with two MQ-1C Gray Eagle Quick Reaction Units (four aircraft each and associated support equipment) and a full-up MQ-1C Gray Eagle Company (12 aircraft and 128 Soldiers) deployed in support of combat operations in Afghanistan.

MQ-1C Gray Eagle Initial Operational Test and Evaluation completed in August 2012. Developmental testing in 4th Quarter FY 2013 and 1st Quarter FY 2014 focused on incorporating the Universal Ground Control Station (UGCS) and Universal Ground Data Terminal (UGDT). Testing consisted of transportability and mobility, electromagnetic environmental effects, and software development. Environmental and Developmental Tests are planned for the 2nd and 3rd Quarter FY 2014. Formal Software Qualification Testing will be performed in 4th Quarter FY 2014 to prove out software functionality. These tests will assure technical maturity for a Follow-on Test and Evaluation (FOT&E) planned for June 2015.

On February 5, 2013, the Chief of Staff of the Army approved an Executive Order (EXORD) changing the MQ-1C Gray Eagle fielding configuration to provide greater capability across the Army. The EXORD directs fielding of MQ-1C Gray Eagle companies to ten Army Divisions, one to the National Training Center (NTC), two Army Special Operations Forces (ARSOF) units, and two to the Aerial Exploitation Battalions (AEB) for a total of 15 companies. The two ARSOF companies will be configured with 12 aircraft each (24 total) and the 13 units assigned to Army Divisions, NTC and the AEB's will be fielded with nine aircraft each (117 total) while Continental United States (CONUS) based. Seven aircraft are assigned to the institutional training base at Fort Huachuca, Arizona. The four remaining aircraft are for attrition. When a company or AEB assigned to a division deploys Outside the Continental United States (OCONUS), the Army will reassign equipment, as required, to bring the company to full Gray Eagle System equipment strength (12 aircraft and associated ground support equipment). All EXORD requirements will be met without exceeding the procurement objective of 152 aircraft and ground support equipment and Program of Record funding.

Each company will be integrated with the following payloads: Electro-Optical/Infrared, Laser Range Finder/Laser Designator, Synthetic Aperture Radar/Ground Moving Target Indicator, communications relay, and four HELLFIRE missiles. Ground support equipment for a 12 aircraft company includes six UGCS, seven UGDT, three Satellite Communication Ground Data Terminals, one Mobile Ground Control Station, and the Automated Take Off and Landing System consisting of six Tactical Automatic Landing System-Tracking Subsystem and ground support equipment.

The Full Rate Production (FRP) Defense Acquisition Board (DAB) completed June 14, 2013 and an Acquisition Decision Memorandum (ADM) approved procurement of up to 49 unmanned aircraft and associated ground support equipment which brings the total program quantity to 152 aircraft. The approved quantity satisfies 100-percent of the total procurement objective for the MQ-1C Gray Eagle program. The ADM changed the program classification from ACAT ID to ACAT IC.

An updated APB based on the DAB approved cost estimate was approved on September 12, 2013. Although the fielding strategy has evolved with the Chief of Staff EXORD, the Army will continue to use the 31 platoon metric to determine program APUC and PAUC. MQ-1C Gray Eagle has demonstrated meeting six of seven Key Performance Parameters (KPP). For the Net Ready KPP, Link-16 has not fully demonstrated meeting the threshold requirement. The Army approved deferring meeting this capability to FOT&E which is planned for June 2015.

Major contracting actions completed since the 2012 SAR include:

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- Initial FRP1 contract. FRP1 is a Firm Fixed Price (FFP) contract for 15 aircraft and associated ground equipment.
- FRP1 also includes a priced option for four aircraft and associated ground equipment. The option was exercised December 6, 2013 using FY 2014 funds.
- Award of a Cost Plus Fixed Fee (CPFF)/Cost Plus Incentive Fee contract for Pre-Planned Product Improvement (P3I) which allows for development efforts for FOT&E.
- Award of a CPFF Engineering Services contract (FY 2013 - FY 2017) which allows for integration, inspection, analysis and corrective action, test and evaluation for system hardware, software, and components and support of the MQ-1C Gray Eagle systems allocated among Base Engineering Service Memoranda.
- Modification to the Performance Based Logistics contract for performance from May 2013 to May 2014.

The FY 2014 RDT&E appropriation funds MQ-1C Gray Eagle at the FY 2014 PB request of $10.9M. However, a Congressional reduction of $81.3M from the Aircraft Procurement, Army budget request of $518.5M has resulted in a deferral of the planned production and incorporation of Ka-band (military) satellite communications.

Additionally, the FY 2014 appropriation did not include funding for the four war replacement aircraft in the Overseas Contingency Operations (OCO) request. The change in fielding strategy within the existing 152 programmed aircraft reduced the number of attrition aircraft from 21 to four, making the impact of the OCO reduction more significant.

There are no significant software-related issues with this program at this time.

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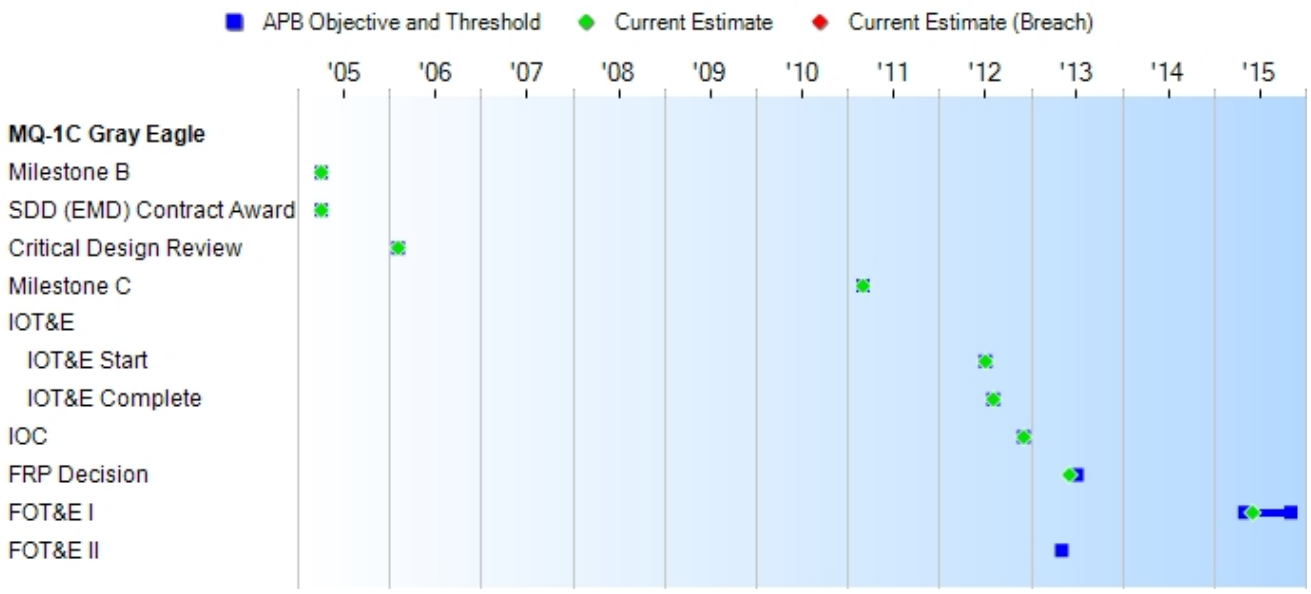
Threshold Breaches

APB Breaches		
Schedule		☐
Performance		☐
Cost	RDT&E	☐
	Procurement	☐
	MILCON	☐
	Acq O&M	☐
O&S Cost		☐
Unit Cost	PAUC	☐
	APUC	☐

Nunn-McCurdy Breaches		
Current UCR Baseline		
	PAUC	None
	APUC	None
Original UCR Baseline		
	PAUC	None
	APUC	None

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Schedule



Milestones	SAR Baseline Prod Est	Current APB Production Objective/Threshold		Current Estimate	
Milestone B	APR 2005	APR 2005	APR 2005	APR 2005	
SDD (EMD) Contract Award	APR 2005	APR 2005	APR 2005	APR 2005	
Critical Design Review	FEB 2006	FEB 2006	FEB 2006	FEB 2006	
Milestone C	MAR 2011	MAR 2011	MAR 2011	MAR 2011	
IOT&E					
IOT&E Start	SEP 2011	JUL 2012	JUL 2012	JUL 2012	
IOT&E Complete	OCT 2011	AUG 2012	AUG 2012	AUG 2012	
IOC	JUN 2012	DEC 2012	DEC 2012	DEC 2012	
FRP Decision	APR 2012	JUL 2013	JUL 2013	JUN 2013	(Ch-1)
FOT&E I	AUG 2012	MAY 2015	NOV 2015	JUN 2015	(Ch-2)
FOT&E II	MAY 2013	N/A	N/A	N/A	

Change Explanations

(Ch-1) The current estimate for FRP Decisions was changed from May 2013 to June 2013 to reflect the date of the FRP Defense Acquisition Board.

(Ch-2) The current estimate for FOT&E changed from April 2015 to June 2015 to allow synchronization with the planned NTC unit rotation schedule.

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Acronyms and Abbreviations

EMD - Engineering and Manufacturing Development
FOT&E - Follow-On Test and Evaluation
FRP - Full Rate Production
IOT&E - Initial Operational Test and Evaluation
NTC - National Training Center
SDD - System Development and Demonstration

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Performance

Characteristics	SAR Baseline Prod Est	Current APB Production Objective/Threshold		Demonstrated Performance	Current Estimate	
Net Ready	The system must fully support execution of all operational activities identified in the applicable joint and system integrated architectures and the system must satisfy the technical requirements for Net-Centric military operations to include 1) DISR mandated GIG IT standards and profiles identified in the TV-1, 2) DISR mandated GIG KIPs identified in the KIP declaration table, 3) NCOW RM Enterprise Services 4) IA requirements including	The system must fully support execution of all operational activities identified in the applicable joint and system integrated architectures and the system must satisfy the technical requirements for Net-Centric military operations to include 1) DISR mandated GIG IT standards and profiles identified in the TV-1, 2) DISR mandated GIG KIPs identified in the KIP declaration table, 3) NCOW RM Enterprise Services 4) IA requirements including	The system must fully support execution of joint critical operational activities identified in the applicable joint and system integrated architectures and the system must satisfy the technical requirements for transition to Net-Centric military operations to include 1) DISR mandated GIG IT standards and profiles identified in the TV-1, 2) DISR mandated GIG KIPs identified in the KIP declaration table, 3) NCOW RM Enterprise Services 4) IA requirements	Met threshold at IOT&E, LINK16 will be demonstrated at FOT&E	The system must fully support execution of all operational activities identified in the applicable joint and system integrated architectures and the system must satisfy the technical requirements for Net-Centric military operations to include 1) DISR mandated GIG IT standards and profiles identified in the TV-1, 2) DISR mandated GIG KIPs identified in the KIP declaration table, 3) NCOW RM Enterprise Services 4) IA requirements including	(Ch-1)

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	availability, integrity, authentica-tion, confident-iality, and non-repudiation, and issuance of an ATO by the DAA, and 5) Operationally effective information exchanges; and mission critical performance and IA attributes, data correctness, data availability, and consistent data processing specified in the applicable joint and system integrated architecture views. The system must be able to enter and be managed in the network, and exchange data in a secure manner.	availability, integrity, authentica-tion, confident-iality, and non-repudiation, and issuance of an ATO by the DAA, 5) Operationally effective information exchanges; and mission critical performance and IA attributes, data correctness, data availability, and consistent data processing specified in the applicable joint and system integrated architecture views.	including availability, integrity, authentica-tion, confident-iality, and non-repudiation, and issuance of an IATO by the DAA, 5) Operationally effective information exchanges; and mission critical performance and IA attributes, data correctness, data availability, and consistent data processing specified in the applicable joint and system integrated architecture views.		availability, integrity, authentica-tion, confident-iality, and non-repudiation, and issuance of an ATO by the DAA, 5) Operationally effective information exchanges; and mission critical performance and IA attributes, data correctness, data availability, and consistent data processing specified in the applicable joint and system integrated architecture views.	
Multi Payload/Weight Capability	The aircraft is capable of simultan-	UA will be capable of simultan-	UA will be capable of simultan-	Met threshold at IOT&E	UA will be capable of simultaneousl	(Ch-2)

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	eously carrying two payloads with a combined minimum weight of 300 lbs.	eously carrying three or more payloads with a combined minimum weight of 300 lbs.	eously carrying two payloads with a combined minimum weight of 200 lbs.		y carrying three or more payloads with a combined minimum weight of 300 lbs.	
Airframe Sensors Payload Capability	The aircraft will be capable of accepting payloads that are: EO/IR/LD capable of providing a 90% PD of a military target from the aircraft's operational altitude out to a minimum of 30km slant range. EO/IR/LD capable of providing a 90% PR of a military target, from the aircraft's operational altitude, out to a minimum of 10km slant range. SAR/GMTI Sensor capable of providing 85% PD of a military target, from the aircraft's operational	MQ-1C UA will be capable of accepting payloads that are: EO/IR/LD capable of providing: 90% PD of a military target, from the UA's operational altitude out to a minimum of 30 km slant range; 90% PR of a military target, from the UA's operational altitude, out to a minimum of 10 km slant range; SAR/GMTI sensor capable of providing 85% PD of a military target, from the UA's operational altitude, out to a minimum of	EO/IR/LD capable of providing: 90% PD of a military target, from the UA's operational altitude out to a minimum of 25 km slant range; 90% PR of a military target, from the UA's operational altitude out to a minimum of 9 km slant range.	Met objective, verified CSP during Production Prove-Out Test.	MQ-1C UA will be capable of accepting payloads that are: EO/IR/LD capable of providing: 90% PD of a military target, from the UA's operational altitude out to a minimum of 30 km slant range; 90% PR of a military target, from the UA's operational altitude, out to a minimum of 10 km slant range; SAR/GMTI sensor capable of providing 85% PD of a military target, from the UA's operational altitude, out to a minimum of	(Ch-2)

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	altitude, out to a minimum 10km slant range in clear weather	10 km slant range in clear weather.			10 km slant range in clear weather.	
Sustainment	The aircraft system must maintain a combat Ao of 90%.	MQ-1C must maintain a combat Ao of 90%.	MQ-1C must maintain a combat Ao of 80%.	Met updated threshold KPP at IOT&E	MQ-1C must maintain a combat Ao of 90%.	(Ch-2)
Aircraft Propulsion	The aircraft engine will be powered by DoD/NATO standard heavy fuel (JP8 Fuel).	UA engine will be powered by DoD/NATO standard heavy fuel (JP8 Fuel).	UA engine will be powered by DoD/NATO standard heavy fuel (JP8 Fuel).	Met objective	UA engine will be powered by DoD/NATO standard heavy fuel (JP8 Fuel).	(Ch-1)
Weapons Capable	The aircraft shall be capable of engaging traditional and non-traditional ground moving, stationary, and water borne moving targets with the AGM-114P-4A and AGM-114N-4 and other AGM-114 variants or similar future AGMs and small light weight precision munitions.	MQ-1C must be capable of engaging traditional and non-traditional ground moving and stationary and water borne moving and stationary targets with the AGM-114P-4A and AGM-114N-4 and other AGM-114 variants or similar future AGMs and small light weight precision munitions.	MQ-1C must be capable of engaging traditional and non-traditional ground moving and stationary targets with the AGM-114P-4A and AGM-114N-4.	Met threshold; (35) Hellfire shots DT/OT; (100+) Hellfire shots in OIF/OEF	MQ-1C must be capable of engaging traditional and non-traditional ground moving and stationary and water borne moving and stationary targets with the AGM-114P-4A and AGM-114N-4 and other AGM-114 variants or similar future AGMs and small light weight precision munitions.	(Ch-1)
Survivability and Force Protection	The GCS-V3 will be mounted onto an Army standard	The GCS will be mounted onto an Army standard tactical	The GCS will be mounted onto an Army standard tactical	Met objective	The GCS will be mounted onto an Army standard tactical	(Ch-1)

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	tactical vehicle with the ability to be up armored.	vehicle with the ability to be up armored.	vehicle with the ability to be up armored.		vehicle with the ability to be up armored.

Requirements Source

Capability Production Document (CPD) dated March 24, 2009

Change Explanations

(Ch-1) The KPP description in the February 28, 2012 APB was not verbatim from the 2009 JROC approved CPD. The wording in the current APB (APB Change 2) was updated to reflect the exact verbiage from the 2009 JROC approved CPD.

(Ch-2) Updated current estimate parameter to align with September 12, 2013 APB.

Acronyms and Abbreviations

% - Percent
AGMs - Air-to-Ground Missiles
Ao - Operational Availability
ATO - Approval to Operate
CPD - Capability Production Document
DAA - Designated Approval Authority
DISR - Department of Defense Information Technology Standards Registry
EO/IR/LD - Electro-Optical/Infrared/Laser Designator
GCS-V3 - Ground Control Station Version Three
GIG IT - Global Information Grid Information Technology
IA - Information Assurance
IATO - Interim Approval to Operate
JROC - Joint Requirements Oversight Council
KIP - Key Interface Profile
km - Kilometers
KPP - Key Performance Parameter
lbs - Pounds
NATO - North Atlantic Treaty Organization
NCOW RM - Net Centric Operations Warfare Reference Model
PD - Probability of Detection
PR - Probability of Recognition
SAR/GMTI - Synthetic Aperature Radar/Ground Moving Target Indicator
TV - Technical View
UA - Unmanned Aircraft

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Track to Budget

RDT&E

Appn		BA	PE		
Army	2040	07	0305204A		
	Project		**Name**		
	D09		Research, Development, Test and Evaluation, Army		(Sunk)
	Notes:		FY 2005 - FY 2010		
Army	2040	07	0305219A		
	Project		**Name**		
	MQ1		Research, Development, Test and Evaluation, Army		
	Notes:		Beginning FY 2011		

Procurement

Appn		BA	PE		
Army	2031	02	0305219A		
	Line Item		**Name**		
	A00020		MQ-1 Payload	(Shared)	(Sunk)
Army	2031	01	0305219A		
	Line Item		**Name**		
	A0005		MQ-1 UAV		
	Notes:		FY 2010 - FY 2036		
Army	2031	02	0313400A		
	Line Item		**Name**		
	A01001		MQ-1 Payload	(Shared)	
	Notes:		Beginning in FY 2015		
Army	2035	02	0030500A		
	Line Item		**Name**		
	00305000		Other Procurement, Army		(Sunk)
	Notes:		FY 2007 - FY 2009		

The MQ-1C Gray Eagle program baseline includes the Common Sensor Payload (CSP) procurement, which is part of the MQ-1 Payloads Aircraft Procurement, Army budget line. The funding line is shared with the CSP, Synthetic Aperture Radar, Ground Moving Target Indicator. and the Tactical SIGINT Payload.

MILCON

Appn		BA	PE
Army	2050	02	0202096A

4828 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Project	Name
069830	Military Construction, Army

4829 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Cost and Funding

Cost Summary

Total Acquisition Cost and Quantity

	BY2010 $M			BY2010 $M	TY $M		
Appropriation	SAR Baseline Prod Est	Current APB Production Objective/Threshold		Current Estimate	SAR Baseline Prod Est	Current APB Production Objective	Current Estimate
RDT&E	895.3	931.7	1024.9	925.7	896.3	945.3	936.1
Procurement	3364.7	2988.0	3286.8	2909.6	3572.0	3217.3	3103.6
Flyaway	--	--	--	2157.9	--	--	2297.7
Recurring	--	--	--	1903.5	--	--	2028.8
Non Recurring	--	--	--	254.4	--	--	268.9
Support	--	--	--	751.7	--	--	805.9
Other Support	--	--	--	484.1	--	--	523.9
Initial Spares	--	--	--	267.6	--	--	282.0
MILCON	992.0	578.5	636.4	597.7	1080.7	640.2	658.2
Acq O&M	0.0	0.0	--	0.0	0.0	0.0	0.0
Total	5252.0	4498.2	N/A	4433.0	5549.0	4802.8	4697.9

Confidence Level for Current APB Cost 50% -

The Independent Cost Estimate (ICE) to support the MQ-1C Gray Eagle program Milestone C decision, like all life cycle cost estimates previously performed by the Cost Assessment and Program Evaluation (CAPE) office, is built upon a product-oriented work breakdown structure, based on historical actual cost information to the maximum extent possible, and, most importantly, based on conservative assumptions that are consistent with actual demonstrated contractor and government performance for a series of acquisition programs in which the Department has been successful.

The confidence level for the Full Rate Production-aproved Acquisition Program Baseline (APB) is 50% and is based on the May 9, 2013, approved Army Cost Position and are in accordance with Army cost guidance, Army Regulations (AR) 11-18. It is difficult to calculate mathematically the precise confidence levels associated with life cycle cost estimates prepared for Major Defense Acquisition Programs (MDAPs). Based on the rigor in methods used in building estimates, the strong adherence to the collection and use of historical cost information, and the review of applied assumptions, we project that it is about equally likely that the estimate will prove too low or too high for execution of the program described.

4830 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Quantity	SAR Baseline Prod Est	Current APB Production	Current Estimate
RDT&E	2	2	2
Procurement	29	29	29
Total	31	31	31

The unit of measure for a MQ-1C Gray Eagle is balanced Platoons, each with four aircraft and associated support equipment and payloads to include: Electro-Optical/Infrared/Laser Range Finder/Laser Designator, communications relay, and up to four Hellfire Missiles. The Common Sensor Payload and STARlite Synthetic Aperture Radar Ground Moving Target Indicator are one per aircraft. Ground equipment per Platoon includes: two Universal Ground Control Stations, three Universal Ground Data Terminals, one Satellite Communication Ground Data Terminal, one Mobile Ground Control Station per Company, an Automated Take Off and Landing System which includes two Tactical Automatic Landing Systems and ground support equipment to include Ground-Based Sense and Avoid.

Although the Army’s fielding strategy has evolved, the Army will continue to use the 29 platoon metric to determine APUC and the 31 platoon metric to determine PAUC. A balanced platoon contains four aircraft and ground support equipment and is the historic metric used to determine APUC and PAUC.

4831 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Cost and Funding

Funding Summary

Appropriation and Quantity Summary
FY2015 President's Budget / December 2013 SAR (TY$ M)

Appropriation	Prior	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	To Complete	Total
RDT&E	878.7	10.9	46.5	0.0	0.0	0.0	0.0	0.0	936.1
Procurement	2330.2	466.3	199.0	49.3	52.2	6.5	0.1	0.0	3103.6
MILCON	437.2	36.0	124.0	22.0	39.0	0.0	0.0	0.0	658.2
Acq O&M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PB 2015 Total	3646.1	513.2	369.5	71.3	91.2	6.5	0.1	0.0	4697.9
PB 2014 Total	3777.3	652.4	266.2	35.0	43.8	113.6	0.6	0.0	4888.9
Delta	-131.2	-139.2	103.3	36.3	47.4	-107.1	-0.5	0.0	-191.0

Quantity	Undistributed	Prior	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019	To Complete	Total
Development	2	0	0	0	0	0	0	0	0	2
Production	0	23	4	2	0	0	0	0	0	29
PB 2015 Total	2	23	4	2	0	0	0	0	0	31
PB 2014 Total	2	25	3	1	0	0	0	0	0	31
Delta	0	-2	1	1	0	0	0	0	0	0

4832 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Cost and Funding

Annual Funding By Appropriation

Annual Funding TY$
2040 | RDT&E | Research, Development, Test, and Evaluation, Army

Fiscal Year	Quantity	End Item Recurring Flyaway TY $M	Non End Item Recurring Flyaway TY $M	Non Recurring Flyaway TY $M	Total Flyaway TY $M	Total Support TY $M	Total Program TY $M
2005	--	--	--	--	--	--	54.3
2006	--	--	--	--	--	--	90.6
2007	--	--	--	--	--	--	123.7
2008	--	--	--	--	--	--	103.4
2009	--	--	--	--	--	--	61.8
2010	--	--	--	--	--	--	135.1
2011	--	--	--	--	--	--	119.2
2012	--	--	--	--	--	--	121.9
2013	--	--	--	--	--	--	68.7
2014	--	--	--	--	--	--	10.9
2015	--	--	--	--	--	--	46.5
Subtotal	**2**	**--**	**--**	**--**	**--**	**--**	**936.1**

4833 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding BY$
2040 | RDT&E | Research, Development, Test, and Evaluation, Army

Fiscal Year	Quantity	End Item Recurring Flyaway BY 2010 $M	Non End Item Recurring Flyaway BY 2010 $M	Non Recurring Flyaway BY 2010 $M	Total Flyaway BY 2010 $M	Total Support BY 2010 $M	Total Program BY 2010 $M
2005	--	--	--	--	--	--	58.8
2006	--	--	--	--	--	--	95.5
2007	--	--	--	--	--	--	127.3
2008	--	--	--	--	--	--	104.4
2009	--	--	--	--	--	--	61.6
2010	--	--	--	--	--	--	132.7
2011	--	--	--	--	--	--	114.8
2012	--	--	--	--	--	--	115.5
2013	--	--	--	--	--	--	63.9
2014	--	--	--	--	--	--	9.9
2015	--	--	--	--	--	--	41.3
Subtotal	**2**	**--**	**--**	**--**	**--**	**--**	**925.7**

4834 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding TY$
2031 | Procurement | Aircraft Procurement, Army

Fiscal Year	Quantity	End Item Recurring Flyaway TY $M	Non End Item Recurring Flyaway TY $M	Non Recurring Flyaway TY $M	Total Flyaway TY $M	Total Support TY $M	Total Program TY $M
2010	6	247.3	67.7	73.0	388.0	100.1	488.1
2011	6	243.2	57.7	92.9	393.8	110.3	504.1
2012	6	305.2	85.6	25.5	416.3	196.0	612.3
2013	4	198.0	110.6	54.2	362.8	87.6	450.4
2014	4	278.3	84.4	19.9	382.6	83.7	466.3
2015	2	131.8	8.4	2.4	142.6	56.4	199.0
2016	--	--	3.4	0.5	3.9	45.4	49.3
2017	--	--	4.8	0.5	5.3	46.9	52.2
2018	--	--	4.5	--	4.5	2.0	6.5
2019	--	--	--	--	--	0.1	0.1
Subtotal	**28**	**1403.8**	**427.1**	**268.9**	**2099.8**	**728.5**	**2828.3**

4835 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding BY$
2031 | Procurement | Aircraft Procurement, Army

Fiscal Year	Quantity	End Item Recurring Flyaway BY 2010 $M	Non End Item Recurring Flyaway BY 2010 $M	Non Recurring Flyaway BY 2010 $M	Total Flyaway BY 2010 $M	Total Support BY 2010 $M	Total Program BY 2010 $M
2010	6	240.8	65.9	71.1	377.8	97.5	475.3
2011	6	232.5	55.2	88.8	376.5	105.5	482.0
2012	6	286.6	80.4	23.9	390.9	184.2	575.1
2013	4	182.0	101.6	49.8	333.4	80.5	413.9
2014	4	250.8	76.1	17.9	344.8	75.4	420.2
2015	2	116.5	7.4	2.1	126.0	49.9	175.9
2016	--	--	2.9	0.4	3.3	39.4	42.7
2017	--	--	4.1	0.4	4.5	39.9	44.4
2018	--	--	3.7	--	3.7	1.7	5.4
2019	--	--	--	--	--	0.1	0.1
Subtotal	**28**	**1309.2**	**397.3**	**254.4**	**1960.9**	**674.1**	**2635.0**

4836 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding TY$
2035 | Procurement | Other Procurement, Army

Fiscal Year	Quantity	End Item Recurring Flyaway TY $M	Non End Item Recurring Flyaway TY $M	Non Recurring Flyaway TY $M	Total Flyaway TY $M	Total Support TY $M	Total Program TY $M
2007	--	--	--	--	--	9.7	9.7
2008	--	--	31.4	--	31.4	24.3	55.7
2009	1	151.2	15.3	--	166.5	43.4	209.9
Subtotal	**1**	**151.2**	**46.7**	**--**	**197.9**	**77.4**	**275.3**

4837 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding BY$
2035 | Procurement | Other Procurement, Army

Fiscal Year	Quantity	End Item Recurring Flyaway BY 2010 $M	Non End Item Recurring Flyaway BY 2010 $M	Non Recurring Flyaway BY 2010 $M	Total Flyaway BY 2010 $M	Total Support BY 2010 $M	Total Program BY 2010 $M
2007	--	--	--	--	--	9.9	9.9
2008	--	--	31.6	--	31.6	24.5	56.1
2009	1	150.2	15.2	--	165.4	43.2	208.6
Subtotal	**1**	**150.2**	**46.8**	**--**	**197.0**	**77.6**	**274.6**

4838 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding TY$
2050 | MILCON | Military Construction, Army

Fiscal Year	Total Program TY $M
2011	102.0
2012	228.0
2013	107.2
2014	36.0
2015	124.0
2016	22.0
2017	39.0
Subtotal	**658.2**

4839 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Annual Funding BY$
2050 | MILCON | Military Construction, Army

Fiscal Year	Total Program BY 2010 $M
2011	96.5
2012	212.4
2013	98.1
2014	31.9
2015	107.6
2016	18.7
2017	32.5
Subtotal	**597.7**

4840 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Low Rate Initial Production

	Initial LRIP Decision	Current Total LRIP
Approval Date	3/29/2010	7/3/2012
Approved Quantity	2	6
Reference	Milestone C ADM	LRIP III ADM
Start Year	2010	2012
End Year	2011	2015

The Current Total LRIP Quantity is more than 10% of the total production quantity due to Milestone Decision Authority directed the LRIP quantities to facilitate the MQ-1C Gray Eagle capability entrance into theater as quickly as possible.

Initial LRIP Decision
The original LRIP quantity was two MQ-1C Gray Eagle systems which equates to six platoon sets (24 aircraft).

Current Total LRIP
The Current Total LRIP quantity is six MQ-1C Gray Eagle systems which equates to 18 platoon sets and includes LRIP I (24 aircraft and two attrition aircraft), LRIP II (24 aircraft and five attrition aircraft) and LRIP III (29 aircraft).

4841 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Foreign Military Sales

MQ-1C Gray Eagle has one inquiry for Pricing and Availability from the Government of Poland. There are no other inquiries or international activity at this time.

Nuclear Costs

None.

4842 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Unit Cost

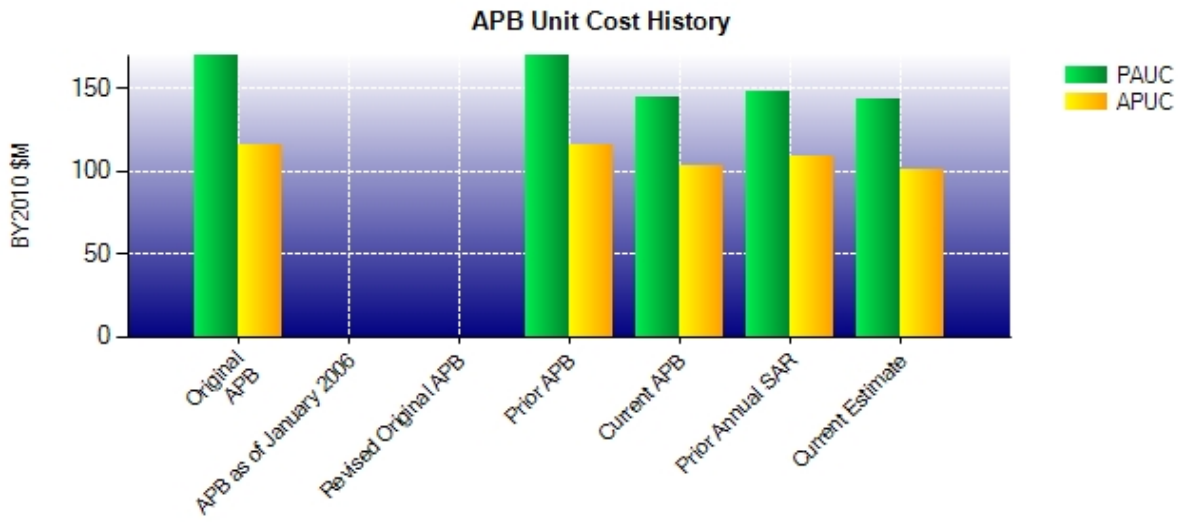
Unit Cost Report

	BY2010 $M	BY2010 $M	
Unit Cost	**Current UCR Baseline (SEP 2013 APB)**	**Current Estimate (DEC 2013 SAR)**	**BY % Change**
Program Acquisition Unit Cost (PAUC)			
Cost	4498.2	4433.0	
Quantity	31	31	
Unit Cost	145.103	143.000	-1.45
Average Procurement Unit Cost (APUC)			
Cost	2988.0	2909.6	
Quantity	29	29	
Unit Cost	103.034	100.331	-2.62

	BY2010 $M	BY2010 $M	
Unit Cost	**Original UCR Baseline (MAR 2011 APB)**	**Current Estimate (DEC 2013 SAR)**	**BY % Change**
Program Acquisition Unit Cost (PAUC)			
Cost	5252.0	4433.0	
Quantity	31	31	
Unit Cost	169.419	143.000	-15.59
Average Procurement Unit Cost (APUC)			
Cost	3364.7	2909.6	
Quantity	29	29	
Unit Cost	116.024	100.331	-13.53

4843 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Unit Cost History



		BY2010 $M		TY $M	
	Date	PAUC	APUC	PAUC	APUC
Original APB	MAR 2011	169.419	116.024	179.000	123.172
APB as of January 2006	N/A	N/A	N/A	N/A	N/A
Revised Original APB	N/A	N/A	N/A	N/A	N/A
Prior APB	FEB 2012	169.419	116.024	179.000	123.172
Current APB	SEP 2013	145.103	103.034	154.929	110.941
Prior Annual SAR	DEC 2012	147.829	108.852	157.706	117.314
Current Estimate	DEC 2013	143.000	100.331	151.545	107.021

SAR Unit Cost History

Initial SAR Baseline to Current SAR Baseline (TY $M)

Initial PAUC Dev Est	Changes								PAUC Prod Est
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
401.600	0.094	-242.537	-7.813	13.968	13.152	0.000	0.536	-222.600	179.000

Current SAR Baseline to Current Estimate (TY $M)

PAUC Prod Est	Changes								PAUC Current Est
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
179.000	1.768	0.000	0.139	0.810	-25.072	0.000	-5.100	-27.455	151.545

4844 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Initial SAR Baseline to Current SAR Baseline (TY $M)

Initial APUC Dev Est	Changes								APUC Prod Est
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
285.100	0.141	-177.121	0.000	14.931	-0.452	0.000	0.573	-161.928	123.172

Current SAR Baseline to Current Estimate (TY $M)

APUC Prod Est	Changes								APUC Current Est
	Econ	Qty	Sch	Eng	Est	Oth	Spt	Total	
123.172	1.341	0.000	0.148	-0.472	-11.717	0.000	-5.452	-16.152	107.021

SAR Baseline History

Item/Event	SAR Planning Estimate (PE)	SAR Development Estimate (DE)	SAR Production Estimate (PdE)	Current Estimate
Milestone A	N/A	N/A	N/A	N/A
Milestone B	N/A	APR 2005	APR 2005	APR 2005
Milestone C	N/A	FEB 2010	MAR 2011	MAR 2011
IOC	N/A	FEB 2012	JUN 2012	DEC 2012
Total Cost (TY $M)	N/A	5322.6	5549.0	4697.9
Total Quantity	N/A	13	31	31
Prog. Acq. Unit Cost (PAUC)	N/A	409.431	179.000	151.545

4845 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Cost Variance

Summary Then Year $M				
	RDT&E	Proc	MILCON	Total
SAR Baseline (Prod Est)	896.3	3572.0	1080.7	5549.0
Previous Changes				
Economic	+7.3	+61.3	+14.9	+83.5
Quantity	--	--	--	--
Schedule	--	+0.7	--	+0.7
Engineering	+38.8	-13.7	--	+25.1
Estimating	+34.8	-180.4	-586.0	-731.6
Other	--	--	--	--
Support	--	-37.8	--	-37.8
Subtotal	+80.9	-169.9	-571.1	-660.1
Current Changes				
Economic	-2.1	-22.4	-4.2	-28.7
Quantity	--	--	--	--
Schedule	--	+3.6	--	+3.6
Engineering	--	--	--	--
Estimating	-39.0	-159.4	+152.8	-45.6
Other	--	--	--	--
Support	--	-120.3	--	-120.3
Subtotal	-41.1	-298.5	+148.6	-191.0
Total Changes	+39.8	-468.4	-422.5	-851.1
CE - Cost Variance	936.1	3103.6	658.2	4697.9
CE - Cost & Funding	936.1	3103.6	658.2	4697.9

4846 DISTRIBUTION A: NOT FOR MISUSE IN SUPPORT OF IDIOTIC THEORIES| | VIOLATORS GO STRAIGHT TO GITMO FOR BALL ZAPPING

Summary Base Year 2010 $M				
	RDT&E	Proc	MILCON	Total
SAR Baseline (Prod Est)	895.3	3364.7	992.0	5252.0
Previous Changes				
Economic	--	--	--	--
Quantity	--	--	--	--
Schedule	--	--	--	--
Engineering	+32.1	-17.5	--	+14.6
Estimating	+30.9	-146.4	-524.3	-639.8
Other	--	--	--	--
Support	--	-44.1	--	-44.1
Subtotal	+63.0	-208.0	-524.3	-669.3
Current Changes				
Economic	--	--	--	--
Quantity	--	--	--	--
Schedule	--	--	--	--
Engineering	--	--	--	--
Estimating	-32.6	-133.7	+130.0	-36.3
Other	--	--	--	--
Support	--	-113.4	--	-113.4
Subtotal	-32.6	-247.1	+130.0	-149.7
Total Changes	+30.4	-455.1	-394.3	-819.0
CE - Cost Variance	925.7	2909.6	597.7	4433.0
CE - Cost & Funding	925.7	2909.6	597.7	4433.0

Previous Estimate: December 2012

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RDT&E	$M	
Current Change Explanations	**Base Year**	**Then Year**
Revised escalation indices. (Economic)	N/A	-2.1
Adjustment for current and prior escalation. (Estimating)	+1.7	+1.8
Army realigned resources to fully fund the program to the approved schedule. (Estimating)	+25.8	+29.0
Revised estimate due to sequestration reduction in FY 2013. (Estimating)	-5.5	-5.9
Revised estimate to align with FY 2015 PB which resulted in reduced RDT&E funding for future planned improvements. (Estimating)	-54.6	-63.9
RDT&E Subtotal	-32.6	-41.1

Procurement	$M	
Current Change Explanations	**Base Year**	**Then Year**
Revised escalation indices. (Economic)	N/A	-22.4
Adjustment for current and prior escalation. (Estimating)	+11.6	+13.0
Revised procurement profile due to FY 2013 Congressional reduction which delays procurement of four aircraft to FY 2015. (Schedule)	0.0	+3.6
Revised estimate for Common Systems Payload based on budget changes. (Estimating)	-13.0	-14.2
Revised estimate due to Congressional reduction in FY 2014 which defers Ka (military) Satellite Communications upgrade. (Estimating)	-51.2	-56.8
Revised estimate to align with FY 2015 PB which resulted in reduced Procurement funding for future planned modifications. (Estimating)	-87.2	-104.6
Revised estimate for Ground Equipment. (Estimating)	+6.1	+3.2
Adjustment for current and prior escalation. (Support)	+5.5	+5.6
Reduction in estimate for Initial Spares due to revised fielding plan. (Support)	-58.8	-65.2
Decrease in Other Support for Test and Evaluation, Software, Training/Devices and Modifications. (Support)	-60.1	-60.7
Procurement Subtotal	-247.1	-298.5

MILCON	$M	
Current Change Explanations	**Base Year**	**Then Year**
Revised escalation indices. (Economic)	N/A	-4.2
Adjustment for current and prior escalation. (Estimating)	+3.9	+4.2
Revised estimate that supports changes in Army baseline strategy for stationing and fielding the MQ-1C Gray Eagle. (Estimating)	+126.1	+148.6
MILCON Subtotal	+130.0	+148.6

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Contracts

Appropriation: Acq O&M	
Contract Name	**Gray Eagle PBL**
Contractor	General Atomics - Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-12-C-0075, CPFF/CPIF
Award Date	May 08, 2012
Definitization Date	September 27, 2012

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
221.4	N/A	N/A	498.3	N/A	N/A	463.3	437.6

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to exercising the FY 2013 option.

Variance	Cost Variance	Schedule Variance
Cumulative Variances To Date (1/31/2014)	+6.3	-7.9
Previous Cumulative Variances	+6.3	-7.6
Net Change	+0.0	-0.3

Cost and Schedule Variance Explanations

The unfavorable net change in the schedule variance is due to Ground Control Equipment Spares that were impacted by technical issues associated with the Ground Data Terminal. An obsolete vendor component drove additional software analysis and impacted assembly.

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Appropriation: Procurement	
Contract Name	**LRIP 3**
Contractor	General Atomics - Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-12-C-0057, FPIF
Award Date	July 06, 2012
Definitization Date	July 06, 2012

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
411.0	424.6	29	438.2	452.7	29	436.8	437.0

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to contract modifications P00001 through P00011 adding a platoon set of ground equipment and updated spares list.

Variance	Cost Variance	Schedule Variance
Cumulative Variances To Date (1/31/2014)	-1.8	-46.8
Previous Cumulative Variances	-0.9	+1.0
Net Change	-0.9	-47.8

Cost and Schedule Variance Explanations

The unfavorable net change in the cost variance is due to Work In Process on lower level assemblies. Performance on lower level assemblies will be claimed when production reaches Earned Value methodology thresholds.

The unfavorable net change in the schedule variance is due to late receipt of Universal Ground Data Terminal (UGDT), Initial Spares, and Tactical Control Data Link (TCDL). UGDT delayed by late receipt of hardware. Initial Spares delayed by lack of agreement on spares kits list with AAI Corporation and late deliveries from L-3 Communications. TCDL impacted by redesign of two Circuit Card Assemblies. The current schedule variance has no impact to the fielding schedule.

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Appropriation: Procurement	
Contract Name	**LRIP II**
Contractor	General Atomics - Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-11-C-0099, FPIF
Award Date	April 08, 2011
Definitization Date	December 06, 2011

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
354.0	N/A	26	310.2	321.8	29	329.0	328.4

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to the Initial Contract Price Target being based on a Not To Exceed price.

Variance	Cost Variance	Schedule Variance
Cumulative Variances To Date (1/31/2014)	-7.0	-10.9
Previous Cumulative Variances	-1.8	-6.8
Net Change	-5.2	-4.1

Cost and Schedule Variance Explanations

The unfavorable net change in the cost variance is due to Integration, Assembly, Test and Checkout hours required during Phase 2 and Phase 3 flight line testing; including troubleshooting Government Furnished Equipment radios, incorporation of engineering changes, payloads, and rework tasks to support/correct critical engine related issues, and Ground Support Equipment line items that are in scope but were unplanned in the baseline.

The unfavorable net change in the schedule variance is due to delays for rework on Universal Ground Data Terminal Generation 3 modem Circuit Card Assemblies and delays related to software version 4.3.1.

Contract Comments

This contract is more than 90% complete; therefore, this is the final report for this contract.

Contract quantity 25 of 29 aircraft were delivered.

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Appropriation: Procurement	
Contract Name	**LRIP-1**
Contractor	General Atomics - Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-10-C-0068, FPIF
Award Date	May 14, 2010
Definitization Date	February 28, 2011

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
242.5	287.9	26	292.6	317.3	26	289.1	286.3

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to contract modifications through P00074.

Variance	Cost Variance	Schedule Variance
Cumulative Variances To Date (1/31/2014)	+10.4	-0.7
Previous Cumulative Variances	+1.4	-1.3
Net Change	+9.0	+0.6

Cost and Schedule Variance Explanations

The favorable net change in the cost variance is due to overestimated support on Program Management and System Engineering.

The favorable net change in the schedule variance is due to completion of Ground Support Equipment, specifically Half Rack and Breakout Boxes that were originally delayed due to engineering changes.

Contract Comments

This contract is more than 90% complete; therefore, this is the final report for this contract.

Contract quantity 25 of 26 were delivered.

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Appropriation: Procurement

Contract Name	**Full Rate Production (FRP)**
Contractor	General Atomics Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-13-C-0109, FFP
Award Date	September 13, 2013
Definitization Date	September 13, 2013

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
199.7	N/A	15	240.0	N/A	19	240.0	240.0

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to exercising an option established under initial contract award.

Cost and Schedule Variance Explanations

Cost and Schedule Variance reporting is not required on this FFP contract.

Contract Comments

This is the first time this contract is being reported.

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Appropriation: RDT&E

Contract Name	**Engineering Services**
Contractor	General Atomics - Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-09-C-0136, CPFF
Award Date	September 30, 2009
Definitization Date	September 30, 2009

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
77.2	N/A	N/A	160.7	N/A	N/A	152.1	153.0

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to Contract Modifications through Mod P00099.

Variance	Cost Variance	Schedule Variance
Cumulative Variances To Date (1/31/2014)	+7.8	-1.8
Previous Cumulative Variances	+10.6	-0.9
Net Change	-2.8	-0.9

Cost and Schedule Variance Explanations

The unfavorable net change in the cost variance is due to efforts on a Sub-Engineering Services Memorandum (SESM) needing additional Electromagnetic Interference (EMI) testing and the purchase of new equipment to resolve compatibility issues.

The unfavorable net change in the schedule variance is due to efforts on a SESM needing additional EMI testing, delays in the alternator delivery, and design rework on the High Power Distribution Module.

Contract Comments

This contract is more than 90% complete; therefore, this is the final report for this contract.

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Appropriation: RDT&E	
Contract Name	**Production Readiness Test Asset (PRTA)**
Contractor	General Atomics - Aeronautical Systems, Inc.
Contractor Location	14200 Kirkham Way Poway, CA 92064
Contract Number, Type	W58RGZ-09-C-0151, CPIF
Award Date	April 28, 2009
Definitization Date	April 20, 2010

Initial Contract Price ($M)			Current Contract Price ($M)			Estimated Price at Completion ($M)	
Target	Ceiling	Qty	Target	Ceiling	Qty	Contractor	Program Manager
48.0	N/A	N/A	83.6	N/A	N/A	72.6	74.6

Target Price Change Explanation

The difference between the Initial Contract Price Target and the Current Contract Price Target is due to contract definitization at $40.60M with options exercised during Calendar Years 2010 - 2012, and Contract Modifications through P00063.

Variance	Cost Variance	Schedule Variance
Cumulative Variances To Date (1/31/2014)	+12.4	-1.1
Previous Cumulative Variances	+8.0	-2.2
Net Change	+4.4	+1.1

Cost and Schedule Variance Explanations

The favorable net change in the cost variance is due to overestimated support on Datalink Spares, Program Management, and System Engineering.

The favorable net change in the schedule variance is due to completion of Datalink Spares kits originally delayed by late material from subcontractor.

Contract Comments

This contract is more than 90% complete; therefore, this is the final report for this contract.

Contract W58RGZ-09-C-0151, Production Readiness Test Asset was included in the 2012 SAR and is listed in the 2013 SAR as a reference. This contract is not currently in the top six largest contracts. The contract is over 90 percent complete so this is the final report for this contract.

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Deliveries and Expenditures

Delivered to Date	Plan to Date	Actual to Date	Total Quantity	Percent Delivered
Development	2	2	2	100.00%
Production	10	10	29	34.48%
Total Program Quantity Delivered	12	12	31	38.71%

Expended and Appropriated (TY $M)			
Total Acquisition Cost	4697.9	Years Appropriated	10
Expended to Date	2210.6	Percent Years Appropriated	66.67%
Percent Expended	47.06%	Appropriated to Date	4159.3
Total Funding Years	15	Percent Appropriated	88.54%

The above data is current as of 1/31/2014.

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Operating and Support Cost

MQ-1C Gray Eagle

Assumptions and Ground Rules

Cost Estimate Reference:
The O&S Current Estimate is based on the June 14, 2013 Defense Acquisition Board (DAB) approved Full Rate Production (FRP) Army Cost Position (ACP). Operation and Maintenance cost was based on actual Unmanned Aircraft System (UAS) consumption data, analogy to Predator, O&S Management Information System (OSMIS) Blackhawk data. The cost is applied as steady state across the MQ-1C Gray Eagle program in accordance with the program schedule which includes a total approved procurement objective of 152 aircraft.

The unit of measure for a MQ-1C Gray Eagle is balanced Platoons, each with four aircraft and associated support equipment and payloads to include: Electro-Optical/Infrared/Laser Designator, communications relay, and up to four Hellfire Missiles. The Common Sensor Payload and STARlite Synthetic Aperture Radar Ground Moving Target Indicator are one per aircraft. Ground equipment per Platoon includes: two Universal Ground Control Stations, three Universal Ground Data Terminals, one Satellite Communication Ground Data Terminal, one Mobile Ground Control Station per Company, an Automated Take Off and Landing System which includes two Tactical Automatic Landing Systems and ground support equipment to include Ground-Based Sense and Avoid. A MQ-1C Gray Eagle Company is configured into three equal platoons and includes nine MQ-1C Gray Eagle aircraft for conventional companies (non-deployed) and when deployed, the Army will bring the company to full MQ-1C Gray Eagle System strength (12 aircraft and associated ground support equipment).

Sustainment Strategy:
The O&S cost is based on 15 MQ-1C Gray Eagle companies with a 20-year service plus one training base with a 27-year service life.

A Performance Based Logistics (PBL) contract was awarded May 8, 2012. The contract includes one base year plus two, one-year options. Soldiers will operate systems and perform 85% of the basic field maintenance. The Field Service Representative (FSR) will support remaining 15% of basic field maintenance through PBL efforts. Some of the Depot Level Reparables will be accomplished by organic depots through a Public Private Partnership (PPP) arrangement. The PPP with organic depot efforts will be determined through Cost Benefit Analysis and application of Title 10 USC 2426 and 50/50 rule.

Antecedent Information:
There is no antecedent to this program.

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Unitized O&S Costs BY2010 $M		
Cost Element	**MQ-1C Gray Eagle Average annual cost per company**	**No Antecedent (Antecedent) N/A**
Unit-Level Manpower	10.300	0.000
Unit Operations	1.300	0.000
Maintenance	3.460	0.000
Sustaining Support	3.750	0.000
Continuing System Improvements	0.360	0.000
Indirect Support	0.870	0.000
Other	2.460	0.000
Total	22.500	--

Unitized Cost Comments:
O&S unitized cost is based on 15 companies with a 20-year service life plus one training base with a 27-year service life. (15 companies x 20 year service life + one training base x 27 year service life = 327 Operational Systems).

The unitized average annual cost per system (Platoon) is $22.5M (BY$ 2010), ($7357.3M / 327 Operational Systems). The $2.460M Other cost is Operations and Maintenance related, Military Pay and Allowances (Medical & Morale, Welfare, Recreation).

	Total O&S Cost $M			
	Current Production APB Objective/Threshold		**Current Estimate**	
	MQ-1C Gray Eagle		**MQ-1C Gray Eagle**	**No Antecedent (Antecedent)**
Base Year	7357.3	8093.0	7357.3	N/A
Then Year	9950.8	N/A	9950.8	N/A

Total O&S Costs Comments:
HISTORICAL NOTES:

1) Prior to the FRP Decision, the average annual cost per MQ-1C Gray Eagle system was $31.84M.

2) Ownership Cost Key System Attribute was not required for post Milestone B documents per the March 10, 2007 Life Cycle Sustainment Outcome Metrics memorandum and the December 1, 2007 Guide to Sustainment Key Performance Parameter memorandum from the Deputy Under Secretary of Defense for Material Readiness and Maintenance Policy. After that time, the program was reclassified as an Acquisition Category ID Major Defense Acquisition Program.

O&S Cost Variance		
Category	**Base Year 2010 $M**	**Change Explanation**
Prior SAR Total O&S Estimate December 2012	11,904.0	
		Based on actual UAS consumption data, the June 2013 DAB

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Cost Estimating Methodology	-4546.7	approved ACP and analogy to Predator and OSMIS Blackhawk data.
Cost Data Update	0.0	
Labor Rate	0.0	
Energy Rate	0.0	
Technical Input	0.0	
Programmatic/Planning Factors	0.0	
Other	0.0	
Total Changes	-4546.7	
Current Estimate	7357.3	

Disposal Costs:

Lifecycle demilitarization/disposal costs are not included in the above estimate.

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Gray Eagle Takes Off With New Capabilities

By Ms Kari Hawkins (Redstone) September 21, 2011



DUGWAY PROVING GROUND, Utah -- For Capt. Travis Blaschke, the mission has shifted.

Deployed three times -- as a Black Hawk helicopter pilot in both Afghanistan and Iraq, and as the commander of the first Quick Reaction Capability 1 team with the Gray Eagle in Iraq -- Blaschke knows how well unmanned aircraft systems augment the Army's manned aircraft on the battlefield.

And now he is putting his battle experience to work as the assistant product manager for Gray Eagle, supporting improvements and added capabilities as this medium-altitude, long-endurance unmanned aircraft speeds toward achieving top performance.

"This is a different mission. One is operational and 100 percent focused on completing the tactical mission," Blaschke said. "I've been in the military eight years and during seven of those years I deployed for 30 months. Now my mission is focused on supporting those who are going to fight the war.

"We are evolving our product to better support the war fighter. Gray Eagle is continuing to be deployed. Reliability continues to get better. The system's development is now closer to 95 percent and will get to 100 percent in the near future."

Blaschke and Gray Eagle were at Dugway Proving Ground the week of Sept. 12 to participate in the Manned Unmanned Systems Integration Capability exercise demonstrating the benefits of manned-unmanned teaming. Those benefits include increased situational awareness for both ground and air crews, better reconnaissance of targets and situations, and improved combat information provided in real time.

During 2009-10, Blaschke commanded a quick reaction capability team in Iraq of 16 Soldiers and 24 civilians that flew 4,000 accident-free flight hours to conduct long-dwell, wide-area reconnaissance, surveillance, target acquisition, communications relay and attack missions.

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"Since we were the first ones to ever field, train and fly this system in wartime we did really well," he said. "Soldiers did all the flying. The team did an extremely good job in supporting the war fighter."

During the first Gray Eagle deployment, Iraqi residents were going to the polls to vote. Gray Eagle was used to provide "a lot of persistence in viewing polling sites and in watching trucks of ballots moving from polling sites," Blaschke said. "We also supported tactically by providing convoy security. We were able to provide full motion video of locations, vehicles and routes. We were used the vast majority of the time for reconnaissance, and for cordon and search of high volume targets and individuals."

As the unit's commander, Blaschke was involved in planning the Gray Eagle's missions based on requests from the division, brigade and company levels.

"We had the opportunity to state how we would support the mission," he said. "We would develop how we were going to execute in coordination with the unit we were supporting. We would ask: How can we support you the best?'"

Gray Eagle is one of several unmanned aircraft systems that are making a difference on the battlefield.

"The unmanned aircraft system is revolutionizing the way we fight wars today," Tim Owings, deputy project manager for Unmanned Aircraft Systems, said. "Vietnam and Korea were known as helicopter wars. Wars in this decade are unmanned aircraft wars. These systems are adding tremendous value on the battlefield every day and they are saving Soldier lives."

Gray Eagle can fly both line of sight involving distances of 200 to 300 kilometers and beyond the line of sight with the help of satellites that can extend its visual capabilities thousands of kilometers from the ground station. It uses electro-optic and infrared systems for target detection and acquisition.

"The system is capable of day and night vision, and it is capable of providing tremendously high fidelity images," Owings explained. "It has a synthetic aperture radar to find moving targets."

Besides running its own missions, the exercise at Dugway Proving Ground demonstrated Gray Eagle's interoperability with the Apache helicopter. The addition of new sensors under each wing to go with the sensor located underneath its fuselage gives Gray Eagle a triple-effect capability, known as triclops. With the currently fielded Block 2 Apache, which was demonstrated at Dugway, these sensors provide added opportunities to view the battlefield. But with the Block 3 Apache, which will be fielded later this year, teaming with a triclops Gray Eagle means on the battlefield that one sensor can be controlled by a crew member aboard an Apache helicopter, a second can transmit video data to a terminal on the ground and the third can be controlled by the Gray Eagle's ground operator.

"The Apache helicopter flies very low, very fast, and has a frontal view of the target," Owings said. "With Gray Eagle, the Apache can also look down. Putting these two systems together is like putting hunting dogs in front of the hunter."

Or, in another battlefield scenario, different sensors can focus on different targets, allowing, for example, a Gray Eagle to track multiple people and vehicles as they scatter after placing an improvised explosive device.

The new sensors give Gray Eagle a "very unique and very powerful capability," Owings said. "This capability is now being tested and will be in theater later this year. Having three sensors on a single aircraft makes it highly capable. The system also can put a laser beacon on a target and then let its missiles fly to that target, which increases its lethality aspect."

Gray Eagle requires two operators. One is the air vehicle operator who flies the vehicle from a ground station. The other is the payload operator who

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controls the camera and any payloads -- such as four Hellfire missiles -- carried by Gray Eagle.

"We take 18- and 19-year-olds from high school to flight school, and give them the capability to fly this highly automated system," Owings said.

One Gray Eagle unit is still deployed in Iraq. Another one -- Quick Reaction Capability 2 -- is in Afghanistan. A third unit -- QRC 3 -- is getting ready to deploy out of Fort Hood, Texas. It will be the first full size company to deploy with Gray Eagle.

Gray Eagle's effectiveness continues to increase, with improvements still being made in a system that was only 85 percent ready for deployment when Blaschke led the first quick reaction team into combat.

"We were deployed earlier than the original timeline," he said. "So there were growing pains and learning that needed to occur along with more development of the aircraft and the system.

"We all went into it knowing there would be hiccups along the way, and some additional challenges we would have to go through. But it was more important to give the capability to the war fighter at 85 percent solution than to wait through two more years of development to a 100 percent solution. It was a time when we were transitioning from the surge, and war fighters were asking desperately for more unmanned aircraft vehicles and reconnaissance-type platforms. We had the call to quickly deploy."

Blaschke's work with Gray Eagle in theater further showed him the complimentary roles that unmanned systems and manned systems have on the battlefield.

"There's really no replacement for having two pilots with four eyes and four ears. There's no substitute for Soldiers in the cockpit working in support of Soldiers on the ground," he said. "But unmanned systems can augment the work of pilots. They can provide additional sensor capabilities for better situational awareness and longer endurance times."

While an unmanned aircraft vehicle can remain in the air on a mission for 24-plus hours, a helicopter working that length of time would require three refuels that, in turn, require three rotations of helicopters to continue around-the-clock surveillance of a target or situation.

"In a team of manned and unmanned systems, the manned system can continue surveillance while a helicopter goes to refuel or as the helicopters are changed out," Blaschke said. "The UAV can continue to keep the positive identification throughout the mission, and that is really important in an urban situation where you can easily lose a moving vehicle or people if they are not kept under constant surveillance."

With Gray Eagle, as with all unmanned aircraft systems, there still remains a Soldier in the loop who manages the system and runs safety checks. But once hooked on a target, there is a lot of autonomous control of an unmanned system.

During the MUSIC demonstration at Dugway, Gray Eagle interface with the Apache helicopter showed improvements in a manned-unmanned teaming connection that furthers Gray Eagle's "game changing capability for the United States Army," Owings said. "Persistence in the key to what we're trying to achieve."

Apache pilot Maj. Ryan Atkins of the 21st Air Cavalry Brigade at Fort Hood agreed that manned-unmanned teaming is the future of air combat.

"This is another way to provide better situational awareness for the attack team and the team on the ground," said the Iraq and Afghanistan combat veteran. "Unmanned aircraft provide a different angle, a different view of the

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threat, and better protection for ground forces."

As a veteran aviator, Blaschke is looking forward to the additional capabilities that will be added to Gray Eagle during his time on the system's development team.

"As the first commander, I was on the receiving end of all the good of this system. We received the property, training, support and sustainment. Now, I am on the giving end," he said.

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TC 3-04.62

Small Unmanned Aircraft System Aircrew Training Program

August 2013

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Training Circular
No. 3-04.62 (1-611)

Headquarters
Department of the Army
Washington, DC, 19 August 2013

Small Unmanned Aircraft System Aircrew Training Program

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Preface

Training circular (TC) 3-04.62 standardizes aircrew training programs (ATPs) and flight evaluation procedures. This aircrew training manual (ATM) provides specific guidelines for executing small unmanned aircraft system (SUAS) aircrew training. It is based on training principles outlined in Army Doctrine Publication (ADP) & Army Doctrine and Reference Publications (ADRP) 7-0 (Training Units and Developing Leaders) at the Army Training Network at: https://atn.army.mil/index.aspx under the "Unit Training" tab. This ATM establishes crewmember qualification, refresher, mission, and continuation training and evaluation requirements. This manual applies to all SUAS crewmembers and their commanders in the Active Army, the Army National Guard Bureau (NGB), the United States (U.S) Army National Guard (ARNG), the U.S Army Reserve (USAR), and Department of the Army Civilians (DACs) unless otherwise stated, and any unmanned aircraft system (UAS) crewmembers and their commanders not covered by another ATM.

This manual is not a stand-alone document; all the requirements contained in Army regulations (ARs) 600-105 (Aviation Service of Rated Army Officers), and AR 600-106 (Flying Status for Non-rated Army Aviation Personnel), and TC 3.04.62 (Small Unmanned Aircraft System Aircrew Training Program) must be met.

The operator's manual is the governing authority for operation of the aircraft. If differences exist between the maneuver descriptions in the operators' manual and this manual, then this manual is the governing authority for training and flight evaluation purposes only. Implementation of this manual conforms to AR 95-1 (Flight Regulations) and TC 3-04.11. If a conflict exists between this manual, and TC 3-04.11, the ATP commander determines the method of accomplishment based upon the requirement and the unit's mission as to which manual takes precedence.

This manual in conjunction with ARs will help SUAS commanders at all levels; develop a comprehensive ATP. By using this ATM, commanders ensure that individual crewmembers and crew proficiency commensurate with units' mission and that unmanned aircraft crewmembers (UACs) routinely employ standard techniques and procedures.

UACs will use this manual as a "how to" source for performing crewmember duties. It provides performance standards and evaluation guidelines so that crewmembers know the level of performance expected. Each task provides a description of how the task should be perform to meet the standard. ATP commanders of active Army, National Guard, and Army Reserve units operating the SUAS will use this ATM to develop individual commander's task lists for assigned operators. ATP commanders will assign contractor/DAC operators to assist in developing individual commander's task lists tailored to the current contract position using this ATM, AR 95-20, AR 95-23, and/or local command directives.

Commanding officers and master trainers (MTs) will use this manual, AR 95-23, and AR 95-20 as the primary tools to assist the commander in developing and implementing the ATP.

The proponent of this publication is the Directorate of Training and Doctrine (DOTD), Flight Training Branch (FTB), United States Army Aviation Center of Excellence (USAACE). Submit comments and recommendations utilizing the electronic (XFDL) version of Department of the Army (DA) Form 2028 (Recommended Changes to Publications and Blank Forms) found on the Army Publishing Directorate (APD) website, to: Director, Directorate of Training and Doctrine (DOTD), ATTN: Flight Training Branch (FTB) (ATZQ-TDT-F), Building 4507, Andrews Avenue, Fort Rucker, Alabama (AL) 36362-5263, at email: usarmy.rucker.avncoe.mbx.ATZQ-TDT-F@mail.mil or online at: https://www.us.army.mil/suite/page/655026.

This publication implements portions of standardization agreement (STANAG) 3114 (Edition Eight).

This publication has been reviewed for operations security considerations.

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Chapter 1
Introduction

1-1. The training objective of any combat unit is for the unit to be able to conduct combined arms training (CAT). The SUAS aircrew training program (ATP) focuses on individual and crew training. Once the unit establishes individual and crew training programs, it must integrate them into an effective collective training program. TC 3-04.62 links individual and unit collective tasks. The design and management of an effective training program requires the commander to analyze each of these elements. The mission essential task list (METL) identifies collective training and defines the unit as a member of the combined arms team. To ensure the combat proficiency of Army SUAS operators in the combined arms effort, individual proficiency in tasks required to operate an SUAS is essential.

RESPONSIBILITIES

COMMANDER

1-2. According to ADP 7-0, the commander is the primary training manager and trainer for the unit and is responsible for safety programs, standardization programs, and the ATP. The commander bases training on the unit's wartime mission, maintains standards, and evaluates proficiency. The commander also provides the required resources and develops and executes training plans that result in proficient individuals, leaders, and units. The commander has subordinate leaders (officers and noncommissioned officers) that help him or her plan and prepare SUAS training.

MASTER TRAINER

1-3. The SUAS MT is the commander's technical advisor. The MT helps the commander develop, implement, and manage the ATP. The MT designated to conduct initial qualification training will conduct this training in accordance with (IAW) a TRADOC-approved SUAS exportable training package.

1-4. To perform MT duties, the MT will be current and mission qualified (MQ) in the SUAS in which the MT will be performing his or her duties. The MT will conduct unit qualification (mission level [ML] progression), refresher, transition differences training IAW a TRADOC-approved SUAS exportable differences training package and continuation training only for personnel who have completed an approved SUAS initial qualification course. Upon completion of the TRADOC-approved MT course or Directorate of Evaluation and Standardization equivalency, the first field grade commander with organic SUAS assets has the authority to appoint MTs.

1-5. Those MTs selected to conduct initial qualification training IAW an USAACE-approved program of instruction, and appendix will be designated by the first colonel in the chain of command. Initial qualification training will be managed at brigade level or higher by a designated MT that is a qualified graduate of the MT course, current and MQ. This provision is effective when the unit qualification training program" is approved and implemented by the proponent of this manual.

AIRCRAFT OPERATOR

1-6. These individuals perform duties that are essential to the operation of the SUAS.

Note. Aircraft operators (AOs) will perform duties as aircraft/mission operators.

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Chapter 2

Aircrew Training Program

This chapter describes requirements for unit qualification (ML progression), refresher and continuation training. The SUAS ATP standardizes UAC training and evaluations to ensure combat readiness. Crewmember qualification requirements will be IAW AR 95-23 and this ATM.

Note. This ATM uses many terms with which SUAS operators may not be familiar. Understanding of these terms is necessary in the use of this publication; therefore, this chapter explains these terms as appropriate.

OVERVIEW

2-1. Goal and applicability. The goal of the ATP is to produce mission-ready SUAS operators. The ATP outlined in this ATM is mandatory for all crewmembers that perform duties controlling the flight of an SUAS or the operation of its mission equipment, as well as preparation, launch, and recovery tasks essential to operate the SUAS. The ATP includes requirements for tasks (see appendix A), SUAS simulator, ML progression, and the Semi-Annual Proficiency and Readiness Test (S-APART). UAC assigned or attached to another service/United States Special Operations Command (USSOCOM) will meet the training program requirements of that service. DA civilian/contractor UAC will be trained and evaluated as specified in writing by the commander as necessary to meet the requirements of their military support job description.

Note. The unit commander may excuse a UAC scheduled for retirement or separation from active duty from all ATP requirements. The UAC may be excused beginning no earlier than 6 months prior to their scheduled retirement or separation date. However, UACs who are excused are prohibited from performing further UAC flight duties.

2-2. Individual/crew qualification. Operators arrive at the unit with various levels of experience. They are recent graduates of a SUAS qualification course or are proven operators with various SUAS backgrounds. These aircrew members progress from mission preparation IAW paragraphs 2-20 and 2-21 to MQ based on a commander's evaluation/proficiency flight evaluation (PFE) by demonstrating proficiency in tasks required (see appendix) and those tasks selected by the commander based on the unit's METL. If required, prior to designation as MQ, training must be conducted and assessed by the appropriate SUAS MT. This process is explained in detail in this TC. This is a prescriptive process mandated by AR 95-23 and must be strictly followed to ensure standardization across our force.

2-3. Mission qualified. MQ operators are those who have completed ML progression training and demonstrated proficiency to be a member of a battle-rostered crew. MQ operators train as crews to sustain and continually improve task proficiency, proficiency in the conduct of the unit's unique METL requirements, and refine the skills necessary to perform as part of the unit.

2-4. Simulators. Simulation is very useful in the conduct of training. Simulators are excellent resources in training emergency procedures, maneuvers that are infrequently conducted with the unmanned aircraft (UA), and as a rehearsal tool for complex portions of operations. They can also be used to correct negative trends found through analysis of accidents, and to practice those skills in a low risk environment. As the fidelity of our simulators improves, environmental training can be very beneficial to our crews.

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STANDARDIZATION PROGRAM

2-5. Proficiency versus currency. The fielding of modern aircraft such as the RQ-11B, while exponentially increasing the combat capabilities of SUAS forces, creates diverse operational and training challenges. These increased capabilities require individual and crew proficiencies in very complex mission equipment packages, sometimes compounded by harsh flight environments. An ATP that focuses on operator currency rather than proficiency will no longer satisfy SUAS readiness requirements and will be a detriment to training and safety.

2-6. The objectives of a standardization program are the improvement and sustainment of proficiency and readiness among Soldiers and units throughout the Army. Standardization is accomplished through the universal application of approved practices, procedures, and standards.

2-7. Standardization roles. The commander with SUAS assets is responsible for the unit's standardization program..The commander must include standardization throughout the overall training strategy. The commander's primary standardization staff members include subordinate commanders and unit MTs. Standardization must be implemented in all training tasks. Standardization enables units of any size—crews, multiple-aircraft formations, teams, squads, companies, battalions, or brigades—to readily function together to accomplish the warfighting combined arms mission.

2-8. ATP implementation. This publication is the commander's guide for implementing the ATP.

2-9. Integrating operators into the ATP. Upon signing into the unit, operators designated for duty as SUAS operators are members of the unit's ATP. Within 14 days of signing into the unit, operators must present their training folder, if applicable, to the commander or the commander's designated representative. If the training folder is not available, operators will provide the MT with small unmanned aircraft systems manager (SUASMAN) account information. ML status determination is per the commander’s evaluation.

COMMANDER’S EVALUATION

2-10. Purpose. The purpose of the commander's evaluation is to determine the proficiency and initial ML status of newly assigned operators. This evaluation consists of a records review and a PFE, if required. The commander or MT will complete the evaluation within 45 calendar days after the operator is designated for duty as an SUAS operator.

2-11. Records review. Unit commanders, or their designated representative (MT), will review the operator's training folder. They will compare the individual's qualifications with the tasks required by the assigned duty position. If the appropriate ML status can be determined from the records review, the commander will document the ML status on the individual's DA Form 7122-R (Crew Member Training Record).

2-12. PFE. If the initial ML status cannot be determined by the records review or if the commander desires, the operator will undergo a PFE. The PFE should include tasks from each flight mode in which the operator can expect to perform duties. The results of the PFE will determine the operator's ML status. The commander will document the ML status on the individual's DA Form 7122-R.

2-13. Considerations. If, at the time of initial ML status designation, 6 months has passed since the operator has completed any element of a S-APART (standardization evaluation or SUAS operator's manual examination), the operator must complete that element before designation as, or progression to, MQ. Graduates of an SUAS course who are on their first utilization tour are exempt from this requirement; therefore, commanders may not assign these individuals an initial mission qualified status solely on the basis of a records review.

2-14. Required training. After determining the initial ML status, the commander will direct unit qualification (ML progression training), refresher (if UAC has not flown in 180 days), or continuation (all training and evaluations used for developing proficiency) training for the operator as applicable. Time allotted for completion of the required training will start accruing on the date of the ML status designation. If recommended by the MT, operators may credit the flight tasks satisfactorily completed on the PFE toward completion of their ML status training requirements.

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MISSION-LEVEL STATUS PROGRESSION

2-15. Definition. MLs are the training status classifications of the individual operator. They identify the training phase in which the operator is participating and measure readiness to perform assigned missions. The MLs provide a logical progression of SUAS training based on task proficiency.

2-16. Progression requirements. Operators will progress in ML status by completing tasks in all areas of the SUAS. Once the operator begins training, he or she will have 90 consecutive days to advance from mission preparation to mission qualified status. Once MQ, the operator will have to perform the minimum requirements to maintain this status.

2-17. Exclusion period. ML status progression will exclude days lost due to—

- Temporary duty (TDY) or deployment to a location where the crewmember is unable to fly.
- For RC crewmembers, this includes TDY for civilian employment purposes where the crewmember is physically unable to participate in unit/facility flying activities. This does not include relocation for permanent change of employment.
- Medical or nonmedical suspension from operations.
- Leave approved by the unit commander.
- Grounding of SUAS.
- Non-availability of SUAS due to maintenance or operational considerations, including movement to deployment/redeployment and aircraft preset/reset; preset/reset requirements only apply if 50 percent of the unit's aircraft are not available.
- Documented flight cancellations due to weather and/or maintenance that have had a significant impact on flight operations, as well as restrictions to flight operations due to no fly times from the host country in which the unit operates.

2-18. If the exclusion period exceeds 45 consecutive days, the operator must restart the ML progression cycle. The operator will have 90 consecutive days from this point to progress to the MQ status level. When an operator has not progressed within the required period, the unit commander will investigate, and based on his or her findings, take action according to appropriate directives.

MISSION PREPARATION

2-19. An operator who has been initially designated mission preparation (MP), based on the commander's evaluation, will begin training on all critical and unit selected tasks IAW the appendix as designated by the unit commander. MP programs help operators verify and develop their ability to perform specific tasks that support the unit's METL. Because the goal is proficiency in mission-related tasks, commanders should tailor their task list to meet specific unit needs. An operator progresses from MP to MQ by demonstrating proficiency in all base (1000) and unit (2000) selected tasks to an MT. An operator has 90 consecutive days to progress from MP to MQ. An operator may progress to the MQ status in less time than prescribed in paragraph 2-16 by demonstrating proficiency to an MT. S-APART requirements do not need to be completed while an operator is designated MP. The only requirements are those designated by the commander with assistance from the MT. All MP operators will only operate the system with an MT present and positioned to gain full access to the controls.

MISSION QUALIFIED

2-20. An operator who has completed MP training is considered mission ready and designated MQ. The operator must perform those tasks designated by the unit commander for the operator's table of organization and equipment or table of distribution and allowance position. Once designated MQ, the operator must complete the S-APART requirements.

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TRAINING YEAR

2-21. The ATP training year is divided into semiannual training periods. The first training period begins the first day of October and continues for 6 months. The second training period begins the first day of April and continues through the end of the fiscal year.

FAILURE TO MEET AIRCREW TRAINING PROGRAM REQUIREMENTS

2-22. Investigations. When ATP requirements are not met, the commander will conduct an investigation. The commander will complete the investigation within 30 days of notification of the failure. After the investigation, the commander will—

- Take one of the following two actions:
  - Extensions of up to 30 days may be given on a one time basis to complete the requirements. The 30-day extension will start after the commander completes the investigation.
  - Request a waiver of requirements IAW paragraphs 2-23 through 2-26.
- Enter restrictions imposed and waivers/extensions granted on DA Form 7122-R in the individual's training folder.
- Restrict operators from performing duties with the SUAS until ATP requirements are met.
- Restrict operators who fail a hands-on performance test from performing the duty for which he or she was evaluated and failed. The restriction will apply to all SUAS with similar operating and handling characteristics. Restrictions will be entered in the operator's DA Form 7122-R and will remain in effect until successful completion of a re-evaluation.
- When the failure is in the operator's primary SUAS, the commander must—
  - Re-designate the individual to MP.
  - Authorize additional training if necessary.
- When the failure is in the operator's additional or alternate SUAS, the commander must—
  - Re-designate the individual to MP.
  - Authorize additional training if necessary.
  - Re-evaluate, retrain or restrict the UAC from performing duties in that SUAS.

Note. A primary SUAS is the system that the UAC primarily operates for that unit (Raven). An additional SUAS would be another SUAS that the UAC is also trained on that is of the same type (Puma). If the UAC were also trained on a rotary-wing UAS, this would be considered an alternate UAS.

2-23. Unit waivers. Unit waivers for primary SUAS ATP requirements may be granted only by commanders of the following:

- Direct reporting unit.
- Army Command
- Army Service Component Command.
- USSOCOM.
- Commander, United States Army Reserve Command (USAR units).
- Chief, ARNG-AV for the Chief, National Guard Bureau (ARNG units).

2-24. Waiver authorization. Commanders ranked colonel and above and the State Army Aviation Officer, may grant unit waivers and/or extensions to ATP requirements for units under their command or state/territory affected by operational deployments. These commanders may grant unit extensions for up to 180 days from their self-established "start training date" after redeployment.

2-25. Individual waivers. Individual waivers to primary SUAS ATP requirements may be granted by the first field grade commander or above in the individual's chain of command.

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REMOVAL FROM MISSION QUALIFIED STATUS

2-26. Training deficiency. An operator removed from MQ status for a training deficiency must still meet all MQ ATP requirements. ATP requirements met while in a MP status will be applied to the MQ requirements.

2-27. Other than a training deficiency. An operator has until the end of the training period to complete ATP requirements. If an operator is removed from MQ status for other than a training deficiency before the end of the training period (for example, a permanent change of station departure), his or her ATP requirements no longer apply.

CURRENCY

2-28. Frequency. To be considered current, an SUAS operator must—

- Perform a launch, a recovery, and a 15-minute flight of the SUAS or utilization of a compatible simulator every 30 consecutive days. For ARNG and USAR the requirement is every 60 consecutive days.
- Perform a launch, a recovery, and a 15-minute flight of the SUAS every 150 consecutive days.

2-29. Tracking. Tracking actual flight time for a flying hour requirement is impractical and not required. Individual flight records folders are not required; however, documentation of flight operations (sorties) for the purpose of tracking currency is required. Commanders will establish procedures for maintenance of personal flight logs. A qualified sortie is a launch, a recovery, and 15-minute flight of the SUAS.

2-30. Currency lapse. The SUAS operator whose currency has lapsed must complete a proficiency flight evaluation IAW this ATM. Simulators may not be used to reestablish currency.

2-31. Waivers. Waivers to currency may only be granted by Deputy Chief of Staff, G-3/5/7 (DAMO-AV), 400 Army Pentagon, Washington, DC 20310-0400, IAW AR 95-23.

2-32. Similar unmanned aircraft systems. Currency in one series SUAS will satisfy the requirement for all SUAS within the series or group; separate currency is required for all other SUAS. Series SUAS with similar operating and handling characteristics are listed below:

- Raven-RQ-11A/B, 4-channel, 8-channel, and Digital Data Link.
- Puma.
- Wasp.

Note. Currency is not considered an element of the ATP.

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Chapter 3

Evaluation

This chapter describes evaluation principles and considerations. It also contains guidelines for conducting academic and hands-on performance testing. Evaluations are a primary means of assessing flight standardization and operator proficiency and are a key part of the Army standardization process. Evaluations will be conducted per AR 95-23 and this ATM.

EVALUATION PRINCIPLES

3-1. The value of any evaluation depends on strict adherence to the fundamental principles described below.

- Selection of MTs. The selection of MTs must not be based only on technical qualifications. Criteria for selecting MTs should include demonstrated performance, objectivity, powers of observation, maturity, judgment, the ability to effectively mitigate risk, and the ability to provide constructive comments.
- Method of evaluation. The method of evaluation must be based on uniform and standard objectives. In addition, the evaluation method must be consistent with the unit's mission and adhere to the appropriate standing operating procedures (SOPs) and regulations.
- Participant understanding. Complete understanding of the purpose of the evaluation, by all concerned, is essential. Moreover, the evaluation must be conducted in a manner that is purpose-oriented.
- Participant cooperation. Cooperation by all participants is necessary to fulfill the evaluation's objectives. The emphasis is on all of the participants, not just the examinee.
- Training needs identification. The evaluation must produce specific findings to identify training needs. General comments do not always provide the direction and guidance essential for improvement. The evaluation must pinpoint both strengths and weaknesses.
- Purpose of evaluation. The evaluation will determine the examinee's ability to perform essential hands-on/academic tasks to prescribed standards. Flight evaluations also will determine the examinee's ability to exercise crew coordination in completing these tasks.

Note. All evaluations of an MT will be conducted by an MT.

SEMI-ANNUAL PROFICIENCY AND READINESS TEST

3-2. Purpose and components. The S-APART measures an operator's proficiency and readiness. It consists of a written examination and a hands-on performance test evaluated by an MT as follows:

- SUAS operator's written examination. This open-book exam is prepared at the local level and consists of 25 objective questions that cover the SUAS operator's manual, local airspace, regulations, SOPs, and other pertinent topics as determined by the commander and MT. The minimum passing score is 70 percent.
- Hands-on performance tests. This component consists of oral and flight position evaluations.
  - Paragraph 3-12 lists of oral subjects for the hands-on performance.
  - The appendix lists the evaluation tasks for the hands-on performance.

3-3. S-APART periods. MQ operators must pass each component of the test during their S-APART periods. The S-APART periods are the two-month period ending on March 30th for the first semiannual training period and the two-month period ending on the last day of the fiscal year. While deployed to

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designated combat or imminent danger areas, the first field grade commander or above in the individual's chain of command should consider reducing this evaluation requirement to once annually. At the end of the training year, the commander must certify that each operator has completed all S-APART requirements. This action serves to recertify the operator in his or her designated duty position(s). An operator designated MQ at any time within this two-month period must complete all S-APART requirements. Operators receive credit for the operator's written examination and hands-on performance test during mission preparation if they complete the tests within the two-month S-APART period.

3-4. Training deficiencies. Operators participating in MP programs are not subject to the S-APART. Operators removed from MQ status due to a training deficiency are subject to the S-APART.

Note. S-APART failures-Operators who fail to meet the S-APART standards will be processed IAW paragraph 2-22.

NO-NOTICE EVALUATION

3-5. A comprehensive no-notice evaluation program is a valuable tool that allows commanders to monitor training effectiveness at all levels. Each commander must establish a no-notice proficiency evaluation program in the unit SOP. No-notice evaluations may be written, oral, hands-on flight evaluation in a UA/compatible flight simulator, or a combination thereof. Ten percent of these evaluations must be hands-on flight evaluations. This program measures the effectiveness of individual, crew, and collective training. Commanders use the results of no-notice evaluations to ensure unit standardization and readiness and to tailor the unit's individual, crew, and collective training programs. Each operator will receive at least one no-notice evaluation per year.

PROFICIENCY FLIGHT EVALUATION

3-6. Administration. The commander directs and administers the PFE using the guidelines established in paragraph 2-12. This evaluation is conducted to determine—

- The individual's ML status upon assignment to the unit if the readiness level cannot be determined through a records review.
- The individual's proficiency when SUAS currency has lapsed IAW paragraph 2-30.
- The individual's proficiency when questioned by the commander.

3-7. Records. After the evaluation, the MT will debrief the individual and complete DA Form 7122-R.

GRADING CONSIDERATIONS

3-8. Oral evaluation. The examinee must demonstrate a working knowledge and understanding of the subject areas presented. The MT will assess the examinee's knowledge during the oral evaluation.

3-9. Hands-on test. Performance standards are based on an ideal situation. Grading is based on meeting the minimum standards. The MT must consider deviations from the ideal during the evaluation and make appropriate adjustments if other than ideal conditions exist.

CONDUCTING EVALUATIONS

3-10. Purpose, sequence and procedures. Evaluations are conducted to determine the operator's ability to perform appropriate duties. Phase 1 and phase 4 are always required. The MT will determine the amount of time devoted to each phase. When the examinee is a MT, the recommended procedure is for the MT to reverse roles with the examinee. When the MT uses this technique, the examinee must understand how the role-reversal will be conducted and when it will be in effect.

PHASE 1-INTRODUCTION

3-11. In this phase, the MT—

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- Reviews the examinee's records to verify that the examinee meets all prerequisites for the qualification IAW AR 95-23, appendix D (for example initial PFE, qualification completion, instructor qualification, and/or medical screening).
- Confirms the purpose of the flight evaluation, explains the evaluation procedure, and discusses the evaluation standards and criteria to be used.

Note. If the examinee is an MT, he or she will be evaluated on the ability to apply the learning and teaching process outlined in the Federal Aviation Administration's (FAA) Aviation Instructor's Handbook. The examinee must demonstrate a working knowledge of the conditions, standards, and descriptions of the tasks he or she will be instructing/evaluating. The examinee must also demonstrate the ability to determine when tasks are not performed to standard and how to train to standard.

PHASE 2-ACADEMIC/ORAL EXAMINATION

3-12. The examinee must have a working knowledge and understanding of all applicable topics in the respective subject areas. At a minimum, the MT will select two topics from each appropriate subject area. If the examinee is an MT, he or she will also demonstrate the ability to instruct and evaluate any topic.

- Regulations and publications (ATM, AR 95-23, local SOPs, and regulations). Topics in this subject area are—
  - ATP requirements.
  - SOP requirements.
  - Weather restrictions and procedures.
  - Local airspace usage.
  - Publications required for using the SUAS.
  - Forms and records.
- Operating limitations and restrictions. Topics in this subject area are—
  - Battery limits.
  - Airspeed limits.
  - Environmental restrictions.
  - Other limitations.
- SUAS emergency procedures and malfunction analysis. Topics in this subject area are—
  - Emergency terms and their definitions.
  - Battery malfunctions.
  - Loss of link.
  - Mission equipment.
  - No hub communication.
  - Loss of global positioning system.
- Tactical and mission tasks (TC 3-04.62 and unit SOP). Topics in this subject area are—
  - Mission statement and employment methods.
  - Terrain analysis.
  - Use of FalconView, navigational chart, map, and tactical overlay interpretation.
  - Battlefield environment.
  - Fratricide prevention.
  - Tactical reports.
  - Fire support.
  - Downed UA procedures.
  - Mission equipment.
  - Tactical airspace coordination.

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- Light amplification by stimulated emission of radiation (LASER) operations.
- LASER performance detractors.
- Night mission operation use of lights.

- Aviation instructor's handbook (FAA-H-8083-9). Topics in this subject area are—
  - The learning process.
  - Effective communication.
  - Teaching methods.
  - Types of evaluations.
  - Planning instructional activity.
  - Flight instructor characteristics and responsibilities.
  - Techniques of flight instruction.
  - Human behavior.
  - Teaching process.
  - The instructor as a critic.
  - Instructional aides.
  - Critiques and evaluations.

PHASE 3-FLIGHT EVALUATION

3-13. If this phase is required, the following procedures apply:

- Briefing. The MT will explain the flight evaluation procedure and brief the examinee on which tasks will be evaluated. When evaluating an MT, the MT must advise the examinee that during role reversal the MT may deliberately perform some tasks outside the standard to check the examinee's diagnostic and corrective action skills. The MT will conduct or have the examinee conduct a crew briefing.
- Before-flight procedures. The MT will evaluate the examinee's use of the appropriate technical manuals (TMs), checklists (CLs), technical bulletins (TBs), and/or the integrated electronic technical manual (IETM) as appropriate.
- Flight tasks. The MT will evaluate those tasks listed in appendix A. An MT must demonstrate the ability to instruct and/or evaluate the appropriate tasks. When used as part of the proficiency flight evaluation, the evaluation may include an orientation of the local area, checkpoints, and other pertinent information.
- After-landing tasks. The MT will evaluate the examinee's use of the appropriate TMs, CLs, TBs, and/or the IETM as appropriate.

PHASE 4-DEBRIEFING

3-14. Upon completing the evaluation, the MT will—

- Discuss the examinee's strengths and weaknesses.
- Offer recommendations for improvement.
- Inform the examinee if he or she passed or failed the evaluation and discuss any tasks not performed to standards.
- Complete the applicable/appropriate forms, and ensure the forms are reviewed and initialed by the examinee.

Note. Inform the examinee of any restrictions, limitations, or revocations that the MT will recommend to the commander following an unsatisfactory evaluation.

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LOCAL AREA ORIENTATION

3-15. Training area orientation. The commander will ensure that operators are given a tour of and a briefing on the training area and facilities. The tour should include the mission planning procedures (location of maps and other flight planning aids) and the airspace operations office. The briefing also should include the items listed below:

- Obtaining maps and charts.
- Obtaining weather information.
- Obtaining range and restricted-area information.
- Information on frequencies and access phone numbers.
- A review of airspace in the local area.

3-16. Range layout and facilities. The commander will ensure that operators are familiar with range facilities.

3-17. Local area orientation flight. Before progressing to MQ, operators will receive a local area orientation flight. Units may conduct this flight along with other training. The commander will determine which orientation items are required for the flight. Items specific to the local area or those that cannot be adequately covered during the ground portion will be pointed out, demonstrated, or discussed during the flight. The orientation flight should include familiarization with local—

- Boundaries.
- Reporting points.
- Prominent terrain features.
- Restricted areas and no-fly areas.
- Tactical training and range areas.
- Airfields, helipads, and frequently used landing zones.
- Obstacles or hazards to flight.

Note. Army commands, particularly those operating near sensitive borders, should establish additional requirements or restrictions for local area orientations.

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Chapter 4
Unit Task Development

AIRCREW TRAINING MANUAL TASK MODEL DEVELOPMENT

4-1. Commanders are authorized to develop additional tasks for inclusion on the commander's task list (CTL), as needed, to accomplish the unit's mission if the appendix does not adequately cover a maneuver or mission that is required. To develop an additional task, the commander will create the task in the format described in this chapter, assign a 3000-series number to the task, and add it to the CTL along with iteration and mode requirements.

4-2. When an additional task is developed by the unit, the commander must perform a risk analysis for performance of the task, and determine training required for personnel to attain proficiency in the task. The commander will ensure that Soldiers receive the necessary academic and flight training for this new task during RL progression and will determine if there is a requirement for an annual evaluation of the task. Commanders will submit a copy of all 3000-series tasks to Commander, USAACE, Directorate of Training and Doctrine, ATTN: ATZQ-TDT-F (UAS Branch), Building 4507, Andrews Avenue, Fort Rucker, Alabama 36362. The additional task(s) must include the following:

- Task number and title.
- Conditions for task performance.
- Standards for task performance.
- Description of task performance.
- Considerations for task performance (such as environmental and safety).
- Training/evaluation requirements.
- References.

TASK FORMAT

4-3. The following format will be used to develop 3000-series tasks (figure 4-1, page 4-2). Each task element is explained further in the following paragraphs.

Note. The following task is intended for *explanation of formatting style only*; it **does not** constitute doctrinal procedure.

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TASK 3000

Perform Close Combat Support

WARNING

All warnings associated with the task will follow the task title.

CONDITIONS: Condition statements set parameters or sample parameters. They explain what to provide and what to withhold, and may be modified if necessary. Condition statements describe the circumstances under which the task is taught or measured in the learning environment. The individual task condition statement describes the field circumstances (on-the-job or full spectrum operations) under which the individual critical task is performed as closely as possible. It also lists what materials, personnel, and equipment must be provided for task accomplishment.

STANDARDS: The individual task standard describes the minimum acceptable level of performance in the field to successfully accomplish the task under the prescribed conditions. It notes how well someone should perform the task to be considered competent. For SUAS flight tasks, standards are based on ideal conditions.

DESCRIPTION:

1. Crew actions.
   a. Ensure that the correct designation for the crewmember is used in the description to avoid confusion.
   b. Make sure crew actions (for example AO) by all individuals involved to accomplish this task are captured.
2. Procedures.
   a. Procedures identify the preferred method of accomplishing the task.
   b. Make sure that all individual (for example AO) procedures involved to accomplish this task are captured.

ENVIRONMENTAL CONSIDERATIONS:

1. Task considerations define the different requirements for performing the task under different flight modes or under adverse environmental conditions.
2. They must address the unique requirements of performing the task under those conditions.

TRAINING AND EVALUATION REQUIREMENTS:

1. Training. Training may be conducted while operating the aircraft or simulator.
2. Evaluation. The evaluation will be conducted while operating the aircraft.

REFERENCES: FM 3-04.126, FM 3-04.140, and AR 95-23.

Figure 4-1. Example of task format

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TASK NUMBER

4-4. Task numbers are uppercase, bolded format. Task numbering begins with 3000 and runs sequentially.

TASK TITLE

4-5. The task title describes the performance required of the Soldier on the job. It is frequently referred to as the task. The task title has one action verb, one object, and may also have a qualifier that describes the required action. Task titles are title case, bolded format. Do not use acronyms in the title. Using standard, well-defined verbs—

- Provides/promotes clarity.
- Allows analysts, task selection boards, trainers, and Soldiers to understand what the task title means.
- Prevents duplication. Using standard verbs makes it simple to group tasks by verbs to avoid duplication.
- Promotes application of sound training principles.

WARNINGS, CAUTIONS, AND NOTES

4-6. Figure 4-2 provides examples of warning, cautions, and notes.

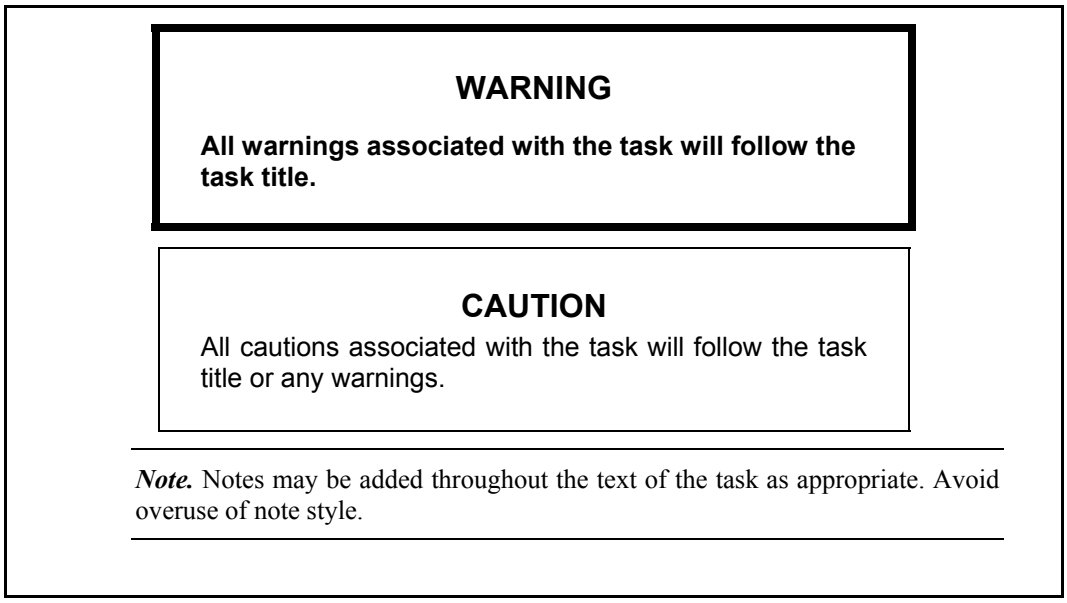


Figure 4-2. Warning, caution, and note examples

CONDITIONS

4-7. Condition statements set parameters or sample parameters. They explain what to provide and what to withhold, and may be modified if necessary. Condition statements describe the circumstances under which the task is taught or measured in the learning environment. The individual task condition statement describes the field circumstances (on-the-job or full spectrum operations) under which the individual critical task is performed as closely as possible. It also lists what materials, personnel, and equipment must be provided for task accomplishment.

4-8. A condition statement has two parts:

- Cue-a word, situation, or other signal for action. An initiating cue is a signal for an individual to begin performing an individual task. An internal cue is a signal to go from one element of a task to another. A terminating cue indicates task completion.

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- Descriptive data-information that identifies when, why, and where the task is performed and what resources (materials, personnel, and equipment) are required to perform the individual task.

4-9. Write the individual task condition statement in standard paragraph format, containing one or more sentences. Use the following guidelines and tips for writing an individual task condition statement:

- Identify the cue.
  - The cue may be very evident or "understood" when writing a condition statement, and may not require detail.
  - Specifically, identify the cue if it is not evident. Identifying the cue may require studying items, such as, organizational diagrams; mission analysis; threat information; actions performed by outside units, Soldiers, leaders, or events; or procedural manuals.
- Identify/describe the physical setting, or the site of individual task performance. The amount of detail provided varies, based on the effect that the setting has on the task performance.

Note. Not all individual critical tasks are performed on the battlefield or during wartime.

- ***DO NOT*** make the setting too generic or too specific. ***DO NOT*** refer to a training environment. (A task condition is written to field performance, ***NOT*** training performance.
- When the task is performed at multiple performance sites, describe all sites, as practicable.

4-10. Figure 4-3, page 4-5, provides examples of individual task condition statements. Write your individual task condition statements in a similar manner. Each example provides discussion points.

Condition #1 Given a constructed defensive position, entrenching tool, and camouflage nets. Discussion: In this example— • When is-anytime a Soldier or the Soldier's unit is in danger of attack. • Where is-anywhere a Soldier or the Soldier's unit is in danger of attack. • Why is-because there is a threat to the Soldier and/or the Soldier's unit. • Resources required-an entrenching tool and camouflage nets.
Condition #2 You have a casualty who is suffering from a burn. The casualty has no other serious wounds or conditions that were not treated. A canteen and first aid packet are available. Discussion: In this example— • When is-upon finding a burned casualty. • Where is-wherever there is a burned casualty. • Why is-the burn is the most serious injury and controls the boundary of the task. • Resources required-are limited to the resources on hand, which includes a canteen and first aid packet.

Figure 4-3. Individual task condition statements examples

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4-11. Figure 4-4 provides questions that are useful in determining whether condition statements have been well written.

Does the condition statement address the following issues:

- Describe the conditions under which this task will be performed under operational (field) or selected training conditions?
- Identify the initiating cue?
- Identify the physical setting (when and where the Soldier performs the task)?
- Identify the resources (materials, personnel, and equipment) needed to accomplish the task?
- Utilize job holder language?
- List special conditions when applicable?
- Utilize standard paragraph format?

Figure 4-4. Condition statement issues

SPECIAL CONDITIONS

4-12. A special condition is an aiding or limiting factor that occasionally occurs and affects a Soldier's ability to perform the task to the established standard. These special conditions include, but are not limited to, wearing of mission oriented protective posture level (MOPP) 4, night vision devices, or self-contained breathing apparatus when performing the task (figure 4-5, page 4-6). These unique circumstances are identified as separate special condition statements when conducting the individual task analysis, and are also entered under the conditions tab in the CAC-approved automated development system.

4-13. Writing special condition statements. Once changes to the task performance standard caused by performing the task under a special condition are identified, developers must include them. When writing a special condition statement, be aware that—

- More than one special condition simultaneously may affect task performance.
- A special condition may affect such standards as speed or accuracy.

Condition

You are in an area where chemical agents have been used. You are wearing protective over-garments and mask, or they are immediately available. You encounter a casualty who is breathing and lying on the ground. The casualty is partially dressed in protective clothing and is wearing the protective mask carrier with mask.

Special Condition: MOPP 4.

Figure 4-5. Special condition statement example

STANDARDS

4-14. The individual task standard describes the minimum acceptable level of performance in the field to successfully accomplish the task under the prescribed conditions. It notes how well someone should perform the task to be considered competent. For SUAS flight tasks, standards are based on ideal conditions.

4-15. Standards must be—

- Written in present tense.
- Written in standard paragraph format. The paragraph may contain one or more sentences and may include subparagraphs and/or bullets.
- Written in job holder language.
- Observable, measurable, achievable, objective, valid, reliable, usable, comprehensive, discriminating, and quantifiable.

4-16. A standard statement has two parts:

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- Performance-A verb phrase that identifies what action the standard will evaluate (that is, the process the Soldier performs, the product produced, or a combination of both).
  - A process standard describes the critical task elements necessary for adequate task performance.
  - A product standard describes the end result of individual task performance. Product standards should be used when the process it takes to perform the task is not important, as long as the product (end result) is correct.
  - A combination standard is used when task performance produces both a product and process.
- Criterion-May include, but is not limited to, accuracy, quantity, speed, and quality. Table 4-1 addresses recommended criteria for each type of task performance.

Table 4-1. Task performance criteria

Individual Task Standard	*Criteria to Use*
Product Standard	Accuracy, tolerances, completeness, format, clarity, number of errors, and quantity.
Process Standard	Sequence, completeness, accuracy, and speed of performance.
Combination Standard	Accuracy, tolerances, completeness, format, clarity, number of errors, quantity, sequence, and speed of performance.

4-17. Parts of example standard statements may include the following:

- Fire all 18 rounds (performance) and hit the target at least 9 times (criterion).
- Camouflage the position (performance), so it cannot be detected from 35 meters forward (criterion).
- Calibrate the altimeter within 1 meter (performance) IAW TM ####-###-#### (criterion).

Note. It is preferred not to use a standard that refers to another document; but, in the case of aircraft maintenance, it is mandatory to use the TM. Duplicating the TM causes extra work and serves no value, since the TM is used when the task is performed.

DESCRIPTION

4-18. Task descriptions are the "how to" portion of the task.

- Descriptions will normally be divided into two sections: crew actions and procedures.
- Ensure that the correct designation for the crewmember is used in the description to avoid confusion.
- Procedures identify the preferred method of accomplishing the task.
- Make sure the standards for the task are clearly defined in the "STANDARDS" section; however, it may be necessary to refer the reader to the description section for specific requirements.
- Deviations from task procedures—but not crew actions—are authorized as long as task standards and safety are not compromised.

CONSIDERATIONS (NOT MANDATORY FOR ALL TASKS)

4-19. Task considerations define the different requirements for performing the task under different flight modes (visual meteorological conditions [VMC], night, or different payload sensors) or under adverse environmental conditions. They must address the unique requirements of performing the task under those conditions.

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ENVIRONMENTAL CONSIDERATIONS

4-20. The environmental considerations section of a task must address the unique requirements of performing the task under different flight modes or under adverse environmental conditions.

4-21. The following are examples of environmental considerations:

- Altitude, apparent ground speed, and rate of closure are difficult to estimate at night.
- Surrounding terrain or vegetation may decrease contrast and degrade depth perception during the approach. Before descending below obstacles, determine the need for artificial lighting.
- Use proper scanning techniques to avoid spatial disorientation.
- Acquire, identify, track and/or designate targets using the sensor's optimum capabilities (electro-optical, infrared) for a given situation based on mission, enemy, terrain and weather, troops and support available, time available, civil considerations (METT-TC).

REFERENCES

4-22. The reference section of the task lists the sources of information relating to that specific task.

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Chapter 5

Unit Training

Unit commanders are authorized to conduct refresher training at unit level. Operators receiving the training must have attended the initial operator qualification course for the SUAS being flown.

TRAINING PROGRAM REQUIREMENTS

5-1. Refresher training. An operator entering refresher training will participate in training that consists of critical and unit-selected tasks. The operator must complete all training before he or she is designated MQ. The operator is designated MP during this training. Refresher training should include academic courses and practice of all tasks. During refresher training, the operator does not have semiannual proficiency and readiness test (S-APART) requirements in the SUAS in which the training is being conducted. The only requirements he or she has are those designated by the commander.

- The operator will complete the appropriate academic requirements IAW paragraph 3-12 and those tasks listed in this manual.
- All flight training in MP will be conducted by an MT.
- The operator will be evaluated by an MT.
- The operator will complete a qualified sortie at night (if applicable).

5-2. Mission training. The SUAS mission and operation of mission equipment is an integral part of being an operator qualified in a SUAS. This training must be completed before an operator is qualified to perform missions within his or her unit with a SUAS.

TRAINING PREREQUISITES

5-3. An operator returning to an operator position after having been prohibited/excused from flying duties for more than 180 consecutive days will receive refresher training. When an operator enters the unit's ATP with fewer than 180 consecutive days of non-operator duties, the commander may require him or her to undergo refresher training based on a records check or a PFE.

TASK CONSIDERATIONS

MASTER TRAINER

5-4. If an MT is part of a condition, he or she will be in a position close enough to assist the operator or assume control as the situation requires.

VISUAL METEOROLOGICAL CONDITIONS

5-5. Unless otherwise specified in the conditions, all in-flight training and evaluations will be conducted under VMC.

EMERGENCY PROCEDURES

5-6. The operator will know all underlined emergency procedures well enough to perform the required action from memory. Upon completion of the procedure, the checklist will be used to verify that no item was overlooked.

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LIMITATIONS

5-7. Operators will maintain operation within SUAS limitations at all times. Operation outside these limits, in other than an emergency situation, is unsatisfactory.

MISSION LEVEL TRAINING/EVALUATIONS

5-8. All ML training and evaluations will be conducted with an MT present and in a position to gain full access to the system controls.

TRAINING STRATEGY

5-9. The training strategy is developed using the outcome of the training assessment. It is then issued to subordinate commanders through the commander's training guidance (CTG).

NEAR-TERM PLANNING

5-10. Near-term planning is used for the monthly training schedule. The operations staff officer (S-3), with assistance from the MT/brigade aviation element (BAE) UAS technician—

- Reviews training aids, devices, simulators, and simulations and allocates training resources to specific trainers.
- Ensures that training events are well structured, efficient, realistic, safe, and effective.
- Must ensure that informal evaluation and feedback by trainers and senior leaders are continuous and that formal evaluations are included in training plans. (Evaluation documentation can range from annotated training and evaluation outlines to Combat Training Center (CTC) take-home packages.)

LONG-RANGE PLANNING

5-11. Long-range planning is used for the new annual training calendar. The S-3, with assistance from the MT/BAE UAS technician—

- Carefully studies the brigade CTG and key training events in which the unit will participate.
- Selects appropriate training scenarios with supporting operations plans from the training support packages.
- Coordinating with the brigade, division, and the military community, chooses training event dates that do not conflict with other key calendar events.

5-12. The tools used to develop a long-range training plan are the battalion training strategy, the brigade and division's CTG, and the brigade and division long-range training calendar—12 to 18 months out. These calendars may be viewed by subordinate commanders during their unit training planning.

QUARTERLY TRAINING CALENDAR

5-13. When preparing the quarterly training calendar, the S-3, with assistance from the MT/BAE UAS technician—

- Studies the brigade CTG and the battalion annual training calendar.
- Identifies, allocates, and coordinates short lead-time resources such as local training facilities.
- Pays particular attention to CTC lessons learned when developing training objectives and tasks to include in an field training exercise operation order.
- Allocates time on the aviation combined arms tactical trainer and other critical training resources.
- Cross-references each event with specific training objectives and coordinates with all supporting agencies, the battalion staff, and unit commanders.

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AIRCREW TRAINING PROGRAM

5-14. The ATP is an integral part of the commander's overall unit training program and should be briefed at each quarterly training brief. Proficient aircrews are essential to effective collective training. SUAS leaders/MTs must maintain a balance between individual, aircrew, and collective training. The ATP, mandated by AR 95-23, is a structured and prescriptive management and evaluation program focused on training Army aircrews. The ATP applies to all Army operators in operational flying positions. Developed IAW this TC and the appropriate ATM appendix, the ATP includes training of the base, mission and additional tasks necessary for the accomplishment of a unit's METL. In today's command operating environment, small unit leadership is critical to mission execution. Training must be tailored to ensure these elements are integrated into the training regime of our units. Leader supervision and participation at all levels is essential to the successful execution of the ATP.

5-15. The ATP, with the factors that affect it, is a major consideration in developing the long-range training plan. Consideration must be given to—

- Individual operator proficiency.
- Aircrew proficiency (battle-rostered crews).
- The unit maintenance program.
- Flight-hour allocation to supported units when SUAS training is conducted during supported unit missions.
- Individual and aircrew training that is usually accomplished while not in a support role; for example, emergency procedures training, and flight evaluations.
- Operator training accomplished in crew and collective simulators/simulations.

5-16. Units are required to have an ATP addressing specific requirements for conducting training, evaluation, assessment, and program revision. Commanders should use multi-echelon training objectives, scenarios, and standard training exercises (STXs) to facilitate the development, execution, and continual assessment of their training program. Scenarios and STXs for individual, crew, and collective training must be mutually supportive and progressive in intensity and complexity. Effective individual and crew training programs form the foundation for a SUAS battle-focused training program. These programs produce combat ready crews and are the basis for the unit's collective training program. Collective training must focus on combined arms/joint operations across the spectrum of the unit's METL. Limited resources, environmental restrictions, new and sophisticated aircraft mission equipment packages, and multiple contingency operations will all impact on the commander's ability to train and maintain proficiency at all levels.

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Chapter 6

Individual Operator Training Record

The commander must ensure that a training record is prepared and maintained for each SUAS operator in an operational duty position assigned or attached to the unit. The ATP records system provides commanders with a comprehensive performance record on each operator in their unit. The required forms can be completed by hand using dark blue or black ink, by typewriter, or digitally. The forms are available at http://armypubs.army.mil. Aircrew training records are important quality control and standardization tools. They should be completed carefully, completely, and legibly. Examples of completed ATP forms with instructions are provided in figures 6-1 and 6-6 (pages 6-2 and 6-4); however, the examples are not intended to be all inclusive of required entries on the forms. Use the Remarks section of the forms and/or the comment slips to explain situations not clearly covered by the written guidelines.

INDIVIDUAL OPERATOR TRAINING RECORD REQUIREMENTS

6-1. The training record will be maintained as follows:

- DA Form 7122-R will be used. It will be maintained in the operator's unit training folder.
- Operators assigned or attached for flight duty will present their DA Form 7122-R to the commander or the commander's representative upon arrival into the unit.
- DA Form 4507-R (Crew Member Grade Slip) should be used to document training and evaluation flights.

DEPARTMENT OF THE ARMY FORM 7122-R

6-2. Purpose. DA Form 7122-R is used to permanently record all individual operator evaluations and summaries. It is also used to record any change in operator status or other significant events. General instructions for completing the form are as follows:

- Type or clearly print all entries in black, dark blue, or red ink (for out-of-sequence date entries only).
- For blocks that do not require an entry, enter "NA" for Not Applicable or a dash (—).
- To make minor corrections, use correction fluid/tape or neatly line through the incorrect information and add the correct information. Use procedures found in paragraph 6-3 to make major corrections.
- Keep entries as clear and concise as possible. Use standard abbreviations and acronyms.
- Significant related events that occur (aircraft qualification or MT course en route) during the time a crewmember departs the previous duty station and is integrated into a new ATP will be entered on DA Form 7122-R prior to the assignment entry.
- DA Form 7122-R is a two-page form; however, it is likely that one page will fill before the other. When one page of the form is filled, close out the other page of the form by drawing a diagonal line from the first unused block to the last unused block.
- Not every possible event or occurrence can be anticipated. If situations arise that are not covered by these instructions, use sound judgment and enter the event in the most logical manner.

6-3. Corrections to DA Form 7122-R may be needed for several reasons. Careful and timely entering of events as they occur will eliminate the need for corrections.

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- Out-of-sequence events. If an event is not entered at the proper time and one or more events have been recorded, enter the event as you would any other event on the next available line. Use red ink when entering the date only (to include year) for the out-of-sequence event.
- Unusable form. If enough mistakes accrue to make the form unusable, transcribe the data to a new form. Place a diagonal line across the front of the unusable form, label it "transcribed," and retain this copy of the form (permanently) under the current form.

Note. Do not destroy or discard any DA Form 7122-R that contains an entry.

DA FORM 7122-R INSTRUCTIONS

6-4. Instructions for completing DA Form 7122-R are as follows.

Crewmember Training Record, Page 1

- **Sheet Number.** Number each sheet in numerical order.
- **Name.** Enter the crewmember's full name (last, first, and middle initial). If reproducing the form on two separate sheets of paper, enter the crewmember's name on the first line of the second sheet, in the Remarks area, followed by the sheet number with which it corresponds.
- **PID.** Until further guidance leave this blank.
- **Rank.** Enter the crewmember's rank.
- **Birth Month.** Enter the crewmember's birth month. **Date.** Enter the day, month, and year of the event. After the first entry, it is acceptable to omit the year until entry of the first event of the following year. If an entry is out of chronological order, only the date will be in red and the year must be included.
- **A/C.** Enter the alphanumeric designation of the appropriate aircraft (for example, RQ-11A or RQ-11B). If the event was performed solely in a flight simulator, enter the simulator designation (RQ-11B SIM or VAMPIRE SIM).
- **Event.** Enter a short summary of the event on one line. Record events listed below:
  - Unit assignments and reassignments. Reassignment within the unit not requiring a DA Form 759 (Individual Flight Record and Flight Certificate-Army) closeout will be treated as a change of duty.
  - Start and completion of time-limited training programs, such as, ML progression or MT qualification.
  - Start and completion of DA qualification courses, both flying and non-flying.
  - Completion of significant training or retraining programs. (Summarize the event on one line.)
  - All evaluations.
  - MT designation.
  - Completion of the written examination.
  - All proficiency flight (oral or written) evaluations. (Specify the type of evaluation; for example a no-notice evaluation, the flight portion of a commander's evaluation, or currency evaluation.)
  - All requests for waivers or extensions and their disposition.
  - Involvements in any class A, B, C, or D accident or incident and the results of any post accident evaluation (if given).
- **Duty.** Not applicable.
- **Day (D), Night (N), Night Google (s) (NG), Night System (NS), Weather (W), Hood (H), and Simulator (Sim).** For the event being recorded, enter the number of qualified sorties conducted under the appropriate flight modes/conditions. The sortie number entered will be the sorties flown on any single flight event (such as an evaluation) or the total sorties flown in multi-flight training programs.

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- **Seat.** Not applicable.
- **Recorded By.** MTs, trainers, operations personnel and others when authorized by the commander will enter their first initial, last name, rank and duty position. If the event was an evaluation and someone is recording it other than the MT, record the MT's name in the remarks section.
- **GR (grade).** If the event was graded, enter an "S" (Satisfactory) or a "U" (Unsatisfactory). For an unsatisfactory evaluation, state the specific tasks the crewmember performed unsatisfactorily and any restrictions imposed due to the failure. Provide a recommendation to the commander for retraining and re-evaluation.
- **CM Init (crewmember initials).** Brief the crewmember on the entry and ensure that the crewmember understands any change in status. Crewmembers will then initial this block. A crewmember's initials indicate that the crewmember is aware of the entry on the form and any remarks and understands any change in status. The crewmember will immediately initial any entry resulting in a change of status, such as, an unsatisfactory evaluation or a suspension. The crewmember will initial routine entries, such as, assignment to a unit or satisfactory evaluations, as soon as practical.
- **Rmk (remarks).** Enter "Yes," "Y," "No," or "N" in this column to show whether comments are entered in the Remarks section regarding the entry. Do not enter "NA" in this column or leave it blank.

Crewmember Training Record, Page 2

- Date. Include date pertinent information was recorded in remarks. Enter the date in the same format used on the front of the form.
- Remarks. Record pertinent information not shown on the front of the form in this section. Do not restate information entered on the front of the form, for example, "This was a satisfactory evaluation." There is no single correct way of entering remarks. However, they should be clear, concise, and specific. When entering remarks, use standard abbreviations and acronyms or logically shortened words. If the remarks require more than one line, do not repeat the date on the second or subsequent line(s). Remarks that could be entered include the issuance of an MT qualification by an MT and an explanation of extension for completion of ATP requirements.

6-5. Only the following events recorded on the DA Form 7122-R require the commander's signature:

- Nonmedical suspension.
- ML designation after failure of a hands-on performance test or a training deficiency.
- Extensions or waivers.
- Return to previous duties after nonmedical suspension or ML designation after failure of a hands-on performance test or a training deficiency.

Note. The commander, pertaining to the training folder, is defined as the commander responsible for the ATP. Waiver and extension authority is IAW AR 95-23, local regulations, and SOPs. The appropriate commander will sign the DA Form 7122-R, page 2, when required. Memorandum for Record granting extensions or waivers signed by the commander will be retained in the miscellaneous section of the training folder until the end of the ATP year.

DA FORM 7122-R SAMPLE

6-6. Figures 6-1 and 6-2, pages 6-4 and 6-5, provide a sample of a completed DA Form 7122-R.

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CREW MEMBER TRAINING RECORD

For use of this form see TC 3-04.11; the proponent agency is TRADOC.

Sheet No: 1

Name: Moody, Dwight L. | PID: | Rank: SPC | Birth Month: Oct

Date	A/C	Event	Duty	D	N	NG	NS	W	H	Sim	Seat	Recorded By	GR	CM Init	Rmk
20120106	RQ-11B	Assignment	-	-	-	-	-	-	-	-	-	F. Franks, 2Lt, Plt Ldr	-	DM	Yes
20120111	RQ-11B	Cdr's eval	-	-	-	-	-	-	-	-	-	C. Spurgeon, SGT, MT	-	DM	Yes
20120126	RQ-11B	Start mission prep	-	-	-	-	-	-	-	-	-	B. Sunday, SGT, MT	-	DM	No
20120206	RQ-11B	Misison qualified	-	2	2	-	-	-	-	-	-	B. Sunday, SGT, MT	S	DM	Yes
20120306	RQ-11B	S-APART	-	-	1	-	-	-	-	-	-	C. Spurgeon, SGT, MT	S	DM	No
20120406	RQ-11B	Written exam	-	1	-	-	-	-	-	-	-	B. Sunday, SGT, MT	S	DM	No
20120607	RQ-11B	No-notice	-	1	-	-	-	-	-	-	-	B. Sunday, SGT, MT	U	DM	Yes
20120706	RQ-11B	Re-eval	-	1	-	-	-	-	-	-	-	C. Spurgeon, SGT, MT	S	DM	No
20121025	RQ-11B	ATP waiver	-	-	-	-	-	-	-	-	-	C. Spurgeon, SGT, MT	-	DM	Yes
20121105	RQ-11B	Completed MT V2 course	-	4.0	-	-	-	-	-	-	-	C. Spurgeon, SGT, MT	-	DM	Yes
20121205	RQ-11B	Designated MT	-	-	-	-	-	-	-	-	-	C. Spurgeon, SGT, MT	S	DM	Yes

DA FORM 7122-R, DEC 2009 PREVIOUS EDITIONS ARE OBSOLETE. APD PE v1.00

SAMPLE

Figure 6-1. Sample DA Form 7122-R, page 1

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Date	Remarks	Commander's Signature
20120106	Assigned to C Trp 4-4 Cavalry, Budingen, GE as qualified RQ-11B operator.	
20120106	Commander's eval completed by records review. Start mission prep training ASAP.	
20120223	Completed msn prep local area orientation. Misison qualified effective this date.	Adrian Rogers, CPT, Infantry
20120706	SM failed to encure airspace coordination. MP status until sat re-eval.	
20120706	Retrained and re-evaluated on airspace coordination. Returned to MQ status.	
20121006	SMs S-APART requirements waived by battalion cdr due to deployment for combat ops.	Adrian Rogers, CPT, Infantry
20121105	Completed master trainer (MT) V2 course.	
20121205	SM designated MT.	Aaron Stanley, LTC, Infantry

PAGE 2, DA FORM 7122-R, DEC 2009 APD PE v1.00

SAMPLE

Figure 6-2. Sample DA Form 7122-R, page 2

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DEPARTMENT OF THE ARMY FORM 4507-R

6-7. The DA Form 4507-R will be filed on the right side of the individual aircrew training folder (IATF) until training has been completed and the event has been documented on the DA Form 7122-R. Once the event has been entered on DA Form 7122-R, then DA Form 4507-R will be removed from the IATF.

DA FORM 4507-R INSTRUCTIONS

6-8. Instructions for completing the form are as follows.

DA Form 4507-R, Page 1

- **Name.** Enter the crewmember's name (last, first, middle initial).
- **Rank**. Enter the crewmember's rank.
- **PID.** Enter the individual's SUASMAN identification.
- **Unit.** Enter the unit to which the crewmember is assigned.
- **Purpose.** Enter the purpose of the training or evaluation using standard phraseology; for example, refresher training or AC evaluation.
- **Aircraft Type.** Enter the alphanumeric designation of the aircraft or flight simulator; for example, MQ-5B, RQ-7B, MQ-1C.
- **Date Started.** Enter the date on which the flight training program starts.
- **Must Complete By.** If the training program is time limited, enter the date on which the crewmember must complete it. If the date changes, line through the original date and enter the new date above it. Explain the change in the Comments section.
- **Date.** Enter the day, month, and year of the flight.
- **Flight Data.** This form provides a cumulative record of the time flown under those flight modes normally requiring minimum amounts. Record all flight time in hours and tenths of hours.
  - **Time Today.** Enter the total time flown today.
  - **Cumulative Time.** Record the total flight time accrued to date.
  - **Day Flight-Today.** Enter the time flown today under day flight conditions. For flights conducted under other than day flight conditions, enter the applicable flight mode or condition in the space provided. Then record the time flown today for that flight mode or condition.
  - **Day Flight-Cumulative.** Record the total time accrued under day flight conditions. For flights conducted under other than day flight conditions, enter the applicable flight mode or condition in the space provided. Then record the total flight time accrued to date for that flight mode or condition.
  - **Duty Position.** Enter the crewmember's duty position for the flight.
  - **Seat Position.** Enter the crewmember's seat position for the flight.
  - **Overall Grade.** Enter either "S" or "U" in the overall grade block after the crewmember completes the flight. This grade reflects the MT's/trainer's overall assessment of the flight. If the overall flight is graded a "U", a comment is required on DA Form 4507-2-R.
  - **Crewmember Initials.** Have the crewmember initial the grade slip to certify that the crewmember has been debriefed. The initials do not mean that the crewmember agrees with the results.
  - **Trainer or Evaluator Name, Rank, and Duty Position.** Enter the trainer's or the evaluator's first initial, last name, rank, and duty position.

DA Form 4507-R, Page 2

- **Date.** Enter date of pertinent comments.
- **Comments.** Enter pertinent comments on DA Form 4507-R. Enter sound, objective comments. If the overall flight or any individual task is graded "U", a comment is required. For unsatisfactory tasks, indicate which standards were not met and any other appropriate remarks.

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These comments are important for reference by other trainers or evaluators during future training or evaluation.

DA FORM 4507-R SAMPLE

6-9. Figures 6-3 and 6-4, page 6-8, provide a sample of a completed DA Form 4507-R.

CREW MEMBER GRADE SLIP

For use of this form see TC 3-04.11; the proponent agency is TRADOC.

Name: Moody, Dwight L.	**Rank:** SPC	**PID:**
Unit: C Trp, 407 Cavalry	**Purpose:** ML Progression	
Aircraft Type: RQ-11B	**Date Started:** 20120123	**Must Complete By:** 20120425

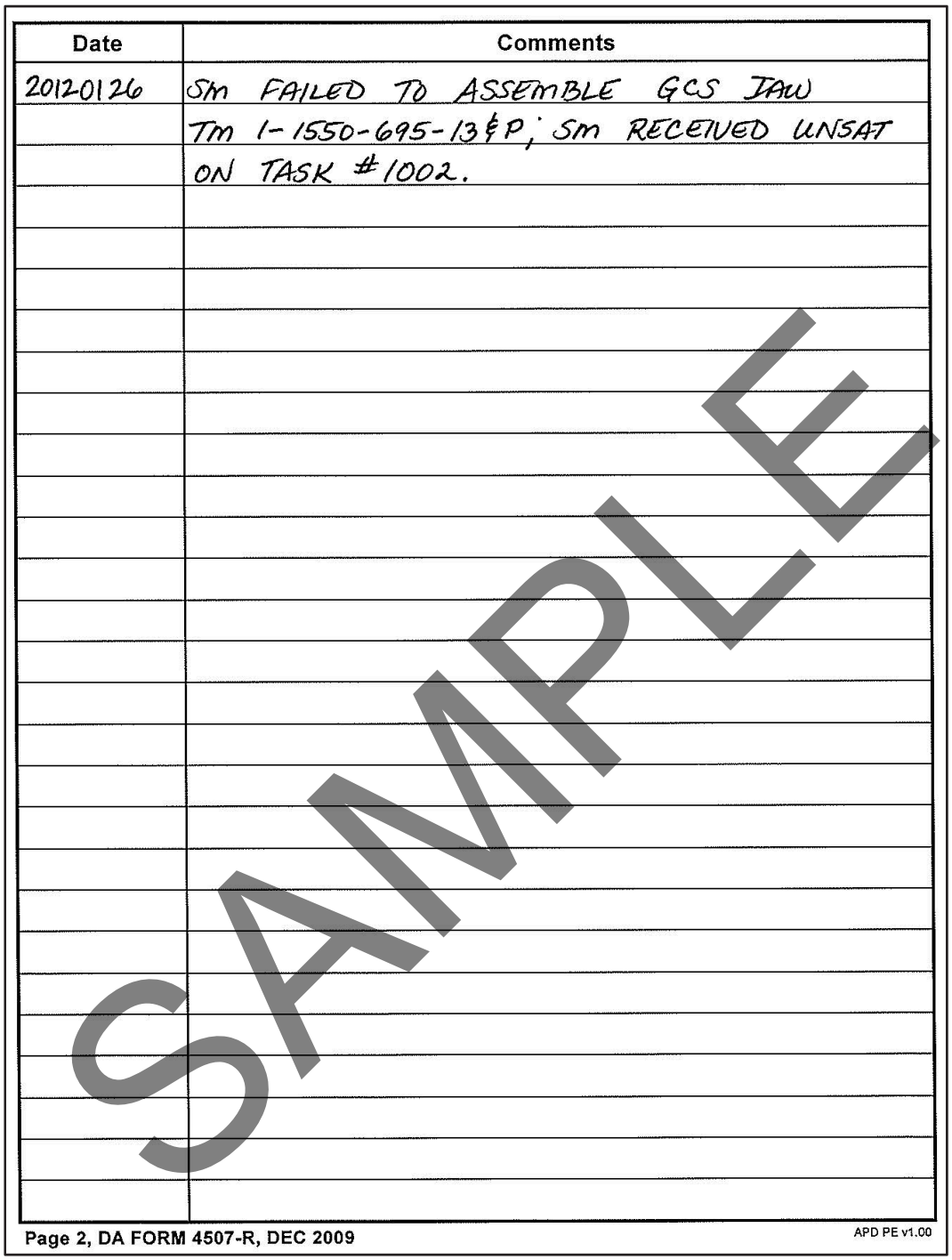
Flight Data	Date: 20120126
Time Today	4.0
Cumulative Time	4.0
Day Flight--Today	2.0
Day Flight--Cumulative	2.0
N Flight--Today	2.0
N Flight--Cumulative	2.0
Flight--Today	
Flight--Cumulative	
Flight--Today	
Flight--Cumulative	
Duty Position	AO
Seat Position	/
Overall Grade	S
Crew Member Initials	DM
Trainer or Evaluator Name, Rank, and Duty Position	B.Sunday, SGT, MT

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SAMPLE

Figure 6-3. Sample DA Form 4507-R, page 1

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Date	Comments
20120126	SM FAILED TO ASSEMBLE GCS IAW
	TM 1-1550-695-13&P; SM RECEIVED UNSAT
	ON TASK #1002.

SAMPLE

Page 2, DA FORM 4507-R, DEC 2009 APD PE v1.00

Figure 6-4. Sample DA Form 4507-R, page 2

DEPARTMENT OF THE ARMY FORM 4507-1-R

6-10. DA Form 4507-1-R (Maneuver/Procedure Grade Slip) is used to grade each task performed.

DA FORM 4507-1-R SAMPLE

6-11. Figure 6-5, page 6-9, provides a sample of a completed DA Form 4507-1-R.

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MANEUVER/PROCEDURE GRADE SLIP

For use of this form see TC 3-04.11; the proponent agency is TRADOC.

Trainee's/Examinee's Name: Moody, Dwight L.

SELECT	Page No. 1 / No. Pages 1 / MANEUVER/PROCEDURE	DATE 20120126									
X	Assemble SUAS	S									
X	Assemble Ground Control Station (GCS)	U									
X	Assemble Remote Video Terminal (RVT)	/									
X	Operate SUAS Battery Charger	S									
	Perform Airspace Management Coordination										
	Complete SUAS Preflight Mission Planning										
	Complete a SUAS Crew Mission Briefing										
	Complete SUAS Preflight Checks										
	Respond to Warning Displays										
	Complete Before Take-off Checks										
	Launch Unmanned Aircraft										
	Complete SUAS In-flight Operations										
	Complete Before Landing Checks										
	Complete Autoland Procedures										
	Complete Post Flight Procedures										
	Respond to an Emergency										
	Complete Remote Launch Procedures										
	Complete Hand-off Procedures										
	Disassemble and Store System										
	Complete SUAS Operator Level Maintenance										
	Complete Mobile Operations										
	Implement Covert Approaches										
	Implement Low-level Flying										
	Implement Low-level Approach										
	Implement Low-level Landing										
	Implement High Altitude Autoland										

DA FORM 4507-1-R, DEC 2009 PREVIOUS EDITIONS ARE OBSOLETE. APD PE v1.00

SAMPLE

Figure 6-5. Sample DA Form 4507-1-R

DA FORM 4507-1-R INSTRUCTIONS

6-12. Instructions for completing the form are as follows.

- **Trainee's/Examinee's Name.** Enter the examinee's name (last, first, middle initial).
- **Select.** If the form is tailored to the training or evaluation being conducted, use as desired. If the form lists all base and mission/additional tasks, place an "X" in the selection column by each task that is mandatory for the training program or evaluation underway based on the guidance in the applicable ATM, this training circular, the commander's task list, the unit SOP, and other documents.

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- **Page No.** Enter the number of this page.
- **No. Pages.** Enter the total number of DA Forms 4507-1-R used.
- **Maneuver/Procedure.** Enter the task number followed by the task title as required by the unit's ATP. Units may list all tasks required by the commander's task list. Another option is to develop separate forms for each training program; for example; night goggle refresher training, RL progression, and mission training. Units may also use a highlighter pen or any other suitable method to track completion of tasks in different modes. Task titles may be abbreviated to fit within the space provided.
- **Date.** Enter the day, month, and year of the flight. It is acceptable to have multiple entries for the same date to specify tasks trained/evaluated in different flight modes. In the blocks under the date, the evaluator/trainer or unit trainer grades each task performed. An unsatisfactory grade "U" requires a brief description of the deficiency in the comments section of DA Form 4507-2-R (Continuation Comment Slip). Place a diagonal (/) in the grade blocks for all maneuvers or procedures not performed. When three or more consecutive tasks are not graded, place a diagonal line in the first and last task and connect the two with a straight vertical line.

DEPARTMENT OF THE ARMY FORM 4507-2-R

6-13. The DA Form 4507-2-R is used to record comments and explain DA Form 4507-R and DA Form 4507-1-R entries, as appropriate.

DA FORM 4507-2-R INSTRUCTIONS

6-14. Instructions for completing the form are as follows.

- **Examinee's/Trainee's Name**. Enter the examinee's name (last, first, middle initial).
- **Date.** Enter date of entry.
- **Comments.** Enter comments as necessary. Comments should be clear, concise and objective. These comments are important for reference by other trainers or evaluators during future training or evaluation.

DA FORM 4507-2-R SAMPLE

6-15. Figure 6-6, page 6-11, provides a sample of a completed DA Form 4507-2-R.

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CONTINUATION COMMENT SLIP

For use of this form see TC 3-04.11; the proponent agency is TRADOC.

Examinee's/Trainee's Name: Moody, Dwight L.

Date	Comments
20120126	THIS FORM IS USED TO CONTINUE COMMENTS FROM DA FORM 4507-R COMMENT SHEET.

SAMPLE

DA FORM 4507-2-R, DEC 2009 PREVIOUS EDITIONS ARE OBSOLETE. APD PE v1.00

Figure 6-6. Sample DA Form 4507-2-R

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Chapter 7

Composite Risk Management

Tough, realistic training conducted to standard is the cornerstone of Army warfighting skills. The battle-focused training environment places stress on both Soldiers and their equipment, creating a high potential for loss. As training realism increases, so does the potential for loss. If risk is not reduced, personnel and equipment losses caused by training mishaps pose a serious drain on warfighting assets. Accidental losses during training are no different from combat losses; in either case, the assets are gone. Commanders must find ways to protect individuals and equipment from accidents during realistic training to prepare for war. Guidance on composite risk management (CRM) is contained in ADP 5-0, FM 5-19, and AR 385-10.

GENERAL

7-1. An effective risk management program is vital at all levels of operations and requires the personal attention and participation of unit commanders and leaders all along the chain of command. The protection of Soldiers and their weapon systems is a way of life in the Army. An effective ATP, thoughtfully planned in conjunction with appropriate regulations and guidance, is arguably the most important factor in any unit's safety program once it is embraced by every Soldier in the unit. Flying "by the book" does not hinder, but actually enhances, a unit's battle focus. The crawl/walk/run approach to training is imperative to reduce risks, as is the active participation of commanders at all levels of the training process.

COMPOSITE RISK MANAGEMENT CONCEPT

7-2. CRM is the decision-making process for identifying hazards and mitigating risks across the entire spectrum of Army missions, functions, operations, and activities. It is a holistic assessment, blending tactical and threat-based risk management with accidental, hazards-based risk management. CRM is not a stand-alone process, a paperwork drill, or an add-on feature to planning. Rather, it is used as a fully integrated element of planning and decision making. It may also be executed intuitively in situations that require hasty planning or immediate action. CRM should be viewed as part of the military art interwoven throughout the Army's military decision- making and training management cycles. CRM follows a process which personnel of all ranks must continually use. The CRM steps are shown in figure 7-1, page 7-5.

7-3. Using the CRM process, leaders identify the hazards that may cause mission degradation and loss of unit combat readiness and effectiveness. These include those hazards that may cause injury and/or death to personnel or damage and/or destruction of equipment. A commander should then determine the possible impact of each hazard on the mission, take action to minimize or eliminate the hazards, then execute the mission or modify the mission to further reduce risk.

7-4. CRM is not a restrictive measure. It is a conscious analysis of the mission itself, possible courses of action, and the implementation of appropriate controls to ensure any risk is reduced or eliminated.

7-5. The CRM process includes several terms all leaders should know. These terms are—

- CRM process. The process of identifying and controlling hazards to protect the force.
- Control. Any action taken to eliminate hazards or reduce their risk.
- Hazard. Any real or potential condition that can cause the loss of an asset. These losses include injury, illness, and death of personnel; damage to or loss of equipment or property; and mission degradation.

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- Risk. The chance of hazard or bad consequences. Exposure to a chance of injury or loss. Risk level is expressed in terms of hazard probability and severity.
- Exposure. The frequency and length of time subjected to a hazard.
- Probability. The likelihood that an event will occur.
- Severity. The expected consequence of an event in terms of the degree of injury, property damage, or other mission impairing factors that could occur.
- Risk assessment. The identification and assessment of hazards.
- Residual risk. Any anticipated level of risk remaining after controls have been identified and selected for hazards that may result in loss of combat power.
- Risk decision. Accept or not accept the risk(s) associated with an action; made by the commander, leader, manager, or individual responsible for performing that action.

7-6. The standard for CRM is leadership at the appropriate level of authority making informed decisions to control hazards or accept risks. Leaders are responsible and accountable for assessing their operation as a total system.

7-7. The degree of risk determines the level of decision authority. When resources to reduce risk to an acceptable level are not available, the risk issue must be elevated to the next higher command. This process continues until the information is presented to the level of command that has the resources and authority to eliminate the hazard or control the risk to an acceptable level. In this manner, a conscious and informed decision is made to either commit the resources to control the hazards or to accept the risk.

RESPONSIBILITIES

7-8. CRM is not complex, technical, or difficult and is not limited to the brigade and battalion commanders. It is a simple decision making process and a way of "thinking through a mission" to balance mission demands against known risks. Trainers/evaluators can maintain realism in training accomplishment through CRM. In peacetime, the process must be deliberate, continuous, and must become second nature to those responsible for planning, approving, or leading activities. In combat, the process is no less deliberate, though risks may be accepted as dictated by the mission priority.

LEADERS

7-9. What is the commanders responsibility, at all levels? Who establishes what risk: extremely high (E), high (H), moderate (M), or low (L)?

7-10. Managing risks is a leadership responsibility. At the crewmember level, MTs and instructors are the principal risk managers. Planning must incorporate consideration for known hazards and must address appropriate control measures to minimize exposure to these hazards. While CRM is introduced in the planning phase of a mission, for MTs, CRM responsibilities are not complete until the mission debriefing is complete.

7-11. To meet these responsibilities, leaders do not accept unnecessary risk. If the risk can be eliminated or reduced and the mission can still be accomplished, the risk is mitigated and acceptable. Find ways to mitigate the risk (for example, change the crew mix, change the mission execution time, provide additional preparation and training, and add additional supervision) that will still allow completion of the mission. Once hazards are identified and controls recommended, compare and balance the residual risk against the mission expectation.

7-12. Pre-mission. The commander, or other designated risk approval authority, decides if the controls are sufficient to accept the risk. If the risk is excessive, the commander can direct additional control measures, modify controls, request the next higher commander's involvement, or reject the mission.

7-13. During mission execution. The commander cannot always be available to make every risk decision. In the aircraft, when the situation, time, or other factors do not allow for the commander's decision, the MTs, instructors, or other unit leaders become the primary risk managers. In such cases, they should use the commander's guidance, their professional experience, unit SOPs, ATMs, regulations, current situation,

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developing conditions, and so forth as the basis upon which they formulate control measures. They should evaluate unexpected hazards that are encountered during the course of the mission and apply the appropriate control measures.

7-14. Make risk decisions at the proper level. Decisions made at the proper level eliminate the involvement of commanders not normally involved in the mission or commanders not authorized to accept the level of risk. ACs must know the appropriate level of approval authority based on the level of risk. The risk approval authority will vary between units and risk approval authority must at all levels be capable of mitigating risk or accepting that level of risk.

7-15. Weigh the risks versus the benefits. The benefits gained by accepting a residual risk must clearly outweigh the potential cost in terms of life, limb, or equipment loss should an incident occur.

7-16. Identify controls. Integrate CRM into all stages of all operations. Integration begins with the pre-mission planning and continues through the completion of the mission debriefing. Consider CRM as contingency planning. The commander and staff should look at factors that could cause the mission to fail (cause loss of life, limb, or equipment) and implement controls to minimize that probability. During the debriefing, unexpected hazards for a completed mission then become expected hazards for follow-on missions.

7-17. While crewmembers are not specifically members of the unit staff, they normally provide input to the battalion staff through their company commander. During operations, the staff normally does not occupy a crew station, but through their work, a significant portion of CRM does occur before any start switch is pressed. Some functions that the staff performs, relative to CRM, are as follows:

- Assist in the planning and identification of hazards for operations.
- Integrate CRM into operations plans and orders. In developing plans, the staff evaluates the risks, recommends controls to minimize the risks, and provides the commander with an assessment of the effectiveness of the imposed controls. In training situations, the staff—
  - Advises the commander of the controls that impact on training realism, so the commander can make the risk acceptance decision.
  - Evaluates imposed safety restrictions to ensure optimal training benefit is achieved without unnecessary restrictive measures applied.
  - Assess the operational risk. Using mission, enemy, terrain and weather, troops and support available, time available, and civil considerations factors to identify the risk to mission accomplishment, the staff begins to assess operational risks. The most important consideration is the outcome of the operation for the unit, higher headquarters, and adjacent units. Risk analysis is formulated using a course of action that is developed along the spectrum of frequent to seldom event occurrence. The staff reviews and expands or refines the list throughout the planning and execution of the exercise. The staff then evaluates the possible consequences of those risks from catastrophic to marginal, for example, the staff plans a multi-aircraft mission to airlift personnel or supplies. If the weather forecast is for marginal conditions, part of the planning should include the possibility of weather conditions degrading during the mission.

7-18. Controls the staff might propose are—

- Reinforcing those sections of the SOP pertaining to adverse weather.
- Briefing crews regarding the current and forecast adverse weather and the possible courses of action selected by the commander.
- Planning alternate transportation.
- Designating recovery airfields.

7-19. The staff should also consider the possibility of additional personnel or equipment showing up for transport than were expected. How will the crews accommodate this change? What impact will the additional payload have on the aircraft performance? Controls could include maximums on payload, additional sorties, backup aircraft, or other controls that would ensure mission accomplishment with minimum risks. There are additional hazards that could be identified in this example.

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SAFETY OFFICER

7-20. The safety officer—

- Is an integral part of the CRM, planning process.
- Is a special staff officer who advises the commander and staff on safety requirements and recommends controls to minimize risks.
- Participates in all phases of the military decision-making process to ensure CRM follows the commander's intent.
- Assists all staffs in integrating the CRM process into other staff functions.
- Assists the command in supervising operations to ensure application and adherence to imposed controls and provides feedback on the effectiveness of the program.

CREWS

7-21. Crewmembers are a critical part of the CRM process. They perform the mission and their involvement in the planning phase is crucial to identification of hazards and controls. Crewmembers must clearly understand the controls implemented to mitigate risks. During mission execution, crewmembers must perform tasks and implement control measures to standard. The employment of good crew coordination is paramount to identifying unexpected hazards (for example enemy situation, wires, and weather) and to continuously refine controls during the mission.

INDIVIDUALS

7-22. Self-discipline is critical to mission accomplishment and to an effective CRM program. The best CRM plan is worthless if the individuals performing the mission do not adhere to established controls or do not perform the tasks to standard. Individuals performing a mission are also responsible for performing CRM. While performing the mission, conditions, hazards and risks change and by necessity, CRM controls may change. The individual must constantly assess the conditions and continuously apply the principles of CRM to ensure minimum risk to themselves, fellow Soldiers, the aircraft, and the mission.

COMPOSITE RISK MANAGEMENT TRAINING

7-23. Commanders must conduct CRM training for their unit. Training should emphasize the process and must reinforce the philosophy that Soldiers—crewmembers and ground personnel—are responsible for performing CRM; without a full range of participation, commanders may not make an informed decision.

COMPOSITE RISK MANAGEMENT PROCESS

7-24. The CRM process is comprised of the following actions: identify hazards, assess risks, develop controls and risk decisions, implement controls, and supervise and evaluate (figure 7-1, page 7-5).

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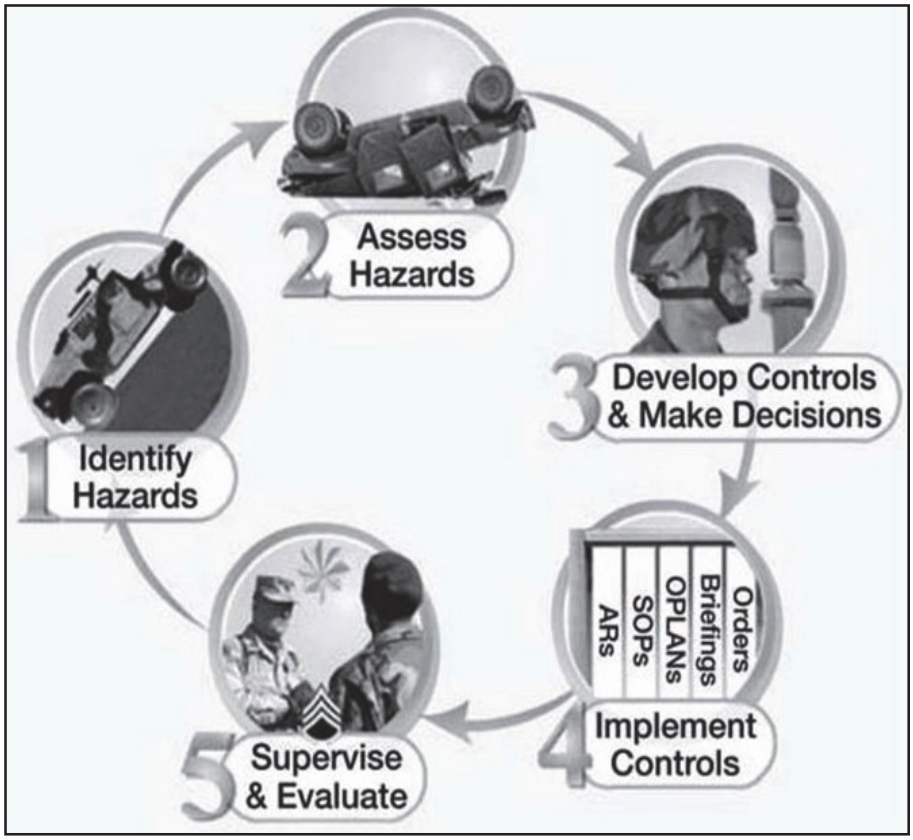


Figure 7-1. Composite risk management steps

STEP 1-IDENTIFY HAZARDS

7-25. Identify the major events in the mission and list chronologically. This will help identify all hazards associated with the specified as well as implied tasks.

7-26. Complete a preliminary hazard analysis of operational events. This identifies, as early as possible, the obvious hazards expected during the mission. Early identification provides more flexibility in addressing the hazards and allows more options for controls, which maximizes a leader's ability to complete the mission.

STEP 2-ASSESS RISKS

7-27. Determine the level of risk associated with each hazard. Commanders should ask, "Can the hazard result in a fatality, damage to equipment, or mission failure?" The degree of risk associated with each particular hazard will help define the level of controls necessary. For example, risks associated with a single operator, night, tactical flight might include lack of situational awareness, inadvertent weather, over tasking, and degraded performance, while risks associated with a multi-ship mission in the same environment would include mid air collision as well. (These are usually contained in the unit SOP or designated by the command.) Controls for the previous example may include a day route reconnaissance to establish minimum weather requirements, change the crew mix, adjust the mission execution time, conduct crew awareness briefings on recovery procedures, and single operator launch training. For multi-ship operations, controls might also include a rehearsal to practice deconfliction procedures and to specify separation distances and altitudes. Consider using the METT-TC format as another means to assess risks. Leader's can subjectively determine the likelihood and extent of accidental loss based on this type of analysis.

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STEP 3-DEVELOP CONTROLS AND MAKE DECISIONS

7-28. All hazards cannot be eliminated. There is a point at which the command must accept the risks and direct the mission to continue, modify the mission, or abort the mission. This is not to say that the CRM process stops. The CRM process is a continual process. There may come a time during a mission when an opportunity exists to eliminate a particular risk. That opportunity might not be apparent if the CRM process is not continual. The intent is to mitigate the probability of an accident or the severity of the consequences with prudent controls whenever the risk is evident. For example, an experienced ground crew on a night launch with sufficient personnel and good illumination still faces the possibility of engine malfunction, human error, or propeller strikes. The command has identified the controls, but cannot eliminate all the risks; it accepts the residual risks, in this case, as necessary and unavoidable.

7-29. In identifying and implementing controls, commanders should—

- Eliminate the hazard. This may include changing the crew, mission time (day versus night), equipment, or aircraft type.
- Guard or control the hazard. For flight operations, this might include routine radio calls to operations, crew mix, safety aircraft, emergency training, and minimum crew requirements.
- Change operational procedures to limit exposure to hazards, for example, minimize the number of systems or personnel or limit exposure to a particular hazard.
- Train and educate personnel in hazard recognition and avoidance. Some good examples include the limitations of night vision and the known performance and operational limits of the aircraft.
- Enforce the use of protective clothing or equipment that will minimize injury and damage potential. Examples include helmets, gloves, hearing protection, fire protected clothing, ground vehicle emergency kits, first aid training, and backup gear. Use color coding and signs to alert personnel of hazards—safety lanes in hangars, stairs, curbs, marking on aircraft for tail rotors, and arming and refueling point markings.

STEP 4-IMPLEMENT CONTROLS

7-30. Integrate controls into the planning. Ensuring awareness of the hazards and controls, from the commander through the individual(s) performing the task, is essential to success.

STEP 5-SUPERVISE AND EVALUATE

7-31. Leaders must enforce the controls and standards. The best CRM program is ineffective if the command does not enforce the controls. AOs are the leaders during SUAS missions and upholding standards must be a high priority. The most common cause of accidents is the failure of an individual to adhere to standards or a failure of the command to enforce a known standard.

7-32. Leaders must supervise activities of subordinate units. Battalion will supervise company operations; the company will supervise platoon operations, and so forth. Supervising a subordinate unit does not imply interference. Only by seeing the character of operations will leaders fully appreciate risk implications or the effectiveness of the CRM program.

7-33. Leaders at all levels are responsible for supervising operations. From private to general, all Soldiers can, and must, share in the responsibility for supervising. The purpose of this supervision is to ensure the identification of hazards and that controls are followed. Additionally, as conditions change, the supervisor continually evaluates the effectiveness of established controls to ensure successful completion of the mission.

RISK ASSESSMENT TOOLS

7-34. Using risk assessment tools, such as matrices and diagrams, is valuable during the planning stage of a mission. These tools do not cover the entire CRM process, but they do provide a systematic approach to identifying and reducing risk. However, do not allow the risk assessment tools to become the overriding concern of the CRM process. Tools merely provide a measurement for leaders to gauge risk and control effectiveness.

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Note. Risk assessment tools do not make decisions. Leaders make decisions.

7-35. Probability is the likelihood of an event. This is your estimate, given what information you know and what others have experienced. The probability levels estimated for each hazard are based on the mission, course of action, or frequency of a similar event. For the purpose of CRM, there are four levels of probability—frequent, likely, occasional, and seldom (figures 7-2 and 7-3).

PROBABILITY-FREQUENT
Occurs very often (known to happen regularly). Given 500 or so exposures to the hazard, expect that it will definitely happen to someone. Two examples of frequent occurrences are rollovers and rear-ending a vehicle.
PROBABILITY-LIKELY
Occurs several times (a common occurrence). Happens every 1,000 or so exposures. Examples are IEDs, wire strikes for aircraft, controlled flight into terrain, and accidental discharges
PROBABILITY-OCCASSIONAL
Occurs sporadically (but is not uncommon). You may or may not get through your deployment without it happening. Two examples are UXO and fratricide.
PROBABILITY-SELDOM
Remotely possible (could occur at some time). Usually several things must go wrong for it to happen. Two examples are heat-related death or electrocution.

Figure 7-2. Probability chart

PROBABILITY / ***SEVERITY***	***FREQUENT***	***LIKELY***	***OCCASSIONAL***	***SELDOM***
CATASTROPHIC	E	E	H	M
CRITICAL	E	H	H	L
MARGINAL	H	M	L	L
E=extremely high……..…..Loss of ability to accomplish the mission.				
H=high…..……..……..Significant degradation of mission capabilities.				
M=moderate…….……..…Expected degraded mission capabilities.				
L=low……...…….……..Little or no impact on accomplishing the mission.				

Figure 7-3. Risk assessment matrix

7-36. Catastrophic is defined as follows:

- Loss of the ability to accomplish the mission or mission failure.
- Death or permanent total disability (accident risk) of personnel.
- Loss of major or mission-critical system or equipment.
- Major property (facility) damage.
- Severe environmental damage.
- Mission-critical security failure.
- Unacceptable collateral damage.

7-37. Critical is defined as follows:

- Significantly (severely) degraded mission capability or unit readiness.
- Permanent partial disability, temporary total disability exceeding 3 months time (accident risk).
- Extensive (major) damage to equipment or systems.
- Significant damage to property or the environment.
- Security failure.
- Significant collateral damage.

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7-38. Marginal is defined as follows:

- Degraded mission capability or unit readiness.
- Minor damage to equipment or systems, property, or the environment.
- Lost day due to injury or illness not exceeding 3 months (accident risk).
- Minor damage to property or the environment.

7-39. One matrix cannot include all of the hazards of every mission, nor can one matrix apply to all units. Commanders must determine the usefulness and content of any risk assessment tool. Commanders must consider a number of basic principles when they use these tools.

Note. Additional risk management tools can be found at https://safety.army.mil.

7-40. Commanders must remember—

- Adding the numbers up and finding the right level of command to accept the risk is not CRM.
- The risk assessment matrix is most valuable during mission planning.
- Each element of the matrix represents a specific hazard that, in the risk assessment process, translates into risk.

7-41. Commanders should review the unit METL as they develop their risk assessment matrices. They should assess each METL task from the highest risk to the lowest risk. Commanders should then select the task(s) or task elements upon which they personally want to initiate risk reduction action and approval. Their risk assessment matrices should clearly show these critical elements.

7-42. Commanders should include additional items when developing the risk assessment matrix, when applicable. An example of a high-risk mission is a relief on station with an inexperienced crew that just arrived in country and restricted visibility caused by fog. The factors that play the biggest role in this example could be lack of experience and the new area of operations. Commanders may wish to refer these types of mission elements to the next higher commander for risk reduction or acceptance, because the effect of these factors greatly increases mission risk.

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Appendix A
Small Unmanned Aircraft System Tasks

A-1. Table A-1 provides a list of SUAS tasks.

Note. Environmental considerations. For operations conducted in conditions such as hot/cold weather, turbulence, rain/thunderstorm, desert/sand/dust, or wind, reference system limitations in the operator's manual, AR 95-23, and FM 3-04.203.

Table A-1. Small unmanned aircraft system task list

Prepare the SUAS for an Aerial Mission	
Task	***Description***
1001	**Title:** Assemble SUAS
	Condition: Given an SUS, TM 1-1550-695-13&P, TM 1-1550-695-CL, and local SOP.
	Standard: Assemble an SUAS IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, and local SOP.
1002	**Title:** Assemble Ground Control Station (GCS)/Ground Control Unit (GCU)
	Condition: Given an SUAS GCS/GCU, TM 1-1550-695-13&P, TM 1-1550-695-CL, and local SOP.
	Standard: Assemble an SUAS GCS/GCU IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, and local SOP.
1003	**Title:** Assemble Remote Video Terminal (RVT)
	Condition: Given a SUAS RVT, TM 1-1550-695-13&P, TM 1-1550-695-CL, and local SOP.
	Standard: Assemble an SUAS RVT IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, and local SOP.
1004	**Title:** Operate SUAS Battery Charger
	Condition: Given an SUAS Unmanned aircraft Battery Charger, TM 1-1550-695-13&P, TM 1-1550-695-CL, and local SOP.
	Standard: Perform Battery charging with an SUAS Unmanned aircraft Battery Charger IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, and local SOP.
Prepare the SUAS for Flight Operations	
Task	***Description***
1005	**Title:** Perform Airspace Management Coordination
	Condition: Given a requirement to conduct airspace management coordination, AR 95-23, FM 3-04.155, TM 1-1550-695-13&P, TM 1-1550-695-CL, and local SOP.
	Standard: Perform Airspace Management Coordination IAW AR 95-23, FM 3-04.155, TM 1-1550-695-13&P, TM 1-1550-695-CL, and local SOP.
1006	**Title:** Complete SUAS Preflight Mission Planning
	Condition: Given a mission requirement, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Complete SUAS Preflight Mission Planning IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, & local SOP.
1007	**Title:** Complete a SUAS Crew Mission Briefing
	Condition: Given a requirement to conduct Crew Mission Briefing, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Complete SUAS Crew Mission Briefing IAW TM 1-1550-695-13&P, TM 1-1550-695-

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Table A-1. Small unmanned aircraft system task list

	CL, FM 3-04.155, and local SOP.
1008	**Title:** Complete SUAS Preflight Checks
	Condition: Given a requirement to conduct Preflight Checks, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Complete SUAS Preflight Checks IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
Conduct SUAS Flight Operations	
Task	***Description***
1009	**Title:** Respond to Warning Displays
	Condition: Given an SUAS and displayed warning(s), TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Respond to Warning Displays of an SUAS IAW TM 1-1550-605-13&P, TM 1-1550-695- CL, FM 3-04.155, and local SOP.
1010	**Title:** Complete Before Takeoff Checks
	Condition: Given a requirement to conduct Preflight Checks, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Complete SUAS Preflight Checks IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
1011	**Title:** Launch Unmanned aircraft
	Condition: Given a requirement to launch an SUAS unmanned aircraft, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Launch an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
1012	**Title:** Complete Unmanned aircraft In-Flight Operations
	Condition: Given an SUAS unmanned aircraft inflight, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Complete SUAS inflight operations IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
1013	**Title:** Complete Before Landing Checks
	Condition: Given a requirement to land an SUAS unmanned aircraft, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Complete Before Landing Checks for an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
1014	**Title:** Complete Autoland Procedure
	Condition: Given a requirement to autoland an SUAS unmanned aircraft, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Complete Autoland Procedures for an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
1015	**Title:** Complete Post Flight Procedures
	Condition: Given a requirement to perform post flight procedures on a landed SUAS unmanned aircraft, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Complete Post Flight Procedures for an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
1016	**Title:** Respond to an Emergency
	Condition: Given an SUAS and an emergency(s), TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Respond to an Emergency of an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
1017	**Title:** Complete Remote Launch Procedures

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Table A-1. Small unmanned aircraft system task list

	Condition: Given a requirement to remote launch an SUAS unmanned aircraft, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Complete Remote Launch Procedures for an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
1018	**Title:** Complete Hand-off Procedures
	Condition: Given a requirement to complete Handoff Procedures with an SUAS unmanned aircraft, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Complete Handoff Procedures with an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
Perform Post-Flight Operations	
Task	***Description***
1019	**Title:** Disassemble and Store System
	Condition: Given a requirement to disassemble and store an SUAS, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Disassemble and store SUAS IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
1020	**Title:** Complete Unmanned aircraft Operator Level Maintenance
	Condition: Given a requirement to complete SUAS unmanned aircraft operator level maintenance, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Complete SUAS unmanned aircraft operator level maintenance IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
Master Trainers	
Task	***Description***
1021	**Title:** Prepare Lesson Plan for SUAS Instruction
	Condition: Given a task to be trained, a subject relating to SUAS, target audience, a list of available resources to include training aids/equipment, ADP 7-0 and the United States Army Aviation Warfighting Center Instructor Pilot Handbook.
	Standard: Develop a lesson plan that provides a training objective, content, and training standards for a selected task or SUAS-related subject.
1022	**Title:** Conduct SUAS Academic Instruction
	Condition: Given a subject relating to SUAS to be trained, a lesson plan, target audience, reference material covering the subject, a list of available resources to include training aids/equipment, ADP 7-0 and the United States Army Aviation Warfighting Center Instructor Pilot Handbook.
	Standard: Train an SUAS-related academic subject IAW the lesson plan.
1023	**Title:** Conduct SUAS Flight Instruction
	Condition: Given flight training in an SUAS, target audience, reference material covering the subject, a list of available resources to include training aids/equipment, ADP 7-0 and the United States Army Aviation Warfighting Center Instructor Pilot Handbook.
	Standard: Train SUAS flight subjects or task(s) IAW the lesson plan.
Unit Selected Tasks	
Task	***Description***
2001	**Title:** Complete Mobile Operations
	Condition: Given a requirement to complete Mobile Operations with an SUAS unmanned aircraft, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Complete Mobile Operations with an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
2002	**Title:** Implement Covert Approaches

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Table A-1. Small unmanned aircraft system task list

	Condition: Given a requirement to implement Covert Approaches with an SUAS unmanned aircraft, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Implement Covert Approaches with an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
2003	**Title:** Implement Low Level Flying
	Condition: Given a requirement to implement Low Level Flying with an SUAS unmanned aircraft, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Implement Low Level Flying with an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
2004	**Title:** Implement Low Level Approach
	Condition: Given a requirement to implement Low Level Approach with an SUAS unmanned aircraft, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Implement Low Level Approach with an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
2005	**Title:** Implement Low Level Landing
	Condition: Given a requirement to implement Low Level Landing with an SUAS unmanned aircraft, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Implement Low Level Landing with an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
2006	**Title:** Implement High Altitude Autoland
	Condition: Given a requirement to implement High Altitude Autoland with an SUAS unmanned aircraft, an SUAS, TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.
	Standard: Implement High Altitude Autoland with an SUAS unmanned aircraft IAW TM 1-1550-695-13&P, TM 1-1550-695-CL, FM 3-04.155, and local SOP.

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Glossary

AO	aircraft operator
AR	Army regulation
ARNG	Army National Guard
ATM	aircrew training manual
ATP	aircrew training program
BAE	brigade aviation element
CAT	combined arms training
CL	checklist
CRM	composite risk management
CTC	Combat Training Center
CTG	commander's training guidance
DA	Department of the Army
FAA	Federal Aviation Administration
FM	field manual
GCS	ground control station
GCU	ground control unit
IATF	individual aircrew training folder
IAW	in accordance with
IETM	integrated electronic technical manual
LASER	light amplification by stimulated emission of radiation
METL	mission essential task list
METT-TC	mission, enemy, terrain and weather, troops and support available, time available, civil considerations
ML	mission level
MOPP	mission-oriented protective posture
MP	mission preparation
MQ	mission qualified
MT	master trainer
PFE	proficiency flight evaluation
RVT	remote video terminal
S-3	operations staff officer
S-APART	Semi-Annual Proficiency and Readiness Test
SOP	standing operating procedures
STX	standard training exercise
SUAS	small unmanned aircraft system
SUASMAN	small unmanned aircraft systems manager
TB	technical bulletin
TC	training circular
TDY	temporary duty

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TM	technical manual
TRADOC	United States Army Training and Doctrine Command
UAC	unmanned aircraft crewmember
UAS	unmanned aircraft system
USAACE	United States Army Aviation Center of Excellence
USAR	United States Army Reserve
USSOCOM	United States Special Operations Command
VMC	visual meteorological conditions

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